Annual Report 2022

Jožef Stefan Institute, Ljubljana, Slovenia

Annual Report 2022

Jožef Stefan Institute, Ljubljana, Slovenia

Jožef Stefan Institute

CONTENTS

INTRODUCTION

A BRIEF HISTORY OF THE JOŽEF STEFAN INSTITUTE

1946

~ Decision taken by the Slovenian Academy of Science and Arts to establish a Physics Institute

1949

~ Research connected to the peaceful use of atomic energy started, financed by the Federal Government

1952

~ Institute renamed the Jožef Stefan Physics Institute and moved to new laboratories on its present site

1954

~ The betatron and an electron microscope installed as the institute's first major pieces of equipment

1956

~ Van de Graaff accelerator, constructed at the institute, started operation

1958

~ Institute reorganised and new fields of activity defined: nuclear physics, solid-state physics, chemistry, and radiobiology

1959

~ Institute renamed the Jožef Stefan Nuclear Institute. The major source of income was provided by the Yugoslav Atomic Energy Commission

Mass spectrometer at the JSI (about 1960)

1962

~ One of the first compounds of a noble gas, XeF_6, synthesised at the institute
~ The first computer for research, ZUSE Z23, installed

1966

~ Nuclear research reactor TRIGA starts operation

1968

~ Yugoslav Atomic Energy Commission ceases to operate; The Republic of Slovenia becomes the institute's dominant source of research funding

1969

~ Institute is renamed as the Jožef Stefan Institute

1970

~ University of Ljubljana becomes a co-founder of the Jožef Stefan Institute, together with the Federal Executive Council

1971

~ A new unit, INOVA, established with the aim of applying the institute's expertise and output to productive use in the national economy

Institute buildings after the opening in 1953

1972

~ New computer Cyber 72 purchased, and the Republic Computer Centre established as an independent unit of the Jožef Stefan Institute

1974

~ Collaboration with the international centre CERN in the field of high-energy physics started
~ SEPO group for evaluating environmental interventions is established

1976

~ First Yugoslav 8-bit processor computer DARTA 80

1979

~ Contract defining cooperation between the Jožef Stefan Institute and the Nuclear Power Plant Krško is signed
~ First robot in Slovenia is constructed

1982

~ Ecological Laboratory with Mobile Unit established as a special unit of the Slovenian Civil Protection Organisation

1983

~ Stefin, a cysteine proteinase inhibitor named after Jožef Stefan, isolated and its primary structure determined

The Reactor Centre, Podgorica, built in 1966

1985

~ "2000 New Young Researchers" project established by the Slovenian Research Council

~ Centre for Hard Coatings established by the Jožef Stefan Institute and the firm SMELT

The beginnings of robotics at the JSI, in 1985

1987

~ INEA established by the Jožef Stefan Institute as an independent company to promote technology transfer in the fields of cybernetics and energy management

1989

~ Milan Čopič Nuclear Training Centre established

1990

~ The first Slovenian supercomputer, CONVEX, installed at the Jožef Stefan Institute

1992

~ New technology centres established by the Ministry of Science and Technology

~ Jožef Stefan Institute restructured by the Slovenian Government as a public research institution

~ Jožef Stefan Technology Park founded, later to become the Ljubljana Technology Park

1995

~ Jožef Stefan Institute is a co-founder of the international postgraduate school for environmental sciences, the Nova Gorica Polytechnic

~ Research institutes in Velenje, ERICo and Valdoltra established by the Institute

1997

~ 3.5-MeV electrostatic accelerator, TANDETRON, installed

1999

~ Jožef Stefan Institute celebrates its 50th anniversary

2004

~ Jožef Stefan International Postgraduate School established

~ Jožef Stefan Institute is chosen as the coordinator of four Research Centres of Excellence

2007

~ Nanomanipulation of single atoms using low-temperature scanning tunneling microscope

~ New ERDA/RBS beamline installed at the TANDETRON accelerator at the Microanalytical center

2013

~ First ERC Grant awarded to researcher at JSI

2015

~ New research infrastructure, including new and renovated laboratory and office space with high-tech instrumentation for environmental research

2020

~ International Research Centre for Artificial Intelligence was established under the auspices of UNESCO

~ Center for Technology Transfer and Innovation spearheaded Innovation Fund initiative resulting in funding for six successful JSI research projects to increase the technology TRL

High-tech instrumentation for environmental research at the JSI in 2015

FORMER DIRECTORS

Prof. Anton Peterlin,
first Director of the Jožef Stefan Institute

Prof. Anton Peterlin, Founder and first Director of the Jožef Stefan Institute, 1949–1955

Karol Kajfež, 1955–1958

Lucijan Šinkovec, B. Sc., 1959–1963

Prof. Milan Osredkar, 1963–1975

Prof. Boris Frlec, 1975–1984

Prof. Tomaž Kalin, 1984–1992

Prof. Danilo Zavrtanik, 1992–1996

Prof. Vito Turk, 1996–2005

Prof. Jadran Lenarčič, 2005–2020

ORGANISATION OF THE JOŽEF STEFAN INSTITUTE

BOARD OF GOVERNORS

DIRECTOR

SCIENTIFIC COUNCIL

RESEARCH DEPARTMENTS

Physics

Theoretical Physics (F-1)
Prof. Jernej Fesel Kamenik
Low and Medium Energy Physics (F-2)
Prof. Primož Pelicon
Thin Films and Surfaces (F-3)
Prof. Miha Čekada
Surface Engineering (F-4)
Prof. Alenka Vesel
Solid State Physics (F-5)
Prof. Igor Muševič[1], Prof. Denis Arčon[2]
Gaseous Electronics (F-6)
Prof. Uroš Cvelbar
Complex Matter (F-7)
Prof. Dragan Dragoljub Mihailović
Reactor Physics (F-8)
Prof. Luka Snoj
Experimental Particle Physics (F-9)
Prof. Marko Mikuž[3], Prof. Borut Paul Kerševan[4]

Chemistry and Biochemistry

Inorganic Chemistry and Technology (K-1)
Asst. Prof. Gašper Tavčar

Physical and Organic Chemistry (K-3)
Prof. Ingrid Milošev

Electronic Ceramics (K-5)
Prof. Barbara Malič

Nanostructured Materials (K-7)
Prof. Sašo Šturm

Synthesis of Materials (K-8)
Prof. Darko Makovec

Advanced Materials (K-9)
Prof. Matjaž Spreitzer

Biochemistry, Molecular and Structural Biology (B-1)
Prof. Boris Turk
Molecular and Biomedical Sciences (B-2)
Prof. Igor Križaj
Biotechnology (B-3)
Prof. Boris Rogelj
Environmental Sciences (O-2)
Prof. Milena Horvat

Electronics and Information Technology

Automation, Biocybernetics and Robotics (E-1)
Prof. Aleš Ude
Systems and Control (E-2)
Asst. Prof. Gregor Dolanc
Artificial Intelligence (E-3)
Prof. Dunja Mladenić
Open Systems and Networks (E-5)
Asst. Prof. Tomaž Klobučar
Communication Systems (E-6)
Prof. Mihael Mohorčič
Computer Systems Department (E-7)
Prof. Gregor Papa
Knowledge Technologies (E-8)
Prof. Sašo Džeroski
Intelligent Systems (E-9)
Prof. Matjaž Gams

Reactor Techniques and Energetics

Reactor Engineering (R-4)
Prof. Leon Cizelj

[1] until 13 April 2022   [2] since 14 April 2022   [3] until 30 April 2022   [4] since 1 May 2022

CENTRES

Reactor Centre (RIC)	**Combined Atomic Microscope (UHV-AFM/STM)**
Prof. Borut Smodiš	*Prof. Maja Remškar*
Networking Infrastructure Centre (NIC)	**Helium Liquifier with Superconducting Magnet and**
Dr. Jan Jona Javoršek	**Helium Regeneration System**
Science Information Centre (SIC)	*Prof. Janez Dolinšek*
Dr. Luka Šušteršič	**Mass Spectrometry Centre**
Energy Efficiency Centre (EEC)	*Dr. Dušan Žigon*
Stane Merše, M. Sc.	**National Centre for Microstructure and Surface Analysis**
Centre for Knowledge Transfer in Information	*Prof. Miran Čeh*
Technologies (CT-3)	**National Centre for High-Resolution NMR Spectroscopy**
Mitja Jermol, M. Sc.	*Prof. Janez Dolinšek*
Milan Čopič Nuclear Training Centre (ICJT)	**Centre for Protein Structure**
Dr. Igor Jenčič	*Prof. Dušan Turk*
Centre for Electron Microscopy and Microanalysis (CEMM)	**Nanolithography and Nanoscopy**
Prof. Miran Čeh	*Prof. Dragan Dragoljub Mihailović*
Centre for Technology Transfer and Innovation (CTT)	**For Experimental Particle Physicis in International**
Dr. Špela Stres[5], MBA, LLM, Dr. Levin Pal[6]	**Laboratories**
Smart Cities and Communities Centre (CSC & C)	*Prof. Marko Mikuž*
Dr. Nevenka Cukjati	**Hot Cells Facility**
Center Factory of the Future (CFoF)	*Prof. Borut Smodiš*
Asst. Prof. Igor Kovač	**Video-Conferencing Centre**
Microanalytical Instrumental Centre (MIC)	*Dr. Dušan Gabrijelčič*
Prof. Primož Pelicon	

ADMINISTRATION, SERVICES AND SUPPORT UNITS

Administration and Services

Legal and Personnel (U-2)	**Technical Services (TS)**
Tamara Kotnik, LL. B.	*Aleš Cesar, B. Sc.*
Purchasing Department (U-3)	
Dejan Ratković, B. Sc.	## Support Units
Finance and Accounting (U-4)	
Regina Gruden, M. Sc.	**Radiation Protection Unit (SVPIS)**
Service for Business Informatics (U-5)	*Matjaž Stepišnik, M. Sc.*
Jože Kašman, B. Sc.	**Quality Assurance (QA)**
International Project Office (U-6)	*Dr. Andrej Prošek*
Marja Mali, M. Sc.	**Workshops**
	Franc Setnikar[7], B. Sc., Matjaž Nimac[8]

PARTICIPATION IN THE REGIONAL DEVELOPMENT OF RESEARCH

Technology Centres

Ljubljana Technology Park Ltd.

University of Nova Gorica

Jožef Stefan International Postgraduate School

Nanotesla Institute Ljubljana

Development Centre for Hydrogen Technologies

Technology Centre for Production Automation, Robotics and Informatics (ARI)

Centres of Excellence

Nanocenter - Center of Excellence in Nanoscience and Nanotechnology

Centre of Excellence for Integrated Approaches in Chemistry and Biology of Proteins (CIPKeBiP)

Centre of Excellence NAMASTE

Centre of Excellence for Polymer Materials and Technologies (PoliMaT)

EN-FIST Centre of Excellence

CEBIC Centre of Excellence for Biosensors, Instrumentation and Process Control

CO NOT: Centre of Excellence for Low-Carbon Technologies

Centre of Excellence for Space Sciences and Technologies SPACE-SI

[5] until 31 March, 1 June–31 August 2022   [6] 1 April–31 May, since 1 September 2022   [7] until 10 December 2022   [8] since 14 December 2022

MANAGEMENT

DIRECTORATE

Director JSI
Prof. Boštjan Zalar

Assistant Director for EU Affairs
Dr. Romana Jordan

Adviser
Marta Slokan, LL. B.

BOARD OF GOVERNORS

Dr. Mark Pleško, *Chair, Cosylab, d. d., Ljubljana*
Mr. Ivo Boscarol, *Pipistrel, d.o.o., until 8. 12. 2022*
Prof. Sašo Džeroski, *JSI, until 8. 12. 2022*
Dr. Gregor Kramberger, *JSI, since 8. 12. 2022*
Prof. Ingrid Milošev, *Deputy Chair, JSI, since 8. 12. 2022*
Janez Novak, *RLS, d.o.o., since 8. 12. 2022*
Prof. Primož Pelicon, *JSI, until 8. 12. 2022*
Stojan Petrič, *Kolektor, Idrija, until 8. 12. 2022*
Prof. Jože Pungerčar, *JSI, until 8. 12. 2022*

Dr. Tomaž Savšek, *TPV Group, d. o. o., Novo mesto, until 8. 12. 2022*
Peter Sterle, *Ministry of Education, Science and Sport*
Dr. Jernej Štromajer, *Ministry for Economic Development and Technology, since 8. 12. 2022*
Prof. Aleš Švigelj, *JSI, since 8. 12. 2022*
Vojmir Urlep, M. Sc., *since 8. 12. 2022*
Tanja Vertelj, M. Sc., *Ministry of Education, Science and Sport, since 8. 12. 2022*
Urška Zupin, *Ministry for Economic Development and Technology, until 8. 12. 2022*

SCIENTIFIC COUNCIL

Prof. Boris Turk, *President*
Prof. Leon Cizelj
Prof. Miran Čeh
Prof. Sašo Džeroski, *Deputy President*
Prof. Svjetlana Fajfer
Prof. Milena Horvat
Prof. Matej Lipoglavšek
Dr. Mitja Luštrek

Prof. Barbara Malič
Prof. Dragan Dragoljub Mihailovič
Prof. Mihael Mohorčič
Prof. Igor Muševič, *Deputy President*
Asst. Prof. Gašper Tavčar
Prof. Aleš Ude
Prof. Boštjan Zalar

INTERNATIONAL ADVISORY BOARD

Prof. Robert Huber, *Nobel Prize Winner*, Max-Planck-Institut, Martiensried, Germany
Prof. Karl A. Müller, *Nobel Prize Winner*, Universität Zürich, Zurich, Switzerland
Prof. Ernst Günther Afting, GSF, Neuherberg, Germany
Prof. Akito Arima, Riken, Tokyo, Japan
Prof. John H. Beynon, University of Wales Swansea, Swansea, United Kingdom
Prof. Richard Brook, EPSRC, Swindon, United Kingdom
Prof. Julio Celis, Aarhus University, Aarhus, Denmark
Prof. Brian Clark, Aarhus University, Aarhus, Denmark
Prof. Børge Diderichsen, Novo Nordisk, Bagsvaerd, Denmark
Prof. Jean Etourneau, Institut de Chimie de la Matière Condensée de Bordeaux, CNRS, Pessac, France
Prof. Reinosuke Hara, Seiko Instruments, Tokyo, Japan

Prof. Oleg Jardetzky, Stanford University, Stanford, California, USA
Prof. Sergey P. Kapitza, Russian Academy of Sciences, Moscow, Russia
Prof. Karl-Hans Laermann, Bergische Universität, Wuppertal, Germany
Prof. Egon Matijević, Clarkson University, Potsdam, New York, USA
Prof. Federico Mayor, Madrid, Spain
Prof. Dietrich Munz, Universität Karlsruhe, Karlsruhe, Germany
Prof. Günther Petzow, Max-Planck-Institut für Metallforschung, Stuttgart, Germany
Prof. Bernard Roth, Stanford University, Stanford, California, USA
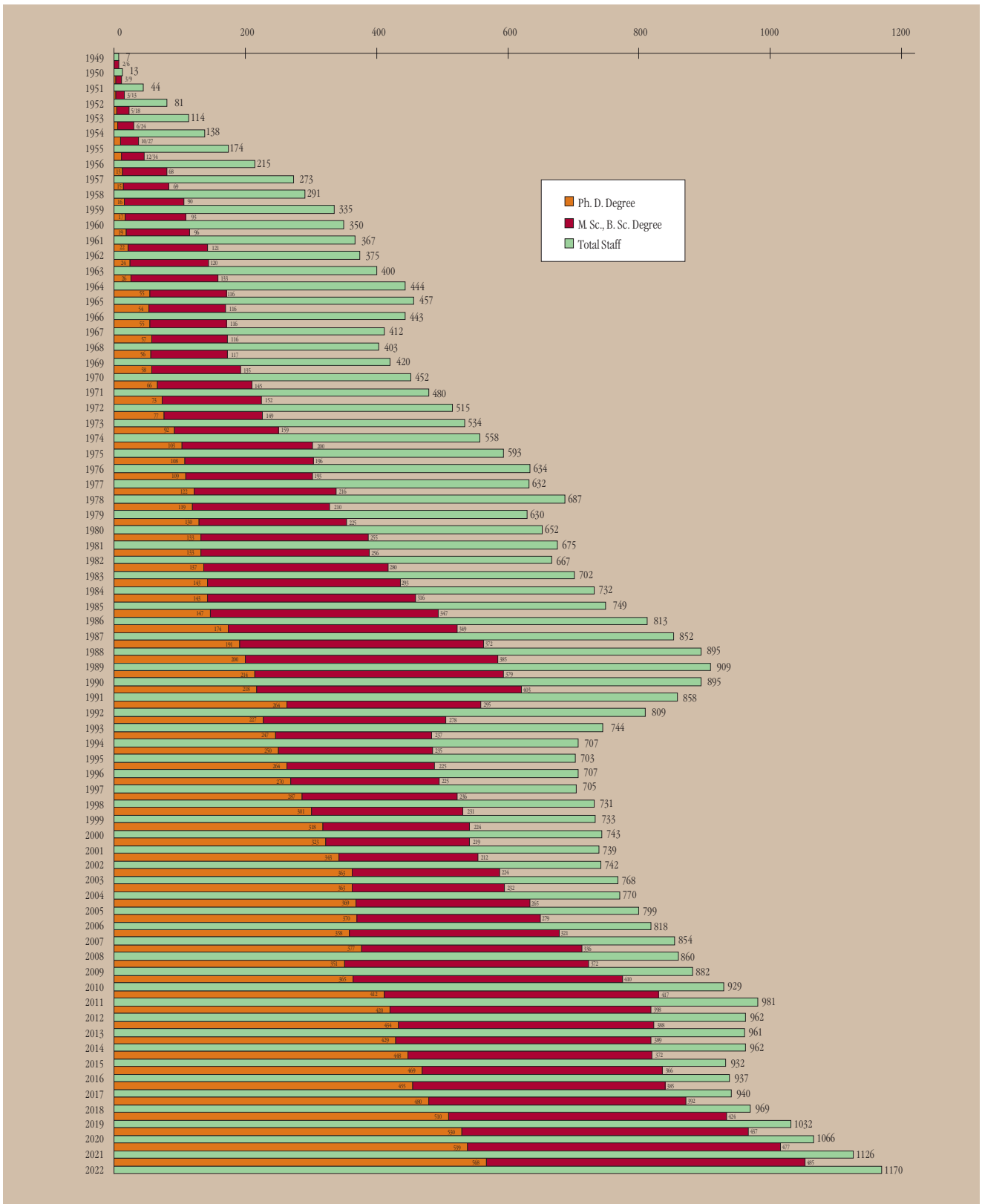Prof. John Ryan, University of Oxford, Oxford, United Kingdom
Prof. Volker Sörgel, Ruprecht-Karis-Universität, Heidelberg, Germany
Prof. H. Eugene Stanley, Boston University, Boston, Massachusetts, USA
Prof. Thomas Walcher, Universität Mainz, Mainz, Germany

STAFF QUALIFICATIONS

1949-2022

Legend:
- Ph. D. Degree
- M Sc., B. Sc. Degree
- Total Staff

RECIPIENTS OF THE JSI AWARDS AND TITLES

HONORARY MEMBERS

Prof. Robert Blinc✝, President of the Scientific Council of the Jožef Stefan Institute from 1992 to 2007 (1933 - 2011)

Prof. Jean-Marie Dubois, Institut Jean Lamour, CNRS - Centre National de la Recherche Scientifique, Paris and Université Lorraine, Nancy, France

Prof. Boris Frlec, Director of the Jožef Stefan Institute from 1975 to 1984

Prof. Robert Huber, Nobel Prize Winner, Max-Planck-Institut für Biochemie, Munich, Germany

Prof. Milan Osredkar✝, Director of the Jožef Stefan Institute from 1963 to 1975 (1919 - 2003)

Prof. Anton Peterlin✝, Founder and First Director of the Jožef Stefan Institute from 1949 to 1955 (1908 - 1993)

Prof. Vito Turk, Director of the Jožef Stefan Institute from 1996 to 2005

ASSOCIATE MEMBERS

Prof. David C. Ailion, University of Utah, Salt Lake City, Utah, USA

Prof. Neil Bartlett✝, University of California, Berkeley, California, USA

Prof. John H. Beynon, University of Wales Swansea, Swansea, United Kingdom

Prof. Wolfram Bode, Max-Planck-Institut für Biochemie, Munich, Germany

Prof. Oscar D. Bonner✝, University of South Carolina, Columbia, South Carolina, USA

Dr. Horst Borrmann, Max-Planck-Institut für chemische Physik fester Stoffe, Dresden, Germany

Prof. Henrik Buchowsky, Politechnika Warszawska, Warszawa, Poland

Prof. Rüdiger Dillmann, Karlsruher Institut für Technologie, Karlsruhe, Germany

Prof. Joseph W. Doane, Liquid Crystal Institute, Kent State University, Kent, Ohio, USA

Prof. Hans Fritz, Universität München, Munich, Germany

Prof. Oskar Glemser✝, Universität Göttingen, Göttingen, Germany

Prof. Paul Hagenmuller✝, Université de Bordeaux I, Bordeaux, France

Prof. John Holloway, University of Leicester, Leicester, United Kingdom

Prof. Rudolf Hoppe✝, Universität Giessen, Giessen, Germany

Prof. Robert J. Jaeger✝, National Institute on Disability and Rehabilitation Research, US Department of Education, Washington, D. C., USA

Prof. Nikola Kallay✝, University of Zagreb, Zagreb, Croatia

Prof. Nobuhiko Katunuma, Tokushima Bunri University, Tokushima, Japan

Prof. Raymond Kind, ETH, Zurich, Switzerland

Prof. Jože Koller, University of Ljubljana, Faculty of Chemistry and Chemical Technology, Ljubljana, Slovenia

Prof. Rüdiger Mews, Universität Bremen, Bremen, Germany

Prof. Donald Michie✝, Edinburgh University, Edinburgh, United Kingdom

Dr. Fani Milia, National Centre for Scientific Research "Demokritos", Athens, Greece

Prof. Tsuyoshi Nakajima, Aichi Institute of Technology, Toyota, Japan

Prof. Vincenzo Parenti - Castelli, University of Bologna, Bologna, Italy

Prof. Herbert W. Roesky, Universität Göttingen, Göttingen, Germany

Prof. John A. Rupley, The University of Arizona, Tucson, Arizona, USA

Prof. Findlay E. Russell, The University of Arizona, Tucson, Arizona, USA

Prof. Hugo V. Schmidt, Montana State University, Bozeman, Montana, USA

Prof. Lev A. Shuvalov✝, Institute for Crystallography, Russian Academy of Sciences, Moscow, Russia

Prof. Neil W. Tanner✝, University of Oxford, Oxford, United Kingdom

Dr. Alain Tressaud, Institut de Chimie de la Matière Condensée de Bordeaux, CNRS, Pessac, France

Prof. Vlado Valković, Zagreb, Croatia

Prof. John Waugh, M.I.T., Cambridge, Massachusetts, USA

EMERITUS SCIENTISTS

Prof. France Bremšak✝

Prof. Mihael Drofenik

Prof. Peter Gosar✝

Prof. Darko Jamnik✝

Prof. Gorazd Kandus

Prof. Gabrijel Kernel

Prof. Borut Mavko

Prof. Miodrag V. Mihailović✝

Prof. Raša Matija Pirc

Prof. Marjan Senegačnik✝

Prof. Saša Svetina

Prof. Boštjan Žekš

Prof. Boris Žemva

EXTERNAL ADVISERS

Prof. Savo Bratoš, Université Pierre et Marie Curie, Paris, France

Marko Bulc✝, B. Sc., Ljubljana, Slovenia

Prof. Davorin Dolar✝, Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia

Zdravko Gabrovšek, B. Sc., Slovenia

Prof. Dušan Hadži✝, National Institute of Chemistry, Ljubljana, Slovenia

Prof. Karl A. Müller, *Nobel Prize Winner*, IBM Research Laboratory, Zurich, Switzerland

Prof. Bogdan Povh, Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Dr. Lev Premrú✝, Lek, d. d., Ljubljana, Slovenia

Prof. Momčilo M. Ristić✝, Academy of Science of Serbia, Belgrade, Serbia

Milan Slokan✝, M. Sc., Ljubljana, Slovenia

Prof. dr. Petar Strohal✝, Zagreb, Croatia

Dr. Novak Zuber✝, Nuclear Regulatory Commission, Washington D. C., USA

Prof. Črt Zupančič✝, Ludwig-Maximillians-Universität, Munich, Germany

Prof. Andrej Župančič✝, Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia

INTERNATIONAL COOPERATION

Multilateral international cooperation	No. of projects
HORIZON EUROPE (HE, EDF, EIT) AND HORIZON EUROPE - EURATOM	37
H2020 (EUROPEAN INSTITUTE OF INNOVATION AND TECHNOLOGY, EXCELLENT SCIENCE, INDUSTRIAL LEADERSHIP, SOCIETAL CHALLENGES, SPREADING EXCELLENCE AND WIDENING PARTICIPATION, SCIENCE WITH AND FOR SOCIETY) AND H2020 - EURATOM	99
ESRR AND ESI (INTERREG, MED, ADRION, DANUBE, SI-IT, ALPINE SPACE, KTT, SRIP, KKP, RZ, NM & EGP…)	18
OTHER INTERNATIONAL AND EU PROJECTS (COST, IAEA, ICTP, JRC, ESA, CEF, EMPIR, ERASMUS+, LIFE+ …)	108
INTERNATIONAL MARKETING PROJECTS	15
OTHER PROJECTS (CERN, KEK, EPFL …)	77
TOTAL	**354**

Bilateral cooperation	No. of projects	Bilateral cooperation	No. of projects
Austria	4	Italy	3
Bosnia and Herzegovina	1	Japan	3
Denmark	2	Latvia	1
Germany	1	Montenegro	2
Finland	1	Norway	1
France	7	Serbia	5
Croatia	6	Turkey	2
India	4	USA	29
		TOTAL	**72**

INTERNATIONAL COOPERATION AGREEMENT

In 2022, an international cooperation agreement was signed between the Jožef Stefan Institute and the National Research Council, Rome, Italy (CNR).

ERC PROJECTS

1. H2020 - Cell-Lasers; Intracellular Lasers: Coupling of Optical Resonances with Biological Processes
    Asst. Prof. Matjaž Humar (F-5)

2. H2020 - LOGOS; Light-Operated Logic Circuits from Photonic Soft-Matter
    Prof. Igor Muševič (F-5)

3. H2020 - FAIME; Flavour Anomalies with advanced particle Identification MEthods
    Prof. Peter Križan (F-9)

4. H2020 - HiPeR-F; Challenging the Oxidation-State Limitations of the Periodic Table via High-Pressure Fluorine Chemistry
    Asst. Prof. Matic Lozinšek (K-1)

erc

European Research Council
Established by the European Commission

COOPERATION WITH HIGHER-EDUCATION ESTABLISHMENTS

FULL-TIME FACULTY MEMBERS

Professors

1. **Prof. Denis Arčon**, University of Ljubljana, Faculty of Mathematics and Physics
2. **Prof. Iztok Arčon**, University of Nova Gorica
3. **Asst. Prof. Rok Bojanc**, University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies
4. **Prof. Janez Bonča**, University of Ljubljana, Faculty of Mathematics and Physics
5. **Asst. Prof. Marko Bračko**, University of Ljubljana, Faculty of Mathematics and Physics; University of Maribor, Faculty of Chemistry and Chemical Engineering
6. **Prof. Dean Cvetko**, University of Ljubljana, Faculty of Mathematics and Physics
7. **Prof. Mojca Čepič**, University of Ljubljana, Faculty of Education
8. **Asst. Prof. Rok Dolenec**, University of Ljubljana, Faculty of Mathematics and Physics
9. **Prof. Janez Dolinšek**, University of Ljubljana, Faculty of Mathematics and Physics
10. **Prof. Irena Drevenšek Olenik**, University of Ljubljana, Faculty of Mathematics and Physics
11. **Prof. Svjetlana Fajfer**, University of Ljubljana, Faculty of Mathematics and Physics
12. **Prof. Darja Fišer**, University of Ljubljana, Faculty of Arts
13. **Prof. Boštjan Golob**, University of Ljubljana, Faculty of Mathematics and Physics
14. **Prof. Ke Guan**, Beijing Jiaotong University, Beijing, China
15. **Prof. Tomaž Gyergyek**, University of Ljubljana, Faculty of Electrical Engineering
16. **Prof. Polona Jaki Mekjavić**, University of Ljubljana, Medical Faculty
17. **Asst. Prof. Branko Kavšek**, University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies
18. **Prof. Borut Paul Kerševan**, University of Ljubljana, Faculty of Mathematics and Physics
19. **Prof. Samo Korpar**, University of Maribor, Faculty of Chemistry and Chemical Engineering
20. **Prof. Janko Kos**, University of Ljubljana, Faculty of Pharmacy
21. **Prof. Samo Kralj**, University of Maribor, Faculty of Education
22. **Prof. Peter Križan**, University of Ljubljana, Faculty of Mathematics and Physics
23. **Prof. Zoran Levnajić**, Faculty of Information Studies, Novo mesto
24. **Prof. Andrej Lipej**, University of Novo mesto, Faculty of Mechanical Engineering
25. **Prof. Marko Mikuž**, University of Ljubljana, Faculty of Mathematics and Physics
26. **Asst. Prof. Matija Milanič**, University of Ljubljana, Faculty of Mathematics and Physics
27. **Prof. Igor Muševič**, University of Ljubljana, Faculty of Mathematics and Physics
28. **Asst. Prof. Natan Osterman**, University of Ljubljana, Faculty of Mathematics and Physics
29. **Asst. Prof. Veljko Pejović**, University of Ljubljana, Faculty of Computer and Information Science
30. **Prof. Uroš Petrovič**, University of Ljubljana, Biotechnical Faculty
31. **Asst. Prof. Tomaž Podobnik**, University of Ljubljana, Faculty of Mathematics and Physics
32. **Asst. Prof. Paula Pongrac**, University of Ljubljana, Biotechnical Faculty
33. **Prof. Peter Prelovšek**, University of Ljubljana, Faculty of Mathematics and Physics
34. **Prof. Saša Prelovšek Komelj**, University of Ljubljana, Faculty of Mathematics and Physics
35. **Prof. Anton Ramšak**, University of Ljubljana, Faculty of Mathematics and Physics
36. **Prof. John Shawe-Taylor**, University College London, Centre for Computational Statistics and Machine Learning, London, UK
37. **Asst. Prof. Urban Simončič**, University of Ljubljana, Faculty of Mathematics and Physics
38. **Asst. Prof. Lea Spindler**, University of Maribor, Faculty of Mechanical Engineering
39. **Asst. Prof. Andrej Studen**, University of Ljubljana, Faculty of Mathematics and Physics
40. **Prof. Simon Širca**, University of Ljubljana, Faculty of Mathematics and Physics
41. **Asst. Prof. Primož Škraba**, Queen Mary University of London, London, UK
42. **Prof. Borut Štrukelj**, University of Ljubljana, Biotechnical Faculty and Faculty of Pharmacy
43. **Prof. Tanja Urbančič**, University of Nova Gorica
44. **Prof. Nataša Vaupotič**, University of Maribor, Faculty of natural sciences and mathematics
45. **Prof. Katarina Vogel-Mikuš**, University of Ljubljana, Biotechnical Faculty
46. **Prof. Danilo Zavrtanik**, University of Nova Gorica
47. **Prof. Primož Ziherl**, University of Ljubljana, Faculty of Mathematics and Physics
48. **Asst. Prof. Dejan Žontar**, University of Ljubljana, Faculty of Health Sciences

Assistants and researchers

1. **Dr. Jurij Leskovec**, Stanford University, Palo Alto, California, USA
2. **Dr. Jure Pražnikar**, University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies, Koper
3. **Dr. Tomaž Rejec**, University of Ljubljana, Faculty of Mathematics and Physics

PART-TIME FACULTY MEMBERS

Professors

1. **Prof. Jan Babič**, University of Ljubljana, Faculty of Electrical Engineering and IPS, Ljubljana
2. **Prof. Andreja Benčan Golob**, IPS, Ljubljana
3. **Prof. Ljudmila Benedik**, University of Ljubljana, Faculty of Chemistry and Chemical Technology, Faculty of Mathematics and Physics and IPS, Ljubljana
4. **Prof. Aleš Berlec**, University of Ljubljana, Faculty of Pharmacy and University of Maribor, Faculty of Agriculture and Life Sciences
5. **Prof. Slavko Bernik**, IPS, Ljubljana
6. **Asst. Prof. Anton Biasizzo**, IPS, Ljubljana
7. **Prof. Vid Bobnar**, IPS, Ljubljana
8. **Prof. Marko Bohanec**, University of Nova Gorica, School of Enginnering and Management and IPS, Ljubljana
9. **Prof. dr. Biljana Mileva Boshkoska**, Faculty of Information Studies, Novo mesto
10. **Asst. Prof. Klemen Bučar**, University of Ljubljana, Faculty of Mathematics and Physics and IPS, Ljubljana
11. **Prof. Leon Cizelj**, University of Ljubljana, Faculty of Mathematics and Physics
12. **Prof. Uroš Cvelbar**, IPS, Ljubljana
13. **Prof. Miran Čeh**, University of Ljubljana, Faculty of Chemistry and Chemical Technology and IPS, Ljubljana

14. **Prof. Miha Čekada**, IPS, Ljubljana

15. **Asst. Prof. Nina Daneu**, IPS, Ljubljana

16. **Prof. Marko Debeljak**, IPS, Ljubljana, University of Ljubljana, University of Nova Gorica

17. **Asst. Prof. Tadej Debevec**, University of Ljubljana, Faculty of Sport

18. **Asst. Prof. Gregor Dolanc**, Faculty of Industrial Engineering, Novo mesto,

19. **Asst. Prof. Goran Dražić**, IPS, Ljubljana

20. **Prof. Jean-Marie Dubois**, IPS, Ljubljana

21. **Prof. Sašo Džeroski**, IPS, Ljubljana, University of Ljubljana, Faculty of Computer and Information Science

22. **Prof. Borka Džonova Jerman Blažič**, IPS, Ljubljana

23. **Asst. Prof. Tome Eftimov**, University of Ljubljana, Faculty of Computer and Information Science

24. **Prof. Tomaž Erjavec**, IPS, Ljubljana

25. **Asst. Prof. Ingrid Falnoga**, University of Ljubljana, Faculty of Maritime Studies and Transport, Biotechnical Faculty

26. **Prof. Andrej Filipčič**, University of Nova Gorica, School of Applied Sciences

27. **Prof. Bogdan Filipič**, University of Ljubljana, Faculty of Computer and Information Science, University of Nova Gorica, Faculty of Engineering and Management, IPS, Ljubljana

28. **Prof. Marko Fonović**, IPS, Ljubljana

29. **Asst. Prof. Andrej Gams**, IPS, Ljubljana

30. **Prof. Matjaž Gams**, University of Ljubljana, Faculty of Computer and Information Science, IPS, Ljubljana

31. **Prof. Marko Gerbec**, IPS, Ljubljana

32. **Asst. Prof. Evgeny Goreshnik**, IPS, Ljubljana

33. **Asst. Prof. Anton Gradišek**, University of Ljubljana, Faculty of Mathematics and Physics

34. **Asst. Prof. Sašo Gyergyek**, University of Maribor, Faculty of Chemistry and Chemical Engineering

35. **Prof. Ester Heath**, University of Ljubljana, Faculty of Pharmacy, Faculty of Chemistry and Chemical Engineering, Faculty of Mechanical Engineering, Faculty of Civil and Geodetic Engineering, Biotechnical Faculty, Faculty of Health Sciences; University of Nova Gorica, School of Environmental Sciences and IPS, Ljubljana

36. **Prof. Milena Horvat**, IPS, Ljubljana, University of Maribor, Faculty of Mechanical Engineering

37. **Asst. Prof. Andrej Hrovat**, Beijing Jiaotong University, Beijing, China; IPS, Ljubljana

38. **Prof. Tomaž Javornik**, IPS, Ljubljana

39. **Prof. Robert Jeraj**, University of Ljubljana, Faculty of Mathematics and Physics, University of Wisconsin, School of Medical Physic, Madison

40. **Asst. Prof. Ita Junkar**, IPS, Ljubljana

41. **Prof. Đani Juričić**, University of Nova Gorica, School of Environmental Sciences, University of Maribor, Faculty of Logistics and IPS, Ljubljana

42. **Prof. Viktor Kabanov**, IPS, Ljubljana

43. **Asst. Prof. Matjaž Kavčič**, IPS, Ljubljana

44. **Asst. Prof. Ivo Kljenak**, University of Ljubljana, Faculty of Mathematics and Physics

45. **Asst. Prof. Tomaž Klobučar**, IPS, Ljubljana, DOBA Faculty of Applied Business and Social Studies, Maribor, Faculty of Commercial and Business Sciences, Celje

46. **Prof. Spomenka Kobe**, IPS, Ljubljana

47. **Prof. Juš Kocijan**, University of Nova Gorica, School of Engineering and Management and IPS, Ljubljana

48. **Prof. Andraž Kocjan**, University of Ljubljana, Faculty of Natural Sciences and Engineering, Faculty of Medicine, IPS, Ljubljana

49. **Asst. Prof. Robert Kocjančič**, IPS, Ljubljana

50. **Prof. Ivan Aleksander Kodeli**, University of Maribor, Faculty of Energy Technology

51. **Prof. Anton Kokalj**, IPS, Ljubljana

52. **Asst. Prof. Matej Andrej Komelj**, University of Ljubljana, Faculty of Mathematics and Physics

53. **Asst. Prof. Boštjan Končar**, University of Ljubljana, Faculty of Mathematics and Physics

54. **Prof. Nataša Kopitar Jerala**, IPS, Ljubljana

55. **Prof. Dušan Kordiš**, University of Ljubljana, Biotechnical Faculty, Faculty of Chemistry and Chemical Technology, Medical Faculty, IPS, Ljubljana

56. **Prof. Barbara Koroušić Seljak**, IPS, Ljubljana

57. **Asst. Prof. Tina Kosjek**, University of Ljubljana, Faculty of Pharmacy, Faculty of Chemistry and Chemical Engineering, Faculty of Mechanical Engineering, Faculty of Civil and Geodetic Engineering, Biotechnical Faculty, Faculty of Health Sciences; University of Nova Gorica, School of Environmental Sciences and IPS, Ljubljana

58. **Asst. Prof. Igor Kovač**, Fachhochschule Joaneum, Graz, Austria

59. **Prof. Janez Kovač**, University of Ljubljana, Faculty of Natural Sciences and Engineering and IPS, Ljubljana

60. **Asst. Prof. Petra Kralj Novak**, Central European University, Vienna, Austria

61. **Asst. Prof. Slavko Kralj**, University of Ljubljana, Faculty of Pharmacy

62. **Prof. Igor Križaj**, University of Ljubljana, Faculty of Chemistry and Chemical Technology, Biotechnical Faculty, Medical Faculty, IPS, Ljubljana

63. **Asst. Prof. Marjan Kromar**, University of Maribor, Faculty of Energy Technology

64. **Prof. Danjela Kuščer Hrovatin**, IPS, Ljubljana

65. **Prof. Zdravko Kutnjak**, University of Ljubljana, Faculty of Mathematics and Physics and Faculty of Mechanical Engineering, IPS, Ljubljana

66. **Prof. Nada Lavrač**, University of Nova Gorica, IPS, Ljubljana, University of Ljubljana

67. **Asst. Prof. Adrijana Leonardi**, University of Ljubljana, Biotechnical Faculty

68. **Prof. Darja Lisjak**, University of Nova Gorica, School of Science and IPS, Ljubljana

69. **Prof. Sonja Lojen**, University of Nova Gorica, School of Environmental Sciences, IPS, Ljubljana

70. **Prof. Boris Majaron**, University of Ljubljana, Faculty of Mathematics and Physics

71. **Prof. Darko Makovec**, University of Maribor, Faculty of Chemistry and Chemical Engineering and Faculty of Medicine, IPS, Ljubljana

72. **Prof. Barbara Malič**, IPS, Ljubljana

73. **Asst. Prof. Sabina Markelj**, IPS, Ljubljana

74. **Prof. Igor Mekjavić**, Simon Fraser University, British Columbia, Canada

75. **Asst. Prof. Alenka Mertelj**, University of Ljubljana, Faculty of Mathematics and Physics and IPS, Ljubljana

76. **Asst. Prof. Tomaž Mertelj**, University of Ljubljana, Faculty of Mathematics and Physics

77. **Prof. Dragan Dragoljub Mihailović**, University of Ljubljana, Faculty of Mathematics and Physics and IPS, Ljubljana

78. **Asst. Prof. Andrej Mihelič**, University of Ljubljana, Faculty of Mathematics and Physics

79. **Asst. Prof. Miha Mihovilovič**, University of Ljubljana, Faculty of Mathematics and Physics, Johannes Gutenberg Universität, Mainz, Germany

80. **Prof. Radmila Milačič**, IPS, Ljubljana

81. **Prof. Ingrid Milošev**, University of Zagreb, Croatia, Faculty of Chemical Engineering and Technology and IPS, Ljubljana

82. **Prof. Dunja Mladenić**, IPS, Ljubljana and University of Zagreb, Croatia, University of Ljubljana, Faculty of Education, University of Nova Gorica, University of Primorska, Koper

83. **Prof. Mihael Mohorčič**, IPS, Ljubljana

84. **Asst. Prof. Helena Motaln**, University of Ljubljana, Biotechnical Faculty

85. **Prof. Miran Mozetič**, IPS, Ljubljana

86. **Asst. Prof. Bojan Nemec**, IPS, Ljubljana

87. **Asst. Prof. Roman Novak**, IPS, Ljubljana

88. **Prof. Saša Novak Krmpotič**, IPS, Ljubljana

89. **Prof. Nives Ogrinc**, IPS, Ljubljana
90. **Asst. Prof. Mojca Otoničar**, IPS, Ljubljana
91. **Asst. Prof. Panče Panov**, Faculty of Information Studies, Novo mesto; IPS, Ljubljana
92. **Prof. Gregor Papa**, IPS, Ljubljana
93. **Asst. Prof. Matija Perne**, Faculty of Industrial Engineering, Novo mesto
94. **Prof. Rok Pestotnik**, University of Ljubljana, Faculty of Mathematics and Physics
95. **Prof. Toni Petan**, University of Ljubljana, Biotechnical Faculty, Faculty of Chemistry and Chemical Technology, IPS, Ljubljana
96. **Prof. Maja Ponikvar-Svet**, IPS, Ljubljana
97. **Asst. Prof. Gregor Primc**, IPS, Ljubljana
98. **Prof. Jože Pungerčar**, University of Ljubljana, Faculty of Medicine, IPS, Ljubljana
99. **Prof. Matthew Purver**, Queen Mary University of London, School of Electronic Engineering & Computer Science
100. **Asst. Prof. Aleksandra Rashkovska Koceva**, Faculty of Information Studies in Novo mesto
101. **Prof. Aleksander Rečnik**, IPS, Ljubljana
102. **Prof. Maja Remškar**, IPS, Ljubljana
103. **Asst. Prof. Peter Rodič**, IPS, Ljubljana
104. **Prof. Boris Rogelj**, University of Ljubljana, Faculty of Chemistry and Chemical Technology, Faculty of Pharmacy, Faculty of Medicine, Biotechnical Faculty
105. **Prof. Tadej Rojac**, University of Ljubljana, Faculty of Natural Sciences and Engineering, IPS, Ljubljana
106. **Prof. Igor Serša**, University of Ljubljana, Faculty of Natural Sciences and Engineering, IPS, Ljubljana
107. **Asst. Prof. Tomaž Skapin**, Jožef Stefan International Postgraduate School
108. **Prof. Borut Smodiš**, IPS, Ljubljana
109. **Prof. Luka Snoj**, University of Ljubljana, Faculty of Mathematics and Physics and Virginia Tech University, USA
110. **Prof. Matjaž Spreitzer**, University of Ljubljana, Faculty of Chemistry and Chemical Technology; IPS, Ljubljana
111. **Prof. Veronika Stoka**, IPS, Ljubljana
112. **Asst. Prof. Luka Šantelj**, University of Ljubljana, Faculty of Mathematics and Physics
113. **Prof. Janez Ščančar**, IPS, Ljubljana
114. **Asst. Prof. Srečo Davor Škapin**, IPS, Ljubljana
115. **Prof. Miha Škarabot**, University of Ljubljana, Faculty of Chemistry and Chemical Technology and Faculty of Mathematics and Physics
116. **Asst. Prof. Zdenka Šlejkovec**, IPS, Ljubljana
117. **Prof. Janez Štrancar**, University of Ljubljana, Faculty of Pharmacy, University of Maribor, Faculty of natural sciences and mathematics and IPS, Ljubljana
118. **Prof. Sašo Šturm**, IPS, Ljubljana
119. **Prof. Aleš Švigelj**, IPS, Ljubljana
120. **Asst. Prof. Gašper Tavčar**, IPS, Ljubljana
121. **Prof. Iztok Tiselj**, University of Ljubljana, Faculty of Mathematics and Physics
122. **Prof. Andrej Trkov**, University of Ljubljana, Faculty of Mathematics and Physics and University of Maribor, Faculty of Energy Technology
123. **Prof. Boris Turk**, University of Ljubljana, Biotechnical Faculty, Faculty of Chemistry and Chemical Technology and IPS, Ljubljana
124. **Prof. Dušan Turk**, University of Ljubljana, Faculty of Chemistry and Chemical Technology and Faculty of Medicine and IPS, Ljubljana
125. **Asst. Prof. Livija Tušar**, University of Maribor, Faculty of Agriculture and Life Sciences
126. **Asst. Prof. Tea Tušar**, IPS, Ljubljana, University of Trieste, Trieste
127. **Prof. Aleš Ude**, University of Ljubljana, Faculty of Electrical Engineering; IPS, Ljubljana
128. **Asst. Prof. Hana Uršič Nemevšek**, IPS, Ljubljana
129. **Prof. Olga Vasiljeva**, IPS, Ljubljana
130. **Prof. Janja Vaupotič**, University of Nova Gorica and IPS, Ljubljana
131. **Asst. Prof. Matjaž Vencelj**, University of Ljubljana, Faculty of Mathematics and Physics and IPS, Ljubljana
132. **Prof. Alenka Vesel**, IPS, Ljubljana
133. **Asst. Prof. Mojca Vilfan**, University of Ljubljana, Faculty of Mathematics and Physics
134. **Asst. Prof. Damir Vrančić**, Faculty of Industrial Engineering, Novo mesto, IPS, Ljubljana
135. **Prof. Boštjan Zalar**, IPS, Ljubljana
136. **Asst. Prof. Rok Zaplotnik**, IPS, Ljubljana
137. **Prof. Marko Zavrtanik**, University of Nova Gorica
138. **Prof. Aleksander Zidanšek**, University of Maribor, Faculty of Education, IPS, Ljubljana
139. **Asst. Prof. Benjamin Zorko**, IPS, Ljubljana
140. **Asst. Prof. Kristina Žagar Soderžnik**, IPS, Ljubljana
141. **Asst. Prof. Bernard Ženko**, Faculty of Information studies Novo mesto, Faculty of Industrial Engineering Novo mesto, IPS, Ljubljana
142. **Prof. Eva Žerovnik**, IPS, Ljubljana
143. **Prof. Matjaž Žitnik**, University of Ljubljana, Faculty of Mathematics and Physics
144. **Asst. Prof. Leon Žlajpah**, IPS, Ljubljana
145. **Asst. Prof. Martin Žnidaršič**, Faculty of Industrial Engineering, Novo mesto; IPS, Ljubljana
146. **Prof. Slobodan Žumer**, University of Ljubljana, Faculty of Mathematics and Physics
147. **Prof. Kristina Žužek Rožman**, IPS, Ljubljana

## Assistants and researchers

1. **Dr. Tilen Brecelj**, University of Ljubljana, Faculty of Mathematics and Physics
2. **Dr. Matjaž Depolli**, University of Novo mesto, Faculty of Mechanical Engineering
3. **Dr. Martin Draksler**, University of Ljubljana, Faculty of Mathematics and Physics
4. **Dr. Samir El Shawish**, University of Ljubljana, Faculty of Mathematics and Physics
5. **Dr. Blaž Fortuna**, IPS, Ljubljana
6. **Dr. Carolina Fortuna**, IPS, Ljubljana
7. **Dr. Dejan Gradišar**, University of Ljubljana, Faculty of Electrical Engineering; Faculty of Industrial Engineering, Novo mesto
8. **Dr. Radojko Jaćimović**, IPS, Ljubljana
9. **Dr. Peter Jeglič**, University of Ljubljana, Faculty of Mathematics and Physics
10. **Dr. Petra Jenuš**, IPS, Ljubljana
11. **Dr. Martin Klanjšek**, University of Ljubljana, Faculty of Mathematics and Physics
12. **Dr. Dragi Kocev**, IPS, Ljubljana
13. **Dr. Igor Lengar**, University of Maribor, Faculty of Energy Technology
14. **Dr. Matjaž Leskovar**, University of Ljubljana, Faculty of Mathematics and Physics
15. **Dr. Mitja Luštrek**, IPS, Ljubljana
16. **Dr. Aljaž Osojnik**, University of Ljubljana, Faculty of Mathematics and Physics
17. **Dr. Matej Petković**, University of Ljubljana, Faculty of Mathematics and Physics
18. **Dr. Senja Pollak**, IPS, Ljubljana
19. **Dr. Andrej Prošek**, University of Ljubljana, Faculty of Mathematics and Physics
20. **Dr. Vladimir Radulović**, University of Ljubljana, Faculty of Mathematics and Physics
21. **Dr. Adam Rambousek**, Faculty of Informatics, Masaryk University, Brno, Czech Republic
22. **Dr. Jošt Stergar**, University of Ljubljana, Faculty of Mathematics and Physics
23. **Dr. Špela Stres**, University of Ljubljana, Faculty of Electrical Engineering
24. **Dr. Andrej Šali**, IPS, Ljubljana
25. **Dr. Mitja Uršič**, University of Ljubljana, Faculty of Mathematics and Physics
26. **Dr. Jelena Vesić**, University of Ljubljana, Faculty of Mathematics and Physics
27. **Dr. Darko Vrečko**, University of Nova Gorica, School of Environmental Sciences
28. **Dr. Andrej Zorko**, University of Ljubljana, Faculty of Chemistry and Chemical Technology and Faculty of Mathematics and Physics
29. **Dr. Andrej Žohar**, University of Ljubljana, Faculty of Mathematics and Physics

IPS: Jožef Stefan International Postgraduate School, Ljubljana

FINANCING

REVENUES JSI (€) AND NUMBER OF PROJECTS

	2022	Contribution 2022	2021	Contribution 2021	Index 2022/2021	No. of Projects in 2022
National Agencies and Ministries	54,148,283	74.1 %	44,596,210	71.4 %	121.4	513
National Market	5,660,661	7.8 %	6,896,083	11.0 %	82.1	328
International Market	13,070,884	17.9 %	10,648,758	17.1 %	122.7	220
Other Revenues	146,524	0.2 %	309,334	0.5 %	47.4	
TOTAL	**73,026,352**	**100.0 %**	**62,450,385**	**100.0 %**	**116.9**	**1061**

Revenues 2021/2022 (€M))
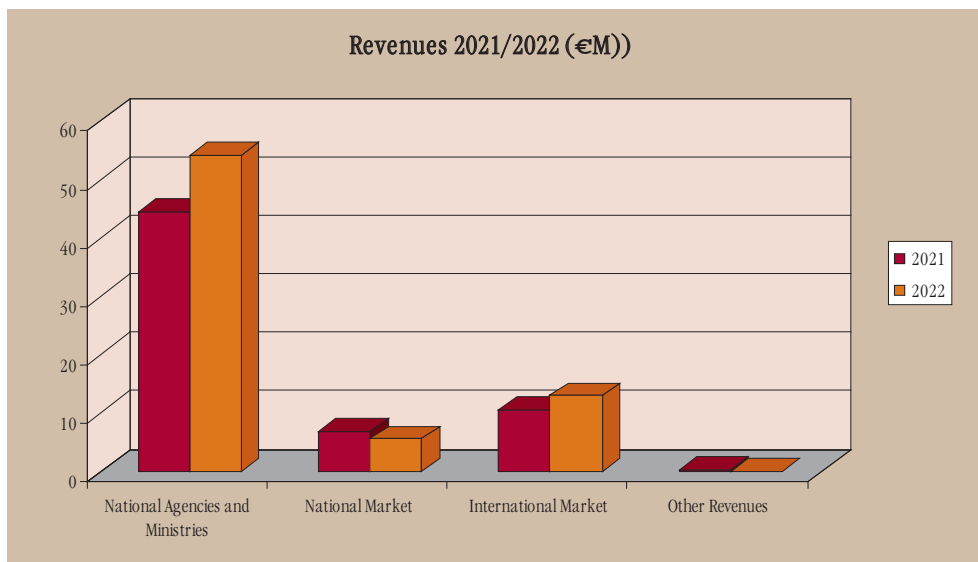
POSTGRADUATES FINANCED   1985-2022

by Slovenian Research Agency
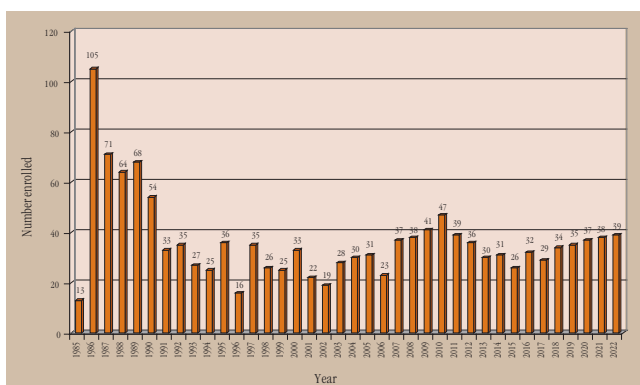
JSI UNDERGRADUATE SCHOLARSHIPS

1977-2022

Year	FMF		FKKT UNI LJ	FKKT UNI MB	NTF	FDV	FA	BF	FE and FRI	Other UNI LJ	FG and FERI	UNG	IPS	Total
	Physics	Mathematics												
... 1990	268	80	155					6	206	21	5			741
1991	23	2	9					2	24	2	1			63
1992	22	3	16					3	17	1				62
1993	21	1	15					3	13	1				54
1994	7	1	8					3	6					25
1995	2		9					3	5					19
1996	2		9					3	5					19
1997	2		12					1	4		1			20
1998	1		6					1	7		1			16
1999	2		7					4	7					20
2000	1		5					3	9					18
2001	3		13					3	10					29
2002	4		20					3	10					37
2003	3		18					2	12	1				36
2004	4		17					1	15	1	2	2		42
2005	3		12			1		2	19		2	1		40
2006	2		12			1		1	17		2	2		37
2007	3		14			1		2	18		2	1		41
2008	2	1	13	3		1		2	15		1	1		39
2009	2	1	17	4		1		5	16		1	2		49
2010	2		11	5	2	1	1	3	10		1	2	5	43
2011	2	1	11	5	4	1	1	4	7		1		6	43
2012	2		10	6	3	1		3	6				5	36
2013	3	2	3	2	1		1		2	2			6	22
2014	14	6	3		2		1		3	2			1	32
2015	21	6	4		1				9	1			10	52
2016	16	2	5						7	1			15	46
2017	11	2	4					2	7				12	38
2018	9	3	5					2	6	1	1		7	34
2019	16	1	5						7		1		12	42
2020	17	1	4						5	1			8	36
2021	19		3						5	1			6	34
2022	15	2	2						4	1			4	28
TOTAL	524	115	457	25	13	8	4	67	513	37	22	11	97	1893

FMF	Faculty of Mathematics and Physics, University of Ljubljana		**FE**	Faculty of Electrical Engineering, University of Ljubljana
FKKT (Uni-Lj)	Faculty of Chemistry and Chemical Technology, University of Ljubljana		**FRI**	Faculty of Computer and Information Science, University of Ljubljana
FKKT (Uni-Mb)	Faculty of Chemistry and Chemical Technology, University of Maribor		**FG**	Faculty of Civil Engineering, University of Maribor
NTF	Faculty of Natural Sciences and Engineering, University of Ljubljana		**FERI**	Faculty of Electrical Engineering and Computer Science, University of Maribor
FDV	Faculty of Social Sciences, University of Ljubljana		**UNG**	University of Nova Gorica
FA	Faculty of Administration, University of Ljubljana		**IPS**	Jožef Stefan International Postgraduate School
BF	Biotechnical Faculty, University of Ljubljana		**Other UNI LJ**	Faculty of Pharmacy, Faculty of Mechanical Engineering, Faculty of Economics, Faculty of Medicine, University of Ljubljana

PATENTS GRANTED

1. Jihed Khiari, Luis Moreira-Matias, Sašo Džeroski, Bernard Ženko, Method and system for model integration in ensemble learning, US11423336 (B2), US Patent Office, 23. 08. 2022

2. Marko Kazič, Nejc Lukač, Blaž Tašič Muc, Matjaž Lukač, Micro-pulsed liquid spray for cooling, US11490945 (B2), US Patent Office, 08. 11. 2022

3. Piotr J. Leszczyński, Adam Krzyszrof Budniak, Wojciech Marek Adamczyk, Jakub Henryk Gawraczyński, Tomasz Edward Gilewski, Piotr Połczyński, Rafał Jurczakowski, Wojciech Rafal Grochala, Zoran Mazej, Methods for obtaining salts of silver(II) and hydrates thereof, products obtained by the methods and use of the same, EP3347309 (B1), European Patent Office, 20. 07. 2022

4. Mirko Faccini, Morillo Martín, David Amantia, Danjela Kuščer, Darko Belavič, Tadej Rojac, A vibration system and a filtering plate for filtering substances, EP3454977 (B1), European Patent Office, 09. 02. 2022

5. Alenka Vesel, Miran Mozetič, Rok Zaplotnik, Gregor Primc, Nina Recek, Method of increasing the hydrophilicity of a surface of an object of polymer containing fluorine atoms, EP3757155 (B1), European Patent Office, 18. 05. 2022

6. Rok Zaplotnik, Miran Mozetič, Gregor Primc, Alenka Vesel, Masaru Hori, Methods for forming carbon nanostructured materials, EP3802418 (B1), European Patent Office, 08. 06. 2022

7. Piotr Połczyński, Rafał Jurczakowski, Piotr J. Leszczyński, Wojciech Rafal Grochala, Zoran Mazej, Method for electrosynthesis of silver (II) sulfate (VI) and the product obtained by this method, PL240270 (B1), Urząd Patentowy Rzeczypospolitej Polskiej, 07. 03. 2022

8. Ksenija Rener-Sitar, Ita Junkar, Uroš Cvelbar, Miran Mozetič, Method for improving the bonding of dental silicate ceramics with composite cements, SI26082 (A), Slovenian Intellectual Property Office, 29. 04. 2022

9. Alenka Vesel, Nives Ogrinc, Method for functionalization of polyolefins with simultaneous combination of nitrogen and oxygen functional groups, SI26091 (A), Urad RS za intelektualno lastnino, 29. 04. 2022

10. Matic Korent, Marko Soderžnik, Urška Ročnik, Karla Kosmač, Zoran Samardžija, Boris Saje, Spomenka Kobe, Procedure for improving the magnetic properties of MQP-B+Nd-Fe-B magnetic powders with a small proportion of intergranular phase and a process for making polymer-bonded magnets from these magnetic powders, SI26141 (A), Slovenian Intellectual Property Office, 29. 07. 2022

ART EXHIBITIONS AT THE JSI

Ančka Gošnik Godec, 10. January–14. February

Dušan Fišer, 14. February–21. March

Zoran Didek, 21. March–19. April

Anja Kranjc, 19. April–9. May

Tomo Vran, 9.–30. May

Boštjan Banfi, 30. May–27. June

Jur Samec, 27. June–21. July

Janez Korošin, 25. July–2. September

Nataša Tajnik Stupar, 5.–29. September

Mojca Fo, 3. October–3. November

Andrej Brumen Čop, 7. November–1. December

Danijel Demšar, 5. December–5. January 2023

Danijel Demšar at the opening of his exhibition

REVIEW OF PUBLICATIONS

FOR 2022

Department	Original Articles*	Books	Patent Appl. and Grants	Ph. D. Theses
Department of Theoretical Physics (F-1)	69			2
Department of Low and Medium Energy Physics (F-2)	68			1
Department of Thin Films and Surfaces (F-3)	9			
Department of Surface Engineering and Optoelectronics (F-4)	58		5	2
Department of Solid State Physics (F-5)	136	4		9
Department of Gaseous Electronics (F-6)	43		1	1
Department for Complex Matter (F-7)	63		1	3
Department of Reactor Physics (F-8)	74	1		4
Department of Experimental Particle Physics (F-9)	86			1
Department of Inorganic Chemistry and Technology (K-1)	45		2	1
Department of Physical and Organic Chemistry (K-3)	14			2
Electronic Ceramics Department (K-5)	55		1	3
Department for Nanostructured Materials (K-7)	51		1	2
Department for Synthesis of Materials (K-8)	25			1
Department for Advanced Materials (K-9)	50			1
Department of Biochemistry, Molecular and Structural Biology (B-1)	16			1
Department of Molecular and Biomedical sciences (B-2)	14			
Department of Biotechnology (B-3)	34		1	3
Department of Environmental Sciences (O-2)	103		1	8
Department of Automation, Biocybernetics and Robotics (E-1)	42			3
Department of Systems and Control (E-2)	19			
Artificial Intelligence Laboratory (E-3)	75			
Laboratory for Open Systems and Networks (E-5)	11			
Department of Communication Systems (E-6)	54			1
Computer Systems Department (E-7)	44	1		1
Department of Knowledge Technologies (E-8)	115	1	1	9
Department of Intelligent Systems (E-9)	41			
Department of Reactor Engineering (R-4)	34			1
Reactor Infrastructure Centre (RIC)	5			
Networking Infrastructure Centre (NIC)	4			
Energy Efficiency Centre (EEC)	8			
Centre for Electron Microscopy and Microanalysis (CEMM)	6			
Centre for Knowledge Transfer in Information Technologies (CT-3)	1			
Milan Čopič Nuclear Training Centre (ICJT)	4			
Centre for Technology Transfer and Innovation (CTT)	3			
Jožef Stefan Institute	1301	7	12	54

* Articles in Journals and Conference Proceedings, and Chapters in Books

COMPLETED THESES UNTIL 2022

Year	Ph. D. Theses	Year	Ph. D. Theses
...2000	560	2012	47
2001	31	2013	56
2002	29	2014	51
2003	41	2015	44
2004	31	2016	42
2005	22	2017	29
2006	22	2018	32
2007	26	2019	26
2008	29	2020	39
2009	30	2021	22
2010	33	2022	54
2011	31	TOTAL	1267
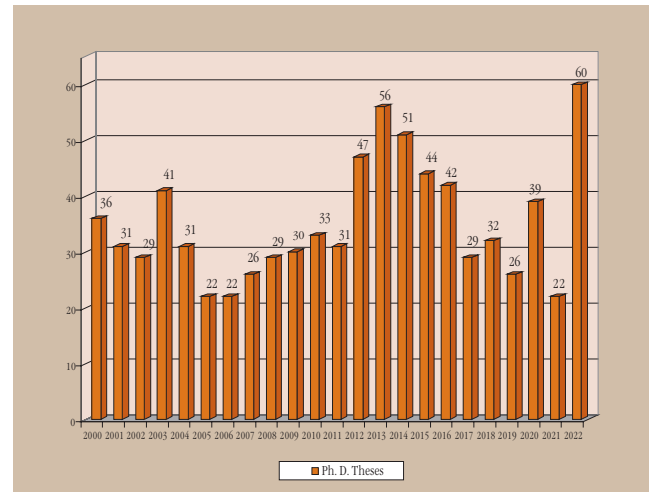
AWARDS AND APPOINTMENTS

AWARDS GIVEN TO JSI RESEARCHERS BY THE REPUBLIC OF SLOVENIA

Zois and Puh Awards and Zois Certificate of Recognition

Ester Heath
Presented with the Zois Award for outstanding achievements in the use of organic analysis in the fields of environment, food and health

Nada Lavrač
Presented with the Zois Award for outstanding scientific achievements in the field of machine learning

Uroš Stanič
Presented with the Puh Lifetime Achievement Award for work in the field of functional electrical stimulation and robotisation

Rok Žitko
Presented with the Puh Certificate of Recognition for developing the theory of nanoscale quantum systems

Special recognition

Leon Cizelj and Matjaž Leskovar
Commemorative coin for dedication in the fight against COVID-19

The winners of Zois anf Puh Awards and Zois Certificate of Recognition: Prof. Rok Žitko, Prof. Nada Lavrač, Prof. Ester Heath and Prof. Uroš Stanič

JSI AWARDS AND APPOINTMENTS

Blinc Award

Alojz Kodre
Blinc Award for lifetime achievements in physics

Enej Ilievski
Blinc award for outstanding achievement in physics

Matjaž Humar
Blinc Award for physicist at the beginning of their career

The Jožef Stefan Golden Emblem Prize

presented to the following for doctoral theses with high impact :

Pavel Kos
Exact solutions of many-body quantum chaotic systems

Žiga Kos
Microfluidic structures from nematic liquid crystals

Matija Gatalo
Synthesis development of binary and ternary alloy nanoparticles of platinum on carbon

The Jožef Stefan Roll of Honour

was awarded for their successful contribution to developing new high-tech products based on scientific and technological achievements of the Jožef Stefan Institute:

Rafael Kitak, Dito, d.o.o.
Srečko Bizjak, Dito, d.o.o.
Dito, d.o.o., Gorica pri Slivnici
Eles, d.o.o., Ljubljana
Janko Kosmač, Eles, d.o.o.
Uroš Salobir, Eles, d.o.o.
Gorenje, d.o.o., Velenje
Samo Gazvoda, Gorenje, d.o.o.
Kolektor Group, d.o.o., Idrija
Boris Saje, Kolektor Group, d.o.o.
Karla Kosmač, Kolektor Group, d.o.o.
Ludvik Kumar, Kolektor Group, d.o.o.
Unior, d. d., Zreče
Jože Ravničan, Unior, d. d.

OTHER SELECTED AWARDS TO JSI RESEARCHERS

2022 European Heritage Awards / Europa Nostra Awards, H2020 Silknow project, European Heritage Europa Nostra

Europa Nostra Grand Prix Award, H2020 Silknow project, Prague, Czech Republic

Aleš Berlec, Recognition of the work in the editorial board of the journal Acta Chimica Slovenica, Slovenian Chemical Society

The winners of the Jožef Stefan Golden Emblem Prize (from left): Dr. Pavel Kos, Dr. Žiga Kos and Prof. Nejc Hodnik (Dr. Matija Gatalo did not attend)

Blaž Bertalanič, **Gregor Cerar**, **Carolina Fortuna**, **Halil Yetgin**, Student Best Paper Award, Bologna, Italy, WiMob'2021, "A Deep Learning Model for Anomalous Wireless Link Detection".

Veronika Bračič (student of the Faculty of Chemistry and Chemical Technology, University of Ljubljana) received a commendation at the 52. Fund of Krka awards. Contribution entitled "Corrosion protection of aluminium alloy by conversion and sol-gel coating" was conducted under the supervision of doc. dr. Petra Rodič.

Oana-Andreea Condurache, Student Award for the contribution: Monitoring Bismuth Ferrite Domain Walls Behavior Under Electric Field With Atomic Resolution by In Situ Scanning Transmission Electron Microscopy, Organization board of the conference: Microscopy & Microanalysis 2022

Miran Čeh is the recipient of the "Spiridion Brusina" award for cooperation with Croatian scientists in the field of natural history and promoting Croatian science in the world. The award is given by the Croatian Naturalist Society from Zagreb, Croatia.

Jean-Marie Dubois is the recipient of the Stoddart International Science Award (named after Sir Frazer Stoddart, Nobel Laureate in Chemistry) for lifetime achievement in materials science. The award is presented by Flogen Star Outreach (a non-profit organization) at the SIPS 2022 Congress in Phuket, Thailand.

Jernej Ekar, ECASIA Student Travel Grant, Limerick, Ireland, European Association on Applications of Surface and Interface Analysis, 19th ECASIA conference, award for the lecture entitled Reduction of Matrix Effect in ToF-SIMS Depth Profiling via $H_{2 \, Flooding}$

Martin Gjoreski, **Mitja Luštrek**, 2020 Best Paper Runner-up Award for IEEE Pervasive Computing, virtual, IEEE Computer Society, paper "Veljko Pejović, Martin Gjoreski, Christoph Anderson, Klaus David, Mitja Luštrek. Toward Cognitive Load Inference for Attention Management in Ubiquitous Systems. IEEE Pervasive Computing 19, 2020

Matjaž Gomilšek, the ceremonial charter for young university teachers and associates for dedicated and innovative teaching and research work, University of Ljubljana

Katja Gosar, **Uroš Seljak** prizes for the best scientific publications by students, Ljubljana, University of Ljubljana and the American-Slovenian Educational Foundation, the prize for her scientific publication "Single-shot Stern-Gerlach magnetic gradiometer with an expanding cloud of cold cesium atoms" in *Physical Review A*

Anton Gradišek, Prometheus in Science Award, Ljubljana, The Slovenian Scientific Foundation, editors of the online magazine *Alternator*, the award for a people-friendly presentation of research achievements in the online form of a magazine for science and about science published by ZRC SAZU

Anton Gradišek, **Anja Pogačnik Krajnc**, **Luka Pirker**, **Maja Remškar**, Prometheus of Science, Ljubljana, Slovenian Science Foundation, for "extensive professional communication to the public about the results of the testing of protective masks from various manufacturers"

Ester Heath, **David Heath**, **Ana Kovačič and David Škufca**, Excellent in Science 2022 (Medicine), ARRS, Modern Organic Pollutants – How Can We Control Them with Algae?

Aljaž Kavčič, Dr. Uroš Seljak prizes for the best scientific publications by students, Ljubljana, University of Ljubljana and the American-Slovenian Educational Foundation, the prize for his scientific publication "Deep tissue localization and sensing using optical microcavity probes" in *Nature Communications*

Boshko Koloski and Ilija Tavchioski won the first place in the DragonHack 2022 competition in the general category and the category Best Google Cloud Hack. They won by presenting a creative solution to the problem of removing bulky waste. Source: https://sta.si/3040708/razglaseni-zmagovalci-tekmovanja-v-uporabi-programske-in-strojne-opreme-dragonhack

Špela Koren, Krka Pharmaceutical Commendation Prize, Krka d.d., Novo mesto, Master thesis entitled "Links between lipid droplets and autophagy in stressed cancer cells", Novo mesto, Slovenia

Žiga Kos, best research achievements of the University of Ljubljana, Ljubljana, University of Ljubljana, the award for his paper "Nematic bits and universal logic gates" in *Science Advances*

Domen Kotnik, Young author award, Portorož, "31st International Conference Nuclear Energy for New Europe – NENE 2022", September 2022, for the paper "Analysis of water activation loop at the JSI TRIGA research reactor" co-authored by Anil Kumar Basavaraj, Igor Lengar

Samo Kralj, the award for outstanding accomplishments in research, Maribor, University of Maribor, The Faculty of Natural sciences and Mathematics

Benjamin Krull, Ronald Lehnigk, Richard Meller, Fabian Schlegel, Matej Tekavčič, Best paper award, 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics - NURETH 19, "OpenFOAM hybrid – a morphology adaptive multifield two-fluid model"

Pasquale Lisena, Daniel Schwabe, Marieke van Erp, Raphaël Troncy, William Tullett, Inger Leemans, Lizzie Marx, Best Resources Paper, Heraklion, Greece, ESWC conference

Barbara Malič, Ferroelectric Recognition Award 2022 of the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society (UFFC-S) for the outstanding contributions to the elucidation of the relationships between chemical and physical properties in ferroelectric, Ultrasonics, Ferroelectrics and Frequency Control Society (UFFC-S) in the frame of Institute of Electrical and Electronics Engineers (IEEE)

Biljana Mileva Boshkoska received the 2022 IFIP Service award for outstanding contributions to the IFIP and the informatics community

Ana Mitrović, Lapanje recognition for outstanding scientific research and professional achievements in the field of biochemical sciences, Slovensko biokemijsko društvo, Ljublj-ana, Slovenija

Ana Mitrović, Excellent in Science 2022, Ljubljana, Slovenija, Slovenian Research Agency, for paper "Evaluation of novel cathepsin-X inhibitors in vitro and in vivo and their ability to improve cathepsin-B-directed antitumor therapy"

Jernej Mlinarič, awarded with the PCT technology network award (Process Control Technology) for his master's thesis entitled "Diagnostics and prognostics of electromechanical systems based on mechanical, electrical, vibrational and acoustic signals", Ljubljana, Slovenia

Aleš Mohorič, recognition of his rich professional activity and long-term editorial work for the magazine *Presek* and other publications, Ljubljana, Society of mathematicians, physicists and astronomers of Slovenia

Klemen Motaln, Best presentation by a young scientist, 28th Croatian-Slovenian Crystallographic Meeting, Sept. 2022, Poreč, Croatia

Klemen Motaln, Best abstract in the field of Nanosciences and Nanotechnologies, 14th Jožef Stefan International Postgraduate School Students' Conference, Jun. 2022, Kamnik, Slovenia

Miran Mozetič, WIPO medal for inventors (World Intellectual Property Organization)

Sebastjan Nemec, Dean's award for the publication of research article entitled A versatile interfacial coassembly method for fabrication of tunable silica shells with radially aligned dual mesopores on diverse magnetic core nanoparticles in high impact factor scientific journal ACS Applied Materials & Interface, Faculty of pharmacy, University of Ljubljana.
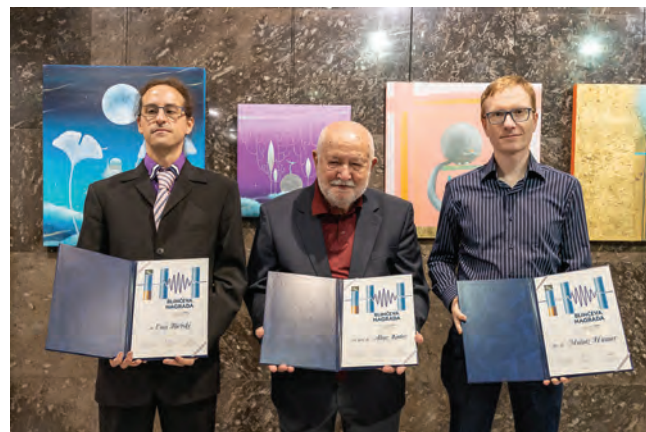
The Blinc award is conferred by the Jožef Stefan Institute and the Faculty of Mathematics and Physics, University of Ljubljana. The winners of the Blinc awards (from left): Dr. Enej Ilievski, Prof. Alojz Kodre and Asst. Prof. Matjaž Humar

Peter Nimac, Prešeren Award for students, Ljubljana, Faculty of Electrical Engineering, University of Ljubljana, Design and implementation of smart traffic light radar

Saša Novak Krmpotič is the recipient of the honorary annual title "Science Communicator 2022" in the field of the importance of communicating science to the public, awarded by the Slovenian Science Foundation.

Gregor Papa, Marina Santo Zarnik, Vida Vukašinović received the ARRS Excellence in Science 2022 in the field of engineering for the scientific article: "Electric-bus routes in hilly urban areas: overview and challenges. Renewable & sustainable energy reviews"

Tina Vida Plavec, Krka Prize for doctoral dissertation, Krka d.d., Novo mesto, Slovenija, Surface display of tumor antigen binders on *Lactococcus lactis* NZ9000 and evaluation of their binding to selected human tumor cell lines

Rok Poličnik, Katja Rostohar, Barbara Koroušić Seljak, Barbara Blaznik, Jerneja Farkaš Lainščak received the ARRS Excellent in Science 2022 in the field of public health for research work: " Energy and nutritional composition of school lunches in Slovenia: the results of a chemical analysis in the framework of the national school meals survey

Kity Požek, Krka Award, Novo mesto, Krka d.d. Novo mesto, Master's thesis entitled "Isolation and characterization of the VaaMPIII-3 protein from the venom of the nose-horned viper"

Kity Požek, Prešeren Prize for Students of the University of Ljubljana, University of Ljubljana, Ljubljana, Master's thesis entitled "Isolation and characterization of the VaaMPIII-3 protein from the venom of the nose-horned viper"

Alja Prah, Pregl award for exceptional doctoral thesis entitled "Exploring the role of electrostatic interactions in monoamine oxidase enzyme catalysis using a multiscale computational model", National Institute of Chemistry, Ljubljana

In the contribution "Tracking Changes in ESG Representation: Initial Investigations in UK Annual Reports", Matthew Purver and Senja Pollak, together with colleagues of the project "Quantitative and qualitative analysis of unregulated parts of financial reporting of companies", analysed the texts of English annual reports from the

point of view of environmental, social and management factors. They received the recognition for the best contribution at the workshop "The First Computing Social Responsibility Workshop-NLP Approaches to Corporate Social Responsibilities" which was part of the LREC 2022 conference. Source: https://aclanthology.org/2022.csrnlp-1.2

Aleksandra Rashkovska Koceva, **Roman Trobec**, Excellent in Science 2021, ARRS, "Personalized management of hidden temperature variables in real-time therapeutic cooling of the knee".

Anna Razumnaya, Seal of Excellence, Brussels, Belgium, the award for the project proposal "Tunable topological chirality in ferroelectric nanomaterials", Horizon Europe

Aleksander Rečnik is the recipient of an honorary award for long-term cooperation and assistance with the doctoral program at the University of Pannonia in Veszprém. The prize is awarded by the Senate of the University of Pannonia, Veszprém, Hungary.

Maja Remškar, **Anton Gradišek**, **Luka Pirker**, **Anja Pogačnik Krajnc**, Prometheus in Science Award, Ljubljana, The Slovenian Scientific Foundation, the award for extensive, professional and irreproachable information to the public about the results of testing protective masks from various manufacturers

Barbara Repič, Best Contribution in Sensor Technology Award for the presentation entitled: Preparation and Electrochemical Characterization of Screen-Printed Graphite Electrodes, Organization Board of 14th Student Conference of Jožef Stefan Postgraduate School

Vesna Ribić is the recipient of the award for the best article entitled: New inversion boundary structure in Sb-doped ZnO predicted by DFTcalculations and confirmed by experimental HRTEM (published in the journal Acta Materialia), awarded by the Scientific Council of the Institute for Multidisciplinary Research in Belgrade, Serbia.

Sorour Semsari Parapari is the recipient of the 2nd best oral presentation at the ELMINA international conference entitled: Heterogeneous Electrochemical Dissolution of Gold Nanoparticles Observed via In-situ Liquid TEM, awarded by the Serbian Academy of Sciences and Arts and the Faculty of Technology and Metallurgy of the University of Belgrade, Serbia.

Sorour Semsari Parapari is the recipient of the European Society for Microscopy scholarship at the 16th MCM (Multinational Microscopy Congress) conference in Brno, Czech Republic, awarded by the European Society for Microscopy.

Emanuela Senjor, Excellent in Science 2022, Ljubljana, Slovenija, Slovenian Research Agency, for paper: Infiltrating natural killer cells bind, lyse and increase chemotherapy efficacy in glioblastoma stem-like tumorospheres. Breznik B et. al, Communications biology.

Vasyl Shvalya, et al., Plasmonic surfaces for the recognition of mycotoxins, Excellence in Science 2022, ARRS.

Gašper Slapničar, Best paper award, Slovenian Conference on AI, Ljubljana, paper "Gašper Slapničar, Peter Us, Erna Alukić, Nejc Mekiš, Miha Mlakar, Janez Žibert. IMF Quality Assurance of Mammograms Using Deep Convolutional Neural Networks and Transfer Learning"

Anja Stajnko, **Agneta A. Runkel**, **Tina Kosjek**, **Janja S. Tratnik**, **Darja Mazej**, **Ingrid Falnoga and Milena Horvat**, Excellent in Science 2022 (Interdisciplinary Research Field), ARRS, Assessment of Susceptibility to Phthalate and DINCH Exposure via Single Nucleotide Polymorphisms in Genes Encoding CYP and UGT Enzymes, 2022

Marjan Stoimchev received the award for the best contribution to the ICT program at the event "The 14th Jožef Stefan International Postgraduate School Students Conference" (IPSSC) in Kamnik, Slovenia.

Spase Stojanov, "Alessandro de Vita", Trieste, Italia, Crossnano workshop, Recognition for a high level of scientific multidisciplinarity

Lidija Strojnik, Best poster award, Rafa 2022, 10th Intenational Symposium in Food Analysis, Praga Tracing the geographical origin of fruits and vegetables: the Slovenian model, 2022

The doctoral student **Hanh Thi Hong Tran** with her colleagues and mentor Senja Pollak won first place in the TextGraphs-16 Natural Language Premise Selection Task competition, situated in the field of natural language understanding for the area of mathematical logic. The goal of the task was the automatic extraction of relevant premises for proving the given mathematical propositions. The approach with contextual text representations and transformer architecture models was proven to be more effective than statistical approaches. Link to the article: https://aclanthology.org/2022.textgraphs-1.12/

Melita Tramšek, Prometheus of Science Awards for Excellence in Communication for 2021

Melita Tramšek, Award for work in the editorial office of the journal Acta Chimica Slovenica, Slovenian Chemical Society Annual Meeting 2022, Sept. 2022, Portorož, Slovenia

Ana Marija Udovič, Würdigungspreis 2022 – award for best diploma and master's degrees, Vi-enna, Austria, awarded by The Federal Ministry of Education, Science and Research, for the academic performance and master's degree The Role of Bicycling for the Resilience and Sustainability of Transport in Urban Areas in the Post-COVID-19 World

Erik Uran, 3rd Place Prize at the Student Paper Contest, Slovenian Chemical Society Annual Meeting 2022, Sept. 2022, Portorož, Slovenia

Erik Uran, Best Poster Award, 20th European Symposium on Fluorine Chemistry, Aug. 2022, Berlin, Germany

Erik Uran, Best Student Oral Presentation Award, 4th International Congress of Chemists and Chemical Engineers of Bosnia and Herzegovina, Jul. 2022, Sarajevo, Bosnia and Hercegovina

Eva Valenčič, University of Newcastle PhD Student Best Paper Award: "Digital Nudging in Online Grocery Stores: A Scoping Review on Current Practices and Gaps", Newcastle, Australia, December 2022

Taja Verovšek, Best Oral Presentation by Young Researcher, 26th International symposium on Separation Sciences, 2022

Abida Zahirović, The second-best short oral presentation award, Paris, France, International Society of Microbiota, Recombinant Lactic Acid Bacteria for Therapy of Inflammatory Bowel Disease

Andrej Zorko, 2022 Science Impact Award, Great Britain, the award for the article "The Ising triangular-lattice antiferromagnet neodymium heptatantalate as a quantum spin liquid candidate" in *Nature Materials*, Science and Technology Facilities Council

Mark Zver, Best Contribution Recognized by Peers Award, Kamnik, Jožef Stefan International Postgraduate School, for the presentation entitled Creating antimicrobial surfaces via advanced functionalization techniques

Katarina Žiberna, Best Poster Award among the top three in the Materials Science section, Organization Board at 16th Multinational Congress on Microscopy

Slobodan Žumer, The Pierre Gilles de Gennes ILCS Prize, Lisbon, Portugal, in recognition of his creative explorations and breakthrough contributions to the understanding of soft matter, in particular, liquid crystals, liquid crystal-colloidal and liquid crystal-polymer hybrid systems, The International Liquid Crystal Society

Slobodan Žumer, Outstanding referee for the journals of APS, American Physical Society

INSTITUTE COLLOQUIA

January 12, 2022: **Rok Žitko**
Jožef Stefan Institute, Faculty of Mathematics and Physics, University of Ljubljana
From quantum impurities to quantum devices

March 16, 2022: **Paolo Giubellino**
Joerg Blaurock, GSI and FAIR, Darmstadt, Germany
FAIR – the universe in the lab

March 21, 2022: **Griša Močnik**
University of Nova Gorica, Jožef Stefan Institute, Haze Instruments d.o.o.
Light absorption in aerosols affects climate – how do we measure it?

March 21, 2022: **Luka Drinovec**
University of Nova Gorica, Jožef Stefan Institute, Haze Instruments d.o.o.
Measurement of aerosol absorption with a photothermal interferometer

March 22, 2022: **Goran Dražić**
National Institute of Chemistry and Jožef Stefan Institute
What does a black and white picture of atoms tell us?

March 23, 2022: **Borka Jerman Blažič**
Jožef Stefan Institute
Challenges of the internet of the future: security, connectivity and humanity aspects

March 24, 2022: **Tamim Asfour**
Karlsruhe Institute of Technology (KIT), Germany
Humanoid robotics – understanding human performance and intelligence

May 5, 2022: **Peter Fantke**
Technical University of Denmark, Denmark
Modelling chemical pollution to support a safe and sustainable chemicals management

June 15, 2022: **Stephen M. Morris**
University of Oxford, United Kingdom
Additive manufacturing and liquid crystal technologies

September 7, 2022: **Thomas Rockwell Mackie**
University of Wisconsin, USA
Innovations in radiation medicine

September 21, 2022: **Bogdan Parakhonskiy**
Ghent University, Belgium
Geo-inspired ceramic carriers: from design to medical applications

October 26, 2022: **Geoff Brennecka**
Colorado School of Mines, USA
Processing matters: materials challenges for the second quarter of the 21st century

November 10, 2022: **Saša Prelovšek Komelj**
Jožef Stefan Institute and Faculty of Mathematics and Physics, University of Ljubljana
Usual and unusual states made of quarks

November 16, 2022: **Tadej Rojac**
Jožef Stefan Institute
Domain-wall dynamics in ferroelectric and relaxor-based ceramics

November 23, 2022: **Alojz Kodre**
Faculty of Mathematics and Physics, University of Ljubljana
In the depths of the atom

December 1, 2022: **Atish Dabholkar**
International Centre for Theoretical Physics (ICTP), Trieste, Italy
Quantum black holes: an encounter between Hawking and Ramanujan

December 7, 2022: **Enej Ilievski**
Faculty of Mathematics and Physics, University of Ljubljana
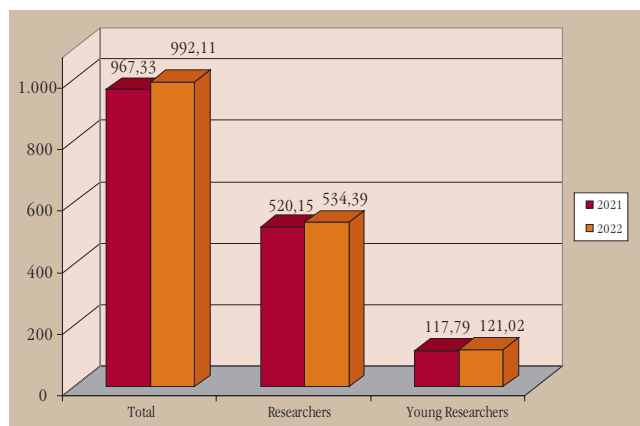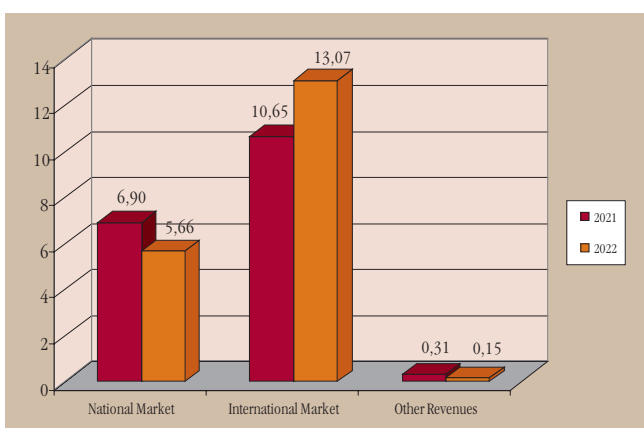***Superdifusion in a Heisenberg magnetic chain***

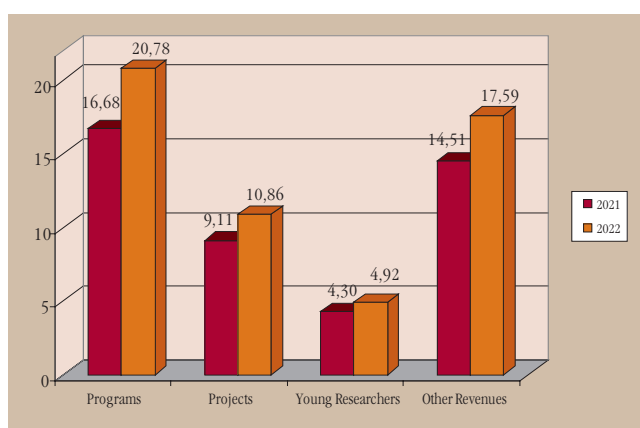# INSTITUTE IN NUMBERS 2021–2022

COMPARISON OF REVENUES (€M)

Public Services — 2021: 44,60; 2022: 54,15
Other Activities — 2021: 17,85; 2022: 18,88
Total Revenues — 2021: 62,45; 2022: 73,03

EMPLOYEES (FTE)

Total — 2021: 967,33; 2022: 992,11
Researchers — 2021: 520,15; 2022: 534,39
Young Researchers — 2021: 117,79; 2022: 121,02
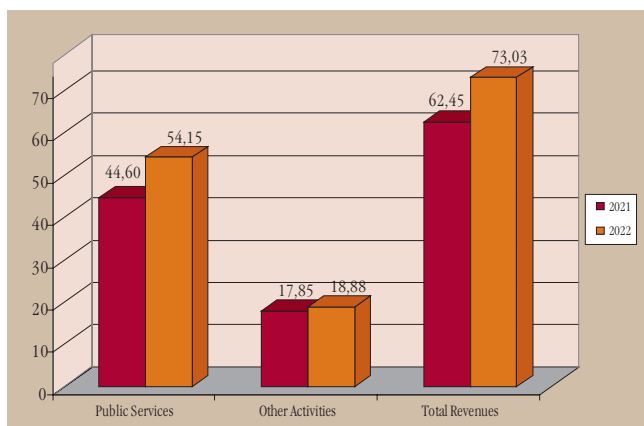
REVENUES FROM OTHER ACTIVITIES (€M)

National Market — 2021: 6,90; 2022: 5,66
International Market — 2021: 10,65; 2022: 13,07
Other Revenues — 2021: 0,31; 2022: 0,15

REVENUES FROM PUBLIC SERVICES (€M)

Programs — 2021: 16,68; 2022: 20,78
Projects — 2021: 9,11; 2022: 10,86
Young Researchers — 2021: 4,30; 2022: 4,92
Other Revenues — 2021: 14,51; 2022: 17,59

NUMBER OF PUBLICATIONS IN THE WEB OF SCIENCE*

2013: 970; 2014: 978; 2015: 1065; 2016: 1137; 2017: 1160; 2018: 1126; 2019: 1206; 2020: 1203; 2021: 1313; 2022: 1058
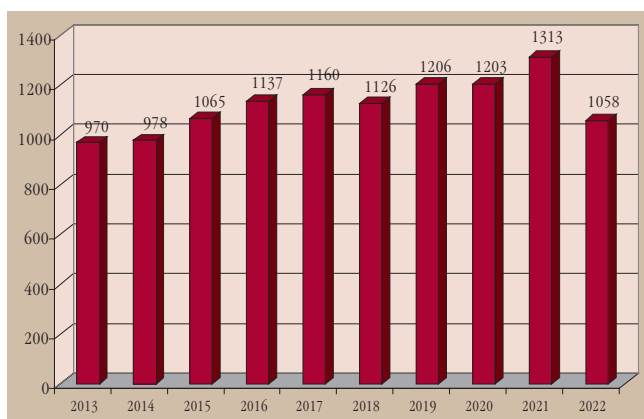
* retrieved 3 November 2023

NUMBER OF CITATIONS IN THE WEB OF SCIENCE*

2013: 24966; 2014: 27657; 2015: 31037; 2016: 35956; 2017: 37153; 2018: 39441; 2019: 43808; 2020: 47076; 2021: 54023; 2022: 50767
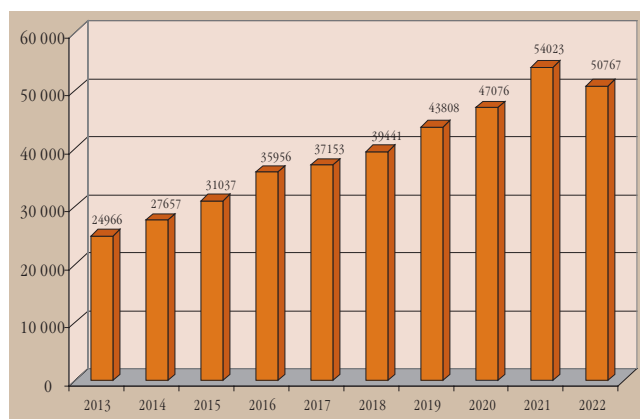
* retrieved 3 November 2023

NUMBER OF EMPLOYEES,
BY TYPE OF STAFF AND GENDER*
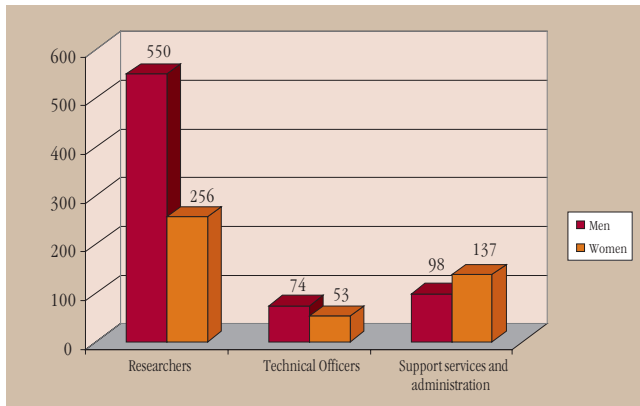
* retrieved 31 December 2022

NUMBER OF RESEARCHERS,
BY SCIENTIFIC FIELDS AND GENDER*
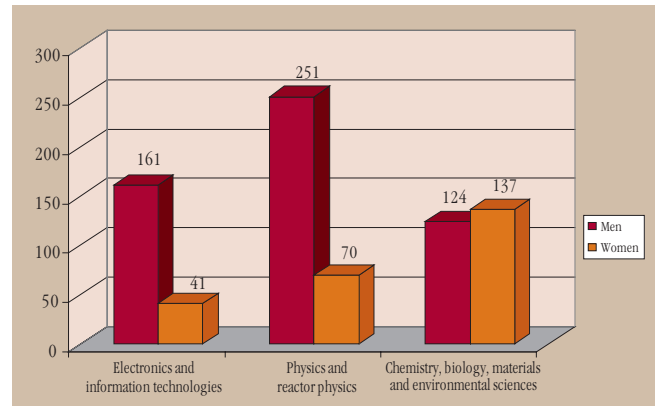
* retrieved 31 December 2022

SHARE OF JSI EMPLOYEES AND MEMBERS OF DECISION-MAKING AND
LEADERSHIP BODIES, BY GENDER*

	Number	Men	Women
Scientific Council	15	80 %	20 %
Board of Governors	9	78 %	22 %
Heads of departments and centres	38	84 %	16 %
JSI TOTAL	1170	62 %	38 %
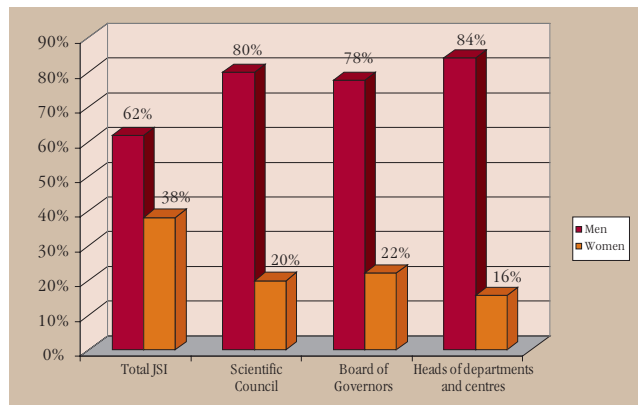
* retrieved 31 December 2022

RESEARCH DEPARTMENTS

DEPARTMENT OF THEORETICAL PHYSICS

F-1

In 2022 members of the programme group THEORY OF NUCLEI, ELEMENTARY PARTICLES AND FIELDS continued with their research on the physics of quark and lepton flavours and CP violation, particle phenomenology at high-energy colliders, unified theory of gauge interactions, neutrino physics, particle astrophysics and cosmology, as well as research in nuclear and hadron physics using quantum chromodynamics on the lattice, and machine learning in high-energy physics with an emphasis on physics beyond the standard model.

Head:
Prof. Jernej Fesel Kamenik

We studied the impact of triple-leptoquark interactions on the matter stability for two specific proton-decay topologies that arise at the tree- and one-loop level if and when they coexist. We demonstrated that the one-loop level topology is much more relevant than the tree-level one regarding the proton-decay signatures. We discussed a model that can accommodate the B-physics anomalies by combining two scalar leptoquarks of mass in the TeV region. We updated the analysis of its parameter space and showed that a model remains viable and consistent with several low-energy and high-energy flavour-physics constraints.

We contributed to a community report on the potential of the LHCb experiment to detect dynamics beyond the standard model that would elude searches that focused on energetic objects or precision measurements of known processes.

We proposed a novel statistical method for disentangling the 4-top signal from the dominant backgrounds in the same-sign dilepton channel at the LHC while simultaneously correcting possible Monte Carlo simulation imperfections in the modelling of the most relevant discriminating observables – the jet multiplicity distributions.

We introduced a physics-inspired variational autoencoder (VAE) architecture, which performs competitively and robustly on the LHC Olympics Machine Learning Challenge datasets.

Using the AdS/CFT correspondence, we modelled the behaviour of the two-point correlator of an operator with arbitrary scale and spacetime dimensions for a low but non-zero temperature. We studied the phase diagram of an E6 grand unified theory with a 650 dimensional scalar field, which allows vacua with symmetries $SU(3)^{\prime 3}$, $SO(10)xU(1)$ and $SU(6)xSU(2)$.

We calculated the false vacuum decay rate at one loop, including the one-loop quantum corrections. We found an analytical expression for the semi-classical action in an arbitrary dimension, together with higher-order corrections. We moved on to the fluctuations and calculated closed-form expressions for arbitrary multipoles that were summed up in a closed form.

We found the first ab-initio theoretical evidence for the longest-lived exotic state Tcc+ composed of quarks, experimentally discovered at CERN by the LHCb collaboration in July 2021. The state consists of two charm quarks together with antiquarks u and d. It contains more than three quarks and therefore represents an exotic hadron.

We studied general features of the effective range expansion for pertinent near-threshold exotic states in the presence of coupled channels, isospin violations and unstable constituents. The developed approach is applied to the state Tcc+. We identified and investigated a possible generic mechanism for the formation of near-threshold molecules through the

- **We studied Standard Model extensions with scalar leptoquarks.**
- **We proposed a novel statistical method for disentangling the 4-top signal from the dominant backgrounds in the same-sign dilepton channel at the LHC.**
- **We computed the first two corrections of the small temperature expansion of the propagator in a generic conformal field theory.**
- **We found an analytic solution for an old problem of calculating the rate of false vacuum decay at one loop for an arbitrary dimension of space-time.**
- **We found the first ab-initio theoretical evidence for the longest-lived exotic state composed of quarks.**
- **We identified a possible general mechanism for the formation of exotic hadronic states near strong thresholds that, inter alia, predicts a rich family of exotic states in the spectrum of bottomonium.**
- **We developed software for the analysis of three-point correlation functions in lattice QCD.**

strong coupling of compact quark states with a hadronic continuum channel. We found a qualitative consistence of this scenario with the phenomenology of the Ds1(2460) and Ds1(2536) charmed mesons.

We performed the classification, spectroscopy, strong and electromagnetic decays of the ground and excited baryon states Ξc/b composed of *usc* or *usb* quarks. The decay widths for these baryons were obtained within the elementary emission model and 3P0 model, where all possible decay channels were taken into account by the selection rules.

We were responsible for the 10-year planning of hadron spectroscopy in the USA, leading the lattice QCD planning and authoring the white papers

We developed high-performance software for the analysis of three-point correlation functions in lattice QCD (within the HLS_3pt software package). We also developed models for three-point correlation functions, where the effects of excited states are taken into account, and implemented them in the software for fitting three-point correlation functions (CorrFit software package). We also developed a package for a reduction of matrix elements to irreducible components – form factors (LorentzDecomp software package). To determine the limit of the infinite volume, we developed the software package MatrixElementFit, which performs the following tasks: calculation of the residual matrix R, an implementation of several classes of parameterization models for transient form factors, a global analysis of matrix elements, fitting transient form factor models to matrix elements and analytical continuation of the transition form factors into a complex plane.
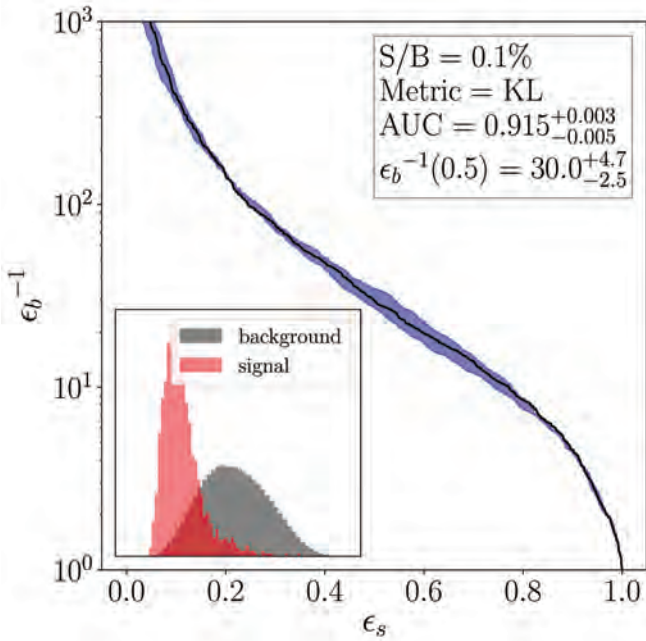
Figure 1: Performance of the physics-inspired variational auto-encoder on the LHC Olympics test data
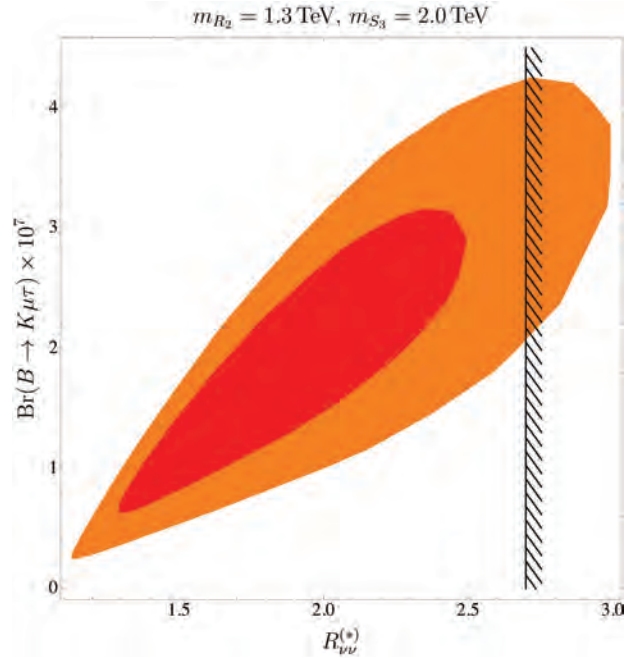
Figure 2: Correlation between lepton flavour violating decay mode B -> K tau mu and a decay with neutrinos in the final state in a model with leptoquarks R2 in S3
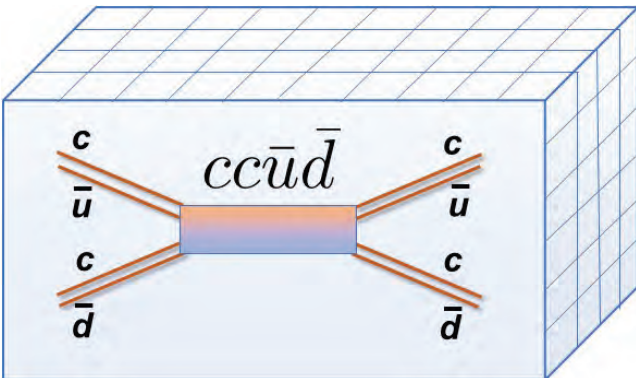
Figure 3: We found the first evidence for an exotic tetra-quark hadron by simulating the scattering of two conventional hadrons on the lattice
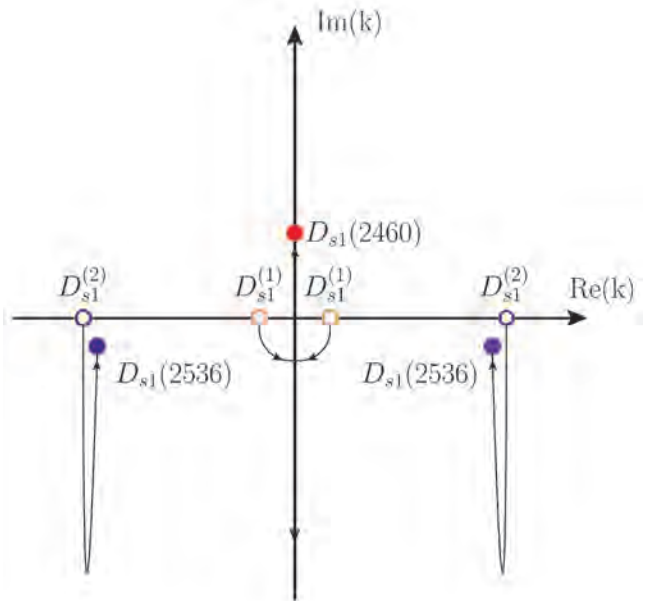
Figure 4: Motion of the poles in a complex momentum plane that visualises the proposed mechanism of the charmed meson $D\_s1(2460)$ formation as a near-threshold molecular state in a strong coupling regime

Some outstanding publications in the past year

1. Borsato, M., Kamenik, Jernej, Zupan, Jure, et al. Unleashing the full power of LHCb to probe stealth new physics: report on progress. Reports on Progress in Physics. 2022, no. 85, no. 2, pp. 024201-45. ISSN 0034-4885. DOI: 10.1088/1361-6633/ac4649. [COBISS.SI-ID 99225859]
2. Ivanov, Aleksandar, Matteini, Marco, Nemevšek, Miha, Ubaldi, Lorenzo. Analytic thin wall false vacuum decay rate. The Journal of High Energy Physics. 2022, vol. 2022, no. 3, pp. 209-1-209-63. ISSN 1029-8479. DOI: 10.1007/JHEP03(2022)209. [COBISS.SI-ID 103098627]
3. Padmanath, M., Prelovšek, Saša. Signature of a doubly charm tetraquark pole in DD* scattering on the lattice. Physical Review Letters. [Print ed.]. 2022, vol. 129, iss. 3, pp. 032002-1-032002-6, illustr. ISSN 0031-9007. DOI: 10.1103/PhysRevLett.129.032002. [COBISS.SI-ID 115216387]
4. Hanhart, Christoph, Nefediev, Alexey. Do near-threshold molecular states mix with neighboring $\bar{Q}Q$ states? Physical Review. D. 2022, vol. 106, iss. 11, pp. 114003-1-114003-14, illustr. ISSN 2470-0010. DOI: 10.1103/PhysRevD.106.114003. [COBISS.SI-ID 139898883]

Researchers involved in the SOLID STATE THEORY AND STATISTICAL PHYSICS studied physical properties of correlated electrons in and out of equilibrium, disordered many-body systems, thermodynamic and transport properties of spin systems, nanosystems and quantum dots as well as complex networks and self-organized structures.

We continued our investigations of transport for disordered quantum systems. For spin chains with random local fields, our results revealed a very large dispersion of diffusion constants for different disorder realizations, apparently related to the emergence of localized islands. Within the subject of perturbed integrable models, we studied the approach to equilibrium, which exhibits multiple relaxation times in the ballistic regime. In the regime of easy-axis spin anisotropy, results indicate that the perturbation changes the diffusion discontinuously into a normal one, unrelated to the anomalous one from the unperturbed case.

We considered a chain of interacting fermions with random disorder that was intensively studied in the context of many-body localization. We have shown that only a small fraction of a two-body interaction represents a true local perturbation to the Anderson insulator. While this true perturbation is nonzero at any finite disorder strength W, it decreases with an increasing W. This establishes the view that a strongly disordered system should be viewed as a weakly perturbed integrable model, i.e., a weakly perturbed Anderson insulator.

We studied ergodicity breaking phase transitions in many-body quantum physics. We focused on the so-called quantum sun model, which describes the breakdown of ergodicity based on an avalanche picture. We benchmarked some key properties of the ergodicity breaking phase transitions. We showcased the ability of our methods to numerically corroborate a theoretically predicted absence of a localization transition in the two-dimensional Anderson model.

We studied the effect of spin Seebeck coefficient on the spin diffusion by preforming numerical simulations in the Hubbard model. We showed that its behaviour can be understood via mapping spins to charges, revealing different extents of scattering between the minority and majority spins well seen in calculated spectral functions. We also studied the thermal conductivity within the 2D Hubbard and Heisenberg models, observed the violations of the Wiedemann-Franz law and further explained the suppression of thermal diffusion by lowering the temperature as an effectively suppressed velocity of relevant excitations.

Strong electronic correlations can lead to a transition between the metal and insulator, which is called the Mott transition. In equilibrium, chemical doping of Mott insulators often leads to a superconducting response at high temperatures. We showed that even in the case of photodoping of a Mott insulator we can stabilise the exotic superconducting state, based on the eta pairing scenario.

We explored certain interesting properties of the finite-temperature spin transport in perturbed integrable quantum-spin chains, particularly in the context of anomalous diffusion and superdiffusion. In similar related paradigms, we also worked on the equivalence of transport coefficients extracted via a linear response in closed quantum systems to that obtained from weakly driven and weakly coupled open quantum systems. In the area of

- **Only a small fraction of a two-body interaction represents a true local perturbation to the Anderson insulator.**
- **We analysed spin-thermal diffusion and heat diffusion in bad metals.**
- **We developed a method to calculate electronic Raman scattering within a realistic approach.**
- **Focusing on a model that describes an avalanche picture of ergodicity breaking, we benchmarked some key properties of the ergodicity breaking phase transitions.**
- **Our ERC StG 2022 application was successful.**
- **We studied the sustenance of superdiffusive spin transport in the presence of SU(2) symmetry preserving perturbations.**
- **The structure of simplicial complexes in the central brain networks maintains a low level of phase synchronization with multifractal fluctuations of the order parameter.**
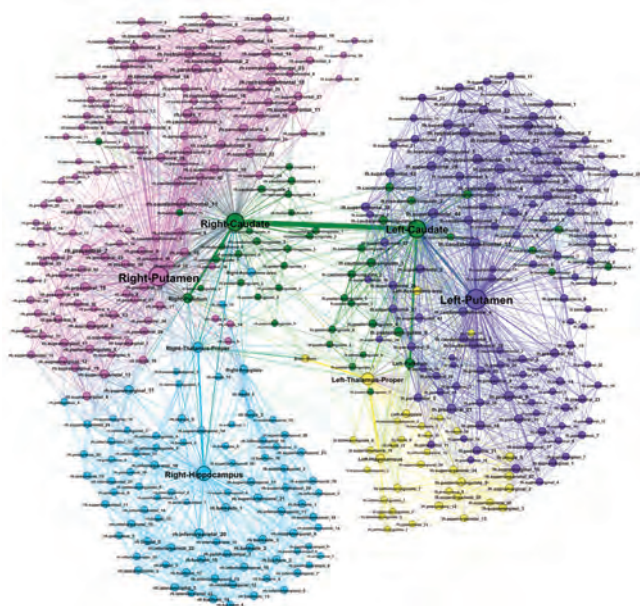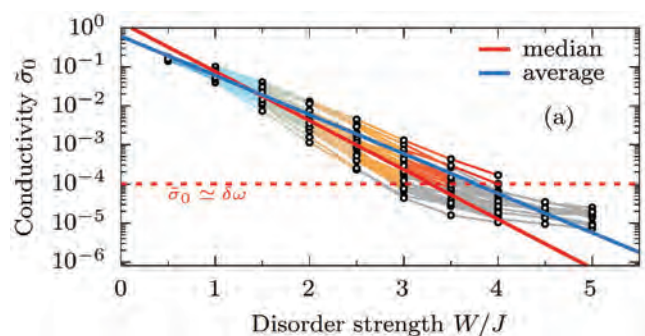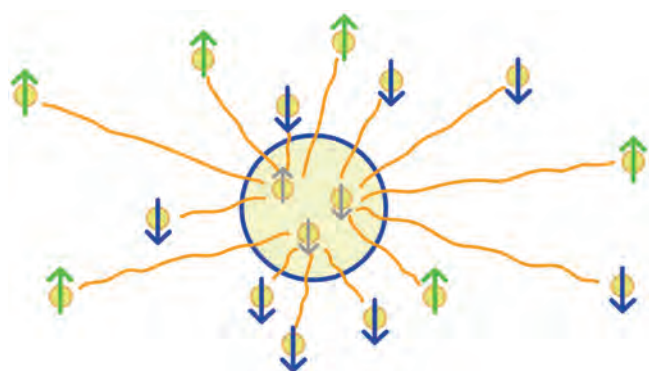
applications of machine learning in many-body quantum physics, we have proposed an algorithm for the Hamiltonian reconstruction assisted by the unsupervised machine learning pre-processing of data, with a dataset that is believed to contain thermal measurements of local operators.

We investigated the electronic structure and lattice vibrational modes of a chanchengite compound (IrBiS) in the presence and absence of spin-orbit coupling effects using ab-initio techniques and compared the results with the experimentally measured room-temperature Raman phonon spectra. We studied the interference pattern of Friedel oscillations in the presence of multiple charged impurities in correlated lattice fermions using the dynamical mean-field theory and reported the absence of oscillations in the Mott insulating regime.

Using numerical simulations and a time-series analysis of complex networks, we studied the impact of the system's architecture on the collective behaviour in dynamic critical states that occur on the hysteresis loop and in stochastic processes. Specifically, our studies of the magnetization reversal in antiferromagnetic–ferromagnetic bilayers reveal how the changing thickness and interlayer couplings modify the shape of the hysteresis loop and the nature of collective magnetization fluctuations. We investigated how the structure of simplicial complexes in human brain networks maintains the necessary phase synchronization at a low level by developing opposite phases of groups of nodes, which leads to multifractal fluctuations of the order parameter. Our analysis of the worldwide time series of Covid-19 infections both before and after immunization unveils the existence of three large groups of countries with similar infection cycles.

Some outstanding publications in the past year

1. Šuntajs, Jan, Vidmar, Lev. Ergodicity breaking transition in zero dimensions. Physical Review Letters. [Print ed.]. 2022, vol. 129, iss. 6, pp. 060602-1-060602-6, illustr. ISSN 0031-9007. DOI: 10.1103/PhysRevLett.129.060602. [COBISS.SI-ID 135335939]

2. Krajewski, Bartosz, Vidmar, Lev, Bonča, Janez, Mierzejewski, Marcin. Restoring ergodicity in a strongly disordered interacting chain. Physical Review Letters. [Print ed.]. 2022, vol. 129, iss. 26, pp. 260601-1-260601-7, illustr. ISSN 0031-9007. DOI: 10.1103/PhysRevLett.129.260601. [COBISS.SI-ID 134950915]

3. Gourgout, A., Mravlje, Jernej, et al. Seebeck coefficient in a cuprate superconductor: particle-hole asymmetry in the strange metal phase and fermi surface transformation in the pseudogap phase. Physical Review X. 2022, vol. 12, no. 1, pp. 011037-1-011037-14. ISSN 2160-3308. DOI: 10.1103/PhysRevX.12.011037. [COBISS.SI-ID 135716099]

4. Schmitt, Markus, Lenarčič, Zala. From observations to complexity of quantum states via unsupervised learning. Physical Review B. 2022, vol. 106, no. 4, pp. l041110-1-l041110-7. ISSN 2469-9950. DOI: 10.1103/PhysRevB.106.L041110. [COBISS.SI-ID 135194627]

5. Brink, M. Ten, Gräber, S., Hopjan, Miroslav, Jansen, David, Stolpp, Jan, Heidrich-Meisner, Fabian, Blöchl, P. E. Real-time non-adiabatic dynamics in the one-dimensional Holstein model: trajectory-based vs exact methods. The Journal of Chemical Physics. 2022, vol. 156, no. 23, pp. 234109-1-234109-42. ISSN 0021-9606. DOI: 10.1063/5.0092063. [COBISS.SI-ID 112517379]

6. Prelovšek, Peter, Nandy, Sourav, Lenarčič, Zala, Mierzejewski, Marcin, Herbrych, Jacek. From dissipationless to normal diffusion in the easy-axis Heisenberg spin chain. Physical Review B. 2022, vol. 106, no. 24, pp. 245104-1-245104-8. ISSN 2469-9950. DOI: 10.1103/PhysRevB.106.245104. [COBISS.SI-ID 133059075]

Figure 5: Asymmetric core network of human connectome with symplicial complexes that are attached to eight key brain regions (hub nodes)

Figure 6: Spin conductivity in a Heisenberg chain with random local fields as the function of disorder strength for different disorder realizations

Figure 7: The so-called quantum sun model, in which the particles with a spin of ½ are coupled to the ergodic grain in the centre

7.   Tadić, Bosiljka, Chutani, Malayaja, Gupte, Neelima. Multiscale fractality in partial phase synchronisation on simplicial complexes around brain hubs. Chaos, Solitons and Fractals. [Print ed.]. 2022, vol. 160, pp. 112201-1-112201-8. DOI: 10.1016/j.chaos.2022.112201. [COBISS.SI-ID 109693443]

The group for THEORETICAL BIOPHYSICS AND SOFT MATTER PHYSICS investigated poly-electrolytes, liquid crystals, colloids, and phospholipid and biological membranes.

We studied the adsorption of short-chained surfactants to various interfaces. The simulation results showed that surfactants enhance the wetting on very hydrophilic and hydrophobic surfaces, whereas moderately hydrophilic surfaces are less affected. We developed a theory to compute the contribution of surfactants to the apparent line tension in aqueous droplets. We showed that even traces of longer-chained surfactants in a pre-contaminated liquid are enough to affect the measurements of the apparent line tension. Neutron scattering experiments and molecular dynamics simulations of typical electrolytes for lithium/sulphur batteries were used to elucidate complex polysulfide structures. We find that a delicate balance between ion-ion and ion-solvent interactions steers the undesired growth of polysulfide dendrimers. We presented a theoretical extension of the concept of membrane permeability to nonequilibrium. We introduced the concept of nonequilibrium of differential permeability, in which selectivity is tuned by driving forces beyond the linear-response level. We derived an equation for the adsorption coefficient, which scales

Using a stochastic micromodel, we studied the passive rheological response of striated muscles.

exponentially with the molecular surface area and the surface wetting coefficient and is in good agreement with the simulation results. We applied it to aqueous sessile droplets containing surfactants, where the competition of surfactant adsorptions to both interfaces alters the contact angle in a nontrivial way.

We showed how to use pyDAMPF to choose one optimal nanoprobe for planned experiments with a hygroscopic polymer and how to evaluate the parameters of an AFM cantilever. We proposed a method for exploiting electrostatic interactions to improve the design of protective face masks. We developed a method that recapitulates the mRNA conformation change of the translation activity and three-dimensional positional interactions between an organelle and its localized mRNAs as end-to-end distances.

We developed an algorithm to detect collisions between the ellipses constrained to the two-dimensional surface of a sphere and we used it to study random close packing configurations in a two-dimensional model of spherical geodesic ellipses. We investigated how the principles of protein packing and the mechanisms driving morphological transformations in capsids manifest themselves in icosahedral viral capsids assembled from identical symmetric structural units. We used an elastic model to explore the mechanics of pollen grain swelling and the role of soft circular pores in this process, identifying and quantifying the mechanical weakness of the pores, which are prone to rapid inflation when a grain swells to a critical extent. Using a stochastic micromodel, we studied the passive rheological response of striated muscles, and we used it to explain the striking qualitative difference between relaxation in experiments involving perturbation of length and those involving perturbation of force.

We studied structures of three-dimensional liquid-crystalline cubic phases with continuous grids of channels. We also focused on ferroelectric nematics, where we studied polar and apolar fluctuation modes and phase transitions in an external electric field.

Some outstanding publication in the past year

1.   Park, Chanbum, Kanduč, Matej, Headen, Thomas F., Youngs, Tristan G. A., Dzubiella, Joachim, Risse, Sebastian. Toward unveiling structure and property relationships from ionic ordering in Li/S battery electrolytes: neutron total scattering and molecular dynamics simulations. Energy Storage Materials. 2022, vol. 52, pp. 85–93

Figure 8: Membrane permeability in nonequilibrium can be tuned by driving forces

We have explained the nature of excitations in nanoscopic heterostructures with strong electron interactions in the superconductors.
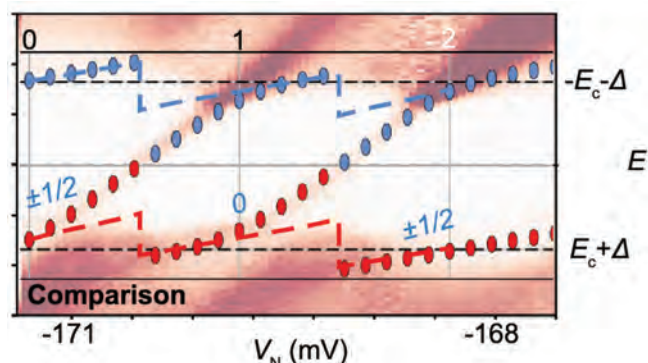
The members of the PHYSICS OF QUANTUM TECHNOLOGIES group studied the properties of hybrid semiconductor-superconductor devices as well as quantum impurity problems, in particular those involving adsorbed magnetic molecules and quantum dots.

We solved quantum impurity models in the context of nanoscopic devices built of a semiconducting and a superconducting part. In collaboration with experimental groups we explained the experiments where the superconducting part of the device is so small that the Coulombic electron repulsion becomes important. We developed a simplified toy model useful for qualitative predictions.

We collaborated in analysing the properties of Josephson junctions with an embedded quantum dot.

Some outstanding publication in the past year

1. Estrada Saldaña, Juan Carlos, Vekris, Alexandros, Pavešić, Luka, Krogstrup, Peter, Žitko, Rok, Grove-Rasmussen, Kasper, Nygård, Jasper. Excitations in a superconducting Coulombic energy gap. Nature Communications. 2022, vol. 13, pp. 2243-1-2243-8. ISSN 2041-1723. DOI: 10.1038/s41467-022-29634-5. [COBISS.SI-ID 106090755]

Figure 9: Comparison of calculated (points) and measured excitation energies in a superconducting gap

Organization of conferences, congresses and meetings

1. International workshop: Quantum many-body dynamics: Thermalization and its violations
2. Institute for basic science (PCS-IBS), Daejeon, South Korea, 24.-28. 5. 2021 (virtual)
3. "Brda 2022, Selected chapters in high energy physics, astrophysics and cosmology", Medana, Slovenija, 28.9.-30.9.2022
4. Trilateral meeting at IFPU, Trieste, Italy, June 2022
5. Trilateral meeting at IJS, Ljubljana, December 2022
6. Many-body systems out of equilibrium: recent advances and future directions, Logarska dolina, Slovenija 19.-23. 9. 2022
7. Satellite Symposium "Higher-Order Topology and Dynamics in Complex Networks" Shanghai, China 11. – 13. 7. 2022 (virtual)
8. 11th Nonequilibrium quantum workshop, Krvavec, Slovenija, 11.-15. 12. 2022

VISITORS FROM ABROAD

1. Prof. Dr Ilja Doršner, University of Split, Split, Croatia, 10.-12. 3. 2022
2. Maksymilian Środa, Wrocław University of Science and Technology, Wrocław, Poland, 1.-15. 5. 2022
3. Prof. Dr Marcin Mierzejewski, University of Silesia, Katowice, Poland, 9.-11. 5. 2022
4. Prof. Dr Jacek Herbrych, Wrocław University of Science and Technology, Wrocław, Poland, 10-13. 5. , 2022, 10.-11. 12. 2022
5. Dr Francesco D´Eramo, University of Padua in INFN, Padua, Italy, 1.-2. 6. 2022
6. Dr Luca Tubiana z Universita di Trento, Trento, Italy, 1.-3. 6. 2022
7. Dr Angelo Rosa, Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy, 1.-3. 6. 2022
8. Dr Joseph Davighi, University of Zürich, Zürich, Switzerland, 8.-11. 6. 2022
9. Prof. Dr Andreas Honecker, CY Cergy Paris Université, Paris, France, 9. 6. 2022
10. Prof. Dr Benjamin Fuks, Laboratory of Theoretical and High Energy Physics (LPTHE), Paris, France, 14.-17. 6. 2022
11. Dr Nina Megier, University of Gdansk, Gdansk, Poland, 14. 6. 2022
12. Dr Bary Dillon, University of Heidelberg, Heidelberg, Germany, 21.-26. 6. 20222.-10. 9. 2022
13. Prof. Dr Jakub Zakrewski, Jagiellonian University, Krakow, Poland, 23.-25. 6. 2022
14. Prof. Dr Jure Zupan, University of Cincinnati, USA, 23.-24. 6. 2022, 14.-15.7.2022, 20.-23. 12. 2022
15. Dr Adam Basci, Szechenyi Istvan University, Gyor, Hungary, 27.-29.6.2022, 10.-12. 11. 2022
16. Dr Patrycja Lydzba, Wrocław University of Science and Technology, Wrocław, Poland, 15.-23. 7. 2022, 18.-19. 9. 2022, 23.-24. 9. 2022, 10.-11. 12. 2022
17. Prof. Dr Haim Taitelbaum, Bar-Ilan University, Ramat Gan, Israel, 19. 7. 2022
18. Prof. Dr Guillermo Silva, Instituto de Física de La Plata-CONICET, Buenos Aires, Argentina, 11. 8. 2022
19. Maria Pedrosa Bustos, University of Granada, Granada, Spain, 15. 8.-15. 11. 2022
20. Bartosz Krajewski, Wrocław University of Science and Technology, Wrocław, Poland, 3.-19. 9. 2022
21. Adithi Udupa, Indian Institute of Science, Bengaluru, India, 6. 9. 2022
22. Dr Philipp M. Schicho, Institute for Theoretical Physics, Goethe University, Frankfurt, Germany, 14.-20. 09. 2022
23. Prof. Dr Fabrizio Nesti, University of L'Aquila, L'Aquila, Italy, 25.-28. 09. 2022
24. Prof. Dr Joan Elias Miró z ICTP, Trieste, Italy, 6. 10. 2022
25. Dr Luiz Vale Silva, University of Valencia, Valencia Spain, 31. 10.-30.11. 2022
26. Kohei Ogane, Tohoku University, Sendai, Japan, 2. 11. 2022-26. 1. 2023
27. Tim Hoehne, Technical University Dortmund, Dortmund, Germany, 15.-18. 11. 2022
28. Simon Jiricek, University of Göttingen, Göttingen, Germany, 16. 11.-3. 12. 2022
29. Dr Martin Novoa Brunet, National Institute for Nuclear Physics - Bari, Bari, Italy, 19.-26. 11. 2022
30. Prof. Dr Bernd Riederer, University of Graz, Graz, Austria, 30. 11.-1. 12. 2022
31. Dr Aleks Smolkovič, University of Bern, Albert Einstein Center for Fundamental Physics, Bern, Switzerland, 9. 12. 2022-7. 1. 2023
32. Adrian Feiguin, Nordeastern University, Boston, USA, 10.-11. 12. 2022, 15.-16. 12. 2022
33. Dr Salvador Rosauro Alcaraz, Institut Joliot Curie, Orsay, France, 14.-17. 12. 2022
34. Dr Alaska Subedi, Ecole Polytechnique, Palaiseau, Paris, France, 15. 12.-17. 12. 2022
35. Dr Jan Hajer, CFTP, IST, Universidade de Lisboa, Lisbon, Portugal, 19.-21. 12. 2022
36. Dr Friedrich Krien, Technische Universität Wien, Vienna, Austria, 19. 12. 2022-8. 1. 2023

INTERNATIONAL PROJECTS

1. COST CA17139; European Topology Interdisciplinary Action
   Dr. Anže Rapoš Božič
   Cost Association Aisbl
2. The Flavor of the Invisible Universe
   Asst. Prof. Nejc Košnik
   Slovenian Research Agency
3. Probing the Origin of Flavour through Precision
   Asst. Prof. Nejc Košnik
   Slovenian Research Agency
4. Machine Learning in High Energy Physics
   Prof. Jernej Fesel Kamenik
   Slovenian Research Agency
5. Exploring Boundaries of Quantum Many-Body Chaos
   Prof. Lev Vidmar
   Slovenian Research Agency

RESEARCH PROGRAMMES

1. Theory of the condensed matter and statistical physics
   Prof. Janez Bonča
2. Theoretical physics of nuclei, particles and fields
   Prof. Jernej Fesel Kamenik
3. Biophysics of polymers, membranes, gels, colloids and cells
   Prof. Primož Ziherl
4. Physics of quantum technologies
   Prof. Rok Žitko

R & D GRANTS AND CONTRACTS

1. Diagnosing nonequilibrium quantum matter
   Prof. Lev Vidmar

2. The influence of additives on nanoscopic wetting
   Dr. Matej Kanduč
3. Multi-scale modeling of non-equilibrium quantum materials
   Dr. Denis Golež
4. Three advances towards realistic description of strongly correlated electron transport
   Asst. Prof. Jernej Mravlje
5. Symmetries and quantum pumping
   Dr. Zala Lenarčič
6. Diamond-assisted quantum processing of fullerene qubits
   Prof. Rok Žitko
7. Coulombic subgap states in superconducting quantum devices
   Prof. Rok Žitko
8. Nonlinear mechanics of biological tissues and their tumors
   Dr. Matej Krajnc
9. Advancing precision flavour studies with machine learning
   Prof. Jernej Fesel Kamenik
10. Lattice QCD study of electroweak transitions between heavy mesons and light hadronic resonances (raziskovalni projekt - Program AD)
    Asst. Prof. Luka Leskovec
11. FLAMENCO: Flavour, Lepton number, And Mass Explorations of Neutrinos at the COmpact muon solenoid
    Prof. Miha Nemevšek
12. Stability of biological liquids under tension
    Dr. Matej Kanduč
13. Neutrino mass origin: from colliders to gravitational waves
    Prof. Miha Nemevšek
14. Cryptographically secure random number generator
    Prof. Rok Žitko
15. Tensor Networks in Simulation of Quantum matter
    Dr. Zala Lenarčič
    Ministry of Education, Science and Sport
16. Financing of projects visits at the Slovenian higher education institutions
    Nevenka Hauschild
    Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia
17. Cryptographically secure random number generator
    Prof. Rok Žitko
    Government Office for the Protection of Classified Information

STAFF

Researchers
1. *Dr. Lamprini Athanasopoulou, left 01.03.22*
2. Prof. Borut Bajc
3. Prof. Janez Bonča*
4. Dr. Banhi Chatterjee
5. Prof. Mojca Čepič*
6. Dr. Ilja Doršner
7. Prof. Svjetlana Fajfer
8. **Prof. Jernej Fesel Kamenik, Head**
9. Dr. Szczepan Glodzik
10. Dr. Denis Golež
11. Dr. Miroslav Hopjan
12. Dr. Matej Kanduč
13. Asst. Prof. Jure Kokalj*
14. Asst. Prof. Nejc Košnik
15. Dr. Matej Krajnc
16. Dr. Zala Lenarčič
17. Asst. Prof. Luka Leskovec
18. *Dr. Adrian Rene Lugo, left 23.08.22*
19. Asst. Prof. Jernej Mravlje
20. Dr. Sourav Nandy
21. Dr. Alexey Vladimirovich Nefediev
22. Asst. Prof. Miha Nemevšek
23. Prof. Peter Prelovšek
24. Prof. Saša Prelovšek Komelj
25. Prof. Anton Ramšak*
26. Dr. Anže Rapoš Božič
27. Asst. Prof. Tomaž Rejec*
28. Dr. Madhumita Sarkar
29. Prof. Bosiljka Tadić
30. Dr. Horacio Andres Vargas Guzman
31. Prof. Nataša Vaupotič*
32. Prof. Lev Vidmar
33. Prof. Primož Ziherl*

34. Prof. Rok Žitko
Postdoctoral associates
35. Dr. German Gabriel Blesio
36. *Dr. Luis Cort Barrada, left 01.09.22*
37. Dr. Jonathan Kriewald
38. Dr. Emmanuel Ortiz Pacheco
39. Dr. Fabio Staniscia
40. *Dr. Manuel Szewc, left 01.11.22*
41. Dr. Michele Tammaro
42. Dr. Lara Ulčakar*
Postgraduates
43. Urška Andrenšek, B. Sc.
44. Blaž Bortolato, B. Sc.
45. Veronika Bukina, B. Sc.
46. Jože Gašperlin, M. Sc.
47. Arman Korajac, M. Sc.
48. Klemen Kovač, B. Sc.
49. Marco Matteini, M. Sc.
50. Luka Medic, B. Sc.
51. Luka Pavešić, B. Sc.
52. Lovre Pavičić, M. Sc.
53. Don Rolih, B. Sc.
54. *Jan Rozman, B. Sc., left 16.06.22*
55. Rafal Piotr Swietek, M. Sc.
56. Marin Šako, M. Sc.
57. Jan Šuntajs*, B. Sc.
58. Martin Ulaga, B. Sc.
59. Iris Ulčakar, B. Sc.
Technical and administrative staff
60. Nevenka Hauschild
61. Tjaša Lazič, B. Sc.

Note:

* part-time JSI member

DEPARTMENT OF LOW AND MEDIUM ENERGY PHYSICS F-2

The Department of Low and Medium Energy Physics is engaged in the research of nuclear, atomic, molecular and optical physics. A deep understanding of basic physical phenomena and processes is paramount in the very interdisciplinary research conducted at our department, which includes environmental radiological monitoring, material research, fusion, biology, energy storage, medicine, pharmacology, environmental sciences and archaeometry. Our research is conducted using our own experimental equipment, consisting of an ion-beam accelerator and beamlines, dedicated detectors of ionizing radiation, calibrated radiation fields, as well as dedicated experimental setups for nuclear, atomic and molecular physics.

Head:
Prof. Primož Pelicon

Researchers from our department are regular users of large experimental research facilities worldwide, such as particle accelerators, synchrotrons, free-electron lasers and tokamaks. These facilities are accessed either through international collaborations, research networks or through self-initiated research proposals. To counterweight the engagement of national human resources at research facilities abroad, we are providing transnational access (TNA) to the tandem ion accelerator at the Jožef Stefan Institute for international users within EU research infrastructure projects.

We continued our work within the A1 Collaboration at the three-spectrometer facility of the Mainz Microtron (MAMI), with the focus on analysing the data acquired during recent runs. We published the first results of the measurements of the electron helicity asymmetry in quasi-elastic proton knockout from ^{2}H and ^{12}C nuclei by polarized electrons (*Kolar et al., Phys. Lett. B 2022*). This asymmetry depends on the so-called "fifth" structure function, which is antisymmetric with respect to the scattering plane, vanishing in the absence of final-state interactions, and thus providing a sensitive tool for their study. The data for ^{2}H were shown to be in very good agreement with theoretical calculations, while the predictions for ^{12}C exhibited differences with respect to the acquired experimental data. Our studies of low-Q2 elastic electron-proton scattering using a newly developed cryogenic supersonic gas jet target have also been published (*Wang et al., Phys. Rev. C 2022*): we measured the proton electric form factor within a four-momentum transfer range of $0.01 < Q2 < 0.045$ GeV^2, and the results were consistent with the existing measurements. Most importantly, from the viewpoint of the future MAGIX spectrometer setup, which is under construction, the data demonstrated the feasibility of the gas jet target and the potential of future scattering experiments using high-resolution spectrometers.

Our work at the Thomas Jefferson National Accelerator Facility (Jefferson Lab) has been focused on an analysis of the data from several experiments performed during the 6-GeV CEBAF era, but we have also obtained new results with the upgraded 12 GeV beam. Given the unique possibility of using a tritium target, we are still in the process of analysing the large body of the ^{3}H/^{3}He data taken in Hall A of the Jefferson Lab. We published the results from our mass spectroscopy experiment carried out with a pair of high-resolution spectrometers and a tritium target (*Pandey et al., Phys. Rev. C 2022*). Thus, (e,e'K+) reaction enhancements, which may correspond to a possible Λnn resonance and a pair of ΣNN states, were observed with an energy resolution of about 1.2 MeV, although greater statistics are needed to make definitive identifications. In addition, although bound A=3 and A=4 Σ-hypernuclei were predicted, only an A=4 Σ-hypernucleus was found, utilizing the (K−, π−) reaction on a ^{4}He target. In the MARATHON experiment, we determined the ratio of the nucleon structure functions, F2n/F2p, from the measurements of deep inelastic scattering of electrons from ^{3}H and ^{3}He nuclei (*Abrams et al, Phys. Rev. Lett. 2022*). These data were analysed using a novel technique exploiting the mirror symmetry of these two target nuclei, which essentially eliminates many theoretical uncertainties in the extraction of a ratio. The results, which cover a Bjorken scaling variable range of $0.19 < x < 0.83$, represent a significant improvement compared to the previous SLAC and Jefferson Lab measurements for the ratio. Our investigations of the ^{3}H/^{3}He mirror system were recognised by a publication in Nature (*Li et al., Nature 2022*): we reported on the extraction of the np/pp ratio of short-range correlations obtained from inclusive scattering from ^{3}H and ^{3}He, and found a marked deviation from the near-total np dominance observed in heavy nuclei (Figure 1). This result implies an unexpected structure in the high-momentum wave-functions for ^{3}H and ^{3}He.
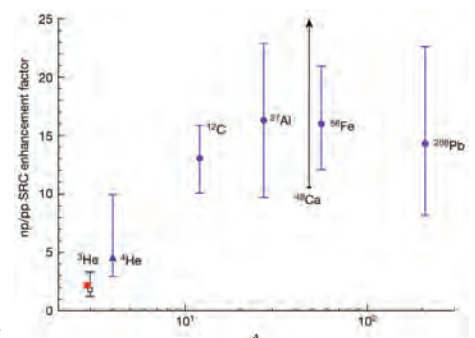

Figure 1: The np/pp ratio of short-range correlations relative to the total number of np and pp pairs. Our results obtained from inclusive scattering from 3H and 3He (red circle) are consistent with the extraction based on the proton knockout cross-section ratios (black square), but significantly different from observations in heavier nuclei, where the near-total np-pair dominance has been seen (blue circles and triangles). This surprising result implies that the neutron in 3H and 3He has a smaller role at high momenta than if np dominance is assumed, as in heavier nuclei (Li et al., Nature 2022).

The cross-sections from our related (unpolarized) experiment on ⁴He are now also available (Iqbal et al., Phys. Rev. C 2022): we observed striking fluctuations in the ratio of data for distorted-wave calculations, which we can interpret as possible signals of initial-state multi-nucleon correlations. Our studies of virtual Compton scattering (*Georges et al., Phys. Rev. Lett. 2022*) and (generalized) nucleon polarizabilities (*Ruth et al., Nat. Phys. 2022*) have also been published; they have the power to discriminate between the existing chiral perturbation theory calculations and will help provide a better understanding of the strong QCD regime. We have also presented new precision measurements of the elastic electron-proton scattering cross-section for momentum transfer up to 15.75 GeV2 (*Christy et al., Phys. Rev. Lett. 2022*). Combined with the existing data, these provide an improved extraction of the proton magnetic form factor at high Q2 and double the range over which a longitudinal or transverse separation of the cross-section can be performed. Our measurements of cross-sections for inclusive scattering on argon have been published (*Jiang et al., Phys. Rev. D 2022*).
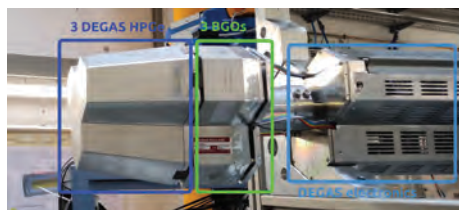
Figure 2: DEGAS detector with mounted BGO scintillation detectors, developed and constructed at the JSI within the DESPEC collaboration at GSI/FAIR.
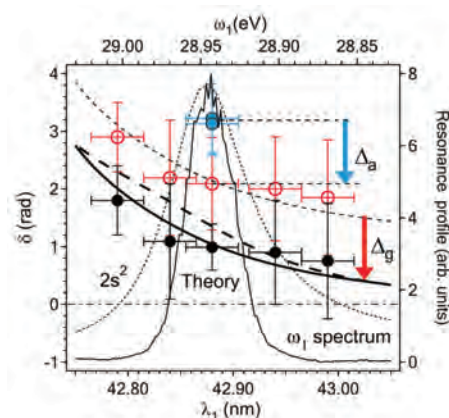
Figure 3: Measured and calculated phase differences between the two-photon amplitudes $\omega_1+\omega_1$ and $3\omega_1-\omega_1$ for the excitation of the $2s^2$ resonance in helium as a function of the wavelength of light (M. Žitnik et al., Optica 2022). Δ_g and Δ_a are the phase shifts due to the passage of the two harmonic components through the gas attenuator and the difference in their focusing, respectively.
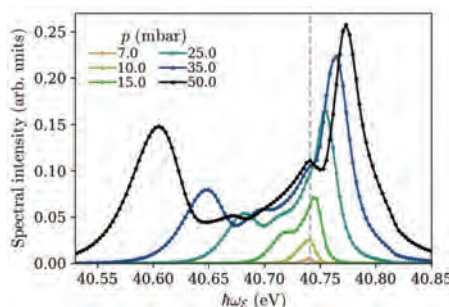

Figure 4: Evolution of the spectral intensity of the self-amplified spontaneous emission in the direction of the pump beam after passing through an 8 mm long He gas column, calculated for different values of the pressure (from dissertation by Š. Krušič, 2022, published in Š. Krušič et al. Phys. Rev. A 2023).

Further engagement in theoretical investigations has resulted in a paper discussing the formation and decay of the $\Lambda(1405)$ resonance within a coupled-channels framework with an underlying chiral quark model to compute the matrix elements (*Golli et al., Eur. Phys. J. 2022*). We have used phenomenological amplitudes obtained with partial-wave analyses (PWAs) of single-pion photo-production in order to evaluate the contribution of this process to the Gerasimov-Drell-Hearn, Baldin, and Gell-Mann–Goldberger–Thirring sum rules, by integrating up to 2 GeV of photon energy (*Strakovsky et al., Phys. Rev. C 2022*). Our study has confirmed that the single-pion contribution to all these sum rules converges even before the highest considered photon energy, but the levels of saturation are very different in the three cases.

Our research engagement at the FAIR (Facility for Antiproton and Ion Research) accelerator centre, which is one of the largest projects for basic research in the world, within the FAIR Phase-0 research programme, is taking place at the GSI premises in Darmstadt. Our primary focus here is the NUSTAR physics programme. We are strongly engaged in the research within the High-Resolution In-Flight Spectroscopy/Decay Spectroscopy (HISPEC/DESPEC) and Superconducting Fragment Separator (Super-FRS) experiment subcollaborations.

The HISPEC/DESPEC experiments aim to address the key issues in a nuclear structure, reactions and nuclear astrophysics at the limits of nuclear existence. For the DESPEC collaboration at GSI/FAIR, we developed BGO scintillation detectors that were first used as part of the DEGAS spectrometer in 2022 (Figure 2). These BGO detectors provide active shielding for germanium detectors and reduce the spectral noise produced by Compton scattered photons. Within the HISPEC/DESPEC collaboration we prepared and tested the HISPEC-10 experimental setup at GSI/FAIR. The HISPEC-10 experiment will be part of the low energy branch at FAIR and will be used for measurements involving slowed-down exotic ions. At the JSI we are developing a cooled segmented silicon detector setup that will be used to measure energy losses, trajectories and total kinetic energy of ions in the HISPEC-10 experiment. We have also started the construction of a new implantation detector FIMP (Fiber Implanter) for DESPEC experiments. The FIMP detector will consist of scintillation fibres stacked in layers, whose signal will be read by silicon photomultipliers. We also participated in the measurements of isomeric and beta decays in isotopes Os-202 and Ir-203 and in an experiment where the r-process was studied, the knowledge of which is the key to understanding the universe.

In the Super-FRS (Superconducting Fragment Separator) experimental collaboration, we participated in two large-scale measurements with the WASA detector system in the intermediate focal plane of the FRS. The two campaigns were aimed at the search for meson nuclei η' in the C-12(p, dp) reaction and at the measurements of the decay times of hypernuclei 3ΛH and 4ΛH. We also participated in the Ion Catcher experiment with a MR-TOF spectrometer for precise mass measurements of Cf-252 fission products and their relative fission yields.

The research resulted in the following publications in 2022: "The DESPEC setup for GSI and FAIR" (*Mistry et al., Nucl. Instr. Meth. A 2022*), "Nature of seniority symmetry breaking in the semimagic nucleus Ru-94" (*Das et al., Phys. Rev. C 2022*), "Commissioning the FAst TIMing array (FATIMA) at FAIR Phase-0: Half-lives of excited states in the N=50 isotones Pd-96 and Ru-94" (*Jazrawi et al., Rad. Phys. Chem. 2022*). We also wrote about our participation in FAIR in the paper "Nuclear Physics at the Jožef Stefan Institute" (*Vesić, Nucl. Phys. News 2022*).

In the field of research in atomic and molecular physics, we published the results of the FERMI free-electron laser experiment, in which we observed the interference between photoionization amplitudes $\omega_1+\omega_1$ and $\omega_3-\omega_1$ in He (*Žitnik et al., Optica 2022*). We measured the dependence of the yield of electrons from the autoionization decay of doubly excited state $2s^2$ ¹S as a function

of the phase difference of light with a single (ω_1) and triple (ω_3) light frequency. As the incident XUV light passed through a nitrogen-filled attenuator, the phase shift was detected by a He atomic interferometer (Figure 3). In February 2022, we carried out a follow-up experiment in which we checked whether the sensitivity of the atomic interferometer was high enough so that it could also work in an energy range that does not coincide with any resonance and, as a result, the electron yield is much smaller. We also tested whether we can get similar results with another gas (neon), but it turns out that the background increases considerably because, due to the higher number of electrons in Ne, the relative probability of sequential two-photon absorption is much higher than in He. Instead of nitrogen, there was argon in the attenuator in order to measure the phase difference with the He atomic interferometer when the light passes through the Ar $3s^{-1}4p$ resonance. By the end of 2022, the analysis of these challenging measurements was not yet completed because the presence of phase-dependent modulation of the third harmonic admixture in the incident light causes a non-trivial background.

In 2022, we completed the analysis of resonant Auger spectra in the region of doubly excited states $1s^{-1}nl$ in argon, which we measured in collaboration with the group led by Marc Simon from the LCPMR laboratory in Paris, France, at the Galaxies beamline at the Soleil synchrotron. We managed to record the first resonant Auger map of doubly excited states. In this regard, we developed a model with which we explained the spectral map and highlighted its connection to a simpler measurement of the photoabsorption spectrum in the same energy range. In doing so, it was necessary to take into account the interference effects and the angle-selective detection of electrons. In the analysis we introduced new methods that will be relevant in such studies of doubly excited states in the future. We presented the results of this work at the EGAS14/ECAMP53 conference held in Vilnius (Lithuania) in 2022.

Our colleague Špela Krušič received her doctorate in 2022 with the work "Spectral properties of superfluorescence in the far ultraviolet and X-ray region", in which she describes the passage of strong XUV light through a helium gas target in the paraxial approximation. She takes into account spontaneous emission, which in fact determines how its self-amplification proceeds in the direction of the pump beam. On the basis of her calculated results, which were accepted for publication at the end of 2022, in the same year we proposed an experiment with free-electron laser light where we not only observed the stimulated emission in He under controlled conditions, but also performed a quantitative comparison of an amplified signal with the simulation (Figure 4). In line with the efforts for a convincing experimental project, in 2022 we initiated a collaboration with the CNR-ISN laboratory in Milan, Italy, where they produced a prototype of the open-end glass capillary for gas retention that we proposed for use in the experiment.

In 2022, we were also involved in the analysis of the results of the experiment that was conducted under the leadership of Andrej Mihelič at the FERMI FEL at the end of 2021 (20209086: "Strong continuum-continuum coupling via core excitation in above threshold ionization"). The purpose of the experiment was to investigate whether excitation with strong light, which is resonant with the transition in a helium ion, affects photoionization of a He atom from the ground state. Due to the non-ideal overlap of the two colours used to excite the gas, we could not confirm the dichroic effect, but we could observe the resonant response of the single-color two-photon ionization signal and the dependence of the absorption line width on the light intensity during the sequential excitation of the $1s \rightarrow 2p$ transition in He$^+$. Since a part of the sought signal is at the detection limit, a very accurate simulation of all phenomena that could affect the final spectral yield is required. This greatly increases the time required for dealing with the problem because accurate models must first be developed so that they are valid for the given experimental conditions, and only then can these models be suitably simplified to obtain the results for a comparison with the experiment in due time.

In the research with twisted light, in collaboration with Giovanni De Ninno (Fermi/UNG), we showed that it is possible to generate magnetization on the nanometer scale through the interaction of twisted light with matter (*Wätzel et al., Phys. Rev. Lett. 2022*). In an experiment at FERMI FEL, we prepared He atoms in singly excited states with a short and highly focused pulse of XUV light, and from there with a pulse of twisted light they were raised to "spinning" Rydberg states. An analysis of dichroism showed the formation of spatially limited and persistent magnetic fields generated by atomic current loops of rotating Rydberg wave packets (Figure 5).

In collaboration with the group of Francis Penent from the LCPMR Laboratory in Paris, France, we published a paper in 2022, reporting on an improved filtering procedure for multielectron coincidences in the single-photon multiple ionization of Xe above the 4d ionization threshold (*Ismail et al., Phys. Chem. Chem. Phys. 2022*). In a measuring scheme with a magnetic bottle
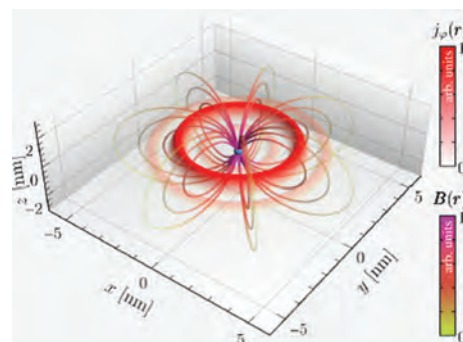
Figure 5: Calculated flux lines of the magnetic field density in a rotating wave packet of Rydberg states for an atom close to the axis of the light beam (Wätzel et al., Phys. Rev. Lett. 2022). According to calculations, the excitation with twisted light created a total magnetic moment of $\mu_z = 5.9 \times 10^{-20}$ J/T ($6378\mu_B$) in the gas sample, which persisted until the decay of the Rydberg wave packet.
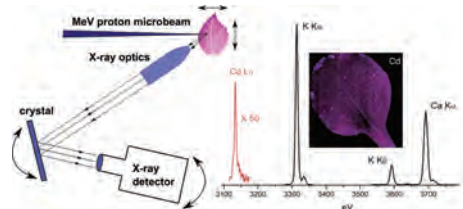
Figure 6: A scheme of the PB-WDS setup installed at the external proton beamline and a cadmium distribution within a Noccaea praecox leaf recorded with the PB-WDS spectrometer.
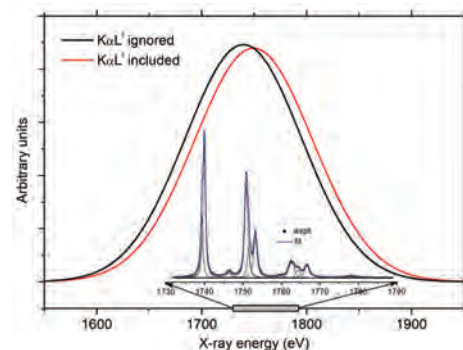
Figure 7: High-energy resolution Ka X-ray emission spectrum of silicon induced with 3 MeV He beam exhibiting KαL^i multiple ionization satellite (MIS) lines. The spectrum convoluted with a 130 eV (FWHM) Gaussian, corresponding to the energy resolution of the solid-state EDS detector, reflects the effect of the Ka MIS in PIXE spectrum measured with the He beam.

electron spectrometer, detection of the final ion state was implemented. The ion signal can be combined with the signal of one or more electrons detected at the same time. With these coincidence data it is possible to map in detail the final states of multiply charged ions, say Xe^{3+}, which cannot be isolated from electronic spectra alone.

In 2022, we analysed the data from the XFEL free-electron laser experiment at the SCS beamline in Hamburg, executed in collaboration with Laurent Mercadier. In the experiment we observed the first transient absorption spectra of intense XUV light ($L_{2,3}$ edges in Cu). The initial phase of the quantitative interpretation of the results was successfully completed, but the development of plasma and its fast cooling on a short time scale and under conditions of high matter density and light intensity needs to be modelled in more detail to fully understand the measured spectra.

Within 2022, sulphur X-ray emission (XES) measurements of several heteroaromatic systems and tiophene-based materials developed for potential organic molecular switches were performed at the Microanalytical Centre. X-ray emission was induced with a 2 MeV proton beam while Kb XES spectra were recorded with a Johansson type Bragg crystal spectrometer providing energy resolution on sulphur core-hole lifetime broadening. High-energy resolution is a crucial experimental parameter yielding the applicability of the S XES for the aromaticity studies of S-bearing systems. The measurements are part of an ARRS joint project with Hungarian researchers from the Wigner Research Center for Physics where we are studying advanced sulphur-based materials in the field of molecular electronics and energy storage materials.

As a part of the experimental development of ion-beam analytical methods at the Microanalytical Centre, a new parallel-beam wavelength-dispersive (PB-WDS) X-ray emission spectrometer was constructed and installed at the external proton beamline used to perform an in-air PIXE analysis. The spectrometer combines polycapillary X-ray optics for efficient X-ray collection with diffraction on a flat crystal analyser and achieves energy resolution in the eV range. High-energy resolution is used to resolve overlapping lines in PIXE spectra recorded with the energy dispersive detector, improving the sensitivity of the analysis. Detailed characterization measurements were performed yielding a quantitative analysis of the main operational parameters, followed by the first applications for in-air PIXE mapping, where the capabilities of the new setup proved to be essential for a successful analysis. With its high-energy resolution, the spectrometer is a novel tool complementary to the energy-dispersive solid-state detectors used commonly in PIXE analyses, significantly enhancing the analytical capabilities of our external proton beamline (Figure 6,7).

Figure 8: N NEXAFS for $C_{59}N$ / Au(111). The 2ML film (upper panel) displays no linear dichroism and quenching of the half-filled orbital (SUMO), consistent with the $(C_{59}N)_2$ dimer structure of the bulk. The monolayer film (lower panel) shows preferential orientation and coupling of the N end of a fullerene cage to Au as evidenced by linear dichroism of the monomer film. The occurrence of orbital SUMO at 400.5 eV evidences the radical character of monomers.

In 2022 we published the results of a series of X-ray Raman (XRS) measurements of oxygen K-edge used to study the redox reaction mechanism of novel redox active organic materials (*Rajh et al. J. Phys. Chem. C 2022*). The measurements were performed at the P01 beamline of the PETRA III synchrotron at DESY, Hamburg, in collaboration with the Group for Modern Battery Systems from the National Institute for Chemistry. Within the field of high-energy resolution PIXE measurements, the study of the multiple ionization K X-ray satellites in He induced spectra, used to improve the accuracy of PIXE analyses with helium beams, has been published (*Cureatz et al., Spectrochim. Acta B: Atomic Spectroscopy 2022*). We also published the results of our proton induced Kα X-ray emission measurements used to study the sensitivity of the measured spectra to the local chemical environment of some 3d elements (Ti, Cr) within different compounds (*Fazinić et al., Spectrochim. Acta B: Atomic Spectroscopy 2022*). In addition, we reported on the role of the multielectron ionization contributions in valence-to-core X-ray emission spectra of third-row elements (*Kavčič and Petric, X-Ray Spectrom. 2022*), as well as on the final results of the upgrade of the external proton beamline at the Microanalytical Centre (*Isaković et al., Nucl. Instr. Meth. B 2022*).

We studied the stability of ultrathin azafullerene ($C_{59}N$) radicals, UHV deposited on an Au(111) surface. Together with the Condensed Matter Physics Department (F-5, IJS) we were granted two beamtime projects at the Elettra synchrotron in 2022 and performed a series of synchrotron-based experiments. We established reliable protocols for a UHV deposition of $C_{59}N$ monolayer films in the form of molecular monomers, whereas thicker films beyond 2 monolayers form diamagnetic dimers $(C_{59}N)_2$ (Figure 8). We have shown that $C_{59}N$ monomers interact with Au(111) with a significant charge transfer, greatly affecting the radical state of monomers. The monolayer of $C_{59}N$ nevertheless serves as a passivating layer for the intact radical phase of $C_{59}N$ monomers grown on top, with a high density of molecular spins. The occurrence of the stable, high-spin density phase of $C_{59}N$ radical monomers opens new routes for designing stable organic radicals as molecular q-bits. Based on our findings we have successfully applied for 2 additional beamtimes with synchrotron light at Elettra in 2023 (ID 20225294 and ID 20220289) and have also been approved for the
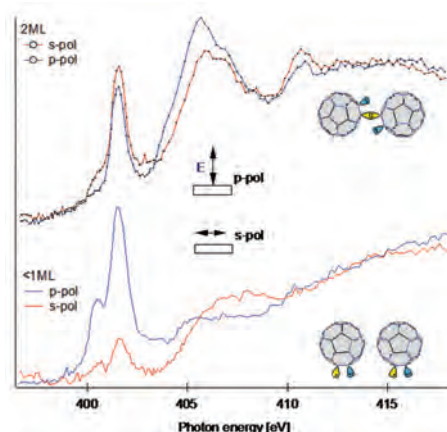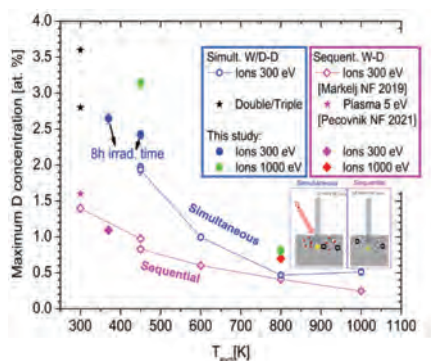

Figure 9: Maximum D concentrations as obtained from the D depth profiles at different experimental conditions for simultaneous and sequential exposures at different W irradiation temperatures. The figure shows an increased deuterium concentration and therefore also a higher number of defects created when deuterium is present during the creation of defects as its capture at the defect site inhibits the process of defect annihilation (Markelj et al., Phys. Scr. 2022).

NFFA-Europe project (ID 447-2023). We have also extended our field of experimental investigations of azafullerene radicals to low-temperature scanning microscopy-spectroscopy (LT-STM).

In the Laboratory for Fusion Research we conducted several tasks that were coordinated within the EUROfusion consortium. One of them was the continuation of the study of synergies between displacement damage creation and hydrogen presence in tungsten (*Markelj et al., Phys. Scr. 2022*). This time we focused on the effect of deuterium ion energy and flux. Tungsten samples were irradiated with 10.8 MeV W ions with and without the presence of deuterium ions with two different energies of 300 eV/D and 1000 eV/D and at different temperatures. By increasing the W irradiation time, ion flux and energy, an increase in the deuterium concentration and D retention was observed during a nuclear reaction analysis and thermal desorption spectroscopy. By fitting the D depth profiles and D desorption spectra with the rate equation code MHIMS-R we could see that additional fill levels were populated with higher flux and ion energy, ending up in higher final D concentration and retention as compared to the experiments with lower D flux and energy.

We have investigated the influence of the grain size on the creation of irradiation-induced defects in tungsten by measuring the deuterium retention and transport. We have observed that in the nanometre-grained samples, deuterium populated a damaged region more than three times faster than in the samples with larger grains. With this we have shown that grain-boundary diffusion increases the D transport through a material. The concentration of defects was assessed based on the final deuterium concentration in the samples. Samples with a smaller grain size showed a larger deuterium concentration in the irradiated area. However, the difference in the deuterium concentration for different-grained samples was not substantial. It can be postulated that the nanocrystaline microstructure did not substantially influence the process of irradiation-defect generation, which could potentially happen due to a defect annihilation at the grain boundaries in tungsten.

In 2021 we won the enabling research project ENR-MAT.01.JSI entitled "Detection of DEfects and HYDROgen by ion beam analysis in Channelling mode for fusion – DeHydroC". In order to obtain experience in the channelling measurement technique we applied for a beamtime at Centro de Micro-Análisis de Materiales (CMAM), Universidad Autónoma de Madrid, Spain, under proposal code P01139, which was approved. In October 2022 we performed measurements on W (111) single crystals irradiated by 10.8 MeV W ions at different ion fluences and temperatures in order to create different defects in the material. We performed measurements, using Rutherford backscattering spectroscopy, in channelling configuration with different ^{4}He ion beam energies. The so-called multi-energy beam analysis method was applied in order to obtain more detailed information about the type of defects and their extension. An example of the measured spectra is shown in Figure 10, where we see different yields of backscattered ions on differently prepared samples, including an undamaged tungsten single crystal in aligned and random configuration.

The JSI tandem accelerator provided 4000 beam hours to the users in 2022. The operation was dedicated to the realisation of a number of national and international research projects. Part of the operation was dedicated to the Transnational Access Programme of EU within the H2020 project RADIATE (https://www.ionbeamcenters.eu/radiate/). In 2022 we executed eight TNA projects in a total duration of 370 beamhours. In 2022 we participated in the successful project proposal ReMade@ARI as a member of the ARIE (The Analytical Research Infrastructures in Europe) in the field of circular economy. ReMade@ARI offers coordinated access to more than 50 European analytical research infrastructures to foster the research dedicated to sustainable technologies, a basis for circular economy. ReMade@ARI includes 1600 hours of transnational access to tandem accelerator at the JSI.

Intense research on high-energy focusing on ion beams in the fields of biology and medicine took place at the JSI microbeam. Chromium and other element localisation in the roots of a plant used in a constructed wetland was determined with the micro-PIXE method and published (*Chen et al., J. Hazard. Mater. 2022*). Histology studies of a tissue were carried out after a porous tantalum tibia baseplate fracture revealed the presence of titanium and tantalum microparticulates in the periprosthetic tissue (*Fokter et al., Materials 2022*). Work on imaging mass spectroscopy with MeV-SIMS was dedicated to both the further development and application of the method (*Jeromel et al, PLoS ONE 2022*).

Among several new installations of scientific equipment at the beamline section of the tandem accelerator, we highlight the construction of a new beamline dedicated to the formation of a high energy ion nanobeam. We implemented several technologies in its construction for the first time in the laboratory, including active antivibration suspension, mu-metal shielding of the beam flight path along the beamline and magnetic quadrupole lens in the form of a separated quadruplet (Figure 11). During the demanding ion optics alignment, we were able to reach beam diameters in a sub-500 nanometer range. A particularly
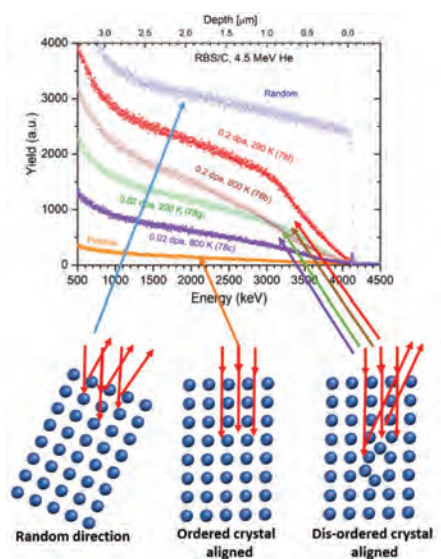

Figure 10: Yield of the backscattered ions in channelling configuration on aligned and randomly oriented pristine single crystal tungsten, together with the spectra obtained on the W single crystal samples damaged by self-implantation of high energy W ions, irradiated to displacement magnitudes indicated in the figure.
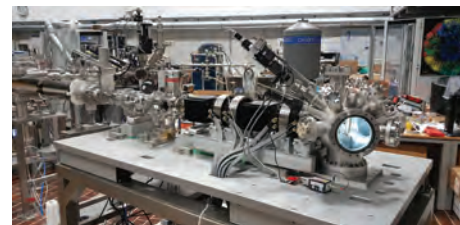

Figure 11: New beamline for creation/applications of high energy ion nanobeams at the tandem accelerator laboratory of the Jožef Stefan Institute.

important added value of the new beamline is its ability to focus heavy high-energy ions with magnetic rigidities of up to 70 MeV amu, which will contribute to the future projects dedicated to molecular imaging and the creation of quantum centres in diamonds.

The Infrastructure Centre for Measurements of Ionising Radiation (ICMIS) carried out monitoring of the radioactivity in the living environment in the Republic of Slovenia, operational radiological monitoring of the Krško Nuclear Power Plant (NPP), monitoring of the radioactivity in the vicinity of the central radioactive waste storage facility in Brinje (ARAO), independent verification of operational monitoring at NEK and monitoring of the radioactivity in drinking water in the Republic of Slovenia. These measurements were made using high-resolution gamma-ray spectrometry and liquid scintillation spectrometry. We also measured personal and environmental doses of ionising radiation using thermoluminescence dosimeters. The laboratories involved in ionising radiation dosimetry are accredited to SIST EN ISO/IEC 17025. As part of the accreditation, we successfully participated in international intercomparisons in 2022 and demonstrated excellence in these activities.

In 2022, under the authorisation of the Slovenian Radiation Protection Administration (SRPA), we carried out personal dose measurements with TL-dosimeters on 2168 exposed workers, including 140 IJS employees. The data are regularly sent to the Radiation Protection Administration of the Republic of Slovenia for the central record of radiation doses. In 2022 we measured the ambient dose equivalent with TL-dosimeters at 132 locations.

In 2022, 265 calibrations were performed at the National Dosimetry Laboratory (NDS), including 167 calibrations of dose rate meters, 53 calibrations of electronic personal dosimeters and 45 calibrations of contamination meters. In addition, 124 series of irradiations of passive dosimeters were performed.

A total of 736 measurements were carried out in the LMR laboratory as part of the regular monitoring programmes and 41 measurements (17 reports) were carried out for sporadic clients. Of these, one report is under the responsibility of the Ministry of Agriculture, Forestry and Food.

In 2022, 188 measurements of tritium content in water samples were carried out in the framework of radioactivity monitoring in the vicinity of the Krško NPP and in the Republic of Slovenia. For occasional consumers, the content of tritium was determined in 3 samples.

In 2022, we continued intensive collaboration with the Metrology Institute of the Republic of Slovenia (MIRS). As a designated institution and the holder of the national standard for the field of ionizing radiation, we continued the activities on the following EU funded EMRP projects:

- EMPIR 2019, *JNT-w08 supportBSS - Support to the European Metrology Network for reliable legislation in the field of radiation protection*
- PR-02570-1 - *Preparation of reference and intercomparison materials, in cooperation with IARMA*

The European project The Partnership for Radiation Protection Research (PIANOFORTE) was launched on 1 June 2022. The JSI is the programme manager for Slovenia; three calls for projects in the field of ionising radiation science and research are expected to take place.

We are participating in the IAEA-sponsored MEREIA programme, which brings together scientists and experts in the field of radiation protection and radioecology; the IJS-F2 has been entrusted with the leadership of WG3 Historical Marine Dumping of Radioactive Waste.

As of 10 June 2022, we started work on project No SLO9022 under the IAEA TC Programme entitled Strengthening the Capacity of Slovenia in Emergency Preparedness and Response Radiation Monitoring.

Within the framework of the ACDPR funding, in 2022 we purchased a portable FLIR SPIRAce spectrometer, which enables flexible identification and quantification of radionuclides in the field, and a Berthold neutron dose rate meter.

In 2022 we completed the project The Third NPP Krško Periodic Safety Review Programme, Safety Factor 15 – Radiological Impact on the Environment. The purpose of the project task is to review the adequacy of the documentation in the area of Safety Factor 15. Based on the findings of the review, we have made a substantial contribution to the authorisation of the NEK operation in the next operating period.

In 2022 we continued with the project Impact of the Brežice Hydroelectric Power Plant (HPP) on the NPP and the Environmental Impact Report relating to the extension of the NPP operating life. After the construction of the Brežice HPP, new hydraulic conditions in the Sava River, which are not well known, have emerged. The changes in the flow regime of the Sava River after the construction of the Brežice HPP are indicated by visual observations by the local population (fishermen) and the evaluation of measured tritium activity concentrations at sampling stations (in the flow storage of the Brežice HPP, above the dam of the Brežice HPP and at Brežice). It is noted that the dilution ratio of the activity concentrations in the Sava River at Brežice changed, but no such change is known for the other locations. According to the technical specification DOSE CALCULATION AND DILUTION MODELLING OF RUN-OF-RIVER BREZICE HYDRO PLANT ACCUMULATION No. TO. RZ-5/2020, a numerical programme for the assessment of population effects (DOSENEK)
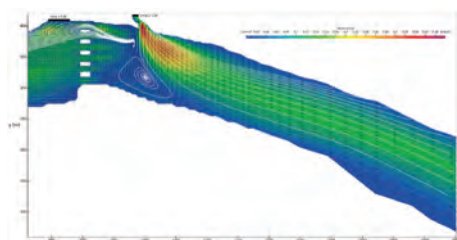

Figure 12: Trajectories in the surface layer (0.0–0.4 m) for the case of a Sava River flow of 50 m³/s downstream of the NPP dam in the Brežice HPP flow reservoir. Based on B. Zorko, R. Rajar, G. Omahen, A. Širca, M. Četina, V. Hatič, Program for calculation of effective doses due to liquid discharges from NPP Nos. 164/2022 and 9/2023.

was developed based on the evaluation of dilution coefficients and dilution ratios of the flow-through accumulation of the Brežice HPP using the tested model PCFLOW3D (Figure 12).

In 2022 we continued activities within the project "Qualitative and quantitative groundwater monitoring in the influence area of the Mokrice HPP dam". The project is led by IRGO d.o.o. and coordinated by the O2 department at the IJS, with the participation of NLZOH, an external entity. The aim of the project is to determine the state of the environment prior to the start of construction of the Mokrice HPP. Our team is involved in determining the concentration of H-3 activities and the total content of alpha and beta emitters in the water from the boreholes in the construction area.

We continued to optimise the method for the determination of organically bound tritium (OBT) and tissue free water tritium (TFWT). A total of 58 measurements of TFWT and OBT were carried out in 2022. 173 samples were taken and analysed within a study on the alpha- and beta-emitter content of drinking water samples in Slovenia. 165 measurements of the C-14 content in water, biota, semi-finished products, urine, fuels and ethanol in its original form or as CO_2 were performed. Tritium levels in urine were also determined in 2022. There were a lot of intercomparison tests in 2022, with a total of 104 measurements performed with different methods. As part of the preparation, testing and characterisation of intercomparison samples for IARMA, we prepared and analysed 139 analytes.

In 2022 we completed the installation of a 320 kV Comet iXRS-320 X-ray tube, which will extend the energy and intensity range of our calibration X-ray field, and in this way increase the scope of our instrument calibration activities.

Organization of conferences, congresses and meetings

1. ICNMTA 2022, Ljubljana, 11–16 September 2022
2. Slovenian national FAIR day, Ljubljana, 16 November 2022

INTERNATIONAL PROJECTS

1. EMPIR - supportBSS; Support for a European Metrology Network on Reliable Radiation Protection Regulation
   Denis Glavič Cindro, M. Sc.
   Euramet E.v.
2. EMPIR; AEROMET II; Advanced Aerosol Metrology for Atmospheric Science and Air Quality
   Asst. Prof. Klemen Bučar
   Euramet E.v.
3. COST CA18222; Attosecond Chemistry
   Asst. Prof. Andrej Mihelič
   Cost Association Aisbl
4. COST CA18212; Molecular Dynamics in the GAS Phase
   Prof. Matjaž Žitnik
   Cost Association Aisbl
5. TC Regional Project RER/7/014: Improving Environmental Monitoring and Assessment for Radiation Protection in the Region
   Asst. Prof. Benjamin Zorko
   IAEA - International Atomic Energy Agency
6. Experiments and Modelling of In Situ Uptake, Transport and Release Studies of Hydrogen Isotopes in Irradiated Tungsten; Hydrogen Permeation in Fusion-Relevant Materials
   Asst. Prof. Sabina Markelj
   IAEA - International Atomic Energy Agency
7. Detection of Hydrogen Isotopes by NRA, Cross Sections and Best Practices; Development and Application of Ion Beam Techniques for Materials Irradiation and Characterization Relevant to Fusion Technology
   Asst. Prof. Sabina Markelj
   IAEA - International Atomic Energy Agency
8. H2020 - TRANSAT; TRANSversal Actions for Tritium
   Asst. Prof. Sabina Markelj
   European Commission
9. H2020 - RADIATE; Research and Development with Ion beams - Advancing Technology in Europe
   Prof. Matjaž Kavčič
   European Commission
10. H2020 - CleanHME; Clean Energy from Hydrogen-Metal Systems
    Prof. Matej Lipoglavšek
    European Commission
11. H2020 - HITRIplus; Heavy Ion Therapy Research Integration
    Asst. Prof. Matjaž Vencelj
    European Commission
12. HE - EUROfusion; WP07: ENR-DeHydroc-1,2,3_HE-FU
    Asst. Prof. Sabina Markelj
    European Commission
13. HE - EUROfusion; WP18: MAT_HE-FU, IREMEV-MAT-1_HE-FU, IREMEV-MAT-2_HE-FU, IREMEV-MAT-3_HE-FU
    Asst. Prof. Sabina Markelj
    European Commission
14. HE - EUROfusion; WP21: PRD-1,2_HE-FU
    Asst. Prof. Sabina Markelj
    European Commission
15. HE - EUROfusion; WP05: PWIE-1,2,3,_HE-FU, PWIE-4-Accelerator
    Asst. Prof. Sabina Markelj
    European Commission
16. HE - EUROfusion; WP24: TRED_HE-FU, EDU_HE-FU
    Prof. Primož Pelicon
    European Commission
17. HE - PIANOFORTE; European Partnership for Research in Radiation Protection and Detection of Ionising Radiation: Towards a Safer Use and Improved Protection of the Environment and Human Health
    Asst. Prof. Benjamin Zorko
    European Commission
18. HE - ReMade-at-ARI; Recyclable Materials Development at Analytical Research Infrastructures
    Prof. Primož Pelicon
    European Commission
19. HE - TITANS; Tritium Impact and transfer in Advanced Nuclear reactorS
    Asst. Prof. Sabina Markelj
    European Commission
20. EMPIR; OpMetBat - Operando Metrology for Energy Storage Materials
    Prof. Matjaž Kavčič
    Euramet E.v.

RESEARCH PROGRAMMES

1. Archaeological heritage research
   Dr. Eva Menart
2. Object and Prestige; taste, status, power (Researches of the material culture in Slovenia)
   Dr. Marijan Nečemer
3. Parallel and Distributed Systems
   Prof. Roman Trobec
4. Structure of hadronic systems
   Prof. Simon Širca
5. Studies of atoms, molecules and structures by photons and particles
   Prof. Matjaž Žitnik
6. Fusion technologies
   Asst. Prof. Sabina Markelj

R & D GRANTS AND CONTRACTS

1. Spatial localization of elements and metabolits in plants
   Prof. Katarina Vogel-Mikuš
2. Structured light as a tool for triggering and probing new states of matter
   Prof. Matjaž Žitnik
3. Alternative approaches to assuring guality and security of buckwheat grain microbiome
   Prof. Primož Pelicon
4. Lessons from nutrient-use-efficient plants to benefit dietary mineral intake
   Prof. Primož Pelicon
5. High-energy aluminium metal-organic batteries
   Prof. Matjaž Kavčič
6. Molecular Imaging Inside the Cell
   Prof. Primož Pelicon
7. Novel proxies of the Holocene climate variability in stalagmites in Slovenia
   Prof. Primož Pelicon
8. Developing tender X - ray spectroscopy probes to tackle problems in materials science and ultrafast science
   Prof. Matjaž Kavčič
9. Detection of defects and hydrogen by ion beam analysis in channelling mode for fusion
   Asst. Prof. Sabina Markelj
10. Precision studies of inclusive response of light nuclei
    Prof. Simon Širca
11. Formation and Design of AM-processed Fe-Al alloys with self-forming Hydrogen Permeation Barriers for the harshest of environments
    Asst. Prof. Sabina Markelj
12. Generation of isolated Nitrogen-vacancy centers in diamond by ion implantation
    Dr. Žiga Barba
13. SiMBION – EuBI
    Prof. Primož Pelicon
14. FAIR
    Dr. Jelena Vesić
15. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
    Prof. Primož Pelicon
    Ministry of Education, Science and Sport
16. Ecology laboratory with mobile unit
    Prof. Matej Lipoglavšek
    Ministry of Defence
17. Environmental radioactivity monitoring of living environment in Republic Slovenia in 2022
    Asst. Prof. Benjamin Zorko
    Ministry of the Environment and Spatial Planning
18. Monitoring of radioactivity in drinking water for the year 2022
    Asst. Prof. Benjamin Zorko
    Ministry of Health
19. Central radioactive waste repository radiological monitoring CSRAO 2022
    Dr. Marijan Nečemer
    Arao, Ljubljana
20. Assessment of the justification for the use of items of general-use containing added radionuclides and radiation protection assessment for minerals or rocks with naturally occurring radionuclides
    Asst. Prof. Benjamin Zorko
    Ministry of the Environment and Spatial Planning
21. Services
    Branko Vodenik, M. Sc.
22. Calibrations
    Boštjan Črnič
23. Different Analyses; Reference Materials
    Dr. Jasmina Kožar Logar
24. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
    Prof. Primož Pelicon
    Helmholtz-Zentrum Dresden-Rossendorf E.v.
25. C-14 Measurements
    Dr. Romana Krištof

NEW CONTRACTS

1. Maintaining emergency preparedness and response by ELME (2020-2023)
   Asst. Prof. Benjamin Zorko
   Krško Nuclear Power Plant
2. Qualitative and quantitative monitoring of groundwater in the impact area of the dam for HPP Mokrice
   Asst. Prof. Benjamin Zorko
   Irgo Consulting d. o. o.
3. Report on the environmental impact assessment of the Brežice hydroelectric power plant and the impact on the operational lifetime extension of the Krško NPP
   Asst. Prof. Benjamin Zorko
   Krško Nuclear Power Plant
4. Support for NEK PSR 3 Project Tasks Environment and Radiation Protection
   Asst. Prof. Benjamin Zorko
   Krško Nuclear Power Plant
5. Calibration of portable radiation protection meters in the secondary laboratory in 2022, 2023 and 2024
   Boštjan Črnič
   Krško Nuclear Power Plant
6. LOT 1: Measurements of gaseous effluents - Specific analyzes of H-3 and C-14 in 2022, 2023, 2024 and 2025; LOT 2: Measurements of gaseous effluents - Gamma spectrometry and analysis of strontium Sr-89/90 in 2022, 2023, 2024 and 2025
   Asst. Prof. Benjamin Zorko
   Krško Nuclear Power Plant
7. Environmental radioactivity monitoring in the vicinity of the Krško Nuclear Power Plant in connection with Hydro Power Plant Brežice for the years 2022 and 2023
   Asst. Prof. Benjamin Zorko
   Krško Nuclear Power Plant

VISITORS FROM ABROAD

1. Ioannis Krimitsas, University of Ioannina, Ioannina, Greece, 1 January – 6 May 2022
2. Dr Juergen Gerl, FAIR/GSI, Darmstadt, Germany, 28–30 March 2022
3. Maxime Martin, University of Bordeaux, Bordeaux, France, 17 April to 17 June 2022
4. Rashid Dallaev, University of Brno, Brno, Czech Republic, 9 May to 9 August 2022
5. Marko Radosavljevic, ISRN, Paris, France, 18 July to 5 August 2022
6. Evgeniya Soboleva, IARMA Limited, Vienna, Austria, 18–19 August 2022
7. Njomza Elezaj, University of Pristina, Pristina, Kosovo, 29 August to 2 September 2022
8. Agnieszka Fulara, Joanna Lemańska, Central Laboratory for Radiochemical Protection, Warsaw, Poland, 3–14 October 2022
9. Dvora Namdar, Hanita Zemah, Agricultural Research Organisation – Volcani Institute, Rishon LeZion, Israel, 6–11 November 2022

STAFF

Researchers
1. Prof. Iztok Arčon*
2. Asst. Prof. Klemen Bučar
3. Dr. Aleksandra Cvetinović
4. Prof. Dean Cvetko*
5. Denis Glavič Cindro, M. Sc.
6. Dr. Darko Hanžel
7. Prof. Matjaž Kavčič
8. Dr. Jasmina Kožar Logar
9. Dr. Romana Krištof*
10. Prof. Matej Lipoglavšek
11. Asst. Prof. Sabina Markelj
12. Asst. Prof. Andrej Mihelič
13. Asst. Prof. Miha Mihovilovič
14. Dr. Marijan Nečemer
15. **Prof. Primož Pelicon, Head**
16. Dr. Toni Petrovič
17. Dr. Paula Pongrac*
18. Dr. Jurij Simčič
19. Prof. Simon Širca*
20. Dr. Primož Vavpetič
21. Asst. Prof. Matjaž Vencelj
22. Dr. Jelena Vesić
23. Branko Vodenik, M. Sc.
24. Prof. Katarina Vogel-Mikuš*
25. Asst. Prof. Benjamin Zorko
26. Prof. Matjaž Žitnik
Postdoctoral associates

27. Dr. Žiga Barba
28. Dr. Boštjan Jenčič
29. Dr. Eva Menart*
30. Dr. Marko Petric
31. Dr. Esther Punzon Quijorna

Postgraduates

32. Žiga Brenčič, B. Sc.
33. *Mateja Hrast, B. Sc., left 25.11.22*
34. Gregor Košir, B. Sc.
35. *Špela Krušič, B. Sc., left 01.10.22*
36. Eva Lovšin, B. Sc.
37. Ava Rajh, B. Sc.
38. Janez Turnšek, B. Sc.
39. Mirjana Vasić, M. Sc.

Technical officers

40. Boštjan Črnič, B. Sc.
41. Polona Gerjol, B. Sc.
42. Mitja Kelemen, B. Sc.
43. Klara Poiškruh, B. Sc.
44. Petra Prem, B. Sc.
45. Matevž Skobe, B. Sc.

Technical and administrative staff

46. Mojca Gantar
47. Sandi Gobec
48. Andrej Košiček, B. Sc.
49. Mirko Ribič, B. Sc.
50. Rok Roš Opaškar

Note:
* part-time JSI member

DEPARTMENT OF THIN FILMS AND SURFACES

F-3

The main research field of the department is the development, deposition and characterization of hard protective PVD coatings, while research is also conducted in other fields of thin films and surface physics. The basic research is concentrated on the study of the physical and chemical properties of various multicomponent, multilayer and nanostructured coatings. Among the applied research, different coatings are developed for the protection of tools for various production processes in industry.

Head:
Prof. Miha Čekada

Over the past year we have worked extensively on hard-coating surfaces and have published several papers on the subject. The narrower topics covered are the contamination of the substrate surface during ion etching, the tribological properties of TiN coatings deposited using three different PVD processes, and the microstructure and topography of TiAlN/CrN multilayer coatings. This is the culmination of several years of research into the influence of the deposition parameters of hard coatings on the surface that forms a tribological contact with the workpiece. Building on our work to date, two members of the department have edited a book entitled "*Surface topography effects on the functional properties of PVD coatings*", which brings together papers covering the whole spectrum from the substrate selection to the final coating. The chapters in the book focus on the mechanical and tribological properties of coatings, deposition methods and the broad topic of defects in hard coatings. Papers on defects in PVD coatings are widely cited, mainly due to the widespread use of PVD processes in optical applications and microelectronics, where these defects also cause the most problems.

Our research work on PVD hard coatings prepared in industrial deposition conditions is also interesting because such publications are rare in the literature. This is because research institutes tend to publish results at the laboratory level, whereas the daily use of industrial devices is the domain of manufacturing companies, which generally do not publish papers. Because of the high profile of research in this niche area, the department's researchers regularly give invited lectures on this topic. In the past year we have evaluated the dependence of the mechanical properties of hard coatings on the vertical location in the vacuum chamber. Although at first sight the issue may seem trivial, it has a major impact in those coating applications where narrow tolerances are required.

For many years we have been researching the physics of plasmas in magnetron discharges. In the past year we have focused on studying the kinetics of ionisation zones in high-power impulse-magnetron sputtering (HiPIMS). We have analysed in detail the velocity of the rotating ionisation zones from plasma images taken with a high-speed camera (one million frames per second). The dynamics were studied for different argon pressures and peak discharge currents. We found that in the initial phase, the ionisation zones move in the opposite direction to the electron motion, i.e., in the $-\mathbf{E}\times\mathbf{B}$ direction, which is the same as in classic DC magnetron discharges. However, as the current increases, the zones reverse their direction of rotation and start to move in the direction of the electron motion (i.e., in the $\mathbf{E}\times\mathbf{B}$ direction). A single ionisation zone, which is formed only at the lowest pressures,
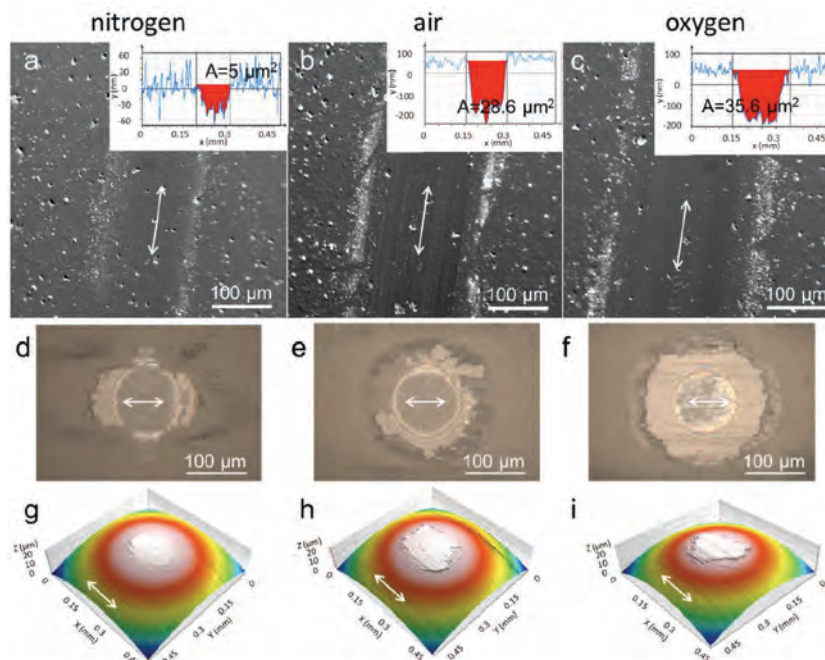

Figure 1: Tribological tests of TiN coating in different atmospheres: nitrogen (a,d,g), air (b,e,h) and oxygen (c,f,i). Above (a,b,c) there are SEM images of the surface of the sample, with a line cross-section in the corner; in the middle (d,e,f) there are optical images of the wear of the Al_2O_3 antibody; below (g,h,i) there are perspective views of the topography of the worn antibody.

rotates in the $-\mathbf{E}\times\mathbf{B}$ direction and has velocities in the range 13–17 km/s. At pressures above 0.5 Pa, however, two zones are formed which rotate at 4–9 km/s. At currents above 30–50 A, the zones rotate in the $-\mathbf{E}\times\mathbf{B}$ direction and have velocities in the range 6–9 km/s. The velocity in the $-\mathbf{E}\times\mathbf{B}$ direction is strongly influenced by the increasing discharge current and partly also by the pressure, while in the $\mathbf{E}\times\mathbf{B}$ direction the velocities are practically independ-
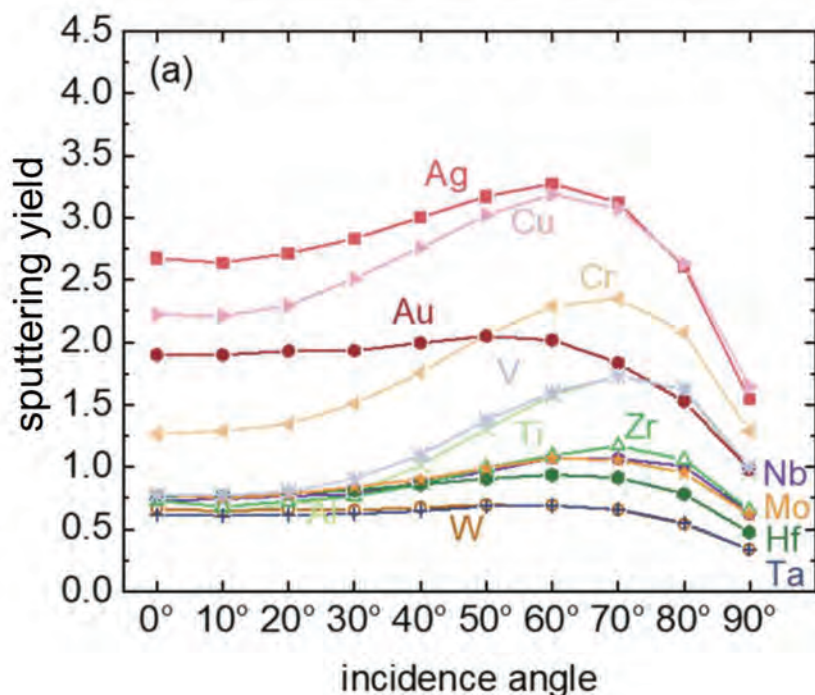
Figure 2: Sputtering coefficients of metals commonly used in sputtering applications as a function of the angle of incidence of the argon ion at 600 eV. The simulation was performed with SRIM.
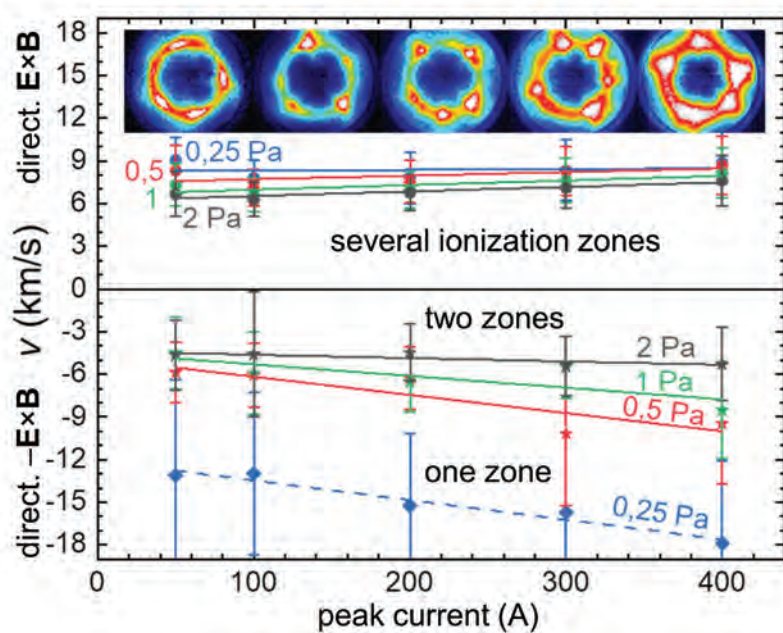

Figure 3: Ionisation zone velocities in high power impulse magnetron sputtering (HiPIMS) at different pressures and currents. The high-speed camera images of the plasma are shown above.

ent of the current and only to a lesser extent depend on the operating pressure.

Over the past year we have continued our research into the physical processes of sputtering. For different element targets, we optimised the free parameters in the SRIM code and then analysed the simulations to obtain information on the sputtering coefficient and angular distributions of the sputtered atoms. Simulations were performed for the normal incidence of argon ions in the range 300–1200 eV and for the oblique incidence for some selected ion energies. The sputtering coefficient and its angular distribution were calculated for transition metals in groups 4–6 and 11, which are important for sputtering applications. From these results we evaluated the dependence on period and group in the periodic table. We have also checked the angular distribution of the sputtered atoms, which is cosine for normal incidence and asymmetric for oblique incidence. The asymmetry effect was also evaluated with respect to the parameters of the simulated experiment.

The influence of surface binding energy, atomic mass and ion energy on the sputtering coefficient has also been studied in detail. These parameters were analysed according to the simplified analytical formula for the sputtering coefficient derived by P. Sigmund. This formula has been modified by introducing a potential dependence on the ion energy. The equation allows a rapid estimation of the sputtering coefficient for transition metal elements sputtered by argon ions with energies up to 1200 eV.

We collaborated with the Faculty of Mechanical Engineering at the University of Ljubljana on research into the lifetime of hard coatings using liquid CO_2 as a coolant in a laboratory environment on a tribometer. We studied the wear resistance of TiAlN coatings at up to 700 °C and in different atmospheres (N_2, CO_2). The focus was on the coefficient of friction, the wear on the pin and disc and the microhardness of the coating on the disc before and after the high-temperature tests. In collaboration with the University of Novi Sad, Serbia, we also investigated the temperature conditions in the contact and in the immediate surroundings. For all standard coatings applied for our industrial partners, tribological measurements were also carried out and the coefficient of friction and the coefficient of wear were measured on a test sample and a counterbody (pin). A new field, which is only just being introduced worldwide, is the nanomechanical evaluation of thin films. This is being carried out both in our home field of hard coatings and on ferroelectric ceramics (in collaboration with the Electronic Ceramics Department).

We investigated the coatings of refractory, high-entropy alloys and their nitrides. We have been working on magnetron sputtering in a coating system of our own design. The deposited coatings were characterised by means of scanning electron microscopy (SEM), focused ion beam (FIB), energy-dispersive spectroscopy (EDS), profilometry, nano-indentation, atomic force microscopy (AFM) and electrochemical methods for the analysis of corrosion processes.

There is collaboration with various research partners where our contribution is in the area of coatings or advanced surface analytics. First of all, we have collaborated with the Faculty of Mechanical Engineering at the

University of Ljubljana, with whom we published a paper in the journal *Photoacoustics* (impact factor 10), which is the top journal in this field. In the paper we describe the deposition and photoacoustic properties of a nanocomposite coating on a flexible substrate. For the Institute of Metals and Technologies we are investigating the deposition processes of CrVN coating for use in high-temperature tribological contacts.

As part of the EUROfusion consortium, we are actively involved in research on the surfaces of the materials of the first wall of a fusion reactor. In the past year we have continued to analyse changes in the surface morphology of materials exposed to the intense plasma in the ASDEX Upgrade fusion reactor in Garching, Germany. In addition, we have studied the composition of tungsten and tungsten oxide thin films using X-ray photoelectron spectroscopy (XPS) in the context of fusion research.

In collaboration with colleagues from the Department of Solid State Physics and partners from the Vinča Institute of Nuclear Sciences, Serbia, we analysed the magnetic properties of the multilayer thin films prepared in our laboratory. In a Si/Ni/Si multilayer structure with a nickel thickness of more than 15 nm, we observed a strong orthogonal magnetic anisotropy, which is otherwise typically present in much thinner nickel layers. Magnetic anisotropy in thicker layers opens up new possibilities for use in magnetic recording media, various sensors, spintronics and other applications.

The department intensively collaborates with Slovenian industry. Companies ask us for help with various issues related to surfaces and thin films. It may relate to development tasks, more advanced analytics or finding the root cause of problems. In the past year we have performed such analyses for the companies: Cetis, Difa, Kolektor, Kovinos, Krka, Le-tehnika, Orodjarstvo Koselj, Phos, Polident, Teroxal and Titus. We also provide coating services for companies to apply hard coatings to their tools; this is carried out within the Hard Coating Centre, which operates within the Department. We have over a hundred partners a year, which includes large companies (e.g. SIJ, Kolektor, Mahle) as well as a multitude of small tool shops.

Some outstanding publications in the past year

1. P. Panjan, A. Drnovšek, P. Terek, A. Miletić, M. Čekada, M. Panjan, Comparative study of tribological behavior of TiN hard coatings deposited by various PVD deposition techniques. *Coatings*, ISSN2079-6412, 22. Feb. 2022, vol. 12, no. 3, pp. 1–23
2. N. Mahne, M. Čekada, M. Panjan, Total and differential sputtering yields explored by SRIM simulations. *Coatings*, ISSN 2079-6412, 2022, vol. 12, no. 10, pp. 1541-1–1541-33

INTERNATIONAL PROJECT

1. HE - EUROfusion; WP05: PWIE-1,2,3,_HE-FU, PWIE-4-Accelerator
   Dr. Matjaž Panjan
   European Commission

RESEARCH PROGRAMME

1. Thin film structures and plasma surface engineering
   Prof. Miha Čekada

R & D GRANTS AND CONTRACTS

1. Initial stages in surface functionalization of polymers by plasma radicals
   Uroš Stele

2. Self-organization of plasma in magnetron sputtering discharges
   Dr. Matjaž Panjan
3. Controllable broadband electromagnetic-radiation shielding
   Dr. Matjaž Panjan
4. Carbon nanowalls for future supercapacitors
   Prof. Miha Čekada
5. Selected area functionalization of polymeric components by gaseous plasma
   Prof. Miha Čekada
6. Waterborne virus inactivation efficiency of a prototype device combining non-equilibrium plasma and hydrodynamic cavitation
   Prof. Miha Čekada
7. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
   Prof. Miha Čekada
   Ministry of Education, Science and Sport

VISITORS FROM ABROAD

1. Marco Beltrami, University of Trieste, Italy, 8–10 March 2022
2. Zoran Bobić, University of Novi Sad, Serbia, 28 August to 10 October 2022
3. Matěj Buřil, Jan Walter, Czech Technical University in Prague, Czech Republic, 19 September to 23 December 2022
4. Dr Marin Tadić, Vinča Nuclear Institute, Belgrade, Serbia, 29 October to 13 November 2022

STAFF

Researchers
1. **Prof. Miha Čekada, Head**
2. Dr. Aljaž Drnovšek
3. Dr. Matjaž Panjan
4. Matej Drobnič, B. Sc.
5. Žan Gostenčnik, B. Sc.
6. Nastja Mahne, B. Sc.

Technical officer
7. Uroš Stele, B. Sc.

Technical and administrative staff
8. Jožko Fišer
9. Damjan Matelič
10. Andrej Mohar
11. Tomaž Sirnik
12. Tadej Stele

DEPARTMENT OF
SURFACE ENGINEERING
F-4

The main activity of our department is the tailoring of surface properties of materials using thermodynamically non-equilibrium gas plasma. The basic principle of processing materials with gas plasma is the following: first, we select a suitable gas or gas mixture, and then we create a discharge in the selected gas so that a suitable density of free electrons is reached. Gas molecules, which are close to the ground state under normal conditions and room temperature, are excited to different states with high potential and/or kinetic energy during inelastic collisions with free electrons. Molecules in such energy states then react with the surfaces of the materials. Interactions of molecules in energy states can lead to functionalization, etching or deposition of coatings.

When functionalizing the surface of a material, we always change only the composition of the surface. The best effects are achieved by choosing neutral molecules or molecular radicals, including neutral atoms in the electronic ground state. Neutral gas particles are not affected by an electric field, so they have negligible kinetic energy. The treatment of the surface of materials with neutral plasma particles leads to a change in the surface chemistry due to an irreversible interaction. The surface properties of the materials treated with neutral plasma particles are often far from a thermodynamically stable state, which is why the materials treated in this way tend to age – the surface energy spontaneously decreases until a stable state is reached. Plasma-functionalized materials are suitable for further processing, for example, the application of a coating, which can be an adhesive, a print, a thin metal coating, or some organic coating with characteristic properties (antibacterial, antioxidant, etc.).

The etching of materials can be the result of intense chemical reactions or the exposure of surfaces to energetic, positively charged ions from the gas plasma. In the first case, the method is chemical plasma etching, and in the second, it is sputtering. Sometimes a combination of both surface interactions is used, and the technique is called reactive ion etching. The etching of workpieces with plasma particles with high potential and/or kinetic energy is often laterally inhomogeneous, which can lead to nanostructuring of the workpiece surface. Nanostructured materials always exhibit exceptional surface properties. By properly choosing the type of neutral plasma particles for processing the materials that we previously nanostructured, we can achieve an extremely wide range of surface wettability, from super-hydrophilic to super-hydrophobic. The super-hydrophilic effect is not permanent due to aging (hydrophobic recovery), but the super-hydrophobic is, making such treatment often the last step of creating the desired surface properties.

The deposition of thin films using plasma particles enables the achievement of surface conditions that cannot be achieved with any other known method. Neutral plasma particles with high potential energy are suitable for the application of thin layers, while particles with high kinetic energy are not desirable because they primarily cause etching upon contact with the surface. For the deposition of thin layers, we, therefore, prefer to use plasma with a low density of positive ions, but if this is not possible, the workpieces are always at a floating potential, i.e., away from the electrodes, near which there is a large electric field. Neutral plasma radicals with moderate potential energy condense on the surfaces of materials; some also polymerize, while those with high potential energy can disintegrate, especially if the substrate is heated to a high temperature. Depending on the type of plasma particles and the temperature of the workpieces, compact thin layers or porous and nanostructured layers can be formed on the surfaces of materials. The nanostructured porous layers deposited with plasma radicals are often super-hydrophobic.

Gas plasma is also a source of energetic photons. In most low-pressure plasmas, photons are most abundant at high energy, corresponding to

Head:
Prof. Alenka Vesel

European patents, EP3802418 for a new method of synthesising carbon nanostructures and EP3757155 for a method of achieving hydrophilicity of fluorinated polymers, were granted.
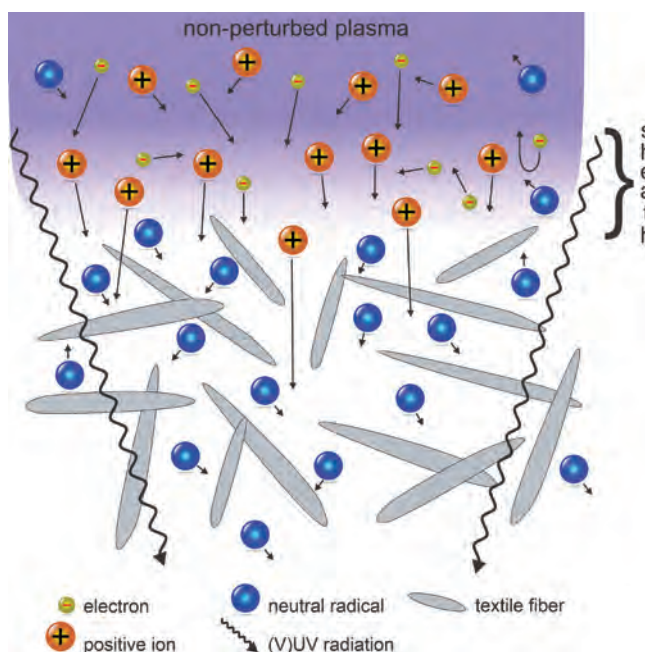

Figure 1: Illustration of the interaction of low-pressure plasma with textiles [1]
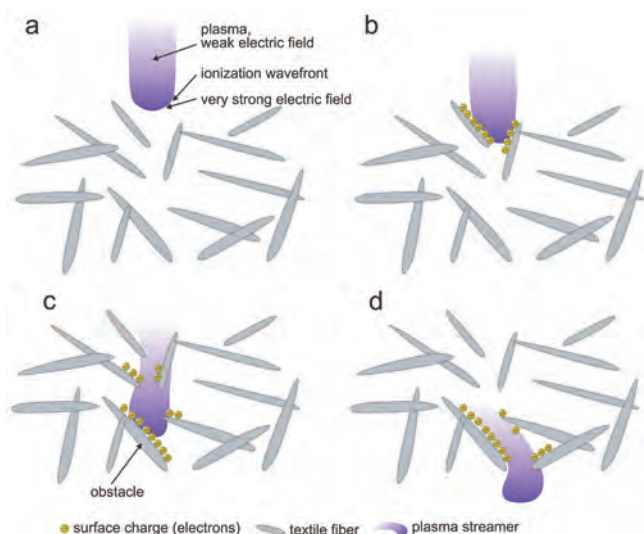
Figure 2: Illustration of the interaction of atmospheric plasma with textiles and the penetration phases of the jet of plasma radicals (a-d) [1]

We explained the role of VUV radicals in achieving the super-hydrophilicity of surfaces.
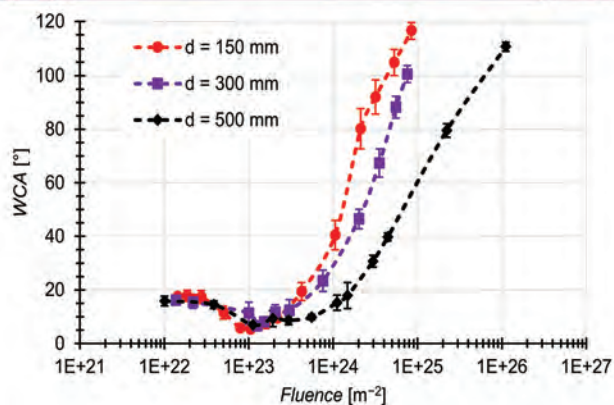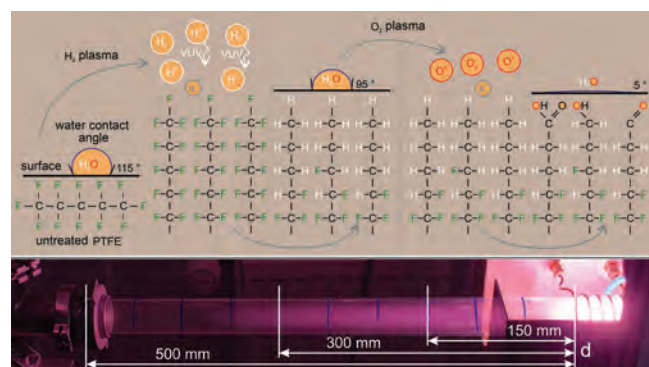

Figure 3: Contact angle of a water droplet on the Teflon surface, first exposed to hydrogen plasma, and then to a weak oxygen plasma at different distances from the radio frequency coil. The mechanism of the interaction of plasma radicals with the surface of the polymer is also shown [4].

vacuum ultraviolet (VUV) radiation. Energetic photons in the surface layer of a workpiece cause the splitting of chemical bonds and, thus, the formation of surface radicals, which are suitable for a chemical interaction with gas molecules or their radicals. The energy of VUV photons is greater than any chemical bond in solid materials, which makes the method suitable for processing almost any material.

Surface functionalization is particularly suitable for processing polymeric and other organic materials. Despite the fact that plasma treatment of such materials has been used in industry for decades, the optimization of process parameters still represents both a scientific and a technological challenge. This is especially true for highly porous materials, such as textiles. We explained the mechanism of the interaction of plasma particles with high potential and moderate kinetic energy with textile materials [1]. We explained the key difference between the use of low-pressure and atmospheric plasma for textile processing. During exposure to low-pressure plasma, particles with increased kinetic energy can only react with the surface of a textile, while the fibres inside are treated only with neutral particles with high potential energy since they easily penetrate into the depth of the textile because they do not lose their potential energy due to super-elastic collisions in the gas phase. The best effects are achieved by not placing the textile in the low-pressure plasma at all, but by treating it only with neutral plasma particles. A schematic of the interaction between low-pressure plasma and textiles is shown in Figure 1.

At atmospheric pressure, plasma particles with high potential and/or kinetic energy cannot penetrate deeply into a textile as they are quickly neutralized, relaxed or recombined due to the high frequency of collisions in the gas phase. For this reason, at atmospheric pressure, textiles can only be treated with short pulses of strong plasma, which can penetrate deeply into porous materials as the ionization wavefront provides an adequate density of plasma particles with high potential energy and moderate kinetic energy (Figure 2). The plasma can penetrate between the fibres due to the negative charge on the surface of the fibres, which is due to a higher mobility of electrons compared to positive ions. The surface charge effectively prevents the loss of electrons in the plasma streamer so that it can penetrate deeply into the textile. It can be seen from the comparison of Figures 1 and 2 that low-pressure plasma enables a uniform treatment of all fibres in the textile, while atmospheric plasma only localises it. This type of localized treatment allows a fairly useful functionalization of textiles, as long as the pulses of strong plasma are sufficiently dense and laterally evenly distributed over the surface of the workpiece.

Low-pressure plasma (Figure 1) was used to treat cotton textiles before applying a protective coating. Cotton is a natural material with excellent properties, making it the most suitable material for comfortable clothing. The disadvantages of cotton clothing are a relatively poor protection against ultraviolet radiation (when worn outdoors in the summer) and hydrophilicity, which is problematic due to water absorption and, thus, discomfort. A plasma-treated textile was impregnated with zinc acetate and then exposed to the actions of extracts from various plants. The extracts reacted chemically with the thin homogeneous layer of zinc acetate and formed nanoparticles of zinc oxide, which is among the best absorbers of ultraviolet radiation. Nanoparticles on the fibre surface also made the fabric super-hydrophobic, making the water uptake negligible. The textile treated in this way maintains the comfort of wearing cotton clothes while at the same time providing excellent protection against ultraviolet radiation, and the clothes do not get wet. The details of the procedure are explained in a scientific article [2].

The wettability of cellulose and many other polymeric materials for good coating adhesion is rapidly improved by using gas plasma sustained in oxygen. Neutral plasma particles with increased potential energy (for example, oxygen atoms) chemically react and form oxygen functional

groups on the surfaces of polymers, which are highly polar, making the polymer hydrophilic. A hydrophilic surface enables a good adhesion of coatings. However, the method is not suitable for processing fluorinated polymers. The bond between carbon and fluorine in Teflon and similar materials is stronger than the bond between carbon and oxygen, so oxygen plasma treatment breaks the bonds between adjacent carbon atoms but not between carbon and fluorine. The result is chemical etching but not surface functionalization of fluorinated polymers with polar oxygen functional groups. A few years ago, we developed a process for achieving super-hydrophilicity of otherwise hydrophobic polymers. The corresponding patent was granted in 2022 [3]. We published the scientific aspects of the technology in an article [4]. A fluorinated polymer is first treated with hydrogen plasma. Low-pressure hydrogen plasma is an extremely powerful source of VUV radiation that easily cleaves the bonds between fluorine and carbon in the surface layer of a workpiece. The hydrogen atoms react with the liberated fluorine to form a strong HF bond. Due to the high flux of H atoms on the surface of the workpiece, the free bonds are filled with hydrogen atoms so that the treatment of the fluorinated polymer with hydrogen plasma enables the formation of a very thin surface layer of polyolefin. The workpiece, which was treated with hydrogen plasma, is treated, in the next step, with oxygen atoms from the oxygen plasma, functionalizing the polyolefin layer with polar groups. An appropriate dose of oxygen atoms enables super-hydrophilicity. It can be seen from Figure 3 that super-hydrophilicity of a material can be achieved in a broad range of atomic oxygen doses. If the dose is too high, the oxygen atoms etch the polyolefin layer, and the opposite effect is achieved. The contact angle of a water droplet, which is a measure of the wettability of materials, is shown in Figure 3 as a function of the dose of atomic oxygen.

Figure 4: Photo of a mobile seed-treatment device. The device is owned by the Slovenian company Interkorn.

Oxygen plasma is also suitable for seed treatment before sowing. Plasma agriculture is one of the modern branches of plasma science, so many research groups around the world are investigating methods for optimizing seed processing. Most scientists conduct experiments in laboratories, but only a few groups report about field experiments and grain yield from gas plasma-treated seeds. Our research group is among the leaders on a global scale and participates in two European projects on the topic of green agriculture. In 2022 we published six scientific articles discussing the scientific aspects of plasma treatment of various seeds. In an article [5], we report on the results of systematic research on fields. We sowed the plasma-treated seeds over two years, comparing the yield with that of the seeds treated previously using techniques that are standard in agricultural practice. We sowed seeds of different wheat varieties and found significant differences with respect to the variety. Field research shows that it is necessary to select different plasma parameters for each wheat variety. For the plasma treatment of seeds, we used a device that is mobile because even for seeds, the high surface energy is not constant, but the hydrophilicity gradually deteriorates. A photo of the device is shown in Figure 4.

Oxygen plasma also enables optimal surface properties of implantable devices, for example, vascular stents. We investigated a method for surface finishing of stainless-steel vascular stents, which provides optimal conditions for the binding of endothelial cells while, at the same time, preventing surface activation of platelets and the proliferation of smooth muscle cells. The latter often leads to complications such as long-term use of antithrombogenic drugs, revision surgeries, increased treatment costs,

Figure 5: Illustration of an innovative method for optimizing the surfaces of stainless steel stents

and a high risk to patients' health. We first deposited a thin layer of titanium to the base material, i.e., stainless steel with appropriate mechanical properties, using the plasma sputtering method. The compact layer was treated with electrochemical method to transform the compact titanium film into a nanostructured titanium oxide with dense layer of nanotubes of about 100 nm in diameter. In the next step, the layer of nanotubes was removed by ultrasound to obtain nanopores, with height of about 20 nm. In the last step, the workpiece was exposed to oxygen plasma to achieve optimal surface chemistry and wettability. Schematic representation of innovative approach for formation of titanium oxide nanopores is presented in Figure 5. Such modification enables improved proliferation of endothelial cells, which present natural antithrombogenic material and at the same time prevents platelet activation and proliferation of smooth muscle cells. The latter is highly relevant to reduce stent induced thrombosis and restenosis. Due to innovative approach the method for fabrication was protected with a patent application, and the scientific aspects were published in an article [6]. Nanostructuring of stainless steel is an extremely interesting research field, as medical devices from stainless-steel are commonly used mainly due to their desired mechanical

Figure 6: Decision on the granting of the EU patent for an innovative method for plasma deposition of nanocarbon
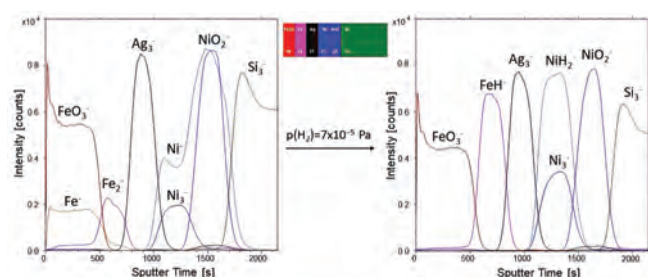

Figure 7: ToF-SIMS depth profile of an FeAgNi multilayer structure etched with a Cs+ ion jet with an energy of 1 keV in a vacuum (left) and in a hydrogen atmosphere at a hydrogen pressure of 7×10^{-5} Pa (right)

properties, however their surface properties are still far from optimal. The scientific aspects of the technological process for surface finishing of stainless-steel have not yet been satisfactorily explained, which we pointed out in a review article [7], where we critically analysed the available literature and provided recommendations for further work.

Non-equilibrium gas plasma is also suitable for the deposition of thin layers of various materials. Years ago, we developed a process for the synthesis of layers of nanostructured carbon with a high content of multi-layered graphene sheets with a thickness of a few nm and a surface area of the order of 10,000 nm. The process is interesting for use in electrochemical converters, which is why we protected it with a patent application. European and Japanese patents were granted in 2022 [8] and we are still waiting for the opinion of the US Patent Office. A copy of the original document, granting an EU patent is shown in Figure 6. Waste plastic is used as a carbon source for the formation of layers of densely distributed graphene sheets. The plastic is placed in a reactor, in which we excite a non-equilibrium gas plasma with a powerful radio frequency discharge in the H-mode of operation. We also place a substrate in the plasma, which is heated to a high temperature upon interaction with plasma species of high potential energy. Plasma particles with high potential and moderate kinetic energy strongly ablate plastic. The resulting radicals are excited in the plasma to states with high potential energy, and the radicals partially dissociate on heated surfaces, forming layers that contain practically only graphene sheets. The sheets can be doped with the desired atoms by exciting the plasma in different gases or gas mixtures. We published the scientific aspects of the technology in an article [9].

To analyse the effects of gas plasma on workpieces, we use cutting-edge techniques for analysing surfaces and thin layers. In addition to analyses of plasma-treated materials, we also perform analyses of other samples. Our laboratory for surface and thin-layer analyses has a 50-year tradition of characterizing surfaces and thin layers. We use the following methods: X-ray photoelectron spectroscopy – XPS, secondary ion mass spectrometry – SIMS, and Auger electron spectroscopy - AES. With the mentioned techniques, we provide analytical support for Slovenian research organizations, academic institutions and industrial partners. The characterization of the above systems is based on complex methods, and the interpretation of the acquired spectra is extremely demanding. We investigated the details of the characterization of thin layers using the ToF-SIMS method. We focused on the influence of the composition of the surface layer on the intensity of individual peaks in the spectra of secondary ions, the increase in the degree of ionization of the material sputtered during bombardment with heavy ions, and the decrease in the surface roughness during depth profiling, which is the result of laterally inhomogeneous etching. These phenomena cause problems in the interpretation of the spectra. An improvement in the quality of depth profiles was achieved by precise dosing of reactive gases into the analysis chamber of the SIMS instrument. We used hydrogen, oxygen, carbon monoxide and acetylene. We determined the optimal pressure range for each gas and compared the effects of different gases. We found that the ionization of metal atoms, their oxides, and molecular fragments increases the most with hydrogen dosing. We checked the effectiveness of the procedure on different samples. In Figure 7, we illustrate the improvement in the resolution of an Fe_2O_3/Fe/Ag/Ni/NiO multilayer structure, prepared with plasma sputtering. The depth profile on the left image was recorded without dosing the reactive gas into the analysis chamber of the SIMS instrument, and on the right image hydrogen was used so that the partial pressure was $7x10^{-5}$ Pa. The improvement of the method was reported in an article [10].

We published about 40 scientific articles in the field of thin layer analysis using our techniques. The results of the surface and thin-layer research obtained with our analysis techniques are often upgraded with alternative ones available from our partners in Slovenia and abroad. The combination of different analytical techniques provides an insight into the kinetics of the synthesis of thin layers. In the above article [10], we compared our SIMS and XPS methods with glow-discharge optical emission spectrometry (GDOES). Stainless steel substrates were coated with a thin polymer layer using the plasma polymerization technique.

Some outstanding publications in the past year

1. Primc, Gregor, Zaplotnik, Rok, Vesel, Alenka, Mozetič, Miran, Mechanisms involved in the modification of textiles by non-equilibrium plasma treatment, *Molecules*, 2022, 27, 24, 9064

2. Verbič, Anja, Brenčič, Katja, Dolenec, Matej, Primc, Gregor, Recek, Nina, Šala, Martin, Gorjanc, Marija, Designing UV-protective and hydrophilic or hydrophobic cotton fabrics through *in-situ* ZnO synthesis using biodegradable waste extracts, *Applied Surface Science*, 2022, 599, 153931

3. Lojen, Dane, Zaplotnik, Rok, Primc, Gregor, Mozetič, Miran, Vesel, Alenka, Optimization of surface wettability of polytetrafluoroethylene (PTFE) by precise dosing of oxygen atoms, *Applied Surface Science*, 2022, 598, 153817-1-153817-7

4. Holc, Matej, Mozetič, Miran, Zaplotnik, Rok, Vesel, Alenka, Gselman, Peter, Recek, Nina, Effect of oxygen plasma treatment on wheat emergence and yield in the field, *Plants*, 2022, 11, 19, 2489-1-2489-11

5. Yelkarasi, Cagatay, Recek, Nina, Kazmalni, Kursat, Kovač, Janez, Mozetič, Miran, Urgen, Mustafa, Junkar, Ita, Biocompatibility and mechanical stability of nanopatterned titanium films on stainless steel vascular stents, *International journal of molecular sciences*, 2022, 23, 9, 4595-1-4595-19

6. Benčina, Metka, Junkar, Ita, Vesel, Alenka, Mozetič, Miran, Iglič, Aleš, Nanoporous stainless steel materials for body implants—review of synthesizing procedures, *Nanomaterials*, 2022, 12, 17, 2924-1-2924-15

7. Vesel, Alenka, Zaplotnik, Rok, Primc, Gregor, Paul, Domen, Mozetič, Miran, Comparison of plasma deposition of carbon nanomaterials using various polymer materials as a carbon atom source, *Nanomaterials*, 2022, 12, 2, 246-1-246-15

8. Ekar, Jernej, Panjan, Peter, Drev, Sandra, Kovač, Janez, ToF-SIMS depth profiling of metal, metal oxide, and alloy multilayers in atmospheres of H_2, C_2H_2, CO, and O_2, *Journal of the American Society for Mass Spectrometry*, 2022, 33, 1, 31-44

9. Kovač, Janez, Ekar, Jernej, Čekada, Miha, Zajíčková, Lenka, Nečas, David, Blahová, Lucie, Wang, Jiang Yong, Mozetič, Miran, Depth profiling of thin plasma-polymerized amine films using GDOES in an Ar-O_2 plasma, *Applied Surface Science,* 2022, 581, 152292

Awards and Appointments

1. Jernej Ekar, ECASIA Student Travel Grant, Limerick, Ireland, European Association on Applications of Surface and Interface Analysis, 19th ECASIA Conference, award for the lecture entitled Reduction of Matrix Effect in ToF-SIMS Depth Profiling via H_2 Flooding

2. Miran Mozetič, WIPO Medal for Inventors (World Intellectual Property Organization)

3. Mark Zver, Best Contribution Recognized by Peers Award, Kamnik, Jožef Stefan International Postgraduate School, for the presentation entitled Creating antimicrobial surfaces via advanced functionalization techniques

Patents granted

1. Ksenija Rener-Sitar, Ita Junkar, Uroš Cvelbar, Miran Mozetič, Method for improving the bonding of dental silicate ceramics with composite cements, SI26082 (A), Slovenian Intellectual Property Office, 29. 04. 2022.

2. Alenka Vesel, Nives Ogrinc, Method for functionalization of polyolefins with simultaneous combination of nitrogen and oxygen functional groups, SI26091 (A), Slovenian Intellectual Property Office, 29. 04. 2022.

3. Rok Zaplotnik, Miran Mozetič, Gregor Primc, Alenka Vesel, Masaru Hori, Methods for forming carbon nanostructured materials, EP3802418 (B1), European Patent Office, 08. 06. 2022.

4. Alenka Vesel, Miran Mozetič, Rok Zaplotnik, Gregor Primc, Nina Recek, Method of increasing the hydrophilicity of a surface of an object of polymer containing fluorine atoms, EP3757155 (B1), European Patent Office, 18. 05. 2022.

INTERNATIONAL PROJECTS

1. COST CA19110; Plasma Applications for Smart and Sustainable Agriculture
Asst. Prof. Gregor Primc
Cost Association Aisbl

2. COST CA20114 - PlasTHER; Therapeutical Action of Cold Atmospheric Plasmas
Asst. Prof. Ita Junkar
Cost Association Aisbl

3. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
Asst. Prof. Ita Junkar
European Commission

4. Low Temperature Plasma Diagnostics and its Applications for Seed Treatment
Prof. Miran Mozetič
Slovenian Research Agency

5. Functionalization of Ti-Based Surfaces Using Energy Beams and Plasma for Biomedical Applications
Asst. Prof. Gregor Primc
Slovenian Research Agency

6. Promising Eco-Sterilization of Pathogenic Fungi on Seeds Using Reactive Species in Gaseous Plasma
Prof. Miran Mozetič
Slovenian Research Agency

7. Facile Preparation of Superhydrophobic Cellulose Nanofibers and Compounding with PLA for Packaging
Prof. Miran Mozetič
Slovenian Research Agency

8. Characterization of Oxygen Plasma Sustained with Powerful Discharges
Prof. Miran Mozetič
Slovenian Research Agency

9. Catalytic Probes for Characterization of Hydrogen Plasma
   Asst. Prof. Gregor Primc
   Slovenian Research Agency
10. HE - EUROfusion; WP05: PWIE-1,2,3,_HE-FU, PWIE-4-Accelerator
    Prof. Janez Kovač
    European Commission
11. HE - AgroServ; Integrated SERvices supporting a sustainable AGROecological transition
    Prof. Miran Mozetič
    European Commission

RESEARCH PROGRAMMES

1. Thin film structures and plasma surface engineering
   Prof. Miran Mozetič
2. Fusion technologies
   Asst. Prof. Rok Zaplotnik

R & D GRANTS AND CONTRACTS

1. Structural and surface properties of fibrous membranes for purification and chromatographic separation of biomacromolecules
   Asst. Prof. Ita Junkar
2. Ecologically friendly in-situ synthesis of ZnO nanoparticles for the development of protective textiles
   Asst. Prof. Gregor Primc
3. Initial stages in surface functionalization of polymers by plasma radicals
   Prof. Janez Kovač
4. Alternative approaches to assuring guality and security of buckwheat grain microbiome
   Prof. Miran Mozetič
5. Investigation of two-way interactions during plasma treatment of solid wood
   Prof. Janez Kovač
6. Cell membrane uptake of bacteria, virions and anorganic particles controlled by membrane mechanics and topology
   Asst. Prof. Ita Junkar
7. Removal of selected antimicrobials by plasma-cavitation hybrid technology from water matrices of varying complexity (Causma)
   Asst. Prof. Gregor Primc
8. Self-organization of plasma in magnetron sputtering discharges
   Prof. Miran Mozetič
9. New startegies for fabrication of biomimetic vascular implants
   Asst. Prof. Ita Junkar
10. Innovative procedures for advanced surface properties of medical stainless steel
    Dr. Metka Benčina
11. Novel Surface Modification of Dental Prosthetic Replacements by Gaseous Plasma
    Dr. Metka Benčina
12. Innovative sensors for real-time monitoring of deposition rates in plasma-enhnced chemical vapour deposition (PECVD) systems
    Asst. Prof. Rok Zaplotnik
13. Nanoparticle-reinforced new metal matrix composites manufactured by selective laser melting for tooling industry
    Prof. Miran Mozetič
14. A Novel High-strength Aluminium Alloy developed for Selective Laser Melting and Lightweight Applications
    Prof. Miran Mozetič
15. Hybrid SLM/DED Additive Manufacturing of Ti6Al4V Advanced Fuel System Components for Aerospace Industry
    Asst. Prof. Ita Junkar
16. Miniature fiber-optics sensors for free-radical detection in plasma assisted processe
    Asst. Prof. Rok Zaplotnik
17. Carbon nanowalls for future supercapacitors
    Prof. Alenka Vesel
18. Selected area functionalization of polymeric components by gaseous plasma
    Prof. Miran Mozetič

19. Innovative method for purification of wastewater
    Asst. Prof. Gregor Primc
20. Development of safe multifunctional surfaces for catheters to combat biofilms (DemoCat)
    Prof. Alenka Vesel
21. Waterborne virus inactivation efficiency of a prototype device combining non-equilibrium plasma and hydrodynamic cavitation
    Asst. Prof. Rok Zaplotnik
22. Plasma VUV and UV radiation – a method for successful deactivation of Aflatoxins
    Dr. Nina Recek
23. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
    Dr. Nina Recek
    Ministry of Education, Science and Sport
24. Method for preparation of bacteriostatic surfaces on 3D printed medical implants
    Dr. Matic Resnik
    Ministry of Education, Science and Sport
25. Use of gaseous plasma for higher yields and lower use of antifungal agents in agriculture
    Asst. Prof. Ita Junkar
26. Use of gaseous plasma for higher yields and lower use of antifungal agents in agriculture
    Asst. Prof. Ita Junkar
    Ministry of Agriculture, Forestry and Food
27. Small Services
    Prof. Janez Kovač
28. Income from Coowners of Invention for Reimbursement of Costs for IP Protection in the Case of EVT140_Mozetič_Carbon Nanowall
    Prof. Miran Mozetič
    Nagoya University
29. EVT770_Mozetič_CNW2_Reimbursement of the Costs for Patent; Income from Coowners of Invention for Reimbursement of Costs for IP Protection in the Case of EVT770_Mozetič_CNW2
    Prof. Miran Mozetič
    Nagoya University

NEW CONTRACTS

1. Small Services
   Prof. Janez Kovač
2. Co-finanicing of L-project L2-1834 Carbon nanowalls for future supercapacitors
   Prof. Alenka Vesel
   Iskra, d. o. o.
3. Innovative sensors for real-time monitoring of deposition rates in plasma-enhanced chemical vapour deposition (PECVD) systems
   Asst. Prof. Rok Zaplotnik
   Iskra, d. o. o.
4. L-project co-financing: Innovative method for purification of wastewater
   Asst. Prof. Gregor Primc
   Induktio d. o. o.
5. L-project co-financing: Selected area functionalization of polymeric components by gaseous plasma
   Prof. Miran Mozetič
   Elvez, d. o. o.
6. Development of safe multifunctional surfaces for catheters to combat biofilms (DemoCat)
   Prof. Alenka Vesel
   Tik d. o. o.
7. Waterborne virus inactivation efficiency of a prototype device combining non-equilibrium plasma and hydrodynamic cavitation
   Asst. Prof. Rok Zaplotnik
   Kolektor Group d. o. o.
8. Plasma VUV and UV radiation - a method for successful deactivation of Aflatoxins
   Dr. Nina Recek
   Interkorn d. o. o.

VISITORS FROM ABROAD

1. Primož Eiselt, Franz Resch, Plasmait, Lannach, Austria, 23 April 2022
2. Prof. Mahendra K. Sunkara, Louisville University, Louisville, Kentucky, USA; Vasanthi Sunkara, Advanced Energy Materials, LLC, Louisville, Kentucky, USA, 2 June 2022
3. Prof. Petr Smolka, dr Ilona Sergeevna, Faculty of Technology, Tomas Bata University in Zlin, Zlin, Czech Republic, 20–24 June 2022
4. Jan Sezemský, Czech Technical University in Prague, Prague, Czech Republic, 12–30 September 2022, 17–21 October 2022, 28 November–2 December 2022
5. Prof. Sanja Ercegović Ražić, Nikša Krstulović, Institute of Physics, Zagreb, Croatia, 11 October 2022

6. Claudia Zoani, ENEA Centro Ricerche Casaccia, Santa Maria di Galeria, Italy, 25 October 2022
7. Danilo Krstić, Vladimir Rajić, Vinča Nuclear Research Institute, Belgrade, Serbia, 5–9 December 2022
8. Jon Simonnæs, John Lyder, Provida Medical, Oslo, Norway, 6–7 December 2022
9. Prof. Katsuhisa Kitano, Takashi Kunizawa, Osaka University, Osaka, Japan, 4–8 December 2022

STAFF

Researchers
1. Dr. Metka Benčina
2. Asst. Prof. Ita Junkar
3. Prof. Janez Kovač
4. Prof. Miran Mozetič
5. Asst. Prof. Gregor Primc
6. **Prof. Alenka Vesel, Head**
7. Asst. Prof. Rok Zaplotnik
8. **Postdoctoral associates**Dr. Matej Holc
9. *Dr. Marian Lehocky, left 01.04.22*
10. *Dr. Dane Lojen, left 16.11.22*
11. Dr. Nina Recek

12. *Dr. Matic Resnik, left 01.09.22*
Postgraduates
13. Jernej Ekar, B. Sc.
14. Domen Paul, B. Sc.
15. Pia Starič, B. Sc.
16. Mark Zver, M. Sc.
Technical officers
17. Tatjana Filipič, B. Sc.
18. Maja Šukarov, B. Sc.
Technical and administrative staff
19. Janez Trtnik

DEPARTMENT OF SOLID STATE PHYSICS

F-5

The research programme of the Department of Solid State Physics focuses on the physics of novel quantum and functional materials as well as on the structure and dynamics of disordered and partially ordered condensed matter, with a special emphasis on phase transitions. The purpose of these investigations is to discover the fundamental laws of physics governing the behaviour of strongly correlated materials and of systems, which represent the link between perfectly ordered crystals, on the one hand, and amorphous matter, soft condensed matter and living systems, on the other. Such knowledge provides the key to our understanding of the interplay between electronic and structural properties and the emerging dynamics at the microscopic scale. It also opens the path to the discovery and development of novel quantum and functional materials, nanomaterials and biomaterials as well as emerging applications. An important part of the research activities is devoted to the development of new experimental methods and techniques in the fields of cold atoms, quantum magnetism, quantum optics, biophotonics and high-resolution fluorescence imaging. The department has numerous ongoing international collaborations and frequently uses large European research infrastructure.

Head (until 13. 4. 2022):
Prof. Igor Muševič

The research programme of the Department of Solid State Physics at the Jožef Stefan Institute is performed in close collaboration with the Department of Physics at the Faculty of Mathematics and Physics of the University of Ljubljana, the Institute of Mathematics, Physics and Mechanics and the Jožef Stefan International Postgraduate School. In 2022, the research was performed within four research programmes:

- Physics of quantum and functional materials
- Physics of soft matter, surfaces, and nanostructures
- Experimental biophysics of complex systems and imaging in biomedicine
- Physics of quantum technologies

I. Research Programme: Physics of quantum and functional materials

Quantum and topological magnetism

Matjaž Gomilšek, in collaboration with partners from the United Kingdom, developed the open-source program MuFinder for studying muon stopping sites in materials via *ab intio* density functional theory (DFT) approaches,

Head (since 14. 4. 2022):
Prof. Denis Arčon

in support of powerful muon spectroscopy (μSR) measurements. For this purpose the authors developed multiple novel algorithms, including: (i) an algorithm for the efficient generation of initial candidate muon sites, which takes the symmetries of the studied system into account, (ii) a procedure for determining final muon sites via an algorithm for cluster identification, which takes symmetries into account and is based on graph theory, and (iii) methods for calculating the dipolar magnetic field distribution at final muon sites, which takes local deformations of the crystal structure around the muon into account. The authors confirmed the performance of the developed novel approaches by comparing MuFinder *ab initio* calculations with experimental μSR results on the compound CoF_2. The work was published in the paper B. M. Huddart et al., "MuFinder: A program to determine and analyse muon stopping sites", Comput. Phys. Commun. 280, 108488 (2022).

Quantum and (multi)functional materials are of utmost importance for sustainable development and our successful transition to a fully digital society. In this context we studied complex excitations in model systems for quantum spin liquids, spin dynamics in massive topological skyrmion lattices, investigated the properties of high-entropy alloys and relaxor physics of epitaxial thin layers, and searched for the connection between magnetism and superconductivity.
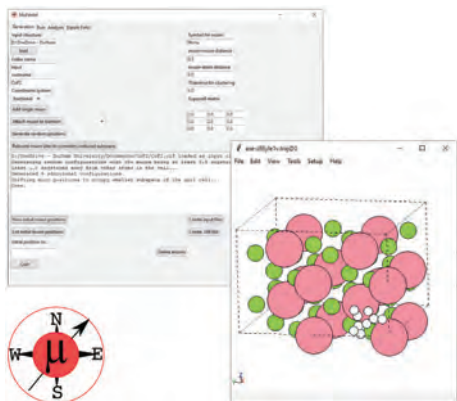
Matjaž Gomilšek and **Andrej Zorko**, in collaboration with partners from India, Switzerland, Germany, France, South Africa, and the USA studied the frustrated spin system Li_4CuTeO_6 using a variety of complementary experimental methods (thermodynamics, muon spectroscopy, electron spin resonance, and scattering) and numerical methods (*ab-initio* DFT and exact diagonalization). The authors discovered that Li_4CuTeO_6 unexpectedly behaves like a 3D quantum-spin liquid, which arises from the disorder (randomness) of non-magnetic Li^+ ions and magnetic Cu^{2+} ions, which form short spin chain fragments connected in a random 3D lattice. Random 3D spin liquids are very rare in nature, and its discovery in Li_4CuTeO_6 confirmed a long-standing prediction from the theory of random singlets. This was further confirmed by the observation of the characteristic power-law scaling

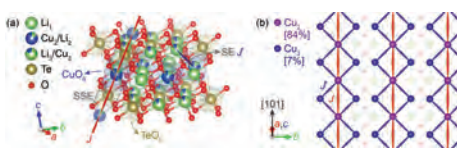Figure 1: Graphical user interface of the MuFinder program for the ab-initio analysis of muon sites in μSR experiments.

Figure 2: Crystal structure of the random 3D quantum-spin liquid Li_4CuTeO_6 and its magnetic exchange interactions J and J' calculated by ab-initio (DFT) methods.
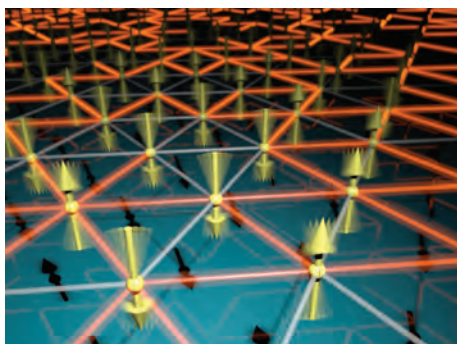

Figure 3: Ising-spin liquid of localized spins (arrows) in neodymium heptatantalate. Shining bonds represent antiferromagnetic correlations between the nearest neighbours on the triangular lattice.
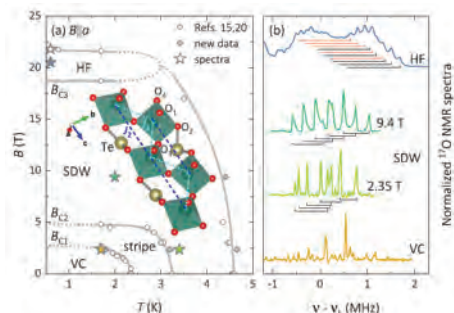

Figure 4: (a) Magnetic phase diagram of β-TeVO₄ in a magnetic field along the a-axis. (b) ¹⁷O NMR spectra measured at different positions in the phase diagram.

of experimental observables at low temperatures, predicted for random-singlet states. The work was published in the paper J. Khatua et al., "Signature of a randomness-driven spin-liquid state", Commun. Phys. 5, 99 (2022).

Tina Arh, **Matej Pregelj** and **Andrej Zorko**, together with collaborators from India, the UK, France and the USA, have discovered a new type of a quantum-spin liquid. This is the first realization of a quantum-spin liquid on a triangular spin lattice with dominant Ising antiferromagntic exchange interactions. The researchers conducted an extensive experimental study showing the absence of magnetic ordering and proving the existence of Ising-type spin correlations in neodymium heptatantalate at temperatures of only a few tens of millikelvins. The discovery of the Ising-spin liquid introduces a new type of this enigmatic quantum entangled state of matter that remains dynamic due to quantum fluctuations down to the lowest temperatures. The work was published in the paper T. Arh et al., "The Ising triangular-lattice antiferromagnet neodymium heptatantalate as a quantum spin liquid candidate", Nat. Mater. 21, 416 (2022).

Stane Vrtnik and **Andrej Zorko** and collaborators from India, France, the USA, South Africa, and Switzerland discovered a spin-liquid state in a rare-earth-based hyperkagome material. Their comprehensive experiments have evidenced neither the signatures of magnetic ordering nor spin freezing down to 38 mK, which suggests the realization of a dynamic liquid-like ground state in this antiferromagnet. The ground state of this material is characterized by low energy spin-1/2 degrees of freedom with short-range spin correlations. The work was published in the paper J. Khatua et al., "Spin liquid state in a rare-earth hyperkagome lattice", Phys. Rev. B 106, 104404 (2022).

Matej Pregelj and **Andrej Zorko** and collaborators from India and Germany studied new realizations of triangular-lattice antiferromagnets in $Ba_3RB_9O_{18}$ (R = Yb, Er). They found that the localized R^{3+} rare-earth moments show neither long-range magnetic order nor spin-glass behavior down to 1.9 K. Magnetization data revealed pseudospin-1/2 degrees of freedom in both compounds. The crystal-electric-field calculations based on the thermodynamic data showed the presence of a small gap between the ground and first excited Kramers doublets. The work was published in the paper J. Khatua et al., „ Magnetic properties of the triangular-lattice antiferromagnets Ba3RB9O18 (R = Yb, Er)", Phys. Rev. B 106, 104408 (2022).

Andrej Zorko and collaborators from France and the USA have studied chemical pressure effects on the structural and magnetic properties of the triple perovskite Sr-doped $Ba_3NiSb_2O_9$. They found that the driving force towards a spin-liquid-like state is quenched disorder, which needs to be incorporated in the J1-J2 honeycomb models. The work was published in the paper M. Viaud et al., "Crystal structures, frustrated magnetism, and chemical pressure in Sr-doped Ba3NiSb2O9 perovskites", Phys. Rev. Mater. 6, 124408 (2022).

Matej Pregelj, **Andrej Zorko**, **Denis Arčon**, **Martin Klanjšek**, **Nejc Janša** and **Peter Jeglič** and collaborators from Switzerland, France and Austria studied magnetic phases in a frustrated spin-1/2 chain compound β-TeVO₄. Using ¹⁷O nuclear magnetic resonance they inspected how the anisotropy of the main exchange interactions and additional weak interchain exchange interactions affect the theoretical phase diagram. Their results confirm the dynamical nature of the spin-stripe phase as well as spin-density-wave order in the high-magnetic-field phase. The work was published in the paper M. Pregelj et al., "Competing magnetic phases in the frustrated spin-1/2 chain compound β-TeVO4 probed by NMR", Phys. Rev. B 150, 035145 (2022).

Matej Pregelj, **Stane Vrtnik** and **Janez Dolinšek** and collaborators from Switzerland and France studied a magnetic-field-driven antiferromagnetic-to-paramagnetic quantum phase transition in a Ce_3Al single crystal via transverse-field muon spin rotation. They found that even at the lowest temperatures of 80 mK with increasing field, applied along the Ce-Al chains, the spin dynamics increases and reaches a maximum exactly at the quantum critical point. The work was published in the paper M. Pregelj et al., "Probing spin fluctuations of the quantum phase transition in Ce3Al by muon spin rotation" Sci Rep 12, 13184 (2022).

Magnetism and superconductivity

Denis Arčon, together with colleagues from Tohoku University in Sendai, Japan, continued to research layered pnictide structures, where superconductivity and magnetism are intertwined. In T. Ogasawara et al., Magnetic field-induced Anderson localization in the orbital-selective antiferromagnet BaMn2Bi2, Phys. Rev. B 106, L041114 (2022) they reported a metal-insulator transition in the multi-orbital antiferromagnet $BaMn_2Bi_2$. Scaling analysis showed weakly correlated gaps in the $3d_{xy}$-derived band, which dominates the transport properties, in the thus supported Anderson localization, while the remaining $3d$ bands show pronounced electronic

correlations, and the Mott localization that is responsible for the antiferromagnetic ordering. This unusual interplay of orbital-dependent electron correlations is also responsible for the extremely strong magnetoresistance observed in this family of materials.

Functional materials

The role of contact-line mobility in inkjet-printed deposit formation. The deposit that forms when a droplet of ink dries on a substrate has a fundamental role in patterning and coating technologies, since advanced applications often require the deposition of structures with uniform thickness. We highlighted the essential role of contact-line mobility in the deposit formation in solution-based inks at dimensions relevant for printing applications. Experiments showed that a pinned contact line produces exclusively ring-like deposits under normal conditions, while drops with a mobile contact line can exhibit a ring-, flat- or dome-like morphology. We proposed a phenomenological model, which revealed that the deposit morphology depends on (i) the solvent evaporation profile, (ii) the evolution of the drop radius relative to its contact angle, and (iii) the ratio between initial and maximum solute concentration. These parameters can be adjusted by the ink solvent composition and substrate wetting behavior, which provides a way for the deposition of uniform and flat deposits via inkjet printing. The work was published in A. Matavž et al., From coffee stains to uniform deposits: Significance of the contact-line mobility, Journal of Colloid and Interface Science 68, 1718, (2022).
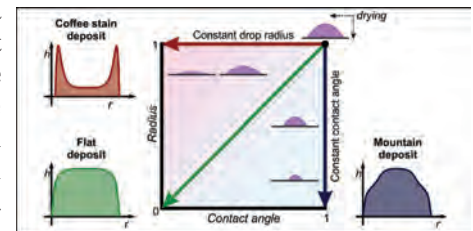

Figure 5: Contact-line motion upon drying of a sessile droplet strongly affects the morphology of a deposit. A drop can dry by following three possible trajectories in $R(\theta)$ diagram: (i) constant drop radius produces a coffee-stain deposit, (ii) decreasing contact angle and radius can produce flat deposit, and (iii) constant contact angle produces mountain-like deposit.

The influence of the substrate on the functional properties of epitaxial PMN-PT thin films. Pure and high-crystalline-quality, 500-nm-thick $0.67Pb(Mg_{1/3}Nb_{2/3})O_3$-$0.33PbTiO_3$ films were grown by pulsed-laser deposition on various $SrRuO_3$-buffered substrates. Under compressive epitaxial strain, i.e., under a small lattice mismatch between the substrate and the PMN–33PT, the high tetragonality and ferroelectric P-E loops are stabilized. On the other hand, the strain is relaxed in PMN–33PT grown on a substrate with a larger lattice mismatch, and the film displays a relaxor-like hysteresis loop and enhanced piezoelectric response. Both the strained and relaxed SRO/PMN–33PT/Au capacitors exhibit a very large negative self-bias, which is induced by the alignment of defect dipoles with the polarization and is tuned by the epitaxial strain. This imprint permits the stabilization of a robust, positive polarization state and low dielectric permittivity. The functional response of our films is in fact comparable to PZT-based thin films with the highest figure of merit, and demonstrates the possibility of developing piezoelectric devices based on high quality PMN–PT thin films. This study was published in v J. Belhadi, Z. Hanani, U. Trstenjak, N. A. Shepelin, V. Bobnar, G. Koster, J. Hlinka, D. Pergolesi, T. Lippert, M. El Marssi, M. Spreitzer, Large imprint in epitaxial 0.67Pb(Mg1/3Nb2/3)O3-0.33PbTiO3 thin films for piezoelectric energy harvesting applications, Applied Physics Letters 121, 182903 (2022).

Improved functional properties of novel PVDF-HFP/PVP thin films. Thermal, mechanical, and dielectric properties of developed poly(vinylidene fluoride-co-hexafluoropropylene)(PVDF-HFP)/polyvinylpyrrolidone (PVP) polymer blend were characterized. The PVP formed a dispersed phase (the poorer conductive islands) in the PVDF-HFP polymer matrix, which reduced its mechanical properties. On the other hand, PVP induced the formation of the polar-phase of PVDF-HFP, which improved its dielectric response. The obtained results suggest that the PVDF-HFP/PVP polymer blend can be employed in various electronic and medical applications. Published in U. Gradišar Centa, M. Mihelčič, V. Bobnar, M. Remškar, L. Slemenik Perše, The effect of PVP on thermal, mechanical, and dielectric properties in PVDF-HFP/PVP thin film, Coatings 12, 1241 (2022).

Study of topological and piezoelectric phenomena in multiferroic and soft matter. Work in the past year was focused on the study of the functional properties of ferroelectrics such as piezoelectric properties, energy harvesting, energy storage, and electrocaloric properties. We continued our research on lead-free multiferroic materials and extended the studies to composite materials. We have shown that 1D and 3D fillers mixed in a polymer network amplify the piezoelectric signal of the composite. It demonstrates the potential of such composites for the development of flexible piezoelectric nanogenerators, which could be used in biomedical applications. We investigated the impact of random-field-type disorder on the stabilization of nematic and smectic A structures in liquid crystalline materials. In a review article, we described the influence of different types of nanoparticles on the arrangement of line defects in chiral liquid-crystal phases. We also started research on lipid systems, where we studied the kinetics of lipid transfer between two systems. The results were presented in 19 scientific articles appeared in international scientific journals and various contributions at international scientific conferences and were published among others in Z. Hananai et al. Nanoscale Adv. 4, 4658-4668 (2022). Publications on multiferroic, multicaloric, and soft matter collected more than 600 clean citations in 2022.
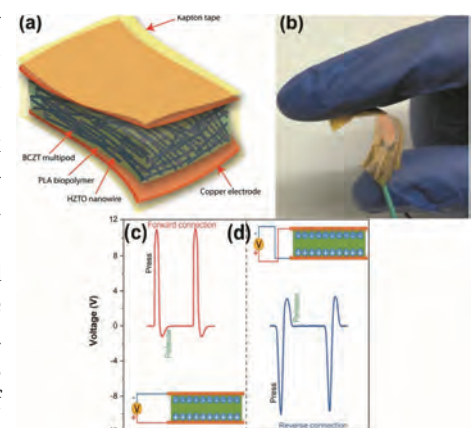

Figure 6: (a) and (b) Flexible polymer matrix composite material filled with 1D and 3D piezoelectric structures. (c) and (d) Piezoelectric signal generated by bending a flexible composite with nanogenerators.

Use of titanate nanorods modified with Fe^{3+} ions as a catalyst for $NH_4^+(aq)$ removal using combined treatment with ozone and solar light irradiation. In collaboration with Romanian researchers Polona Umek continued with her research into the catalytic properties of titanate/TiO_2 nanostructures. Sodium titanate nanorods $NaTi_3O_6(OH)\cdot 2H_2O$ were modified with a precursor of $Fe3+$ ions, where part of the iron ions exchanged with sodium cations between the layers and part formed Fe_2O_3 nanoparticles on the surfaces of the nano rods. To compare the catalytic properties, Fe_2O_3 nanocubes were also synthesised. Iron-modified titanate nanorods and nanocubes were suspended in dilute ammonia solutions (20 ppm) and the samples were then exposed to ozone and simulated sunlight. The decrease in the concentration of ammonia and the resulting products containing nitrogen (NO_3^-) was monitored by ion chromatography measurements. In the investigated materials, we also monitored the formation of reactive oxygen species ($\bullet OH$ and O_2^-) and their photoelectrochemical behaviour. The morphological and structural properties (SEM, XRD, XRF, UV-Vis, H2-TPR, NH3-TPD, PL, PZC) of the studied catalysts were linked to their activity in ammonia decomposition in the presence of ozone and light. With a rational approach, we significantly increased the conversion of ammonia and influenced the reduction of NO_3^- ions. Results were published in S. Preda, P. Umek et al., Iron-Modified Titanate Nanorods for Oxidation of Aqueous Ammonia Using Combined Treatment with Ozone and Solar Light Irradiation, Catalyst 12, 666-1-666-20 (2022).
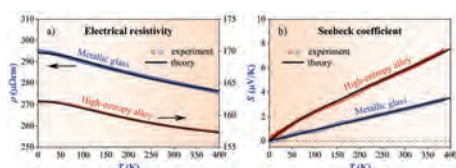

Figure 7: Comparison of the electrical resistivity (left) and Seebeck coefficient (also called the thermopower, right) of $Al_{0.5}TiZrPdCuNi$ synthesized in the form of a high-entropy alloy and metallic glass. The points on the graph are measurements, the full line is a theoretical model fit to this data.
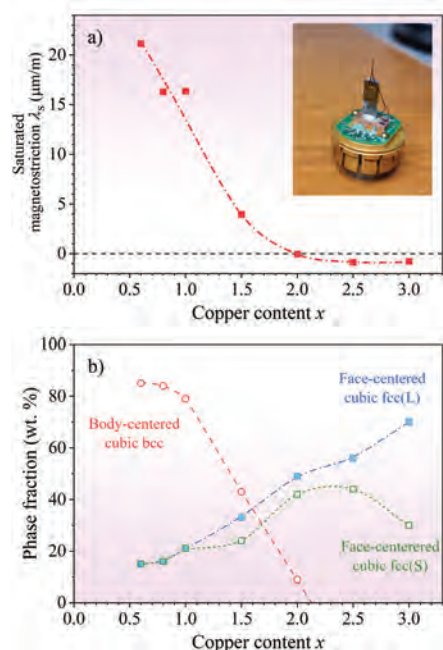

Figure 8: a) Magnetostriction of $AlCoFeNiCu_x$ goes from positive to negative with increasing copper content x. At x = 2.0 the magnetostriction is exactly zero, which means that the material does not change dimensions and therefore does not "hum" in an AC magnetic field. b) The phase fractions in $AlCoFeNiCu_x$ change as a function of copper content. The zero magnetostriction at x = 2.0 is thus a consequence of the compensation of the positive and negative magnetostrictions of the constituent phases of the material.

Observing short-range orientational order in small-molecule liquids. Local molecular ordering in liquids has attracted a lot of interest from researchers investigating crystallization, but is still poorly understood on the molecular scale. Cluster formation and local order fluctuations in liquid media are difficult to study due to the limited spatial resolution of electron- and photon-imaging methods. We used NMR relaxometry to demonstrate the existence of dynamic clusters with short-range orientational order in nominally isotropic liquids consisting of elongated molecules. We observed clusters in liquids where the local ordering is driven by polar, steric, and hydrogen-bond interactions between the molecules. In the case of a liquid crystal, measuring the local orientational order fluctuations allowed us to observe the size of these clusters diverging when approaching the phase transition from the isotropic to the nematic phase. These fluctuations are described in terms of the rotational elasticity as a consequence of the correlated reorientations of the neighbouring molecules. Our quantitative observations of the dynamic clusters in liquids, numbering about ten or fewer molecules, indicate that this is a general phenomenon in various types of liquids. An article was published in A. Gradišek, T. Apih et al. "Observing short-range orientational order in small-molecule liquids." Scientific Reports 12.1 (2022): 22500.

High-entropy alloys and intermetallic compounds

In 2022 the research group of the Laboratory for Electrical, Magnetic and Thermal properties of materials at the Condensed Matter Physics Department F5 (**Darja Gačnik**, **Andreja Jelen**, **Magdalena Wencka**, **Jože Luzar**, **Primož Koželj**, **Peter Mihor**, **Stanislav Vrtnik** and **Janez Dolinšek**) investigated the physical properties of high-entropy alloys and intermetallic compounds.

High-entropy alloys are metallic materials in which the main phase is a solid solution of five or more main elements in equimolar or near-equimolar concentrations. In the publication The Effect of Scandium on the Structure, Microstructure and Superconductivity of Equimolar Sc-Hf-Nb-Ta-Ti-Zr Refractory High-Entropy Alloys, **M. Krnel, A. Jelen, S. Vrtnik, J. Luzar, D. Gačnik, P. Koželj, M. Wencka**, A. Meden, Q. Hu, S. Guo, **J. Dolinšek**, *Materials* 15, 1122 (2022) we reported on an attempt at the incorporation of scandium (Sc) into the known system of superconducting medium- and high-entropy alloys of Hf-Nb-Ta-Ti-Zr. Based on previous research it can be expected that the addition of Sc can improve the properties of these alloys, for example, improve the hardness and thermal stability. All of the nine synthesized alloys (four-, five- and six-component) exhibit a complicated microstructure composed out of a body-centred cubic phase, which does not contain Sc and is analogous to the one from the parent Hf-Nb-Ta-Ti-Zr, and a hexagonal phase, which contains all the scandium. With measurements of electrical resistivity, Meissner effect and low-temperature specific heat we demonstrated that all the alloys are superconducting but that the superconducting properties are solely a consequence of the phase which does not contain scandium.

In the context of the research presented in the article "Electronic Transport Properties of the Al0.5tizrpdcuni Alloy in the High-Entropy Alloy and Metallic Glass Forms", M. Wencka, M. Krnel, A. Jelen, S. Vrtnik, J. Luzar, P. Koželj, D. Gačnik, A. Meden, Q. Hu, C. Wang, S. Guo, J. Dolinšek, Sci. Rep. 12, 2271 (2022) we were interested in a more basic question – namely, to what extent are the transport properties in high-entropy alloys determined by substitutional disorder and to what extent by the presence of a crystalline lattice. Like with metallic glasses, the atoms in these alloys are randomly intermixed among themselves, but at the same time their positions

are not random due to the underpinning lattice similar to that in ordinary crystals (e.g., leading to the existence of energy bands, etc.). The alloy $Al_{0.5}TiZrPdCuNi$ can be synthesized at the same composition in the form of a piece of high-entropy alloy or as thin ribbons of metallic glass. The measured electrical resistivity, Seebeck coefficient, thermal conductivity and Hall coefficient of both materials were compared and analysed within the Kubo-Greenwood formalism using the spectral conductivity model. Our conclusion is that the substitutional disorder is more important for the transport properties of high-entropy alloys than the crystal lattice, so that in this aspect high-entropy alloys are very similar to metallic glasses. Investigations of $Al_{0.5}TiZrPdCuNi$ were continued with colleagues from our programme group in the publication ^{27}Al NMR local study of the $Al_{0.5}TiZrPdCuNi$ alloy in high-entropy alloy and metallic glass forms, **M. Wencka**, **M. Bobnar**, **T. Apih**, Q. Hu, S. Guo, **J. Dolinšek**, *Phys. Rev. B* **105**, 174208 (2022), where we used the method of NMR to look at more local properties of the materials. From the temperature-independent part of the Knight shift we could confirm a similar electronic density of states at the Fermi level in the high-entropy-alloy and bulk-metallic forms of $Al_{0.5}TiZrPdCuNi$. On the other hand, the width of the distribution of the eigenvalues of the EFG tensor is twice that of the amorphous alloy compared to the high-entropy alloys due to the absence of the crystalline lattice.

In the article "Zero-Magnetostriction Magnetically Soft High-Entropy Alloys in the $AlCoFeNiCu_x$ (x = 0.6 – 3.0) System for Supersilent Applications", J. Luzar, P. Priputen, M. Drienovský, S. Vrtnik, P. Koželj, A. Jelen, M. Wencka, D. Gačnik, P. Mihor, B. Ambrožič, G. Dražić, A. Meden, J. Dolinšek, *Adv. Mater. Interfaces* 9, 2201535 (2022) we presented research aiming for the practical use of high-entropy alloys as magnetically soft materials in applications with AC magnetic fields (e.g., transformers, power supplies). Besides good magnetically soft properties (small coercivity, small remanent magnetization, large magnetic permeability, large saturation magnetization, large electrical resistivity), it is desirable that such materials also have low magnetostriction, which enables the design of machines that do not emit an annoying humming sound. With a newly developed measurement set-up, which incorporates the combination of the superconducting magnet of the PPMS system and electrical measurements of strain gauges, we were able to characterize the magnetostriction – in other words the change of material dimensions due to magnetic fields – see Figure 3. The entire series of $AlCoFeNiCu_x$ materials (x = 0.6–3.0) has decent magnetically soft properties, while the best combination of properties is achieved in the alloy with x = 2.0 (i.e., $AlCoFeNiCu_{2.0}$), which has a zero saturated magnetostriction λ_s = 0, a reasonably low coercivity $H_c \approx 650$ A m^{-1} and a decent saturated magnetic polarization $J_s \approx 0.55$ T. The magnetostriction in the $AlCoFeNiCu_x$ alloys is closely related to the microstructure. With increasing copper content x the microstructure changes to include less of the body-centred cubic phase and more of the two face-centred cubic lattice phase, which at copper content x = 2.0 leads to a compensation of the negative and positive magnetostrictions of the constituent phases.

The publication "Probing Spin Fluctuations of the Quantum Phase Transition in Ce3Al by Muon Spin Rotation", M. Pregelj, Z. Guguchia, M.-C. de Weerd, P. Boulet, S. Vrtnik, J. Dolinšek, *Sci. Rep.* 12, 13184 (2022) presents our research into the spin fluctuations in the intermetallic compound Ce_3Al with the technique of muon spin rotation, as performed in collaboration with colleagues from our programme group. In Ce_3Al we can, at sufficiently low temperatures, approach a quantum phase transition between the antiferromagnetic and paramagnetic phase under the influence of the magnetic field as a control parameter, which we have already investigated in previous years. With the help of the technique of muon spin rotation in transverse magnetic fields (TF-μSR) we were able to show that the fluctuations of the Ce magnetic moments on the Ce-Al chains are strongest exactly at the phase transition and that the fluctuations are certainly quantum in nature as the local magnetic field and rate of transverse relaxation are independent of temperature (and hence obviously not thermally driven).
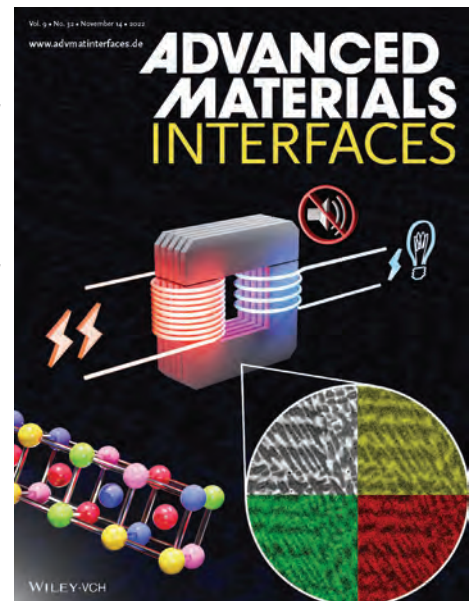

Figure 9: Back cover of Advanced Materials Interfaces (Vol. 9, No. 32) schematically depicts the potential use of $AlCoFeNiCu_x$ and similar materials in applications with AC magnetic fields. At a copper content of x = 2.0 the material combines decent magnetic softness and zero magnetostriction, which leads to a "supersilent" magnetic material.
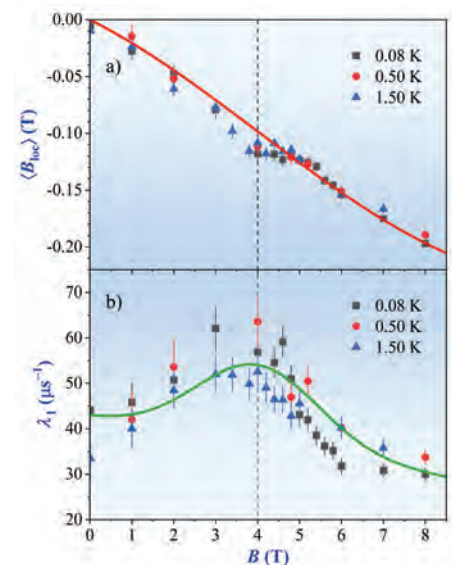

Figure 10: a) Average local magnetic field $\langle B_{loc} \rangle (T)$ at the muon stopping site or sites is independent of temperature (all the lines overlap). b) Muon transverse relaxation rate exhibits a maximum at the quantum phase transition as the fluctuations of the cerium magnetic moments are largest there.

Deep tissue localization and sensing using optical microcavity probes. In collaboration with researchers from Graz University, Aljaž Kavčič, Maja Garvas, Matevž Marinčič and Matjaž Humar have presented a new method for imaging through scattering tissues based on the localization of whispering-gallery-mode microresonators with spectrally narrow emission. This method enables the decomposition of the diffuse signal into contributions from individual microresonators. The developed method combines the ability of precise localization at the cellular level with the possibility of sensing various parameters such as temperature, pH and refractive index. This makes it a versatile and promising tool in the field of deep-tissue imaging. The work was published in the paper "Deep tissue localization and sensing using optical microcavity probes", Nature Communications 13, 1269, (2022).

We have discovered a new method for imaging through scattering tissues based on the localization of whispering-gallery-mode microresonators. We investigated new forms of particle transport in nematic liquid crystals and used topological defects in nematic liquids as computational elements. We were the first to elucidate the structure of the blue phase type III (BPIII) found in liquid crystals with a high degree of chirality. We studied the opto-mechanical interaction of optical and topological solitons, which is related to the transfer of momentum between light and matter and to the force due to the nonlocal orientational elasticity of a chiral liquid crystal. We studied the role of crystal structure and oxygen vacancies on the optical properties of various nanomaterials from the family of tungsten sub-oxides.

Continuous generation of topological defects in a passively driven nematic liquid crystal. We demonstrate a mechanism of topological-defect creation in a soft-matter system consisting of a passively driven nematic liquid crystal confined in a wedge-like thin film with hybrid anchoring (M. Mur, Ž. Kos, M. Ravnik in I. Muševič, Continuous generation of topological defects in a passively driven nematic liquid crystal. Nature Communications 13, 6855, (2022)). We have found that such a film allows for the spontaneous creation and annihilation of pairs of topological defects over long timescales. In our experimental setting, the film was formed on the surface of an aqueous medium containing small organic molecules that diffused into the liquid-crystal film. The concentration gradient of these molecules induced a flow. While in the laminar regime, the flow caused counter-rotating vortex rolls to appear. This flow profile gave rise to a splay instability in the director field, located between two neighbouring vortex rolls. Above a velocity threshold, the flow transitioned into a turbulent regime, where the splay instability was self-amplified, resulting in the creation of a pair of oppositely charged topological defects. The reported experimental findings were supported by numerical simulations. The work describes one of the few mechanisms of topological defect creation in soft matter.

Nematic colloidal micro-robots and micro-swimmers. Žiga Kos and Miha Ravnik, in collaboration with the experimental group led by Kathleen Stebe at UPenn, published two papers about a new type of particle transport in nematic liquid crystals. In the first paper „Topological defect-propelled swimming of nematic colloids" Science Advances 8, eabn8176 (2022) they present a new swimming mode of colloidal particles in nematic fluids. Such "microswimmers" are propelled by dynamic patterns of topological defect lines within the nematic orientational order. The defect lines are driven far from equilibrium by the rotation of the ferromagnetic cylindrical particles due to an external magnetic field. The authors show the main mechanisms of propulsion and the interaction modes between pairs of microswimmers. The results contribute towards new types of microswimmers in active soft matter and the development of novel, non-equilibrium nematic colloidal materials. In the second paper, „Nematic Colloidal Micro-Robots as Physically Intelligent Systems." *Advanced Functional Materials*, *32*, 2205546 (2022), ferromagnetic particles with four protrusions are used as microrobots and controlled by an external magnetic field. Controlled rotation and translation of the microrobot are used to perform various robotic tasks: cargo capture, transport, and release. The work contributes to soft microrobotics and allows for new strategies of microstructure assembly in anisotropic fluids.

Nematic bits and universal logic gates. Žiga Kos, in collaboration with Jörn Dunkel (MIT), published a paper titled "Nematic Bits and Universal Logic Gates" in Science Advances. They show how topological defects in nematic liquid crystals can be understood as computational bits, i.e., nematic bits. The work uses a mathematical formulation of nematic bits analogous to a Poincare or a Bloch sphere, and then demonstrate that the n-bit state can be controlled by an external electric field. By employing different temporal electric fields, the authors implement logic gates on single nematic bits. In systems of multiple nematic bits, the elasticity of the nematic liquid crystal leads to strong correlations between the bit states, which can be utilized to implement universal logic gates. The results represent an important step towards utilizing soft materials for information processing.

Blue Phase III: Topological fluid of skyrmions. We employ several experimental techniques supported by numerical calculations and simulations to elucidate the intriguing and as yet not
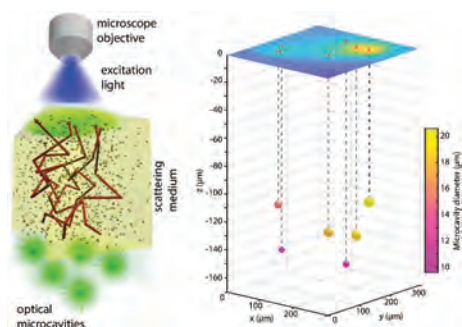

Figure 11: Schematics of the experimental configuration with the light propagation and the resulting localization of microcavities deep in the tissue.
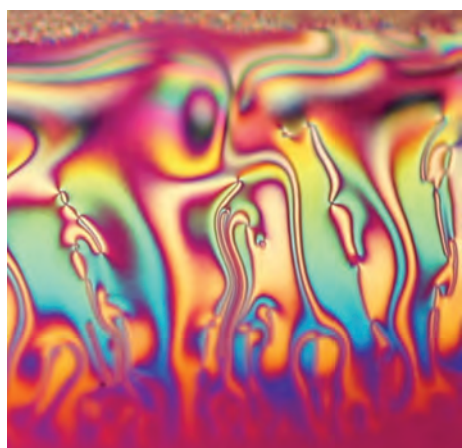

Figure 12: Topological defects are continuously forming in the turbulent flow of a passively driven nematic liquid crystal, confined in a thin, wedge-like film with hybrid anchoring.

definitively explained structure of the Blue Phase III (BPIII) found in highly chiral liquid crystals. Through direct optical observations, we demonstrate that the structure of cubic BPI melts into the amorphous and dynamic structure of BPIII with increasing temperature. Both phases transform into a quasi-2D lattice of half-skyrmions when strongly confined, indicating that the basic constituents of both are the same skyrmionic filaments. Numerical simulations confirm BPIII is a disordered tangle of skyrmion filaments intertwined with the 3D tangle of defect lines. The dynamics of BPIII is characterized by two branches separated by their rates. The signature slow-rate branch is understood because of filament and disclination re-ordering within the structure, while the faster-rate branch is due to director fluctuations within them. The skyrmion filaments resemble long ropes with a vortex-like cross-section whirling from the center to the periphery. In terms of their structure, they are similar to magnetic skyrmions, which have been extensively researched in recent decades for applications in information storage. Due to their relatively broad stability close to room temperature, these liquid crystal skyrmions could serve as a platform for soft-matter skyrmionic devices, where information-storing skyrmions are created and detected using light. (J. Pišljar et al., Blue Phase III: Topological Fluid of Skyrmions, Physical Review X, 12, 011003 (2022)).

Interaction and co-assembly of optical and topological solitons. Slobodan Žumer, in collaboration with the Smalyukh group (Univ. of Colorado), published an article titled "Interaction and co-assembly of optical and topological solitons." *Nature Photonics*, **16**, 454 (2022). The authors focused on thin layers of frustrated chiral nematics, which, on one hand, allow the self-focusing of laser light with the formation of optical solitons, and on the other hand, exhibit topological solitons, fascinating localized topologically protected disturbances in the order parameter. Through theoretical, simulation, and experimental approaches, they studied the optomechanical interaction of optical and topological solitons, which is related to the transfer of momentum between light and matter and to force due to the nonlocal orientation elasticity of chiral liquid crystals. The delicate balance of these forces enables the dynamic control and spatial localization of topological solitons. Furthermore, an unusual traction effect of optical solitons that enables a light-induced periodic arrangement of topological solitons was identified.

Microfluidic-based liquid-crystal elastomer tubes. Venkata Jampani and his collaborators from the University of Luxembourg have reported the development of microfluidic-based liquid-crystal elastomer tubes that self-assemble from LCE oligomeric precursors (*Small*, **18**, 2204693, (2022)). The team used a glass-based microfluidic setup with a three-phase coaxial flow to achieve arbitrarily long LCE tubes, with immiscible aqueous inner and outer phases surrounding the middle phase of LCE-precursor solutions stabilized by surfactants. The key requirement of LCE alignment for utilization as an actuator was achieved through shear-induced flow alignment and in-situ photo-crosslinking. The researchers demonstrated that the resulting LCE tubes were birefringent, as shown in the figure, and capable of acting as fluid pumps under externally controlled heating and cooling. Such a tubular actuator has the potential to realise active artificial vasculature in biological systems with further improvements.

Molecular motors and filaments as a model system for biological cilia. Andrej Vilfan and his collaborators from MPI Göttingen published several papers on the dynamics of motor proteins (kinesins or dyneins) and elastic filaments (microtubules). When two filaments are clamped parallel together on one end while molecular motors maintain a shearing force between them, they buckle in a similar way to Euler buckling at a certain threshold force. At higher forces, there is a pair of secondary bifurcations with a transition from planar to chiral shape with spontaneous symmetry breaking. When the response of motors to transverse forces is considered, the model predicts the emergence of planar or helical waves. Similar dynamics are observed experimentally with two microtubules with a patch of dynein motors on one of them. By means of theory, they could explain the observed shapes and determine the number of active motors. In larger bundles of filaments, they observed random bending depending on the distribution of filament polarity. (Small, **18**, 2197854 (2022)).

Nanoparticle and soft-matter-based multifunctional smart materials. With collaborators, we published a review article on graphene-based smart materials and biosensor applications. We focused mainly on graphene, which possesses a high surface area, a high density of charge carriers, and exhibits extraordinary mechanical qualities (*Critical Reviews in Solid State and Materials Sciences*, **47**, 691 (2022)). In combination with other nanoparticles and immersed in various soft matrices, its range of potential technological utilities and applications widens enormously. The
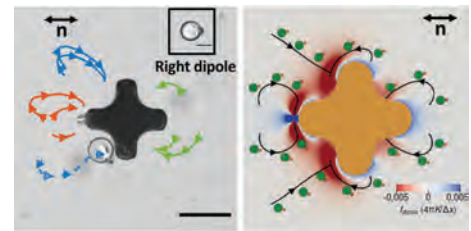

Figure 13: Attractive trajectories of a spherical particle towards the colloidal microrobot. The microrobot is controlled by an external magnetic field and can selectively attract, transport and repel the microcargo.
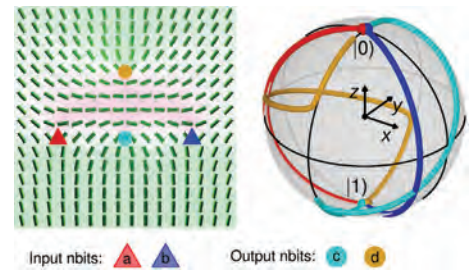

Figure 14: Application of NAND and NOR universal logic gates in a system of four nematic defects.
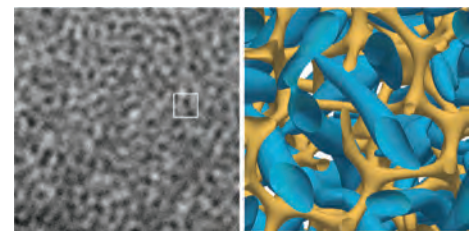

Figure 15: (left) Image of bulk BPIII structure under high magnification and (right) its numerically calculated structure consisting of skyrmions (blue) and disclinations (yellow).
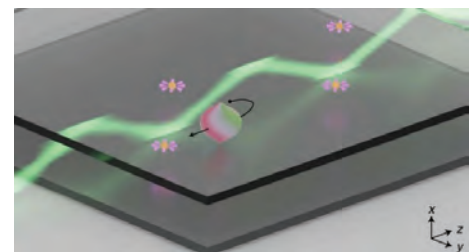

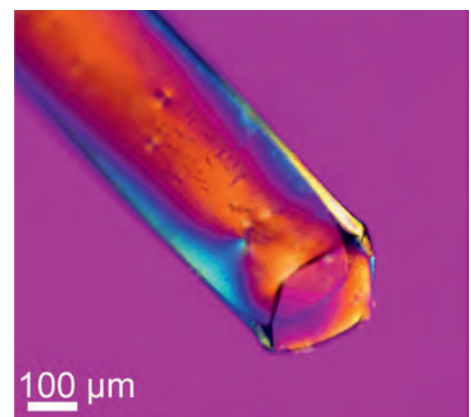*Figure 16: Schematic representation of the bouncing optical solitons.*

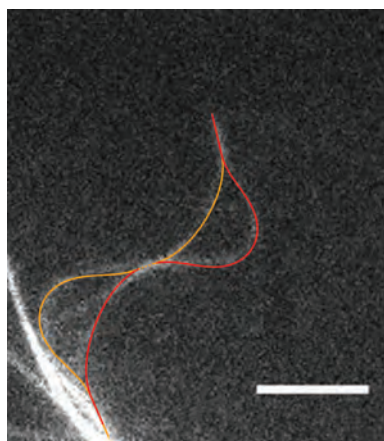*Figure 17: A liquid-crystal elastomer tube.*

Figure 18: A pair of microtubules with theoretically calculated shape.

article addresses nanographene-based materials and their versatile integrations, utilized for substantial enrichment of desired properties. Targeted properties, in addition to extraordinary material properties, include the cost-effectiveness, plasticity, and environment-friendliness of such systems. Biomedical applications are listed, including cancer nanotechnology, drug delivery, tissue manufacturing, scaffolding, photo-thermal therapy, and antimicrobial effects.

Optical properties of nanostructured multi-stoichiometric tungsten suboxides. We examined the role of crystal structure and oxygen gaps on the optical properties of four different nanomaterials from the group of tungsten sub-oxides: two quasi-two-dimensional crystals with the chemical formula W_nO_{3n-1}, and two types of nanowires with stoichiometry W_5O_{14} and $W_{18}O_{49}$. All four materials have photoluminescence emission peaks in the UV region. The interplay of the crystal structure, oxygen vacancies and shape results in changes in optical behaviour. Understanding these effects enables intentional tuning of the selected properties in the direction of an application. (*Nanotechnology* **33**, 275705 (2022)).

Pollution of the atmosphere by fireworks. Fireworks pollute the atmosphere with various chemical compounds and elements that can endanger the health of the local population, especially in poorly ventilated valleys. We measured the mass and numerical concentrations of nanoparticles, PM10 particles and black carbon in the air before, during, and after the New Year's fireworks in 2016/2017 in Ljubljana. We found a statistically significant correlation between all three pollutants. Chemical analysis of the collected samples showed increased concentration of heavy metals, which are regular components of pyrotechnic devices. The results agree with the chemical analyses of the samples at ARSO, where greatly increased concentrations of heavy metals were found in the first two days of the New Year. (*Air Qual Atmos Health* **15**, 1275 (2022)).

Neuronal-like spiking dynamics in memristive AgPt-nanoparticle assemblies. A conductive atomic force microscopy approach is applied to probe the memristive dynamics of nanoscale assemblies of AgPt-nanoparticles at the stability border of the conducting state, where physical forces causing the formation and decay of filamentary structures appear to be balanced. This unveils a dynamic regime where the memristive response is governed
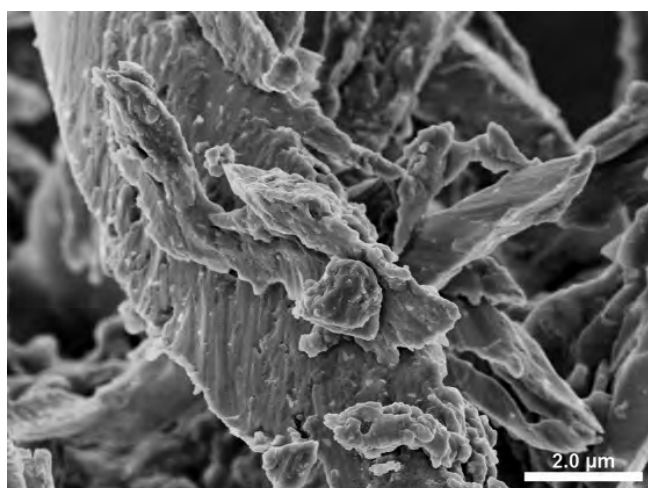

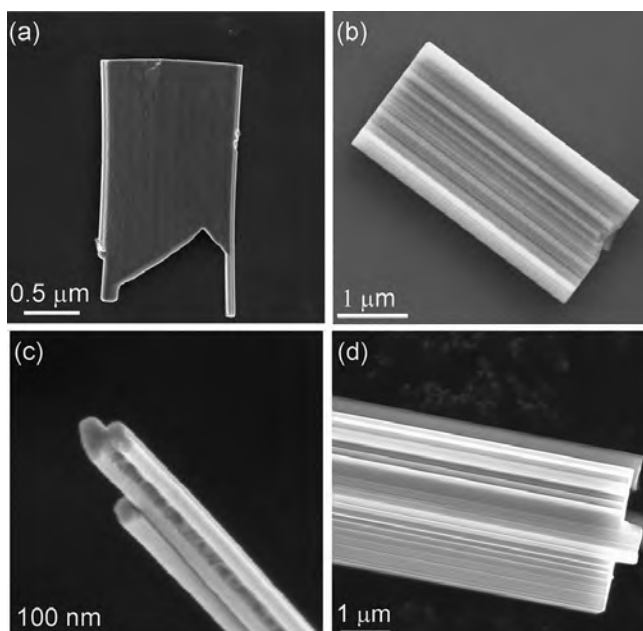*Figure 19: Graphene-oxide liquid-crystal hybrid nanofiber composite.*

Figure 20: SEM micrographs W_nO_{3n-1} crystals (a,b) and nanowires with stoichiometry W_5O_{14} (c) and $W_{18}O_{49}$(d).
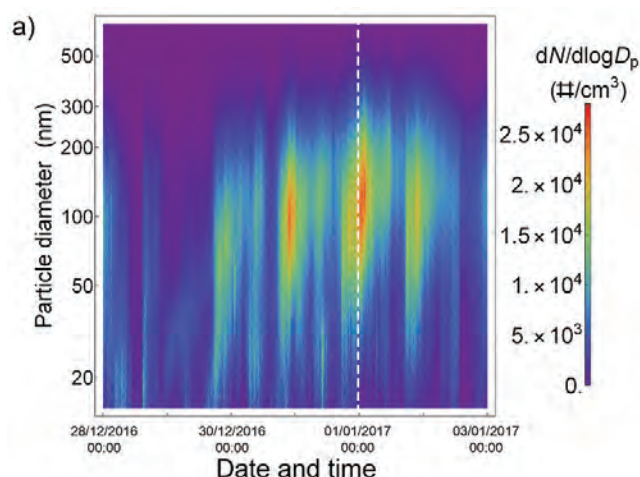

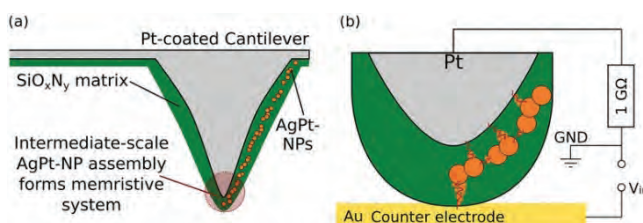*Figure 21: Normalized concentration of nanoparticles distributed by size.*

Figure 22: Experimental design of integrated nano-memristive system.

by irregular firing patterns. The significance of such a dynamical regime is motivated by close similarities to the excitation and inhibition-governed behaviour in biological neuronal systems, which is crucial to tune biological neuronal systems into a state most suitable for information representation and computation. The study was conducted in collaboration with researchers from the University of Kiel and will be published in *Particle & Particle system characterization*.

III. Research Programme: Experimental biophysics of complex systems and imaging in biomedicine

The research programme **Experimental biophysics of complex systems and imaging in biomedicine** combines research of processes and structures of biological systems by developing new, advanced experimental techniques of super-resolution microscopies, microspectroscopies and nanoscopies as well as new imaging techniques. Their research aims to understand the response of molecular and supramolecular structures to interactions between materials and living cells, as well as the interactions between light and living cells. The group is particularly interested in molecular events and physical mechanisms with which these events are causally connected, time scales, conditions, and the applied value of the investigated mechanisms, especially for their use in medicine and in the field of health care in general. With the development of the new-coupled super-resolution and spectroscopic techniques, they want to open new possibilities to investigate biological systems and from there onwards to open new possibilities for designing medical materials and devices, for diagnostics, therapy and tissue regeneration, representing key challenges due to the population aging. The investment into the new, super-resolution STED system opened a variety of fluorescence microscopy

The Laboratory for Biophysics and its spin-out company Infinite d.o.o. have assembled a highly renowned international consortium composed of research, industrial and regulatory partners and successfully secured the coordination of the new 4-year EU project nanoPASS. Its primary objective is to develop and validate novel, animal-free predictive technologies for long-term safety assessments.

approaches: STED microscopy and two-photon (2PE) microscopy, multichannel spectrally resolved fluorescence lifetime imaging (spFLIM), fluorescence microspectroscopy (FMS). These, coupled with optical tweezers, can be used to examine interactions between materials, nanomaterials and cell lines and the phenomena involved such as lipid wrapping and nanomaterial passivation, membrane disintegration, and cellular membrane translocation bypassing conventional signalling pathways.

The group has also introduced a method that enables the monitoring of the electric field in tumours during cancer treatments with electroporation. They have also developed a method of multiparametric magnetic resonance imaging for the characterization of food, medicines, and various industrial processes. High-resolution magnetic resonance imaging can monitor the effectiveness of surface treatments, the formation and dissolution of gels, as well as measure the diffusion in confined geometries with the use of modulated gradients.

The group has acquired a European project within the HORIZON programme, with the acronym nanoPASS, Bridging the gaps in nanosafety for the animal-free prediction of adverse outcomes (project ID: 101092741), where we are the project coordinator.

In the scope of two national research projects devoted to intelligent microscopy (J7-2596, N1-0240), conducted in collaboration with the Visual Cognitive Systems Laboratory (Faculty of Computer and Information Science, University of Ljubljana), the group has developed tools for fully automated, high-throughput imaging that adapts the acquisition mode to the content and searches for rare events. They are applying it to quantify the cellular events after exposure to nanoparticles, as well as for the characterization of rare nuclear condensates relevant for gene transcription – the latter in collaboration with the group of Prof. Jernej Ule (Chemical Institute, Ljubljana, and the Francis Crick Institute, UK).

In collaboration with University Medical Centre Ljubljana, they successfully concluded a national research project, "J3-1758 Adverse outcome pathway leading to atherosclerosis", where they identified local thrombin activation as a possible triggering event of atherosclerosis related to polluted air exposure. They thus gathered additional evidence for the hypothesis they originally proposed in 2018 in *Nano Letters*, where they hypothesized a causal link between the inhalation of nanoparticles and cardiovascular disease.

In cooperation with the Laboratory of Thermal Engineering (LTT), Faculty of Mechanical Engineering, they continued the collaboration focused on fluorescently detected, micro-boiling processes and published one study dedicated to the spatial analysis of local thermal processes within optically transparent materials.

As part of the CROSSING project, they forged exciting new collaborations with Elettra-Sincrotrone Trieste. With successful beam-time proposals on both the unique soft X-ray microscopy (TwinMic beam line) and FTIR microscopy and SR-nanoFTIR (SISSI beam line), they were able to conduct the high-resolution chemical imaging of subcellular structures. Their goal was to quantify cellular mechanisms following exposure to various toxic nanomaterials, and they used a novel correlative microscopy approach to achieve this. Their study yielded interesting results, which they plan to present to the scientific community in 2023.

They have begun collaborating with Educell d.o.o. to investigate the initial cellular responses to novel anti-microbial materials using their state-of-the-art fluorescence-microscopy infrastructure. The project is being funded through the HORIZON-CL4-2021-RESILIENCE-01 (Triple-A-COAT, 101057992) European programme, and their partner has dedicated third-party funds for this collaboration.

As part of the newly established Center of Advanced Optical Microscopies (CNOM), which operates within the scope of the Center for Electron Microscopy and Microanalysis (CEMM), they have launched a project aimed at building a cutting-edge, high-throughput fluorescence Structured Illumination Microscopy (SIM) system, combined with 2.5D microscopy. Their goal is to complete the experimental system by the end of 2023.

They continued to develop advanced microscopy and microspectroscopy techniques and applied them to elucidate diverse molecular and cellular mechanisms. In collaboration with the University of Oxford (UK) and the University of Jena, they investigated the interaction between molecules involved in transport of components to and from peroxisomes. With partners from University of Olomouc (CZ), they investigated the uptake of carbon nanodots as potential cancer therapeutics.

In 2022 they upgraded their super-resolution STED microscope with a package for long-term multicolour live-cell imaging. The upgrade included additional lasers and detectors, with a dedicated channel for efficient scattering detection of non-fluorescent nanoparticles, an on-stage incubator, as well as new electronics for adaptive illumination. They obtained co-financing from the ARRS package 20.

As part of the industrial cooperation with their spin-out company Infinite d.o.o., they have discovered new, early molecular events following the exposure of the new in-vitro osteo model. This model was developed by their spin-out company to address the problem of unexplained inflammation associated with bone implants. Some of these findings have already been implemented in the new technology for predicting implant-related health risks.

Together with their spin-out company Infinite d.o.o., they have discovered several surprising material-driven, cell-phenotype evolutions. These evolutions, which are unexpected according to the current dogmas of modern biology, occurred in the type of cell lines used in the corresponding in-vitro models. This discovery has opened a new field of research and presents new possibilities for simplifying the perspective on cell differentiation.

Magnetic resonance imaging of electric current density and its application to monitor the response of plant tissues to treatments with a pulsed electric field. The change in cell membrane permeability upon the exposure of plant tissues to pulsed electric fields (PEFs) is associated with physical changes in cellular and subcellular structures. The aim of our research was to investigate possible heterogeneities in PEF treatment due to the structural heterogeneity of plant tissues. We tested the use of PEF on the following plant tissues: apples, potatoes and carrots. Specifically, we measured the spatial distribution of T_2 NMR relaxation by magnetic resonance imaging as a function of the local electric field during PEF treatment, where the electric field was measured by magnetic resonance electrical impedance tomography (Figure 1). The results showed increasing heterogeneity of the distribution of T_2 relaxation times with increasing complexity of tissue structure (carrot > potato > apple). This study was published in the article: Genovese Jessica, Stručić Marko, Serša Igor, Novickij Vitalij, Rocculi Pietro, Miklavčič Damijan, Mahnič-Kalamiza Samo, Kranjc Matej. PEF treatment effect on plant tissues of heterogeneous structure no longer an enigma: MRI insights beyond the naked eye. Food chemistry 134892, p. 1-9 (2022). We also developed a new method of magnetic resonance imaging of electric current density. It was shown that the presence of an electric current in the sample causes the formation of a magnetic field gradient, which leads to a decrease in the T_2^* NMR relaxation time. This effect was both theoretically and experimentally confirmed, and a method was presented to estimate from the measured T_2^*, or signal reduction, the density of the electric current that caused this change. This study was published in the article I. Serša Electric current detection based on the MR signal magnitude decay. Magnetic resonance in medicine. 88, 1282-1291 (2022).

Importance of multiparametric magnetic resonance imaging in planning the interventional treatment of an ischemic stroke. Accurate thrombus characterization in ischemic stroke can facilitate the process of recanalization of vascular occlusion and increase the success of stroke treatment. We studied how well brain thrombi can be evaluated with computed tomography (CT), magnetic resonance (MR) and histology, and how the parameters obtained with these methods correlate both with each other and with the course of the interventional treatment process and with the patient's clinical parameters. The cerebral thrombi of 25 patients with ischemic stroke were interventionally imaged with CT and then retrieved by mechanical thrombectomy. The retrieved thrombi were then imaged at the IJS with MR microscopy, which included apparent diffusion constant (ADC) mapping, T_2 relaxation time mapping, and histological analysis. In the study, it was shown that there are significant correlations between ADC variability and the duration of mechanical recanalization, between the variability in the average CT numbers and the number of passes with the thrombectomy device, the length of the thrombus, and the content of red blood cells. With this study, we also demonstrated the clinical potential of multiparametric MR imaging in the characterization of thrombi and its use for interventional procedure planning. This study was published in the article: V. Rebeka et al.

An intermodal correlation study among imaging, histology, procedural and clinical parameters in cerebral thrombi retrieved from anterior circulation ischemic stroke patients. Journal of clinical medicine. 11, 5976-1- 5976-15 (2022).

Magnetic resonance imaging of wood. The physical and mechanical properties of wood, as well as its susceptibility to fungal decay, are strongly influenced by the moisture content. Therefore, understanding the state of the water in the wood, i.e., the ratio between free and bound water, depending on the moisture content in the wood, is very important. To investigate this dependence, we monitored the distribution of relaxation times T_1 and T_2 in 1D and their correlation with correlation NMR relaxometry in 2D on beech samples during drying from green (freshly cut) to completely dry state. The relaxometry results are consistent with the model of homogeneous pore emptying in a bioporous system with connected pores. The results of this study confirmed that NMR is an effective tool for the study of water transport pathways in wood during drying and that it also allows determining the state of water and its distribution in wood. This study was published in the article U. Mikac et al. MR study of water distribution in a beech (Fagus sylvatica) branch using relaxometry methods. Molecules. 26, 4305-1-4305-10 (2021).

Magnetic resonance microscopy of peripheral nerves. Understanding the micro-anatomy of nerves is important because various neuropathies and some nerve neoplasms are accompanied by fascicle enlargement. The aim of our study was to obtain clinically oriented knowledge of the fascicular anatomy of the nerve using different anatomical imaging modalities. The study was carried out on sections of the median and ulnar nerve, which were imaged with spatially high-resolution, ultrasound imaging at 22 MHz, with clinical magnetic resonance imaging at 3T, and at the IJS we also performed imaging of nerve samples with magnetic resonance microscopy at 9.4 T. Anatomical imaging followed a histological analysis of the nerves as a reference method. All three imaging methods were then compared for their ability to count and distinguish fascicles and measure the interfascicular distance and their cross-section. The results of the study confirmed that among these anatomical imaging modalities, magnetic resonance microscopy, which we have at IJS, enables the best analysis of the fascicular anatomy of the nerve (Figure 2). The study was published in the article: Snoj Žiga, Serša Igor, Matičič Urša, Plut Domen, Cvetko Erika, Omejec Gregor. Median and ulnar nerve fascicle imaging using MR microscopy and high-resolution ultrasound. Journal of neuroimaging 32, 420-429 (2022). The continuation of this study on the above-mentioned peripheral nerves was aimed at the development of the diffusion tensor imaging method and its application to study the diffusion properties and fractional anisotropy of different anatomical structures of the nerve. The high spatial resolution of the imaging, which was 35 micrometres and was a particular challenge, made this study one of the first of its kind in the world. Results of this study are published in the article: A. Kanza et al. Diffusion tensor imaging of a median nerve by magnetic resonance : a pilot study. Life. 12, 748-1-748-13 (2022).

IV. Research Programme: Physics of quantum technologies

Preparation of ultracold atomic-ensemble arrays using time-multiplexed optical tweezers. We used optical tweezers based on time-multiplexed acousto-optic deflectors to trap ultracold caesium atoms in one-dimensional arrays of atomic ensembles. For temperatures between 2.5μK and 50nK, we studied the maximum time between optical tweezer pulses that retain the number of atoms in a single trap. This time provides an estimate of the maximum number of sites in an array of time-multiplexed optical tweezers. We demonstrated the evaporative cooling of atoms in arrays of up to 25 optical tweezer traps and the preparation of atoms in a box potential. Additionally, we demonstrated three different protocols for the preparation of atomic-ensemble arrays by transfer from an expanding ultracold atomic cloud. These result in the preparation of arrays of up to 74 atomic ensembles consisting of ∼100 atoms on average. (K. Gosar et al. Phys. Rev. A 106, 022604 (2022)).

Figure 23: Time series of the splitting of 5 atomic ensembles into 10 using time-multiplexed optical tweezers.

ERC projects

1. H2020 - Cell-Lasers; Intracellular Lasers: Coupling of Optical Resonances with Biological Processes
   Asst. Prof. Matjaž Humar
   European Commission
2. H2020 - LOGOS; Light-Operated Logic Circuits from Photonic Soft-Matter
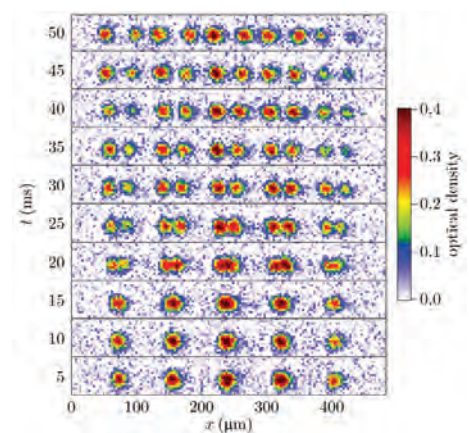   Prof. Igor Muševič
   European Commission

Some outstanding publications in 2022

1. T. Arh et al., "The Ising triangular-lattice antiferromagnet neodymium heptatantalate as a quantum spin liquid candidate", Nat. Mater. 21, 416 (2022).
2. J. Luzar, P. Priputen, M. Drienovský, S. Vrtnik, P. Koželj, A. Jelen, M. Wencka, D. Gačnik, P. Mihor, B. Ambrožič, G. Dražić, A. Meden, J. Dolinšek, Zero-Magnetostriction Magnetically Soft High-Entropy Alloys in the Al-CoFeNiCux (x = 0.6 – 3.0) System for Supersilent Applications", Adv. Mater. Interfaces 9, 2201535 (2022).
3. Z. Hananai, Z. Kutnjak et al. Nanoscale Adv. 4, 4658-4668 (2022).
4. T. Yao, Ž. Kos, Qi Xing Zhang, Yimin Luo, E. B. Steager, M. Ravnik, K. J. Stebe, Topological defect-propelled swimming of nematic colloids, , Sci. Adv. 8, eabn8176 (2022).
5. Ž. Kos, and J. Dunkel, Nematic bits and universal logic gates, Sci. Adv. 8, eabp8371 (2022).
6. J. Pišljar, S. Ghosh, S. Turlapati, N. V. S. Rao, M. Škarabot, A. Mertelj, A. Petelin, A. Nych, M. Marinčič, A. Pusovnik, M. Ravnik, and I. Muševič, Blue Phase III: Topological Fluid of Skyrmions, Phys. Rev. X 12, 011003 (2022).
7. G. Poy, A. J. Hess, A. J. Seracuse, M. Paul, S. Žumer, I. I. Smalyukh, Nature Photonics 16, 454–461 (2022).
8. Galiani, Silvia, Reglinski, K., Carravilla, P., Barbotin, Aurélien, Urbančič, Iztok, Ott, J., Sehr, J., Sezgin, Erdinc, Schneider, F., Waithe, Dominic, Hublitz, P., Schliebs, W., Erdmann, R., Eggeling, Christian, Diffusion and interaction dynamics of the cytosolic peroxisomal import receptor PEX5. Biophysical reports, 2, 1-15 (2022).
9. M. Leroux, B. Kokot, H. Kokot, T. Koklič, J. Štrancar et al. Aerosol–cell exposure system applied to semi-adherent cells for aerosolization of lung surfactant and nanoparticles followed by high quality RNA extraction. Nanomaterials 12, 1362 (2022).
10. I. Serša, Electric current detection based on the MR signal magnitude decay. Magnetic resonance in medicine. 88, 1282-1291 (2022).
11. K. Gosar et al. Preparation of ultracold atomic-ensemble arrays using time-multiplexed optical tweezers, Phys. Rev. A 106, 022604 (2022).

Some outstanding publications in 2021

1. Schymura, Stefan, Drev, Sandra, Podlipec, Rok, Rijavec, Tomaž, Lapanje, Aleš, Štrok, Marko, et al., Dissolutionbased uptake of CeO2 nanoparticles by freshwater shrimp : a dual-radiolabelling study of the fate of anthropogenic cerium in water organisms, *Environmental science, Nano,* 2021, **8**, 7, 1934–1944
2. Everts, J. C., Ravnik, M., Ionically charged topological defects in nematic fluids, *Phys. Rev. X*, 2021, **11**, 1, 011054
3. Papič, M., Mur, U., Zuhail, K. P., Ravnik, M., Muševič, I., Humar, M., Topological liquid crystal superstructures as structured light lasers, *Proc. Natl. Acad. Sci. U.S.A.*, 2021, **118**, 49, e2110839118
4. Peddireddy, K., Čopar, S., Le, V.K., Muševič, I., Bahr, C., Jampani, V.S.R., Self-shaping liquid crystal droplets by balancing bulk elasticity and interfacial tension, *Proc. Natl. Acad. Sci. U.S.A.*, 2021, **118**, 14, e2011174118
5. Pirker, L., Pogačnik Krajnc, A., Malec, J., Radulović, V., Gradišek, A., Jelen, A., Remškar, M., Mekjavić, I. B., Kovač, J., Mozetič, M., Snoj, L., Sterilization of polypropylene membranes of facepiece respirators by ionizing radiation, *J. Membr. Sci.*, 2021, **619**, 118756
6. Del Pupo, S., Zupanič, E., et al., Tuning graphene doping by carbon monoxide intercalation at the Ni(111) interface, *Carbon*, 2021, **176**, 253–261
7. Nasour, B., Vilfan, A., Golestanian, R., Minimum dissipation theorem for microswimmers, *Phys. Rev. Lett.*, 2021, **126**, 3, 034503
8. Hickey, D., Vilfan, A., Golestanian, R., Ciliary chemosensitivity is enhanced by cilium geometry and motility, *eLife*, 2021, **10**, e66322
9. M. Klanjšek, Singlets singled out, *Nature Physics*, 2021, **17**, 1081–1082
10. X. Chen, T. Yang, Q. Zhang, L. Q. Chen, V. Bobnar, C. Rahn, Q. M. Zhang, Topological structure enhanced nanostructure of high temperature polymer exhibiting more than ten times enhancement of dipolar response, *Nano Energy*, 2021, **88**, 106225
11. Y. Tanama et al., Robust coherent spin centers from stable azafullerene radicals entrapped in cycloparaphenylene rings, *Nanoscale*, 2021, **13**, 47, 19946-19955

Some outstanding publications in 2020

1. T. Arh, M. Gomilšek, P. Prelovšek, M. Pregelj, M. Klanjšek, A. Ozarowski, S. J. Clark, T. Lancaster, W. Sun, J.-X. Mi, A. Zorko, Origin of magnetic ordering in a structurally perfect quantum kagome antiferromagnet. *Phys. Rev. Lett.*, 2020, **125**, 027203

2. P. Khuntia, M. Velazquez, Q. Barthélemy, F. Bert, E. Kermarrec, A. Legros, B. Bernu, L. Messio, A. Zorko, P. Mendels, Gapless ground state in the archetypal quantum kagome antiferromagnet $ZnCu_3(OH)_6Cl_2$, *Nat. Phys.*, 2020, **16**, 469

3. J. Hess, G. Poy, Jung-Shen B. Tai, S. **Žumer**, I. I. Smalyukh, Control of light by topological solitons in soft chiral birefringent media, *Phys. Rev. X*, 2020, **10**, 031042

4. G. Poy, A. J. Hess, I. I. Smalyukh, S. **Žumer**, Chirality-Enhanced Periodic Self-Focusing of Light in Soft Birefringent Media. *Phys. Rev. Lett.*, 2020, **125**, 077801

5. T. Strübing, A. Khosravanizadeh, A. Vilfan, E. Bodenschatz, R. Golestanian, I. Guido, Wrinkling Instability in 3D Active Nematics. *Nano Lett.,* 2020, **20**, 6281–6288

6. J. Binysh, Ž. Kos, S. **Čopar**, M. Ravnik, G. P. Alexander, Three-Dimensional Active Defect Loops, *Phys. Rev. Lett.,* 2020, **124**, 088001

7. K. Pal, A. Si, G. S. El-Sayyad, M. A. Elkodous, R. Kumar, A. I. El-Batal, S. Kralj, S. Thomas, Cutting edge development on graphene derivatives modified by liquid crystal and CdS/TiO_2 *hybrid matrix: optoelectronics and biotechnological aspects, Critical Reviews in Solid State and Materials Sciences*, 2020

8. H. Massana-Cid, A. Ortiz-Ambriz, A. Vilfan, P. Tierno, Emergent collective colloidal currents generated via exchange dynamics in a broken dimer state., *Sci. Adv.*, 2020, **6**, eaaz2257

9. D. Richter, M. Marinčič, M. Humar, Optical-resonance-assisted generation of super monodisperse micro-droplets and microbeads with nanometer precision. *Lab Chip*, 2020, **20**, 734–74.

10. P. Campinho, P. Lamperti, F. Boselli, A. Vilfan, J. Vermot, Blood Flow Limits Endothelial Cell Extrusion in the Zebrafish Dorsal Aorta. *Cell Reports*, 2020, **31**, 107505

11. L. Pirker, B. Višić, S. D. **Škapin**, G. Dražić, J. Kovača, M. Remškar, Multi-stoichiometric quasi-two-dimensional W_nO_{3n-1} tungsten oxides, *Nanoscale, 2020,* **12**, 15102–15114

12. Hassanien, B. Zhou, A. Kobayashi, Spontaneous Antiferromagnetic Ordering in a Single Layer of $(BETS)_2GaCl_4$ *Organic Superconductor, Advanced Electronic Materials,* 2020*,* **6**

13. H. Kokot, B. Kokot, A. Sebastijanović, R. Podlipec, A. Krišelj, P. **Čotar**, M. Pušnik, P. Umek, S. Pajk, I. Urbančič, T. Koklič, J. **Štrancar**, et al., Prediction of chronic inflammation for inhaled particles:the impact of material cycling and quarantining in the lung epithelium., *Adv. Mater.*, 2020, **32**, 2003913

14. Barbotin, I. Urbančič, S. Galiani, C. Eggeling, M. J. Booth, Background reduction in sted-fcs using a bi-vortex phase mask. *ACS Photonics*, 2020, **7**, 1742–1753

15. Frawley, V. Wycisk, Y. Xiong, S. Galiani, E. Sezgin, I. Urbančič, A. Vargas Jentzsch, K. G. Leslie, C. Eggeling, H. L. Anderson, Super-resolution resolft microscopy of lipid bilayers using a fluorophore-switch dyad., *Chem. Sci.,* 2020, **11**, 8955–8960

Awards and Appointments

1. Dr Matjaž Gomilšek: the ceremonial charter for young university teachers and associates for dedicated and innovative teaching and research work, Ljubljana, University of Ljubljana

2. Katja Gosar, MSc: Dr Uroš Seljak prize for the best scientific publications by students, Ljubljana, University of Ljubljana and the American-Slovenian Educational Foundation, the prize for her scientific publication "Single-shot Stern-Gerlach magnetic gradiometer with an expanding cloud of cold cesium atoms" in *Physical Review A*

3. Asst. Prof. Anton Gradišek: Prometheus in Science Award, Ljubljana, The Slovenian Scientific Foundation, editors of the online magazine *Alternator*, the award for a people-friendly presentation of research achievements in the online form of a magazine for science and about science published by ZRC SAZU

4. Asst. Prof. Matjaž Humar: the Blinc Award for physicists at the beginning of their career, Ljubljana, Faculty of Mathematics and Physics, University of Ljubljana and the Jožef Stefan Institute

5. Aljaž Kavčič, MSc: Dr. Uroš Seljak prize for the best scientific publications by students, Ljubljana, University of Ljubljana and the American-Slovenian Educational Foundation, the prize for his scientific publication "Deep tissue localization and sensing using optical microcavity probes" in *Nature Communications*

6. Dr Žiga Kos: best research achievements of the University of Ljubljana, the award for his paper "Nematic bits and universal logic gates" in *Science Advances*

7. Dr Žiga Kos: the Jožef Stefan Golden Emblem Prize, Ljubljana, the Jožef Stefan Institute, the award for an outstanding contributions made to science in PhD dissertations in the fields of natural sciences, and medicine and biotechnology

8. Prof. Dr Samo Kralj: the award for outstanding accomplishments in research, Maribor, University of Maribor, The Faculty of Natural sciences and Mathematics

9. Dr Anna Razumnaya: Seal of Excellence, Brussels, Belgium, the award for the project proposal "Tunable topological chirality in ferroelectric nanomaterials", Horizon Europe

10. Asst. Prof. Aleš Mohorič: recognition of his rich professional activity and long-term editorial work for the *Presek* magazine and other publications, Ljubljana, Society of Mathematicians, Physicists and Astronomers of Slovenia

11. Prof. Dr Maja Remškar, Asst. Prof. Anton Gradišek, Dr Luka Pirker, Anja Pogačnik Krajnc, MSc: Prometheus in Science Award, Ljubljana, The Slovenian Scientific Foundation, the award for extensive, professional and irreproachable information to the public about the results of testing protective masks from various manufacturers

12. Prof. Dr Andrej Zorko: 2022 Science Impact Award, Great Britain, the award for the article "The Ising triangular-lattice antiferromagnet neodymium heptatantalate as a quantum spin liquid candidate" in *Nature materials,* Science and Technology Facilities Council

13. Prof. Dr Slobodan Žumer: the Pierre Gilles de Gennes ILCS Prize, Lisbon, Portugal, in recognition of his creative explorations and breakthrough contributions to the understanding of soft matter, in particular, liquid crystals, liquid crystal-colloidal and liquid crystal-polymer hybrid systems, The International Liquid Crystal Society

14. Prof. Dr Slobodan Žumer: outstanding referee for the journals of APS, American Physical Society

INTERNATIONAL PROJECTS

1. COST CA17121; Correlated Multimodal Imaging in Life Sciences
   Prof. Janez Štrancar
   Cost Association Aisbl
2. COST CA17139; European Topology Interdisciplinary Action
   Prof. Slobodan Žumer
   Cost Association Aisbl
3. COST CA9108 - HiSCALE; High-Temperature SuperConductivity for AcceLerating the Energy Transition
   Dr. Abdelrahim Ibrahim Hassanien
   Cost Association Aisbl
4. BIO-OPT-COMM; A Living Optically-Communicating Neural Network
   Asst. Prof. Matjaž Humar
   Hfspo- International Human Frontier
5. H2020 - ENGIMA; Engineering of Nanostructures with Giant Magneto-Piezoelectric and Multicaloric Functionalities
   Prof. Zdravko Kutnjak
   European Commission
6. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Maja Remškar
   European Commission
7. H2020 - Cell-Lasers; Intracellular Lasers: Coupling of Optical Resonances with Biological Processes
   Asst. Prof. Matjaž Humar
   European Commission
8. H2020 - LOGOS; Light-Operated Logic Circuits from Photonic Soft-Matter
   Prof. Igor Muševič
   European Commission
9. H2020 - FoodTraNet; Advanced Research and Training Network in Food Quality, Safety and Security
   Asst. Prof. Matjaž Humar
   European Commission
10. H2020 - QMatCh; Towards Quantum States of Matter via Chemistry under Extreme Conditions
    Prof. Denis Arčon
    European Commission
11. Conservation of Cultural Heritage Indoors - The Case of Leonardo da Vinci's „Last Supper"
    Prof. Griša Močnik
    Slovenian Research Agency
12. New Electronic States Emergent via Cross-Coupling between Magnetism and Electrical Conduction in Itinerant Antiferromagnetic Systems
    Prof. Denis Arčon
    Slovenian Research Agency
13. Hemoglobin-Based Nano-Spectral Non-Linear Imaging for Future Label-Free Medical Diagnostics
    Dr. Rok Podlipec
    Slovenian Research Agency
14. Impact of Fireworks on Air Pollution in Urban Environments
    Asst. Prof. Anton Gradišek
    Slovenian Research Agency
15. Investigation of Air Pollution with Nanoparticles Caused by Fireworks
    Prof. Maja Remškar
    Slovenian Research Agency
16. Positioning and Spatial Control of Magnetic Fullerides
    Prof. Denis Arčon
    Slovenian Research Agency
17. Tunable Memristive Switching in Carbon Nanotube Network for Neuromorphic Computing
    Dr. Abdelrahim Ibrahim Hassanien
    Slovenian Research Agency
18. Plasmon-Coupled Microcavities for Real-Time Molecular Sensing Inside Live Cells
    Asst. Prof. Matjaž Humar
    Slovenian Research Agency
19. Criticality Concept in Antiferroelectric Materials (CAMat)
    Dr. Nikola Novak
    Slovenian Research Agency
20. High-Temperature Polymer Blends with Greatly Enhanced Electrical Breakdown Strength
    Prof. Zdravko Kutnjak
    Slovenian Research Agency
21. Novel Quantum Materials from a Local-Probe Perspective
    Prof. Andrej Zorko
    Slovenian Research Agency
22. 3D Printed Internals for Optimized Water Electrolysis
    Prof. Janez Dolinšek
    Slovenian Research Agency
23. Topological Excitations and Quasi-Particles in Nematic Liquid Crystals
    Prof. Samo Kralj
    Slovenian Research Agency
24. Initiation of Coagulation by Lung Epithelium Exposed Nanoparticle in Vitro
    Dr. Tilen Koklič
    Slovenian Research Agency
25. EIT Health - Miniaturised Sensor for Monitoring and Prevention of Airborne Inflicted Diseases
    Prof. Maja Remškar
    Eit Health E.v.
26. HE - FerroChiral; Tunable Topological Chirality in Ferroelectric Nanomaterials

Prof. Zdravko Kutnjak
European Commission

27. COST CA21126; NanoSpace: Carbon Molecular Nanostructures in Space; Scientific Meeting of the Nanospace Project
Prof. Denis Arčon
Cost Association Aisbl

28. COST CA21144; Superconducting Nanodevices and Quantum Materials for Coherent Manipulation
Dr. Abdelrahim Ibrahim Hassanien
Cost Association Aisbl

RESEARCH PROGRAMMES

1. Physics of quantum and functional materials
   Prof. Denis Arčon
2. Physics of Soft Matter, Surfaces and Nanostructures
   Prof. Miha Ravnik
3. Experimental Biophysics of Complex Systems
   Prof. Janez Štrancar
4. Nonequilibrium Quantum System Dynamics
   Davorin Kotnik
5. Physics of quantum technologies
   Dr. Peter Jeglič

R & D GRANTS AND CONTRACTS

1. Reconstruction of electrical conductivity of tissues by means of magnetic resonance techniques
   Prof. Igor Serša
2. Phase transitions towards coordination in multilayer networks
   Dr. Uroš Jagodič
3. Development of building blocks for new European quantum communication network
   Dr. Peter Jeglič
4. Development of high-performance piezoelectric coatings for self-powering of nonwovens used in e-mobility
   Prof. Vid Bobnar
5. Cell membrane uptake of bacteria, virions and anorganic particles controlled by membrane mechanics and topology
   Georgios Kordogiannis
6. Study of intracellular forces by deformable photonic droplets
   Asst. Prof. Matjaž Humar
7. Electrocaloric elements for active cooling of electronic circuits
   Prof. Vid Bobnar
8. Advanced inorganic and organic thin films with enhanced electrically-induced response
   Prof. Vid Bobnar
9. Adverse outcome pathway leading to atherosclerosis
   Dr. Tilen Koklič
10. Stabilization and destabilisation of spin liquids by perturbations
    Prof. Andrej Zorko
11. Physics of Majorana fermions in Kitaev magnets
    Asst. Prof. Martin Klanjšek
12. Novel experimental approach for determination of quantum spin liquids
    Prof. Andrej Zorko
13. Topological turbulence in confined chiral nematic fields
    Prof. Miha Ravnik
14. Controllable broadband electromagnetic-radiation shielding
    Dr. Matej Pregelj
15. Intelligent Content-Aware Nanospectroscopy (iCAN) of molecular events in nanoparticles-induced neurodegeneration
    Asst. Prof. Iztok Urbančič
16. Self-assembly of Photon-Enabled Circuits using Topologically Reconfigurable

Anisotropic Liquids
Venkata Subba Rao Jampani

17. Advanced optical magnetometry of vortices in unconventional superconductors
    Prof. Denis Arčon
18. Diamond-assisted quantum processing of fullerene qubits
    Prof. Denis Arčon
19. Coulombic subgap states in superconducting quantum devices
    Prof. Denis Arčon
20. Solving the Early Eventome of Cellular Responses by Intelligent Content-Aware nanoscopy
    Asst. Prof. Iztok Urbančič
21. Changes of neuro-musculo-fascial system in diabetes analyzed by 3D microscopy and biomechanic tests
    Prof. Igor Serša
22. „Antiferroelectric materials for cooling and high power electronic applications"
    Dr. Nikola Novak
23. Exploring the biofilm phenotype and surfactome of Listeria monocytogenes to predict its persistence and pathogenicity potential using machine learning
    Dr. Boštjan Kokot
24. Magnetic, electric and stress – field programming of shape response in polymer-dispersed liquid crystal elastomers – based actuators
    Dr. Andraž Rešetič
25. Development of integrated multi-channel artificial nose for detection of cancer
    Prof. Igor Muševič
26. Concept development for mechanistic prediction of material-induced fibrosis and blood coagulation initiation (uCellnNet)
    Dr. Tilen Koklič
27. Cryptographically secure random number generator
    Dr. Peter Jeglič
28. SiMBION – EuBI
    Prof. Igor Serša
29. Cryptographically secure random number generator
    Dr. Peter Jeglič
    Urad Vlade Republike Slovenije Za
30. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
    Prof. Janez Štrancar
    Helmholtz-Zentrum Dresden-Rossendorf E.V.

NEW CONTRACTS

1. Detecion of Non-Anthropogenic Air Pollution project (DNAAP)
   Prof. Griša Močnik
   Aerosol d. o. o.
2. Development and maintenance of PHP and MS SQL Server
   Prof. Igor Muševič
   Src d. o. o.
3. Magnetic, electric and stress - field programming of shape response in polymer-dispersed liquid crystal elastomers - based actuators
   Dr. Andraž Rešetič
   Kmz - Zalar Miran S.p.
4. Research and analysis of new molecular events and their causal connections in vitro
   Prof. Janez Štrancar
   Infinite d. o. o.
5. Magnetic resonance imaging of tablets in various media
   Prof. Igor Serša
   Lek d. d.
6. Mechanistic prediction of material-induced fibrosis and blood coagulation initiation (uCellnNet)
   Dr. Tilen Koklič
   Infinite d. o. o.
7. Development of integrated multi-channel artificial nose for detection of cancer
   Prof. Igor Muševič
   RLS Merilna Tehnika d. o. o.

VISITORS FROM ABROAD

1. Dr Gudimalla Apparao, Chanubanda, India, 1 January to 1 May 2022
2. Dr Magdalena Wencka, Polish Academy of Sciences, Institute of Molecular Physics, Poznań, Poland, 15 January to 31 March 2022
3. Dr Shishkina Yulia, I. M. Frantsevich, Institute for Problems of Materials Science of NASU, Kyiv, Ukraine, 8 January to 1 June 2022
4. Hotz Fabian, University of Zürich, Switzerland, 28 February to 12 March 2022
5. Dr Višić Bojana, Institute of Physics, Belgrade, Serbia, 24–31 March 2022
6. Prof. El Marssi Mimoun, Université de Picardie Jules Verne, LPMC, Amiens, France, 20–29 April 2022
7. Stefan Ščepanović, University of Podgorica, Montenegro, 9 May to 1 August 2022
8. Arso Ivanović, University of Podgorica, Montenegro, 9 May to 1 August 2022
9. Rajko Dragojević, University of Podgorica, Montenegro, 9 May to 1 August 2022
10. Dr Anna Razumnaya, Université de Picardie Jules Verne, Laboratoire de Physique de la Matière Condensee (LPMC), Amiens, France, 31 May to 31 August 2022
11. Dr Ticijana Ban, Institute of Physics, Zagreb, Croatia, 5 July 2022
12. Dr Surajit Dhara, School of Physics, University of Hyderabad, India, 16–24 July 2022
13. Prof. Dr M'barek Amjoud, University Cadi Ayyad, Marrakesh, Morroco, 20 July to 19 September 2022
14. Lakouader Afaak, University Cadi Ayyad, Marrakesh, Morroco, 16 July to 12 October 2022

15. Hadouch Youness, University Cadi Ayyad, Marrakesh, Morroco, 20 July to 19 August 2022
16. Dr Zuhail Kottoli Poyil, University of Calicut, Department of Physics, Kerala, India, 20 July to 28 August 2022
17. Jonathan Neuwald, University of Regensburg, Germany, 31 July to 5 August 2022
18. Robin Schock, University of Regensburg, Germany, 31 July to 5 August 2022
19. Prof. Dr Ali Yetisen, Imperial College London, Great Britain, 4–6 August 2022
20. Prof. Dr Daoud Mezzane, University Cadi Ayyad, Marrakesh, Morroco, 12–22 August 2022
21. Serap Namli, Middle East Technical University, Ankara, Turkey, 23 August to 4 September 2022
22. Dr Pankaj Kumar, Chitkara University, Institute of Engineering and Technology, Punjab, India, 29 August to 28 September 2022
23. Dr Vandna Sharma, Chitkara University, Institute of Engineering and Technology, Punjab, India, 29 August 2022 to 28 February 2023
24. Yuri Tanuma, University of Hokkaido, Faculty of Engineering, Laboratory of Integrated Function Materials, Center for Advanced Research of Energy and Materials, Hokkaido, Japan, 1 September to 1 December 2022
25. Julia Oliveira, University of Mons, Belgium, 7 September to 26 October 2022
26. Tomasz Krehlik, Universy Jagiellonian in Krakow, Poland, 11–24 September 2022
27. Prof. Dr Agnese Araja, University of Latvia, Department of Analytical Chemistry, Riga, Latvia, 3–9 October 2022
28. Ddr Carla Bittencourt, University of Mons, Belgium, 9–18 October 2022
29. Dr Dorota Dardas, Polish Academy of Sciences, Institute of Molecular Physics, Poznań, Poland, 17–26 October 2022
30. Prof. Dr Igor Lukyanchuk, Université de Picardie Jules Verne, Laboratoire de Physique de la Matière Condensee (LPMC), Amiens, France, 8–16 November 2022
31. Bastien Aneza, Univerza Nantes, France, 14–20 November 2022
32. Anindita Dasgupta, Leibniz Institute of Photonic Technology, Jena, Germany, 28 November to 9 December 2022
33. Prof. Dr Milena Jovašević-Stojanović, Marija Živković, Dr Duška Kleut, Dr Miloš Davidović, Vinča Nuclear Institute, Belgrade, Serbia, 4–8 December 2022

STAFF

Researchers
1. Prof. Tomaž Apih
2. **Prof. Denis Arčon*, Head**
3. Prof. Vid Bobnar
4. Prof. Janez Dolinšek*
5. Dr. Gregor Filipič
6. Asst. Prof. Anton Gradišek
7. Dr. Alan Gregorovič
8. Abdelrahim Ibrahim Hassanien, B. Sc.
9. Asst. Prof. Matjaž Humar
10. Dr. Venkata Subba Rao Jampani
11. Dr. Peter Jeglič
12. Dr. Andreja Jelen
13. Dr. Martin Klanjšek
14. Dr. Tilen Koklič
15. Dr. Georgios Kordogiannis
16. Prof. Samo Kralj*
17. Prof. Zdravko Kutnjak
18. Dr. Mojca Urška Mikac
19. Prof. Griša Močnik*
20. Asst. Prof. Aleš Mohorič*
21. Prof. Igor Muševič*
22. Dr. Nikola Novak
23. Dr. Andriy Nych
24. Asst. Prof. Dušan Ponikvar*
25. Dr. Matej Pregelj
26. Dr. Amid Ranjkesh Siahkal
27. Prof. Miha Ravnik*
28. Dr. Anna Razumnaya
29. Prof. Maja Remškar
30. Asst. Prof. Brigita Rožič
31. Dr. Anna Ryzhkova
32. Prof. Igor Serša
33. Prof. Miha Škarabot
34. Prof. Janez Štrancar*
35. Asst. Prof. Uroš Tkalec*
36. Dr. Polona Umek
37. Asst. Prof. Iztok Urbančič
38. Dr. Herman Josef Petrus Van Midden
39. Dr. Mahendran Vellaichamy
40. Asst. Prof. Jernej Vidmar*
41. Asst. Prof. Andrej Vilfan
42. Dr. Stanislav Vrtnik
43. Prof. Aleksander Zidanšek
44. Prof. Andrej Zorko
45. Asst. Prof. Erik Zupanič
46. Prof. Slobodan Žumer

Postdoctoral associates
47. Dr. Matej Bobnar
48. Dr. Matjaž Gomilšek
49. Dr. Apparao Gudimalla
50. Dr. Saša Harkai
51. Dr. Uroš Jagodič
52. Dr. Tilen Knaflič
53. Dr. Žiga Kos*
54. Dr. Zuhail Kottoli Poyil
55. Dr. Primož Koželj
56. *Dr. Mitja Krnel, on leave since 07.04.21*
57. Dr. Marta Lavrič
58. Dr. Jože Luzar
59. Dr. Deepshika Malkar
60. Dr. Aleksander Matavž
61. Dr. Tadej Mežnaršič
62. Dr. Maruša Mur
63. Dr. Luka Pirker
64. Dr. Rok Podlipec
65. *Dr. Gregor Posnjak, on leave since 01.08.19*
66. Dr. Andraž Rešetič
67. Dr. Yuliia Shyshkina
68. Dr. Bojana Višić
69. Dr. Maja Zorc

Postgraduates
70. Abdur Rehman Anwar, M. Sc.
71. Tina Arh, B. Sc.
72. Dejvid Črešnar, B. Sc.
73. Nikita Derets, B. Sc.
74. *Darja Gačnik, B. Sc., on leave since 01.10.22*
75. Žiga Gosar, B. Sc.
76. Katja Gosar, B. Sc.
77. Anton Hromov, M. Sc.
78. Vida Jurečič, B. Sc.
79. Aljaž Kavčič, B. Sc.
80. Dr. Hana Kokot
81. Boštjan Kokot, B. Sc.
82. Darin Lah, B. Sc.
83. Matjaž Malok, B. Sc.
84. Bojan Marin*, M. Sc.
85. Matevž Marinčič, B. Sc.
86. Matic Morgan, B. Sc.
87. Dr. Mimoza Naseska
88. Rok Peklar, B. Sc.
89. Julia Petrović, M. Sc.
90. Gregor Pirnat, B. Sc.
91. Jaka Pišljar, B. Sc.
92. Anja Pogačnik Krajnc, B. Sc.
93. *Aleksandar Sebastijanovič, B. Sc., left 01.10.22*
94. Linsy Jane Selvin Robert, M. Sc.
95. *Dr. Marion Antonia Van Midden Mavrič, on leave since 01.09.21*
96. Rebeka Viltužnik, B. Sc.

Technical officers
97. Petra Čotar, B. Sc.
98. Dr. Luka Drinovec*
99. Maša Kavčič Rosič, B. Sc.
100. *Ana Krišelj, B. Sc., left 01.09.22*
101. Ivan Kvasić, B. Sc.
102. Blaž Mencinger, M. Sc.
103. Jaka Močivnik, B. Sc.
104. Arkalekha Neogi, M. Sc.

Technical and administrative staff
105. Dražen Ivanov
106. Janez Jelenc, B. Sc.
107. Davorin Kotnik
108. Vesna Lopatič, B. Sc.
109. Silvano Mendizza
110. Peter Mihor
111. Janja Milivojević
112. Ana Sepe, B. Sc.
113. Marjetka Tršinar

Note:
* part-time JSI member

LABORATORY OF GASEOUS ELECTRONICS
F-6

The research activities within the Laboratory of Gaseous Electronics cover various research areas, ranging from the science of gases and gaseous discharges, plasma nanoscience, plasma biology and biomedicine, advanced sensors, surface electronics and crystals to advanced vacuum science and technology. Within this scope, we are exploring different gaseous and plasma systems and their use in various fields important for the progress of humanity. The research activities are, therefore, quite diverse. The most important achievements and progress beyond the existing state of the art are communicated in the paragraphs below.

Head:
Prof. Uroš Cvelbar

The major activities of the department encompass interconnected fields of research such as the science of gases and gaseous discharges, plasma nanoscience, processing and synthesis of nanomaterials, plasma chemistry, plasma electrochemistry and catalysis, plasma biomedicine and biotechnology, gas sensors, research on field emission from nanostructured materials, optoelectronics, vacuum science, design of vacuum systems, vacuum thermal insulation and other emerging topics relevant to the manipulation of atoms and electrons. These topics of research are brought together to solve different problems and tackle grand challenges in science and technology as well as to support new emerging fields of research.

Use of atmospheric pressure plasma in the food industry. Low-temperature plasmas exhibit great potential for microbial decontamination of surfaces in the food industry; however, the industrial intake of the technology is limited due to scaling limitations. In collaboration with partners from the University of Liverpool, UK, the F6 department researchers developed a prototype conveyor-based cold atmospheric pressure plasma (CAP) system. The system was tested under realistic conditions expected within food-processing facilities. Two common foodborne pathogens (*i.e., Listeria monocytogenes* and *Salmonella Typhimurium*) were inoculated onto the surfaces of two different types of commonly used conveyor-belt materials, stainless steel and poly(ether)-thermoplastic poly(urethane), in order to evaluate the antimicrobial potential of the designed CAP system. Testing was performed according to a procedure based on the EN 13697:2015 industrial protocol. A significant microbial reduction was achieved, up to 3.03 ± 0.18 and 2.77 ± 0.71 logCFU/mL of *L. monocytogene*s and *S. Typhimurium*, respectively, within a 10 s total treatment on stainless steel surfaces, and a 2.56 ± 0.37 logCFU/mL reduction of *S. Typhimurium* was achieved within a 4 s total treatment on the PE-TPU material. During a plasma decontamination process, the surfaces of conveyor belts can get into contact with reactive plasma species responsible for the inactivation of microor-

Figure 1: XPS spectra with depth profiles and spectra for stainless steel and PE-TPU polymer with the surface microstructure before and after plasma exposure

ganisms, causing potential modifications of the material surface. XPS and AFM were used for surface characterisation and testing the possible effects on the conveyor-belt material treated under the same plasma parameters. Multiple passes showed some effects on the topography and chemical composition of the surface, showing that proper parameters have to be tailored to achieve the maximum elimination of harmful microorganisms and minimal negative effects on the treated surface.

Design of advanced sensors with plasma tailoring of nanomaterials. Plasma was used to design a nanoplasmonic sensor intended for ultrafast DNA recognition. The F6 researchers demonstrated the investigation of bacterial DNA with inelastic photon scattering measurements and nanoplasmonics chips. Surface-enhanced Raman spectroscopy (SERS) exhibited the ability to detect bacteria based on their genetic DNA fingerprint, which can
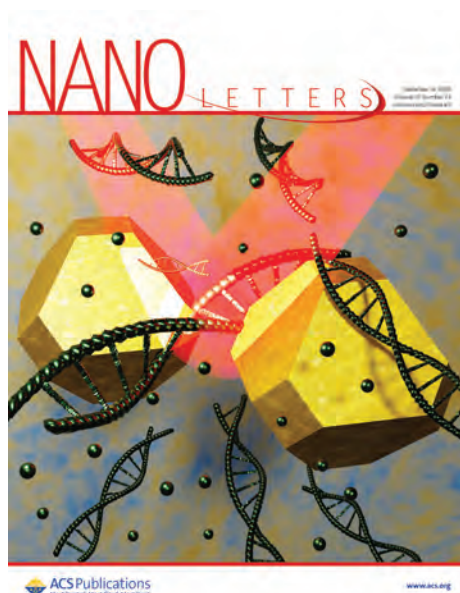
Figure 2: Nano Letters featured article and its cover page

serve as a marker for distinguishing samples. An effective differentiation of bacterial species was achieved using nanogold clusters produced via a single-step plasma reduction of gold-containing vapoured precursor ions. SERS probing of small sample amounts in the nanogram range was possible due to a high enhancement factor (EF = 10^7) for truncated, coupled plasmonic particles. Simulations confirmed that the strongest electric-field confinement occurred in nanoscale gaps between gold dimers/chains, which amplified the photon scattering of molecular fingerprints from bacterial DNA fragments. The primary Raman modes associated with essential molecular vibrations of base pairs were separated and then utilised for the estimation of the nitrogenous base content. The genetic composition (guanine-cytosine and adenine-thymine percentages) was validated through third-generation sequencing, which used the nanopore technology, further substantiating the applicability of the SERS technique in rapidly identifying bioentities through the use of a discriminant principal component analysis. The results were published as a featured article entitled *Bacterial DNA Recognition by SERS Active Plasma-Coupled Nanogold*" in the *Nano Letters* journal.

Part of this research was mastering atmospheric jet plasma for the finely controlled gold-nanoparticle deposition process. The utilisation of cold-atmospheric plasma-assisted deposition has emerged as an effective means for synthesising gold nanoparticles (AuNPs). This method relies on the interaction between plasma and vapours to simultaneously reduce and deposit AuNPs from an inorganic precursor ($HAuCl4$). As surface analyses indicate, the efficiency of reduction is heavily influenced by the plasma input power, while a reduction in the argon flow rate results in the formation of smaller particles. This study reveals that the presence of ethanol in a gold reactive mixture facilitates improved reduction to nanostructures due to its volatile properties. A comprehensive exploration of both the plasma and the deposited nanostructures indicates that the reduction is mainly induced by free electrons and in-situ hydrogen peroxide formation within the plasma. The developed technique demonstrated that nanostructured thin films can be fabricated within 5 minutes by regulating plasma parameters. The deposited AuNPs display excellent plasmonic surface-enhanced Raman scattering responses, verified with the Raman marker Rhodamine R6G, indicating their potential application as a quick and dependable optical analytical biochemical sensing substrate. The results were published in the paper *From faceted nanoparticles to nanostructured thin film by plasma-jet redox reaction of ionic gold*, *Journal of Alloys and Compounds*.

One of the F6 team's excellent interdisciplinary reports on the development of nanoplasmonic optical sensors was presented at the annual Slovenian Research Agency (ARRS) meeting, "Excellence in Science." In the report entitled *Label-Free Mycotoxin Raman Identification by High-Performing Plasmonic Vertical Carbon Nanostructures*, published in *Small*, we demonstrated the development of new plasmonic substrates based on carbon nanostructures that can rapidly detect small amounts of various mycotoxins on the surfaces of collected samples. This achievement has general applicability in the rapid detection of natural toxins in agriculture and the food industry without the need for time-consuming analyses in authorised laboratories.

Figure 3: Atmospheric plasma deposition of gold nanoparticles

Furthermore, the F6 researchers helped build a graphene-based ultrasonic photoacoustic emitter. Devices utilising photoacoustic effects to produce high-amplitude and high-frequency ultrasound have potential applications in medical therapies and on-chip bio-applications. In this study we investigate the photoacoustic response of a composite material consisting of graphene nanoflakes embedded in polydimethylsiloxane. A procedure was developed to obtain well-dispersed graphene in the polymer without requiring surface functionalisation. Different weight percentages of the composite were spin-applied onto a polydimethylsiloxane substrate. Our findings reveal that the photoacoustic amplitude increases with optical absorption, reaching a maximum of 11 MPa at a laser fluence of approximately 228 mJ/cm². The team observed that an increase in the laser fluence results in a deviation from the linear pressure amplitude, indicating a decrease in the Grüneisen parameter. Spatial confinement of high-amplitude (> 40 MPa, laser fluence > 55 mJ/cm²) and high-frequency (Bw-6db ~ 21.5 MHz) ultrasound was achieved by embedding a freestanding film in an optical lens. The acoustic gain promoted the formation of cavitation microbubbles at moderate fluence levels in both water- and tissue-mimicking materials. The findings opened up new possibilities for the development of innovative photoacoustic medical devices and integrated components. These achievements were published in a paper, *Ultrasonic photoacoustic emitter of graphene-nanocomposites film on a flexible substrate*.
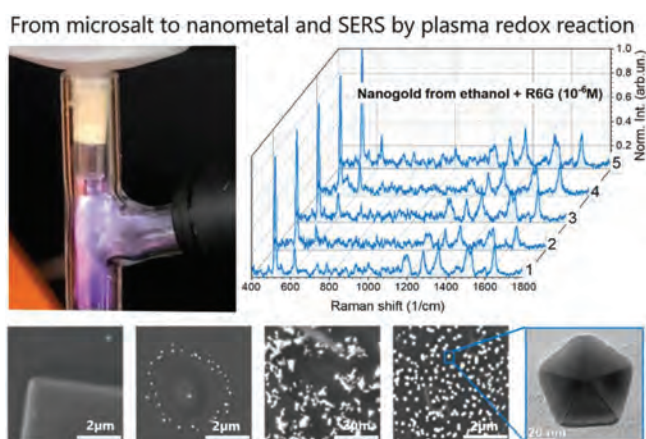
Plasma-designed hybrid carbon-based nanostructures for energy applications. Carbon nanostructures have significant potential in energy-storage applications due to their unique structural, morphological and electrical properties. Due to their easy functionalisation and tailoring features, carbon-based structures are widely used for enhancing the electrochemical energy-storage capabilities of electrode materials. In this respect, the F6 researchers continued their efforts to design hybrid carbon-based nanostructures for energy-related applications in the last year. Based on the research activities, we established a fast, facile, plasma-assisted approach for fabricating a smart hybrid binder-free electrode consisting of molybdenum sulphide (MoS_2) supported by a vertical carbon nanotube (VCNT) backbone in the form of MoS_2@VCNT. This smart nanoarchitecture was achieved with the plasma deposition of VCNT, later anchored with metallic Mo nanoparticles using plasma sputtering followed by low-temperature annealing in the presence of H_2S. Plasma produced vertical carbon nanotubes (VCNT) directly on a conductive substrate and anchored them with molybdenum. Later, thermal processing was employed to convert them to corresponding metal sulphides. In this way, we obtained a binder-free composite anode with a vertical carbon nanotube/molybdenum sulfide (VCNT/MoS_2) nanostructure. The vertically aligned morphology of the binder-free VCNT/MoS_2 hybrid composites facilitates electrolyte penetration and shortens ion diffusion channels. Direct contact between the VCNTs and the current collector improves the ion/electron conductivity of the electrode. These advantageous features enable the binder-free VCNT/MoS_2 hybrid composite electrodes to exhibit superior electrochemical properties when used as an anode for SIBs, including an exceptional rate capability with a specific discharge capacity of 403 mA h g^{-1} at a high current density of 3200 mA g^{-1}. The surface morphology and the possible charge pathways of the designed smart MoS_2@VCNT electrode are presented in Figure 6. These findings could open up efficient designing of smart hybrid electrodes using green techniques for next-generation energy storage systems.

In collaboration with the researchers from Instituto Superior Técnico, Lisbon, Portugal, the F6 researchers demonstrated the superior efficiency of nitrogen-doped vertical carbon nano-forest structures (NCNF) for filtering AC signals, exhibiting capacitance performance at high frequencies (above 100 Hz). The NCNF electrode materials were designed following an environmentally friendly plasma-enabled approach using a fast, controllable and low-cost method. The binder-free electrode preparation allows direct contact between the current collector and electrode material, minimising Ohmic coupling at the current collector–material interface and also improving the charge transfer and efficient electrolyte interaction. Along with this, the hierarchical morphology of carbon nanostructures enhances the effective area for electrode-electrolyte interaction while nitrogen doping of carbon nanostructures increases the hydrophilic properties of the materials and stimulates the electrode-electrolyte interaction during the electrochemical processes, which, in turn, improves the total electrochemical response of the material. The capacitors including the NCNF electrodes delivered a high capacity of 1145 μF with a phase angle close to −80° at 100 Hz in a lab-scale two-electrode set-up. A prismatic prototype capacitor fabricated by stacking ten pairs of electrodes (2.5 × 3.5 cm^2) exhibited one of the lowest equivalent series resistance values, about 5.8 mΩ, with a high capacitance of ~12 mF at 100 Hz and demonstrated high stability of filtering capabilities for a long time. The performance of designed NCNF-based capacitors at high frequencies, filtering capabilities over time, and a schematic of the process are presented in Figure 8. This performance delivered at the lab scale and in industrially relevant environments suggests that such electrochemical capacitors represent a suitable alternative to conventional aluminium electrolytic capacitors for high-frequency filtering applications. Designing hybrid carbon nanostructures is critical for developing high-performing device applications and it is one of the significant tasks tackled within our H2020 FET-open project PEGASUS and EU FLAGERA project VEGA. All the developed methods and achieved/measured performances were published in high-impact journals.

Nanoscale catalysis and electronics of surfaces and crystals. In collaboration with the researchers from KI, the team was investigating materials for catalytic reactions. Based on the TEM-based methods, the electronic states of nanocrystal surfaces were explored and correlated to their reactivity. With tilt-series micrograph reconstruction, the
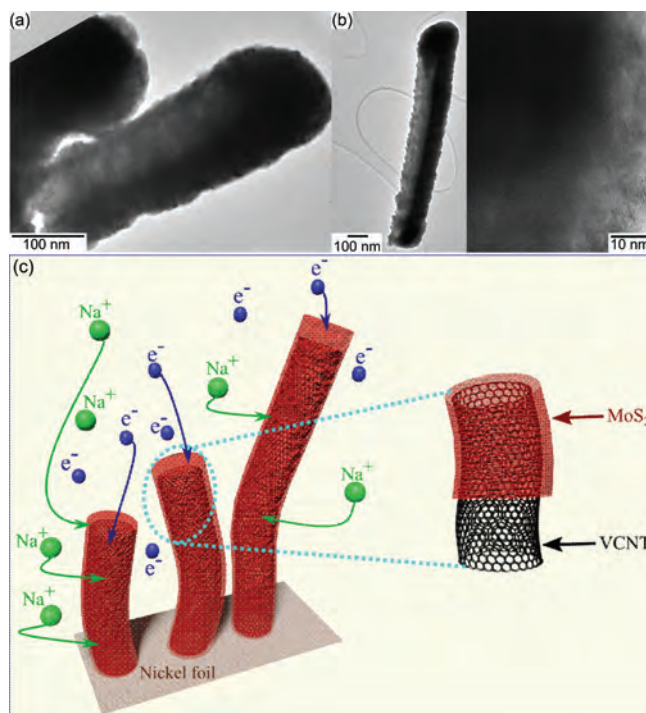

Figure 4: Cover page of Crystal Growth & Design

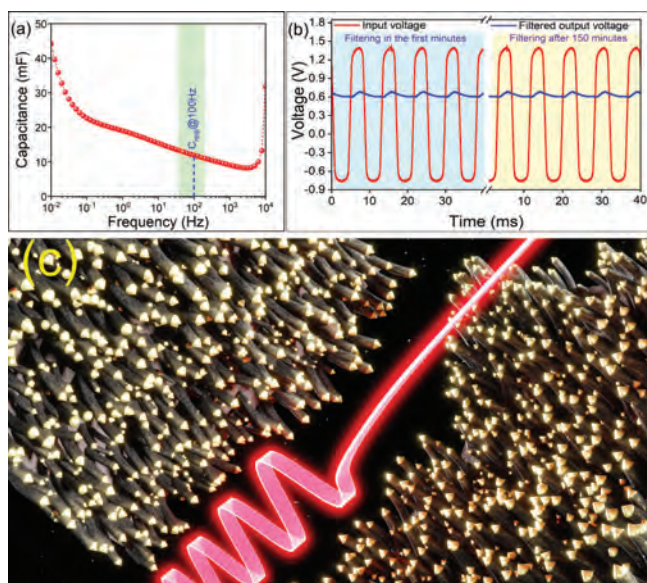*Figure 5: Hybrid MoS_2/VCNT architecture for electrode materials*

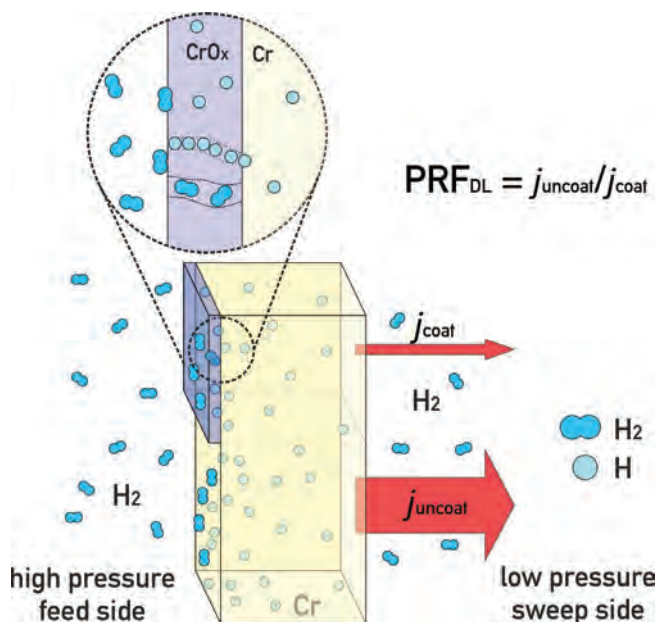*Figure 6: AC line filtering to DC using NCNF electrodes*

Figure 7: Schematic of the permeation experiment

morphology of the nanoparticles and their distribution over the substrate were reconstructed. Several different catalyst systems were researched: CeO_2, TiO_2 and ZrO_2 as substrates, combined with Au and Ni nanocrystals. This was done to reveal the mechanisms for dry methane reforming and CO_2 hydrogenation to methanol.

Interactions of hydrogen isotopes with fusion-related materials and other fusion-related research. The F6 researchers are part of the EUROfusion consortium, which works in the fields of fusion-related research following the current plan to confirm the operational principle of nuclear fusion. The current research program focuses on the interactions of hydrogen isotopes with structural materials used for fusion purposes, in particular, tritium-permeation barriers. The retention of radioactive tritium in the materials is difficult to control because it easily penetrates reactor metal walls from where it can leak into the environment through the cooling system. Besides the fact that the main focus is currently placed on the ITER-relevant physics, the concept of a reactor DEMO opens up many new problems. Anyhow, there are two main differences: the ITER vacuum chamber is made of austenitic stainless steel and will operate in the pulsed mode, while DEMO will be made of martensitic steel termed Eurofer and will operate continuously. Consequently, keeping the total amount of tritium at a safe level seems to be achieved without putting a permeation barrier on the inner vacuum surfaces in ITER, but it will be mandatory in DEMO.

The role of chromium in steel was recognised as crucial for many key technologies as it is well established that a thin chromium oxide film formed on an exposed surface in specific external conditions plays a crucial role as a hydrogen barrier and corrosion protection layer. For the planned nuclear fusion reactors, Eurofer-97 steel, an alloy of Fe and Cr, was selected as the material of choice 25 years ago. As it is a highly permeable martensitic steel, efficient barriers are thus mandatory to prevent tritium migration and escape to the environment. Many technical papers investigate chromium oxide formed on steels as a hydrogen permeation barrier, but analogue studies of *in situ*-grown oxide on pure chromium are rare. Such a study would probably reveal the highest achievable barrier efficiency as only chromium oxide is formed. In a paper, the F6 team explained that a permeation rate permeation-rate suppression by three orders of magnitude was realised with controlled *in situ* oxidation in wet deuterium up to 850 °C. Still, the film structure and thickness were not determined. The details on the hydrogen interaction with the chromium oxide surface responsible for limited barrier efficiency are partially known.

Furthermore, the hydrogen permeation through chromium membranes at 400 °C and the role of the superficial chromium oxide were researched. The upstream hydrogen pressure was detected at ~1000 mbar before and after the chromium membrane oxidation in pure oxygen. A native oxide was already formed in the high vacuum during the initial pre-processing procedure. The formation of an additional oxide film during controlled oxidation reduced the permeation rate by up to ~980 times. In parallel, the permeation rate through an identical palladium-coated chromium referential membrane was measured between 200 and 500 °C to avoid the impact of the native oxide. Compared to these new data, the highest oxide barrier efficiency at 400 °C was even higher as the permeation reduction factor was ~3900. The corresponding $P_{CrOx}(400\ °C)= 7.0\times10^{-20}\ mol\ H_2/(s\ m\ Pa^{0.5})$ is the lowest value ever reported for any barrier at 400 °C. The surface morphology and oxide thickness were investigated with SEM, while the thickness and type of oxide were investigated with XPS.

Within EUROFusion consortium projects, the F6 researchers also worked on the evaluation of the light-element migration and retention in *bcc* metals. The focus of the research was nanoscale analyses of the thin oxide films formed by the electrochemical or thermal oxidation of polycrystalline tungsten. For evaluation, thin foils for analyses were prepared at a focused ion beam (FIB) at the nanocenter facilities, and the samples were evaluated using transmission electron microscopes (TEM) available at the JSI and KI. In parallel, the team was developing the non-destructive SEM-based electron channelling contrast imaging technique (ECCI) within a reaction cell equipped with an electron column available at the F6 department. The technique allows us to observe and identify

near-surface dislocations, low-angle grain boundaries and other structural defects at depths of up to several microns. The method is especially useful for precise crystallographic orientation of a sample before a FIB-assisted TEM sample preparation (Figure 8).

JSI-MPIE partner group. Activities of the joint partner group including colleagues from the JSI and Max-Planck-Institut für Eisenforschung were carried out remotely. The F6 researchers worked on the optimisation of electron microscopy techniques in correlation with atom-probe tomography (APT). For scanning electron microscopy (SEM), the team worked on the algorithm for a 3D reconstruction of surface morphology using a tilt set of micrographs correlated with the signal obtained with an annular back-scattered detector. For transmission electron microscopy (TEM), the team developed a set of statistical methods for the evaluation of scanning TEM micrographs. Such evaluation of defects was successfully implemented in the characterisation of the He-irradiated tungsten (Figure 9).

Figure 8: Electron channelling pattern developed on a W sample as a function of the accelerating voltage

Figure 9: (a) HAADF-STEM micrograph of He-implanted polycrystalline W; (b) the size and spatial distribution of He bubbles depend on pre-existing structural defects, such as grain boundaries and dislocations; results obtained in collaboration with F2, K7 and CEMM

Some outstanding publications in the past year

1. Vasyl Shvalya, Martina Modic, Cene Skubic, Nejc Nadižar, Janez Zavašnik, Damjan Vengust, Aleksander Zidanšek, Damjana Rozman, Uroš Cvelbar, et al., Bacterial DNA recognition by SERS active plasma-coupled nanogold, *Nano Letters*, Dec. 2022, vol. 22, iss. 23, pp. 9757–9765, illustr., ISSN 1530-6992, DOI: 10.1021/acs.nanolett.2c02835, [COBISS.SI-ID 127669763]

2. Jorge Dias, Neelakandan Marath Santhosh, Uroš Cvelbar, Janez Zavašnik, et al., N-graphene-metal-oxide(sulfide) hybrid nanostructures: single-step plasma-enabled approach for energy storage applications, *Chemical Engineering Journal*, Feb. 2022, vol. 430, pt 4, pp. 1–13, illustr., ISSN 1385-8947, DOI: 10.1016/j.cej.2021.133153, [COBISS.SI-ID 82177795]

3. Ana Kovačič, Martina Modic, Nataša Hojnik, Anja Vehar, Tina Kosjek, David John Heath, James L. Walsh, Uroš Cvelbar, Ester Heath, Degradation of bisphenol A and S in wastewater during cold atmospheric pressure plasma treatment, *Science of the Total Environment*, 2022, vol. 837, art. 155707, 15 pp., ISSN 0048-9697, DOI: 10.1016/j.scitotenv.2022.155707, [COBISS.SI-ID 106290691]

4. Aswathy Vasudevan, Vasyl Shvalya, Martin Košiček, Janez Zavašnik, Andrea Jurov, Neelakandan Marath Santhosh, Aleksander Zidanšek, Uroš Cvelbar, From Faceted Nanoparticles to Nanostructured Thin Film by Plasma-Jet Redox Reaction of Ionic Gold, *Journal of Alloys and Compounds*, [Print ed.], Dec. 2022, vol. 928, [article no.] 167155, pp. 1-11, illustr., ISSN 0925-8388, DOI: 10.1016/j.jallcom.2022.167155, [COBISS.SI-ID 121112067]

5. Martin Košiček, Janez Zavašnik, Oleg B. Baranov, Barbara Šetina, Uroš Cvelbar, Understanding the growth of copper oxide nanowires and layers by thermal oxidation over a broad temperature range at atmospheric pressure, *Crystal Growth & Design*, Nov. 2022, vol. 22, iss. 11, pp. 6566–6666, illustr., ISSN 1528-7483, DOI: 10.1021/acs.cgd.2c00863, [COBISS.SI-ID 127082755]

6. Daniele Vella, Aleš Mrzel, Aljaž Drnovšek, Vasyl Shvalya, Matija Jezeršek, Ultrasonic photoacoustic emitter of graphene-nanocomposites film on a flexible substrate, *Photoacoustics*, Dec. 2022, vol. 28, pp. 1–10, illustr., ISSN 2213-5979, https://www.sciencedirect.com/science/article/pii/S2213597922000787, DOI: 10.1016/j.pacs.2022.100413, [COBISS.SI-ID 126257667]

7. Janez Zavašnik, Andreja Šestan, Srečo D. Škapin, Degradation of asbestos-reinforced water supply cement pipes after a long-term operation, *Chemosphere*, [Print ed.], 2022, vol. 287, pp. 131977-1-131977-9, illustr., ISSN 0045-6535, DOI: 10.1016/j.chemosphere.2021.131977, [COBISS.SI-ID 73941507]

8. Ana Oberlintner, Vasyl Shvalya, Aswathy Vasudevan, Damjan Vengust, Blaž Likozar, Uroš Cvelbar, Uroš Novak, Hydrophilic to hydrophobic: ultrafast conversion of cellulose nanofibrils by cold plasma fluorination, *Applied Surface Science*, [Print ed.], Apr. 2022, vol. 581, pp. 1–8, ISSN 0169-4332, https://www.sciencedirect.com/science/article/pii/S016943322103302X?via%3Dihub, DOI: 10.1016/j.apsusc.2021.152276, [COBISS.SI-ID 92151043]

9. Andreja Šestan, Lekshmi Sreekala, Sabina Markelj, Mitja Kelemen, Janez Zavašnik, Christian Liebscher, Gerhard Dehm, Tilmann Hickel, Miran Čeh, Saša Novak, Petra Jenuš, Non-uniform He bubble formation in W/W2C composite: experimental and ab-initio study, *Acta Materialia*, [Print ed.], 2022, vol. 226, art. 117608, 15 pp., ISSN 1359-6454, DOI: 10.1016/j.actamat.2021.117608, [COBISS.SI-ID 92528131]
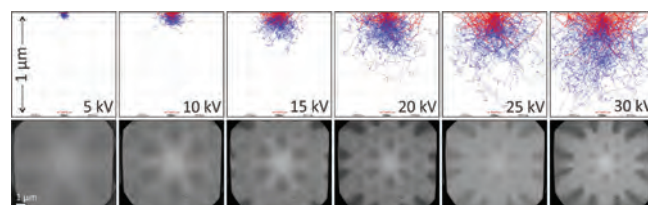
Awards and Appointments

1. Vasyl Shvalya, et al., Plasmonic surfaces for the recognition of mycotoxins, Excellence in Science 2022, ARRS

Organization of conferences, congresses and meetings

1. Second International Workshop on Plasma-Tailored Nanostructures and Applications (SWOPTAN), Rogla, Slovenia, 30 January to 2 February 2022

Patent granted

1. Ksenija Rener-Sitar, Ita Junkar, Uroš Cvelbar, Miran Mozetič, Method for improving the bonding of dental silicate ceramics with composite cements, SI26082 (A), Slovenian Intellectual Property Office, 29. 04. 2022.

INTERNATIONAL PROJECTS

1. Max Planck Partner Group
   Asst. Prof. Janez Zavašnik
   Max-Planck-Institut Für Eisenforschung GmbH
2. COST CA18113; Understanding and Exploiting the Impact of Low pH on Microorganisms
   Dr. Martina Modic
   Cost Association Aisbl
3. COST CA18116; Aniridia: Networking to Address an Unmet Medical, Scientific and Societal Challenge
   Prof. Uroš Cvelbar
   Cost Association Aisbl
4. COST CA19110; Plasma Applications for Smart and Sustainable in Agriculture
   Dr. Martina Modic
   Cost Association Aisbl
5. NATO: NOOSE - Nanomaterials for Explosive Traces Detection with SERS
   Prof. Uroš Cvelbar
   Nato - North Atlantic Treaty Organisation
6. COST CA20120 - Therapeutical Applications of Cold Plasma
   Dr. Martina Modic
   Cost Association Aisbl
7. COST CA20129 - Multiscale irradiation and chemistry driven processes and related technologies
   Prof. Uroš Cvelbar
   Cost Association Aisbl
8. H2020 - PEGASUS; Plasma Enabled and Graphene Allowed Synthesis of Unique nano Structures
   Prof. Uroš Cvelbar
   European Commission
9. Beyond Graphene - The New Materials based on 2D and 3D Graphene
   Prof. Uroš Cvelbar
   Slovenian Research Agency
10. Exploration of Metal/Metal-Oxide Sensor Capabilities
    Dr. Gregor Filipič
    Slovenian Research Agency
11. Designing Plasmonicity of Carbon-Based Nanomaterials
    Prof. Uroš Cvelbar
    Slovenian Research Agency
12. Free Radicals and Oxidative Stress in Microbial Biofilms
    Dr. Martina Modic
    Slovenian Research Agency
13. How Plasma Influences Catalytic Activity of Nanomaterials
    Prof. Uroš Cvelbar
    Slovenian Research Agency
14. HE - EUROfusion; WP07: ENR-DeHydroc-1,2,3_HE-FU
    Asst. Prof. Janez Zavašnik
    European Commission
15. HE - EUROfusion; WP18: MAT_HE-FU, IREMEV-MAT-1_HE-FU, IREMEV-MAT-2_HE-FU, IREMEV-MAT-3_HE-FU
    Asst. Prof. Janez Zavašnik
    European Commission
16. HE - EUROfusion; WP05: PWIE-1,2,3,_HE-FU, PWIE-4-Accelerator
    Dr. Vincenc Nemanič
    European Commission
17. HE - ThermoDust; A Paradigm Shift for the Future's Thermal Management Devices through Radical Innovation in New Materials and Additive Manufacturing
    Asst. Prof. Janez Zavašnik
    European Commission
18. ERASMUS+; HERawS - Highlights on European Raw Materials Sustainability
    Prof. Uroš Cvelbar
    European Commission

RESEARCH PROGRAMMES

1. Vacuum technique and materials for electronics
   Dr. Vincenc Nemanič
2. Thin film structures and plasma surface engineering
   Prof. Uroš Cvelbar
3. Plasma and quantum structures
   Prof. Uroš Cvelbar

R & D GRANTS AND CONTRACTS

4. Plasma In-situ reactions and single crystal Transitions
   Prof. Uroš Cvelbar
5. Plasma decontamination of mycotoxins and inactivation of fungi in food industry
   Dr. Martina Modic
6. Controlling plasma-bio interactions for global food security
   James Leon Walsh
7. Detection of defects and hydrogen by ion beam analysis in channelling mode for fusion
   Asst. Prof. Janez Zavašnik
8. Formation and Design of AM-processed Fe-Al alloys with self-forming Hydrogen Permeation Barriers for the harshest of environments
   Asst. Prof. Janez Zavašnik
9. Plasma activated nanobubbles: A new approach for high-level disinfection of flexible endoscopes
   James Leon Walsh
10. „Advanced DNA-scale Plasmonic Vibroscopy for Nanomedicine Research"
    Vasyl Shvalya
11. Designing Low Environmental Footprint Yarns with Atmospheric Pressure Plasma Processing
    Prof. Uroš Cvelbar
12. Atmospheric pressure plasma for removal of airborne allergens (RemoveALL)
    Dr. Nataša Hojnik
13. Multifunctional Vertical Graphene Hybrids for High-Density Supercapacitors
    Dr. Neelakandan Marath Santhosh
14. VEGA - Vertical Graphene for Aluminium-Ion Batteries
    Prof. Uroš Cvelbar
    Ministry of Education, Science and Sport

VISITORS FROM ABROAD

1. Naomi Northage, University of Liverpool, United Kingdom, 25–30 January 2022
2. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 4–8 April 2022
3. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 9–13 May 2022
4. Dr Vilko Mandić, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 12 May 2022
5. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 13–17 June 2022
6. Dr Mahendra Sunkara, University of Louisville, USA, 3 June 2022
7. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 18–22 July 2022
8. Dr Petr Slobodian, University Tomas Bata Zlin, Czech Republic, 14–24 August 2022
9. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 22–26 August 2022
10. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 10–14 October 2022
11. Dr Nikša Krstulović, Institute of Physics, Zagreb, Croatia, 11 October 2022
12. Rafaela Radičić, Institute of Physics, Zagreb, Croatia, 11 October 2022
13. Dr Andrea Jurov, Faculty of Chemical Engineering and Technology, Zagreb, Croatia, 14–18 November 2022
14. Dr Nikša Krstulović, Institute of Physics, Zagreb, Croatia, 20 December 2022
15. Rafaela Radičić, Institute of Physics, Zagreb, Croatia, 20 December 2022

STAFF

Researchers
1. **Prof. Uroš Cvelbar, Head**
2. Dr. Gregor Filipič
3. Dr. Martina Modic
4. Dr. Vincenc Nemanič
5. Dr. Vasyl Shvalya
6. Dr. James Leon Walsh
7. Asst. Prof. Janez Zavašnik

Postdoctoral associates
8. Dr. Nataša Hojnik
9. Dr. Neelakandan Marath Santhosh

Postgraduates
10. Martin Košiček, B. Sc.
11. Marko Žumer, B. Sc.

Technical officers
12. Jaka Olenik, B. Sc.
13. Damjan Vengust, B. Sc.

Technical and administrative staff
14. Urška Kisovec, B. Sc.

DEPARTMENT FOR COMPLEX MATTER
F-7

The research within the Department of Complex Matter encompasses a variety of research fields, ranging from fundamental investigations of elementary excitations in quantum materials, nonequilibrium quantum matter, self-organizing behaviour adaptive functionality in complex systems and soft matter as well as nano-biosystems, biomolecules and various nanomaterials. The department's experimental activities are strongly complemented by theory on different levels and supported by diverse materials synthesis. Our research into ultrafast non-equilibrium transitions, investigations of new emergent hidden orders and ferroic liquids are of significant interest worldwide.

Head:
Prof. Dragan D. Mihailović

European Research Council
Established by the European Commission

The research achievements of the department are quite diverse, and we are able to report on important research developments in a number of areas.

In the last two years, significant effort by the department was spent on establishing the technological foundations for new research directions. In particular, the completion of the Advanced Quantum Devices Laboratory (AQDL), as a joint-venture facility of F7 and the Nanocenter, has opened up many different possibilities. Thus, various devices and elaborate chip circuits can be nanofabricated using e-beam patterning down to <50 nm in an oxygen-free environment, entirely with local equipment. The controlled atmosphere is of particular importance when the devices use oxygen- or water-sensitive materials, such as CCM memory devices, superconducting resonators and transmon qubits. The facility makes it possible to assemble Moire single-atomic-layer heterostructures, with materials such as hBN, graphene and transition-metal dichalcogenides. The project was also supported by departments F3 and K3 in supporting the purchase of a new and versatile AFM.

The AQDL thus supplements the experimental methods already used at the department, including different femtosecond laser spectroscopies from THz to XUV, a variety of optical techniques, ultrafast transport and superconducting device studies as well as synthetic chemistry and thin-film deposition methods such as MBE, AfiD and EBE, laser biomedical studies, femtosecond STM and magnetometry.

In 2022 the commissioning of a new laboratory for resonant XUV ellipsometry began. The first XUV light was successfully observed and the lab is planned to go into routine operation in the second half of 2023. A new apparatus, which is otherwise available only at free-electron laser facilities, will expand the range of ultrafast spectroscopies available at the JSI and in Slovenia, providing a more direct and detailed insight into exotic electronic states, ultrafast spin dynamics in composite materials, non-collinear spin textures, etc. During the designing of the system great attention was devoted to stability and sensitivity. Using a special normalization routine in combination with the polarization sensitivity of the broadband detector, it will be possible to measure also weak signals, which are normally inaccessible with noisy FEL and HHG sources. This is especially important in correlated materials, which are extremely susceptible to external perturbations.

In order to investigate structural polarity in ferroelectric materials, we built an optical microscope that enables imaging of the polarization profile of samples (the ferroelectric domain structure) based on a phase-sensitive signal at the second-harmonic optical frequency. This is a special non-linear optical instrument that cannot be purchased commercially. With it, in the second half of 2022, we obtained the first images of the spatial profile of the spontaneous electric polarization in the ferroelectric nematic liquid crystalline phase. An article reporting on the results obtained with the mentioned measurements is in the process of being published in the journal Nature Communications. We also assembled a differential dynamic microscopy (DDM) system based on the original idea of combining images from two randomly triggered video cameras. This is a device that expands our set of instruments for the analysis of dynamic light scattering (DLS) and has the advantage of a simultaneous signal acquisition over a wide range of scattering vectors. It is very convenient for the analysis of dynamic processes in various soft materials.
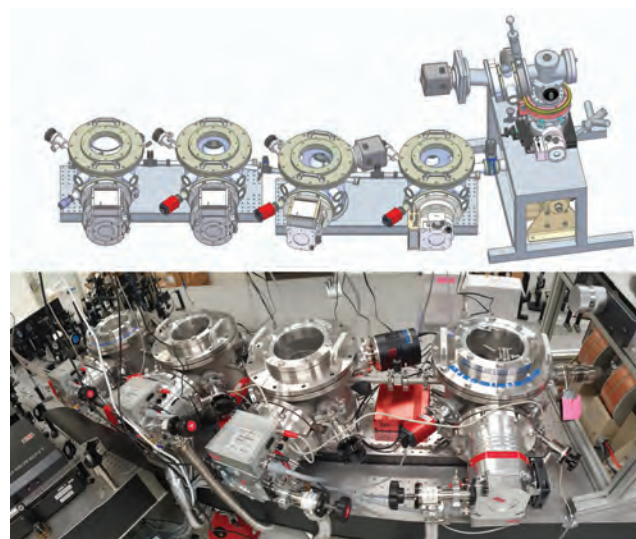

Figure 1: Time-resolved resonant XUV ellipsometry set-up

The experimental research within the department is strongly supported by theory, ranging from analytical approaches to modelling with Monte-Carlo simulations. In 2022 significant advances were made with quantum annealing simulations on a D-wave quantum processor (QPU), to the point where it became a useful technique for modelling non-equilibrium phenomena in quantum materials with numerous publications in the pipeline.

A number of spin-out research projects have recently gained importance, most recently ultrafast, low-energy cryo-memory devices based on our studies of ultrafast electronic transitions, resulting in technological breakthroughs reported in 2022.
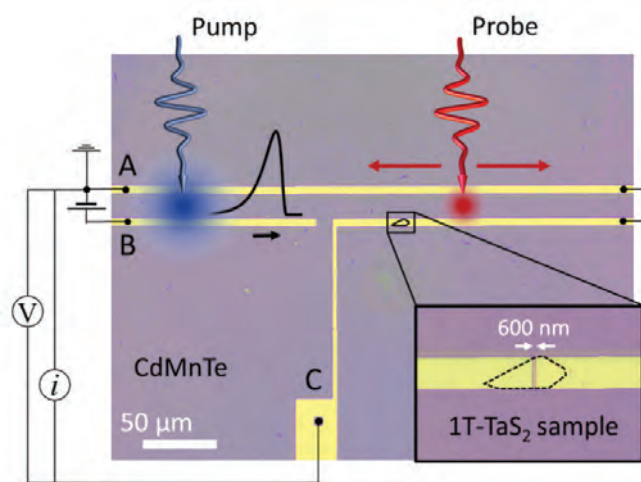

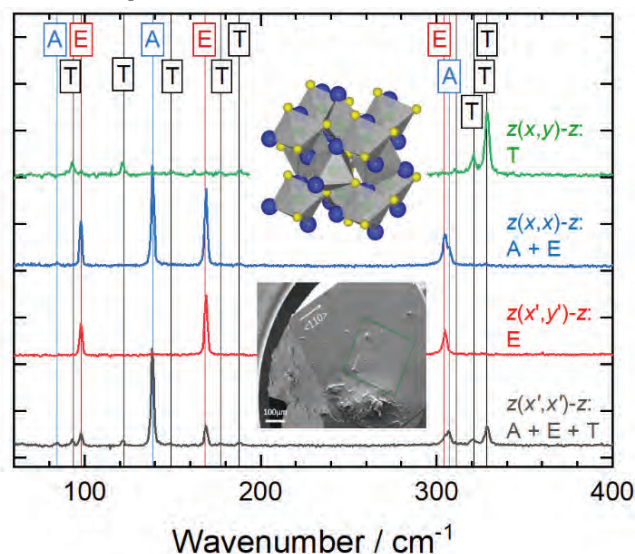Figure 2: "Laboratory-on-a-chip" for investigating ultrafast memory device switching

Figure 3: Phonon Raman spectra and structure of changchengite (IrBiS)

Ultrafast memory devices

Progress in high-performance computing demands significant advances in the memory technology. Among novel memory technologies that promise efficient device operation on a sub-ns timescale, resistance switching between charge-ordered phases of $1T$-TaS$_2$ has shown to be potentially useful for the development of high-speed, energy-efficient non-volatile memory devices. Measurement of the electrical operation of such devices in a picosecond regime is technically challenging and hitherto still largely unexplored. Here, we use an optoelectronic "laboratory-on-a-chip" experiment for measuring ultrafast memory switching, enabling an accurate measurement of electrical switching parameters with 100 fs temporal resolution. Photoexcitation and electro-optic sampling on a (Cd,Mn)Te substrate are used to generate and, subsequently, measure electrical-pulse propagation with inter-band excitation and sub-gap probing, respectively. We demonstrate high-contrast non-volatile resistance switching from the high to low resistance states of a $1T$-TaS$_2$ device, using single sub-2 ps electrical pulses. Using detailed modelling, we find that the switching-energy density per unit area is exceptionally small, E_A = 9.4 fJ/μm^2. The speed and energy efficiency of an electronic "write" process place the 1T-TaS$_2$ devices into a category of their own among the new-generation non-volatile memory devices. The results were published in **Applied Physics Letters** *120, 253510 (2022)*.

Optical characterization of new materials

We synthesized and measured, for the first time, the room-temperature phonon Raman spectra of changchengite (IrBiS) and, in collaboration with the Department of Theoretical Physics (F1), compared the experimental phonon frequencies to the theoretical ones obtained by means of the ab-initio density-functional-theory calculations in the presence and absence of the spin-orbit coupling effects. Combining two different excitation photon energies, all the symmetry predicted Raman modes are experimentally observed. The electronic properties of IrBiS are found to be similar to the recently studied isostructural compound IrBiSe showing a large Dresselhaus spin-orbit valence-band splitting. Good agreement between the experimental and theoretically predicted Raman phonon frequencies is found only when the lattice parameter is constrained to the experimental value. The inclusion of the spin-orbit coupling does not significantly affect the phonon frequencies. The results were published in the **Journal of Raman Spectroscopy** 2023, https://doi.org/10.1002/jrs.6491.

Charge-configuration memory devices

In the manuscript published in **Nano Letters** (doi: 10.1021/acs.nanolett.2c01116) we investigated scaling of the switching energy of a charge-configuration memory (CCM) device in a non-volatile regime as a function of the device size and switching pulse length, particularly relevant for the incorporation of the CCM device into cryocomputing environments where the device has potential applications. We found that the switching energy scales almost linearly with both parameters over multiple orders of magnitude and only departs from linearity at ultra-high frequencies, which most likely occurs due to the limitations of the microwave circuit and is not due to intrinsic properties of the CCM device. Demonstrated switching with 16-ps-long electrical pulses (2.2 fJ) shows that CCM devices are faster and more energy efficient when compared to other memory technologies. They are also extremely durable with over 10^6 successful write/erase cycles. Switching energy scaling also suggests that CCM

devices can be driven directly by extremely small single-flux-quantum (SFQ) pulses, if the dimensions of the device are further scaled down, which is in reach with the current lithography procedures, and if the ultra-high-frequency transmission-line electrodes are optimised. We also examined the electrical contact structure with high-resolution transmission electron microscopy (TEM), energy-dispersive spectroscopy (EDS) and Kelvin probe force microscopy (KPFM) in search of potential interfacial layers that may limit the device performance. TEM revealed that no additional layers (e.g., leftover residue, oxides...) were present at the interface between the device and metal electrodes, and the KPFM measurement also suggested an ohmic contact between the device and the metal electrode. This behaviour was confirmed by linear voltage-current curves and the before-mentioned linear-scaling behaviour.

In a publication currently under review by Nature Communications we investigate how the electronic domain structure in a CCM device behaves microscopically under an applied electrical current using a multi-tip scanning tunnelling microscope. We follow the evolution and annihilation of non-trivial topological defects in the form of dislocations and reveal how

Figure 4: Analysis of the CCM device's contact structure. On the left is a TEM image of the interface between the device and the metal electrode, and on the right is an EDS analysis of the same cross-section with identified individual layers.

the injected charge becomes fractionalised and distributed along the intricate domain-wall network. We find that the dislocations are stable at low currents, but at higher currents they show pairwise annihilation, which also correlates to the macroscopic change of the sample's electrical resistance. Using detail device modelling we also show that the observed switching is non-thermal.

Theoretical studies on the nanoscale

Metastable states appear in many areas of physics as a result of symmetry-breaking phase transitions. An important challenge is to understand the microscopic mechanisms which lead to the formation of the energy barrier separating a metastable state from the ground state. In a paper we describe an experimental example of the hidden metastable domain state in $1T-TaS_2$, created by photoexcitation or carrier injection. The system is an example of a charge density wave superlattice in the Wigner-crystal limit displaying discommensurations and domain formation when additional charge is injected either through contacts or with photoexcitation. The domain walls and their crossings in particular display interesting, topologically entangled structures which have a crucial role in the metastability of the system. We model the properties of experimentally observed thermally activated dynamics of topologically protected defects – dislocations – whose annihilation dynamics can be observed experimentally with scanning tunnelling microscopy as the emergent phenomena indicated by a doped Wigner crystal. Different dynamics of trivial and non-trivial topological defects are quite striking. Trivial defects appear to become annihilated quite rapidly at low temperatures on the timescale of experiments, while non-trivial defects are annihilated rarely, if at all. The results of this theory were published in **Symmetry** 14, 926 (2022).

We perform ab-initio calculations of a heterostructure based on the ferroelectric phase of barium titanate and dielectrics lanthanum manganese (LaMnO3) or silicon (Si). We analysed the structures of BaTiO3/LaMnO3 and BaTiO3/Si interfaces, investigated the magnetic properties and impact of ferroelectric polarization. The use of ferroelectric polarization in a heterostructure plays a crucial role; in particular, ferroelectric polarization leads to the formation of a conducting state at the interface and in the layers close to it. We showed that the defects (here, oxygen vacancies) incorporated into a system may change electronic and magnetic properties of the system. The results were published in **Materials** 15, 23, pp. 1–11, (2022).

An analytic theory of the spectral function of electrons coupled with phonons is formulated in the adiabatic limit. In the case when the chemical potential is large and negative the ground state does not have the adiabatic deformation and the spectral function is defined by the standard perturbation theory. In this limit, we use the diagram technique in order to formulate an integral equation for the renormalized vertex. The spectral function is evaluated by solving Dyson's equation for the self-energy with the renormalized vertex. The moments of the spectral function satisfy the exact sum rules up to the 7th moment. In the case when the chemical potential is pinned at the polaron binding energy the spectral function is defined by the ground state with a nonzero adiabatic deformation. We calculate the spectral function with the finite polaron density in the adiabatic limit. Contrary to the case of zero polaron density the spectral function with the finite polaron concentration shows some contributions which are characteristic for polarons. The results are published in the **Journal of Physics Communications** 6, 115002 (2022).
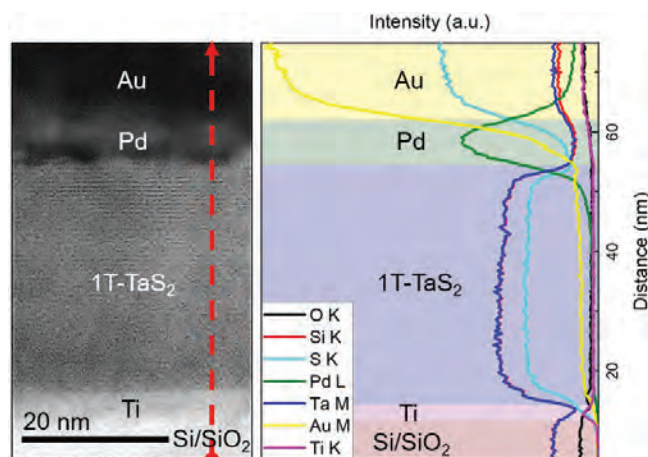
Nanomaterials

We contributed to the measurements and analyses of photoluminescence and extinction spectra of the tungsten suboxide quasi-2D nanoplatelets (W_nO_{3n-1}) and nanowires (W_5O_{14}, $W_{18}O_{49}$) and the analyses of their electronic properties, specifically the surface plasmon resonances and excitonic transitions in relation to the shape and structure of nanocrystals. (Collaboration with the Department of Condensed Matter Physics, IJS, and the Institute of Physics, University of Belgrade); (**Nanotechnology** 33, 275705, 2022).

Ultrasonic photoacoustic emitting of a graphene-nanocomposite film onto a flexible substrate

Researchers from the Jožef Stefan Institute and researchers from the LASTEH laboratory (Laboratory for Laser Technology) from the Faculty of Mechanical Engineering of the University of Ljubljana have prepared, based on their patent-protected process, optoacoustic lenses, using a graphene/PDMS composite, for photoacoustic ultrasound generation. They investigated in detail the photoacoustic response of the film when irradiated with a nanosecond pulsed laser, for different graphene concentrations and thicknesses. They showed that the amplitude of a time-limited ultrasound wave is linearly dependent on the laser power. They recorded the formation of cavitation microbubbles in water and agar, which otherwise serves to simulate tissue. The paper on this topic explains some fundamental properties of the photoacoustic ultrasound generation, as well as the photoacoustic parameters of a graphene-based composite, which are important for the preparation of photoacoustic lenses. Possible uses of this flexible photoacoustic composite in various biomedical and biochemical applications are discussed. The paper was published in the journal **Photoacoustics**.
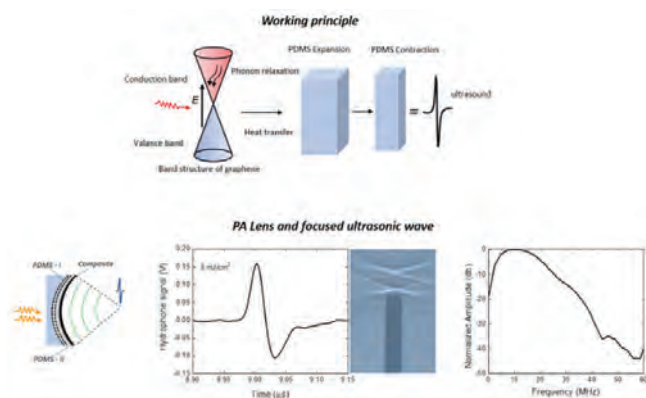

Figure 5: PA lens and a focused ultrasonic wave

Soft matter

We investigated the mechanisms of a guanosine wire (G-wire) formation in the guanosine-rich DNA sequence d(G2AG4AG2) and its variations with different loop residues. A combination of different complementary experimental methods (DLS, AFM, NMR, etc.) provided an important insight into the behaviour of these nanostructures at the molecular level. We found that the crucial step of the revealed sophisticated self-assembly mechanism includes a structural rearrangement of a kinetically favoured G-quadruplex building block into a thermodynamically preferred one. We showed that the properties of the resulting G-wires, i.e., their length and thermal stability, can be tailored by changing the type and, therefore, the features of loop residues. Unravelling details of this mechanism enables the regulation of the G-wire self-assembly process. The work was reported in **Nature Communications** 13, art. 1062 (2022).

A large part of our research activities in 2022 was focused on tunable optical properties of liquid-crystalline materials. In cooperation with researchers from the Nankai University in China we investigated the influence of quantum dots on the photoluminescence properties of a cholesteric liquid crystal (**Liquid Crystals** 49, 2095 (2022)). We also continued with the collaborative investigations of the tuneable optical diffractive structures from liquid crystalline materials incorporated into periodic polymeric scaffolds. In cooperation with the University of Belgrade we studied optical illumination-induced structural transitions in bent-core liquid crystals with an azocinnamic acid scaffold (**Journal of Molecular Liquids** 366, 120182 (2022)). We started investigations of the light-induced dynamics of liquid-crystalline droplets on the surface of iron-doped lithium niobate photorefractive crystals.

In collaboration with researchers from the East Bavarian Technical High School (OTH) in Regensburg and the Faculty of Mechanical Engineering of the University of Ljubljana we continued the exploration of various aspects of magnetically regulable surface properties of magneto-active elastomers (MAEs). MAEs are composite materials comprised from magnetic microparticles embedded in a soft elastomer matrix. We demonstrated that laser micromachining of MAEs can be used to fabricate surface micropatterns of various sizes and shapes (**Advanced Materials Technologies** 7, 2101045 (2022)). We also showed that lamellar surface microstructures fabricated with this method can be used for switchable wettability (**Polymers** 14, 3883 (2022)).

We continued the investigations of polar, i.e., ferromagnetic and ferroelectric nematic liquids. We studied the dynamics of the magnetic domain formation in a ferromagnetic liquid. We optimized a material which allows a reproducible and controllable analysis of domain structures and their formation dynamics, with the domains forming on a time scale of the order of seconds (**Journal of Molecular Liquids** 366, 120308 (2022)). In collaboration with researchers from TU Braunschweig and Otto von Guericke University, Magdeburg, Germany, we studied magnetic dynamics in suspensions of ferrimagnetic platelets. We explored the magnetic dynamics in suspension in the range of the isotropic and nematic phases using magnetic AC susceptometry and torsional balance. We demonstrated that

even in a low-concentration isotropic regime, a simple Debye-type mechanism cannot describe the dynamics. Clustering of the particles results in low-frequency contributions (**Journal of Molecular Liquids** 360, 119484 (2022)). In collaboration with researchers from the Faculty of Chemistry and Chemical Technology, University of Ljubljana, we contributed to the understanding of amino-functionalization of magnetic nanoplatelets with silanes and phosphonates (**Nanomaterials** 12, 2123 (2022)) and in collaboration with researchers from the Faculty of Electrical Engineering and Computer Science, University in Maribor, we developed a miniature magneto-optic angular position sensor (**Optics Letters** 47, 4696 (2022)).

Editors of Physical Review E invited us to write a perspective article on ferroelectric liquid crystals, in which we gave an overview of this emerging field by linking history and theoretical predictions to a general outlook of the development and properties of the materials exhibiting ferroelectric nematic phases. We highlighted the most relevant observations to date, e.g., giant dielectric permittivity values, polarization values of an order of magnitude larger than in classical ferroelectric liquid crystals, and non-linear optical coefficients comparable with several ferroelectric solid materials. The key observations of anchoring and electro-optic behaviour were also examined. The collected contributions led to the final discussion on open challenges in materials development, theoretical description, experimental explorations and possible applications of ferroelectric phases (**Physical Review E** 106, 021001 (2022)).

Figure 6: DNA sequence d(G4C2) self-assembles into quadruplex structures which form liquid crystalline phases in concentrated solutions: a chiral nematic phase (upper part of the image) and a columnar hexagonal phase (lower part of the image).

Biomedical optics

We continued with the development of innovative applications based on our unique optical technique for non-invasive characterization of the human skin *in vivo*. By combining diffuse reflectance spectroscopy and pulsed photo-thermal radiometry with a dedicated numerical model of light transport in strongly scattering multi-layer structures, we can assess several physiologically relevant parameters of the human skin (*e.g.*, the contents

Figure 7: Photographs of bruised human skin at different times after the injury

of melanin and blood, together with its oxygen saturation level in different skin layers). The values obtained with longitudinal monitoring of traumatic bruises in human volunteers were successfully matched with a dedicated mathematical description of bruise evolution and healing. Such technology could enable the development of a more accurate bruise ageing methodology for forensic investigations. (Collaboration with the Faculty of Mathematics and Physics, UL) (**Doctoral thesis, FMF UL**, 2022)

Our innovative technique for optical characterization of bruises on the human skin and the mathematical model of their evolution could enable development of a methodology for an objective assessment of the time of injury, which would benefit forensic investigations.

We participated in a study which demonstrated three-dimensional localization and tracking of biological cells at depths well beyond the optical transport length. This was achieved by exploring the unique spectral features of spherical optical microcavities that are not affected by tissue scattering, absorption or autofluorescence. The same microcavities were functionalized also for remote sensing of their environment in terms of temperature or pH value, which extends their versatility beyond the capabilities of customary fluorescent labels. (collaboration with the Department of Condensed Matter Physics, the IJS; Faculty of Mathematics and Physics, UL; and the Institute of Solid State Physics, Graz University of Technology) (**Nature Communications** 13, 1269-1-10, 2022)

We studied upconversion fluorescence in inorganic nanoparticles, such as $NaYF_4$:Yb^{3+}, Er^{3+}, which have a great potential for application in

Figure 8: Optically assessed values of the blood volume contents in the papillary and reticular dermis as well as bilirubin concentration at the above time points, matched with a dynamical model of bruise evolution and healing (lines)

diagnostic imaging in biomedicine. We focused on the role of phosphonate coatings, which improve their chemical stability under physiological conditions and thus minimize cytotoxicity, but also affect the efficiency of upconversion fluorescence. (collaboration with the Department for Materials Synthesis and Department of Inorganic Chemistry and Technology, the IJS; the Institute of Pharmacology and Experimental Toxicology, Faculty of Medicine, UL; and the Institute of Macromolecular Chemistry, Czech Academy of Sciences) (**Methods Appl. Fluoresc.** 10, 014001, 2022)
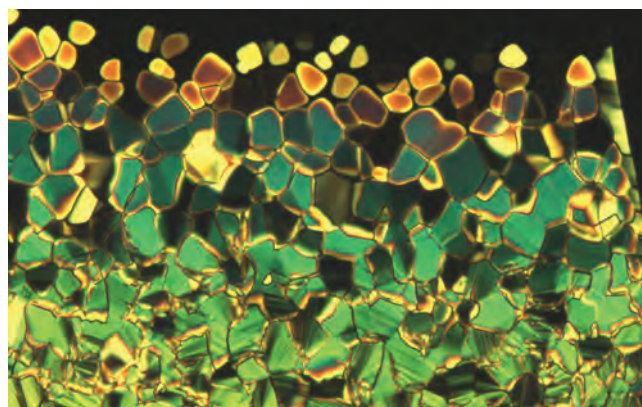
Figure 9: Upconversion fluorescence spectra of nanocrystals NaYF4:Yb3+,Tm3+ under excitation with 976 nm light: as-synthesised in chloroform, and bare vs. polymer-coated in water suspensions. The labels indicate the most relevant electronic transitions within the Tm3+ ions. (Acta Chim. Slov. 2022, 69, 448–457)

We revisited the issue of a single-beam substitution error, a common artifact in the measurements of diffuse reflectance using integrating spheres (IS). We have shown that the expression for its removal proposed earlier can be inaccurate. However, accounting for the spectral variation of the reflectance of the IS inner surface removed this second-order error. In a related study, based on Monte Carlo modelling of light transport in a multiple scattering regime, we determined the previously unreported absorption and scattering properties of Spectralon (the most common white-standard material for diffuse reflectance measurements using the IS) in the visible spectral range. (**Proc. SPIE** 12147, 121470L, 2022; **Proc. SPIE** 12147, 1214704, 2022)

Confined colloidal systems and microfluidics

Research on colloidal systems in confined geometries, such as microfluidic chambers or 2D surfaces, was carried out in close collaboration with the Laboratory for Experimental Soft Matter at the Faculty of Mathematics and Physics, University of Ljubljana, and more recently also with industrial pharmaceutical partners.

In collaboration with the Northwestern University and Argonne National Laboratory, USA, we continued our research on microfluidics by studying collective dynamics of active particles. We have shown that a confined droplet enclosing motile Quincke rollers, whose movement is controlled by an external electric field, exhibits strong shape fluctuations, while the rollers self-organise into vortices, depending on the particle activity. The results were published in **Comm. Phys.** 5, 91 (2022).

In collaboration with pharmaceutical company Lek (part of Novartis), we studied the dynamics, adsorption and aggregation of particles in liquids and at their phase boundaries.

Brewster angle microscopy was used for the real-time observation of thin layers of monoclonal antibodies on an air-water interface. Protein films were disrupted during the experiment by puncturing them with a microscopic needle, and the subsequent reconstitution of a film was observed as a function of the protein concentration and the surfactants added. We have shown that the characteristic film recovery times are much shorter than a second at typical concentrations, which is important for the production and transport of biological drugs. The experimental observations were corroborated by a numerical Comsol model, which successfully predicted the surface film reconstruction, and the results were published in **Colloids and Surfaces** B 218, 112757 (2022).

We also collaborated with the Department of Biotechnology (B3) to study the dynamics of stress granules. These are cytoplasmic organelles that appear after a cell exposure to stressful conditions and allow the cell to survive. We have shown that optical tweezers are suitable for studying the mobility of lipid droplets, which are used as a model for membraneless organelles, and measure the mobility as a function of external parameters. In addition, we developed and valida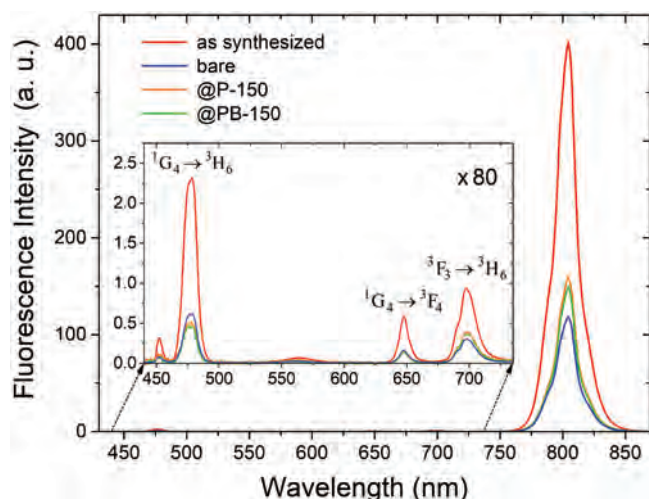ted a new method for the determination of viscoelastic properties of surface films based on a magnetic needle rheometer. The work was included in a successfully defended master's thesis at the FMF.

We studied collective dynamics of active particles in a droplet and observed the droplet displacement and shape fluctuations as a function of the particle activity.

Some outstanding publications in the past year

1. Kavčič, Aljaž, Zorc, Maja, Marinčič, Matevž, Unger, Katrin, Coclite, Anna Maria, Majaron, Boris, Humar, Matjaž. Deep tissue localization and sensing using optical microcavity probes. *Nature Communications*. 2022, vol. 13, pp. 1269-1-10.

2. Višić, Bojana, Pirker, Luka, Opačić, Marko, Milosavljević, Ana, Lazarević, Nenad, Majaron, Boris, Remškar, Maja. Influence of crystal structure and oxygen vacancies on optical properties of nanostructured multi-stoichiometric tungsten suboxides. *Nanotechnology*. 2022, vol. 33, pp. 275705-1-11.

3. Sebastián, Nerea, Čopič, Martin, Mertelj, Alenka. Ferroelectric nematic liquid-crystalline phases. *Physical Review E*. 2022, vol. 106, no. 2, pp. 021001-1-021001-27.

4. Pavc, Daša, Sebastián, Nerea, Spindler, Lea, Drevenšek Olenik, Irena, Koderman Podboršek, Gorazd, Plavec, Janez, Šket, Primož. Understanding self-assembly at molecular level enables controlled design of DNA G-wires of different properties. *Nature Communications*. Feb. 2022, vol. 13, 11 pp, 1062.

5. Kravanja, Gaia, Belyaeva, Inna A., Hribar, Luka, Drevenšek Olenik, Irena, Shamonin, Mikhail, Jezeršek, Matija. Laser micromachining of magnetoactive elastomers as enabling technology for magnetoresponsive surfaces. *Advanced Materials Technologies*. May 2022, vol. 7, art. no. 2101045, 8 pp.

6. Gak Simić, Kristina, Rybak, Paulina, Pociecha, Damian, Cmok, Luka, Drevenšek Olenik, Irena, Tóth-Katona, Tibor, Trišović, Nemanja. Introducing the azocinnamic acid scaffold into bent-core liquid crystal design: a structure–property relationship study. *Journal of Molecular Liquids* [Print. ed.]. Nov. 2022, vol. 366, art. no. 120182, 7 pp.

7. Venturini Rok, Mraz Anže, Vaskivskyi Igor, Vaskivskyi Yevhenii, Svetin Damjan, Mertelj Tomaž, Pavlovič Leon, Trivedi Sudhir B., Sobolewski Roman, Mihailović Dragan. Ultraefficient resistance switching between charge ordered phases in 1T–TaS2 with a single picosecond electrical pulse. *Applied Physics Letters* [Electronic ed.]. ISSN 1077-3118. 2022, vol. 120, iss. 25, art. no. 253510, pp. 253510-1-253510-6.

8. Venturini Rok, Mraz Anže, Vaskivskyi Igor, Svetin Damjan, Sever Vitomir, Mihailović Ian, Ambrožič Bojan, Dražić Goran, Kazaziz Dimitrios, Ravnik Jan, Ekinci Yasin, Mihailović Dragan. Charge configuration memory devices: energy efficiency and switching speed. *Nano Letters* [Electronic ed.]. ISSN 1530-6992. 2022, vol. 22, no. 12, pp. 4814-4821.

Patent granted

1. Marko Kazič, Nejc Lukač, Blaž Tašič Muc, Matjaž Lukač, Micro-pulsed liquid spray for cooling, US11490945 (B2), US Patent Office, 08. 11. 2022.

INTERNATIONAL PROJECTS

1. COST CA17123; MAGNETOFON; Ultrafast Opto-Magneto-Electronics for Non-Dissipative Information Technology
Prof. Dragan Dragoljub Mihailović
Cost Association Aisbl

2. COST CA17140 - Nano2Clinic; Cancer Nanomedicine - From the Bench to the Bedside and COST Action 2nd CA17140 Training School (Institute of Oncology Research (IOR), Bellinzona, Switzerland), From 13 March 2023 to 14 March 2023
Prof. Boris Majaron
Cost Association Aisbl

3. COST CA20129; Multiscale Irradiation and Chemistry Driven Processes and Related Technologies
Asst. Prof. Lea Spindler
Cost Association Aisbl

4. COST-CA17123;COST-CA17123; Ultrafest opto-magneto-electronics for non-dissipative information technology – MAGNETOFON
Asst. Prof. Tomaž Mertelj
Cost Association Aisbl

5. H2020 - INTERFAST; Gated INTERfaces for FAST information processing
Asst. Prof. Tomaž Mertelj
European Commission

6. H2020 - MAGNELIQ; A Magneto-Electric Liquid - Better Sensing
Asst. Prof. Alenka Mertelj
European Commission

7. Studies of Structure and Dynamics of Liquid Magnets by SAXS and SANS
Asst. Prof. Alenka Mertelj
Slovenian Research Agency

8. Tunable Optical Diffractive Structures from Liquid Crystalline Materials
Prof. Irena Drevenšek Olenik
Slovenian Research Agency

9. Novel Liquid Crystalline Materials for Application in Diffractive Optical Elements
Prof. Irena Drevenšek Olenik
Slovenian Research Agency

10. Stretchable Lasers
Dr. Luka Cmok
Slovenian Research Agency

11. COST CA21144; Superconducting Nanodevices and Quantum Materials for Coherent Manipulation
Prof. Viktor Kabanov
Cost Association Aisbl

RESEARCH PROGRAMMES

1. Medical physics
Prof. Matija Milanič
2. Theory of the condensed matter and statistical physics
Prof. Svjetlana Fajfer
3. Theoretical physics of nuclei, particles and fields
Prof. Svjetlana Fajfer
4. Light and Matter
Prof. Irena Drevenšek Olenik
5. Nonequilibrium Quantum System Dynamics
Prof. Dragan Dragoljub Mihailović
6. Physics of quantum technologies
Prof. Dragan Dragoljub Mihailović

R & D GRANTS AND CONTRACTS

1. Methods and materials for photoalignment templates for chiral liquid crystal lenses and photonic components
Prof. Irena Drevenšek Olenik
2. Stabilization and destabilisation of spin liquids by perturbations
Prof. Andrej Zorko
3. Multi-scale modeling of non-equilibrium quantum materials
Dr. Denis Golež
4. Liquid Magnets: fundamental studies of ferromagnetic order in liquids
Dr. Nerea Sebastian Ugarteche
5. Surface-selective hybridization technology for magneto-electric hybrids
Asst. Prof. Alenka Mertelj
6. Controllable broadband electromagnetic-radiation shielding
Dr. Matej Pregelj
7. Magneto Responsive Surfaces for Manipulation of Light and Liquids
Prof. Irena Drevenšek Olenik
8. Exploitation of the magneto-mechanical effect in the treatment of neurodegenerative diseases
Asst. Prof. Alenka Mertelj
9. Single-flux-quantum controlled charge configurational memory (CCM) devices
Prof. Dragan Dragoljub Mihailović
10. CMEM: Ultrafast all-electronic charge density wave memory for next generation computing
Dr. Igor Vaskivskyi
Ministry of Education, Science and Sport

VISITORS FROM ABROAD

1. prof. dr. Valentin Alek Dediu, CNR-ISMN, Bologna, Italy, 10 March - 11 March 2023
2. mag. Dejan Bošnjaković, University of Osijek, 16 May – 20 May 2022
3. Luka Matović, Jelena Lađarević, University of Belgrade 25 September – 1 October 2022
4. mag. Dejan Bošnjaković, University of Osijek, 9 October – 13 October 2022
5. prof. dr. Georg Mehl, University of Hull, UK, 29 November – 3 December 2022
6. prof. dr. Martin Fally, University of Vienna, Faculty of Physics, 7 December – 10 December, 2022

STAFF

Researchers
1. Dr. Steven Daniel Conradson
2. Prof. Irena Drevenšek Olenik*
3. Dr. Denis Golež
4. Prof. Viktor Kabanov
5. Dr. Matjaž Lukač*
6. Prof. Boris Majaron
7. Asst. Prof. Alenka Mertelj
8. Asst. Prof. Tomaž Mertelj
9. **Prof. Dragan Dragoljub Mihailović, Head**
10. Asst. Prof. Matija Milanič*
11. Dr. Aleš Mrzel
12. Asst. Prof. Natan Osterman*
13. Dr. Nerea Sebastian Ugarteche
14. Asst. Prof. Lea Spindler*
15. Dr. Igor Vaskivskyi
16. Asst. Prof. Mojca Vilfan

Postdoctoral associates
17. Dr. Yelyzaveta Chernolevska
18. Dr. Luka Cmok
19. *Dr. Patricija Hribar Boštjančič, left 25.11.22*
20. Dr. Qing Hu
21. Dr. Gašper Kokot
22. Dr. Andrei Shumilin
23. Dr. Jaka Vodeb

Postgraduates
24. Neža Golmajer Zima, B. Sc.
25. Žiga Gregorin, B. Sc.
26. Gregor Jecl, B. Sc.
27. *Andrej Kranjec, B. Sc., left 01.02.22*
28. Matija Lovšin, B. Sc.
29. Anže Mraz, B. Sc.
30. *Dr. Mimoza Naseska, 01.10.22, transferred to Department F5*
31. *Ankita Sarkar, M. Sc., 01.03.22, transferred to Department K5*
32. Yevhenii Vaskivskyi, M. Sc.
33. Rok Venturini, B. Sc.

Technical officers
34. Davor Grabnar, B. Sc.
35. Peter Medle Rupnik, B. Sc.
36. Damjan Svetin, B. Sc.
37. Petra Šutar, B. Sc.
38. Damjan Vengust, B. Sc.

Technical and administrative staff
39. Ula Groznik, B. Sc.
40. Nataša Kutnjak
41. Barbara Paternoster, B. Sc.
42. Eva Trpin, B. Sc.

Note:
* part-time JSI member

DEPARTMENT OF REACTOR PHYSICS
F-8

During the past year we were working mainly on:
- ***theoretical, experimental and applied reactor physics***
- ***plasma physics***
- ***neutron-transport calculations in fusion reactors***
- ***medical physics***

Head:
Prof. Luka Snoj

In the field of **reactor physics**, research continued primarily in the development of new computational and experimental methods for the analysis of research and power fission and fusion nuclear reactors.

The main objective of the project launched in 2020, entitled Stability of Nuclear Reactors in Load-Follow Mode of Operation, is to study the constraints of the load-following operation of nuclear power plants on the nuclear aspects of the reactor core and nuclear fuel, and to provide the operator with effective solutions for optimising the plant's operation. Last year, radial temperature distribution analyses were performed. The results showed that the deviation for the initial fuel cycles was negligible compared to the measurements for the all-rods-out (ARO) condition. Additional analyses were performed to compare the coupled neutron and thermal-hydraulic models. A nonlinear two-point model of a pressurised water reactor with power control was developed in the Matlab Simulink environment, allowing a rough simulation of balancing the power generation profile by adjusting the power output of the nuclear power plant. The simulation results showed that well-controlled tracking of the reference power variation for power control via boric acid concentration and axial power drift control via the control rod position is possible. Updated nuclear data libraries have been created for the uncertainty sensitivity analysis and will be used in the propagation of uncertainties to reactor power variation simulations. Last year, a collaboration with the SANDY software development team was established, within which the development of the code for applying the package in the propagation of uncertainties from nuclear data to the results of power transient simulations was initiated. A review of uncertainty propagation methods was also undertaken, and pilot calculations were performed using one-at-a-time and simultaneous sampling methods.

In 2022, the project Design of Selective Catalytic Processes for the Conversion of CO_2 to Ethanol was launched. Within the project we study the effects of ionising neutron and gamma radiation on the decomposition of CO_2. Tests will be conducted in the extremely intense radiation field of the IJS TRIGA research reactor. Irradiations will be performed in the gamma ray and neutron field during operation and with gamma rays only after shutdown. Irradiations are performed at irradiation sites in and near the reactor core. The irradiations will be accurately modelled using Monte Carlo particle transport models. The design of the process/catalyst will be optimised for the fraction of the irradiation energy that leads to a stable decomposition of CO_2.

The objective of the research entitled Sensitivity of Nuclear Reactor Physical Parameters to Thermal Nuclear Data is to generate thermal neutron scattering cross-sections and the corresponding covariance data in a rigorous manner that is from first principles, by using state-of-the-art atomistic simulations based on the density functional theory in combination with lattice or molecular dynamics calculations. Within the project, atomistic simulations are performed for the generation of thermal scattering data. Communication channels have been established with the North Carolina State University, whose experts will provide the expertise that will lead to the successful launch of the project. Work on the project is proceeding according to the timetable set out in the project proposal. In 2022, data on the thermal scattering cross-section for the ZrH_2 material were generated. The data on the thermal scattering cross-section for the $ZrH_{1.5}$ material will also be produced. The calculations were compared with experimental values and other calculated values in several calculation steps to validate them. The results for both materials will be compared with other calculated data and tested with reference experiments that are sensitive to the ZrH material. In the future, covariance data will also be generated.

The objective of the proposed research entitled Advances in Thermal Scattering Law Analysis is to generate thermal neutron scattering cross-sections for the materials that have not yet been investigated, such as uranium hydride fuel, as well as conventional moderators, such as polyethylene, Lucite, Teflon, and graphite. In addition to the thermal neutron scattering cross-sections, the corresponding covariance data must also be determined. A method for generating thermal neutron scattering cross-sections in a form suitable for the Monte Carlo code from a predetermined density of states was developed and tested. The procedure was carried out with NJOY modules (LEAPR, RECONR, BROADR, THERMR and ACER modules). The data obtained are currently being validated with
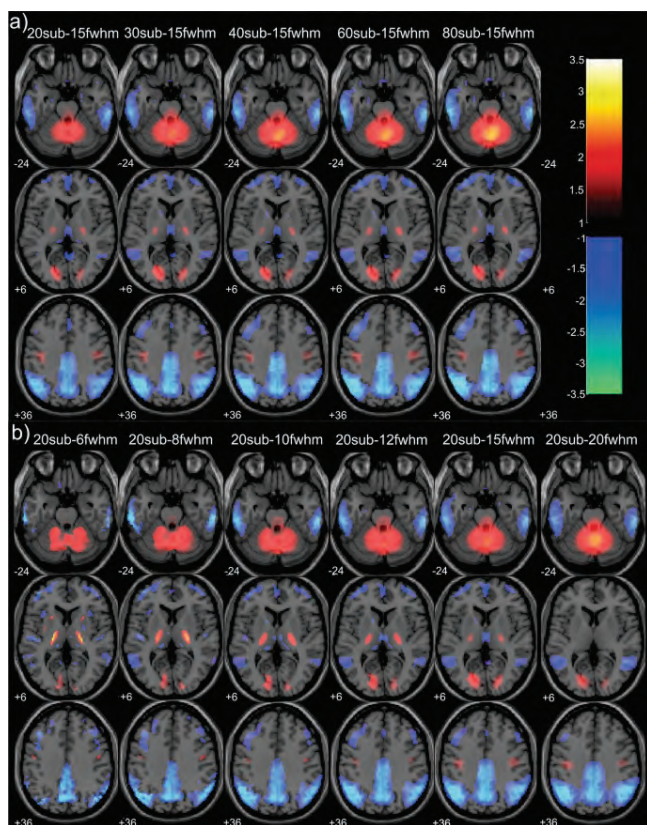
Figure 1: Alzheimer's disease-related patterns calculated from FDG-PET images for: a) different group sizes and b) different resolutions

experimental values. In 2022, thermal scattering cross-sections were created for the ZrH material used in many research reactors such as TRIGA. The thermal scattering cross-section for the ZrH material was created for two different phases, the delta phase for a ratio of 1.5 and the epsilon phase for a ratio of 2. We performed the basic calculations in several consecutive steps and compared the results of these calculations with experimental values and other calculated values. This was done to confirm the reliability and correctness of our calculations. The results for both materials will be further tested with reference experiments that are sensitive to the ZrH material.

The primary objective of the European TOURR project, launched in 2020, is to develop a strategy for Research Reactors in Europe and prepare the ground for its implementation. This strategic goal can be divided into specific goals: assessing the current status of the European RR fleet, including plans for upgrading; evaluation of urgent EU needs; developing tools for the optimal use of the RR fleet and rising awareness among decision makers of the (future) role of RRs. The JSI successfully completed the first work package in which we were responsible for collecting information on the status and plans of the European research reactor fleet. Last year, we worked with the consortium on work packages two and three, in which we developed a strategy for the optimised use of research reactors in Europe and developed a platform where research reactors and researchers can apply to facilitate their collaboration. The basis of all research work was to analyse the gaps in the use of European research reactors and to identify opportunities for improvement in the areas of scientific research, medical isotope production and education. In addition, we were involved in a strategy to disseminate the results to the target audience, where we presented the project's conclusions at three international conferences.

Researchers from the Reactor Physics Department continued to provide technical support for the safe operation of the Krško Nuclear Power Plant (NPP) in 2022. We performed independent core-design calculations for the fuel cycle 33 and the start-up tests for the new fuel cycle. An independent evaluation of the reload safety of the cycle 33 was performed. In addition, the expertise and computational support for the future dry storage of spent nuclear fuel were provided. The focus was on the sensitivity analysis of the main parameters for the characterization of spent fuel elements.

In the scope of collaboration with the International Atomic Energy Agency (IAEA), we participated in the CRP project Spent Fuel Characterization. We have completed a sensitivity analysis of the influence of irradiation parameters and the impact of different nuclear data libraries on the characterization of 16×16 fuel. We have started an analysis of the influence of 3D effects on fuel characterization and SKB-50 test case calculations.

In 2022, our team worked on the project Support for Implementation and Calculations in the SFDS Project, the primary objective of which is to support the Krško Nuclear Power Plant (NPP) in the design and implementation of a dry storage facility for spent fuel. In agreement with the NPP, analyses and improvements were carried out in 2022 to increase the accuracy of the spent fuel core and reduce the uncertainty of future core calculations. As part of the project, we have recently updated the core parameter calculation tools, allowing the codes to be compiled with modern compilers and simulations to run simultaneously in a Linux environment.

In the framework of the international project E-SiCure2 – Enhancing security at borders and ports, conducted as an international collaboration and funded by the NATO Science for Peace and Security programme, we initiated the development of silicon carbide (SiC) based detectors of multiple radiation types. The research activities are being carried out on the basis of the results of a previous project – E-SiCure (2016–2019). Their goal is the development of pixelized detectors that will enable simultaneous detection of thermal and fast neutrons, charged particles as well as X and gamma radiation. The project investigated new converter materials that would allow sensitivity to fast neutrons. We performed experimental measurements of the response of a SiC diode equipped with a potassium chloride (KCl) converter, as well as computational analyses to support the understanding of the experimental results.

In collaboration with the University of Lancaster we have proven that neutrons can be used for communication.

In 2022 we continued work in the framework of the European project EURAD, in WP3 CORI – cement-organic interactions between radionuclides and WP8 SFC – spent fuel characterization. In WP8 we performed several detailed calculations of the delayed heat, neutron and photon source in the fuel for PWR reactor fuel assemblies.

In 2022 we continued our collaboration efforts in the framework of the European project ENEEP – European Nuclear Experimental Educational Platform. The aim of the project is the establishment of a platform at the

European level, enabling experimental education activities in the field of nuclear science and engineering for students at all educational levels and young professionals. The project is being carried out as a collaboration with STU (Slovakia), CTU (Czech Republic), ATI (Austria) and BME (Hungary). In 2022, we organized demonstration training courses as part of the work package 7 (https://www.eneep.org/courses/previous-courses/), and the JSI was involved in three of them.

As part of our collaboration with the Laboratory of Instrumentation, Sensors and Dosimetry Laboratory of the French Commissariat for Atomic and Alternative Energies (CEA – Cadarache), we have continued our work in the framework of several bilateral ARRS-CEA research projects as well as projects in collaboration with industry.

We have investigated the possibility of using pulsed reactor operation for certain applications, such as testing nuclear instruments at extremely high neutron fluxes, i.e., up to 10^{16} n cm^{-2} s^{-1}, which can be achieved only when a reactor is in pulsed operation. This requires the ability to continuously measure the absolute neutron flux, which changes by 6–7 orders of magnitude within a few milliseconds. In 2022, we conducted a large-scale experimental campaign, in which 137 reactor pulses were generated. We measured the time dependence of the neutron flux and gamma-ray dose rates using:

- miniature fission cells and the MONACO measurement system developed at the CEA,
- miniature ionization chambers and the LIBERA current measurement device from the Slovenian manufacturer I-TECH d.o.o.,
- the Cherenkov reactor power meter developed at the JSI as part of Julian Peric's MSc dissertation and based on the RedPitaya module from I-TECH d.o.o.,
- the TRIGA reactor pulse instrumentation channel.

Activation foils of Al-0.1%Au, Al-1%Co and Ni were irradiated at three locations to determine the neutron fluence during the pulses.

As part of the ARRS-CEA bilateral project Reference Experiment for Validation of Modelling of the Response of Nuclear Instrumentation to Neutrons and Gamma Rays, two large-scale experimental campaigns were conducted in March and April 2022, in collaboration with CEA researchers. We measured activation rates for various nuclear reactions using activation foils and measured neutron and gamma ray fluxes using fission and ionisation chambers, and self-powered neutron and gamma ray detectors. We also measured neutron and gamma-ray dose rates using thermoluminescence dosimeters (TLDs). In addition to the experiments, most of the processing of the experimental data was performed in 2022, in parallel with the development of the computational models that will be used to compare the results with the measurements.

In 2022, the ARRS-CEA project New Nuclear Reactions with Inelastic Scattering for Epithermal Dosimetry continued. The first goal of the project, the search for suitable (n, n') type reactions for the irradiation in the TRIGA reactor of the IJS, was completed. The second goal, irradiation of standard and activation materials via (n, n') reactions in the TRIGA reactor, was planned for 2023. The third goal, a comparison of the results of the calculations and measurements, was planned for the end of 2022 or 2023.

Figure 2: Comparison of the 3D reactor power distributions between fresh fuel and burnt fuel at 15.4 MWd/kg. The absolute comparison between fresh fuel and power distribution is shown in the lower left-hand figure and the relative comparison of the fission source distribution with Serpent is shown in the lower right-hand figure.

The CEA is collaborating with the Slovenian company I-TECH d.o.o. to develop a commercial version of the MONACO data acquisition system for neutron flux measurements with fission chambers in nuclear reactors, such as the future Jules Horowitz reactor being built at CEA's Cadarache centre in southern France. In 2022 we carried out an experimental campaign for the CEA at the TRIGA reactor, testing and validating the MONACO system.

As part of the EURO-LABS project, we have performed calculations for a potential irradiation device aimed at reducing the low-energy component of neutrons that causes radioactivity in the materials used in integrated circuits, but does not contribute significantly to radiation damage in the silicon itself. In our calculations, we have assumed the use of cadmium (Cd), which absorbs thermal neutrons, in the tangential irradiation channel of IJS's TRIGA reactor, currently intended for irradiation of chips and integrated circuits. This channel is lined with a 1.4 mm thick Cd sheet tube liner. We have computationally investigated the effect of the length of the tube lining. It turns out that such linings reduce the damage to silicon by 4–5%, while the activity of the most common materials in integrated circuits is reduced by 10%, to two orders of magnitude, at the expense of a reduction in the fraction of thermal neutrons, which depends on the materials themselves.
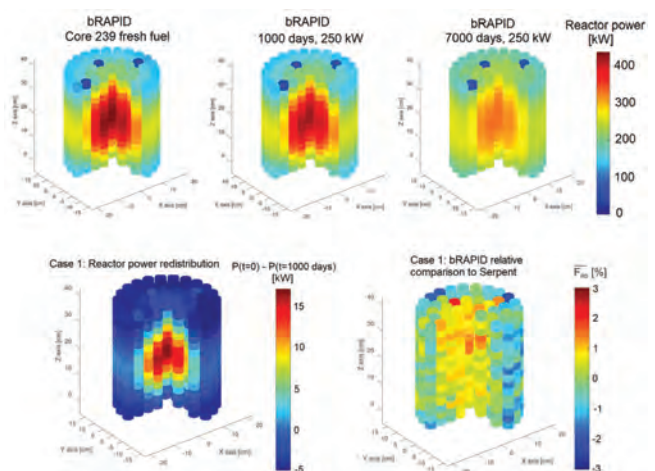
On the topic of using nuclear radiation as a catalyst for chemical processes, we have reviewed the literature and the physical processes involved when ionising radiation affects chemical reactions. In the literature, linear energy transfer (LET), which indicates the average energy deposited per unit of distance travelled, is observed to allow us evaluate the effectiveness of radiation in accelerating chemical reactions. It has been found that radiation with the same LET can excite different reactions. Therefore, we have proposed a new metric, the average distance between reactions and the average energy deposited per reaction, as a function of the incident energy of the particle. We have also studied the effects of adding materials that convert one type of radiation to another, usually radiation that interacts very infrequently, e.g., neutral particles such as neutrons and gamma rays into charged particles of ionising radiation such as electrons, alpha rays, beta rays, etc.

In 2022, as part of the IAEA-funded Activation Measurements with Neutron Filters project, validating dosimetry data, we performed a series of Monte Carlo particle transport calculations to determine experimental conditions in specific irradiation channels in the TRIGA reactor and support the design of the enriched boron carbide neutron filters that we plan to use in the campaign.

Figure 3: Nuclear heating in the plasma divertor of the future DEMO fusion power plant. Detailed knowledge of the energy distribution of neutron and gamma ray deposition is important for the design of the cooling system that will provide suitable temperatures throughout the confiner.

In 2022 we continued our participation in the European SANDA project. The JSI is involved in several areas, such as the development and use of software for the sensitivity and uncertainty analysis, the recalculation of reference experiments and the use of both to validate and improve nuclear data.

2022 was an important year for the **Laboratory of Plasma Physics** as we continued our FP9 projects within the EUROfusion consortium. We were successfully involved in experimental campaigns at the MST and JET tokamaks. We were also active in the field of simulations and development of simulation models of filament transport within the RT15 research task. The research focused on the effects of the recirculation of deuterium from the divertor and the walls of the reactor vessel and the effects of the size of the filaments. The computing time of the Marconi HPC supercomputer was used for the simulations, and work was continued in 2022. In addition to developing a coupled particle model and a simple thermal model of the monoblock in the divertor, we successfully verified and validated our analytical model of the inverted sheath arising from high thermionic emission. The validation was performed with a particle code that revealed some new physical properties, but also some shortcomings of the particle calculation method/code we used, which we plan to address in the future. We have also continued our work on two development tasks for a DEMO reactor, namely the development of kinetic and gyrokinetic codes and the development of divertor models. In the first task, we are involved in the development of boundary conditions for gyrokinetic codes, and in the second task, we are involved in the modelling of a divertor plasma in the DEMO reactor, the results of which will improve our understanding of the phenomena in this type of plasma and our ability to predict the behaviour of plasmas in this type of low-temperature divertor.

In the field of **calculating neutron transport in fusion reactors**, we have expanded and continued our work and collaboration within the EUROfusion projects and other collaborations for DEMO, IFMIF-DONES, JET and FNG fusion devices.

We have continued our work on the project for the design of the future fusion power plant DEMO in the field of neutronic calculations, activation, delayed heat and dose rate calculations. Our task is to calculate the activation and delayed heat in divertor components for different times after reactor shutdown. The irradiation scenario consists of about 5 years of continuous irradiation followed by several reactor pulses, at a fusion power of 2 GW. We are also involved in the review of the DEMO safety report with the aim of providing as many long-term recommendations as possible. Our group focuses on the conventional hazard analysis and quantification of radiation sources. We were also involved in the integration process of a plasma confinement system (limiter), where we calculated the nuclear heating, material damage and helium production in different components of the system, and the results were provided as input data for other analyses, e.g., the component cooling analysis.

In 2022 we continued our work on the project Machine Learning-Based Optimization of Fusion Reactor Neutronics Performance. The work included parametrisation of simpler models of tokamak that can be used in combination with optimisation algorithms. We also started to look for suitable optimisation algorithms for use with these models based on genetic algorithms.

In 2022 we started our participation in the EUROfusion WPENS (Work Package Early Neutron Source) project, which is dedicated to analyses in support of IFMIF-DONES, a device that will produce large amounts of neutrons with fusion-relevant energies based on the D+Li reaction. In 2022 we performed analyses of the uncertainties of
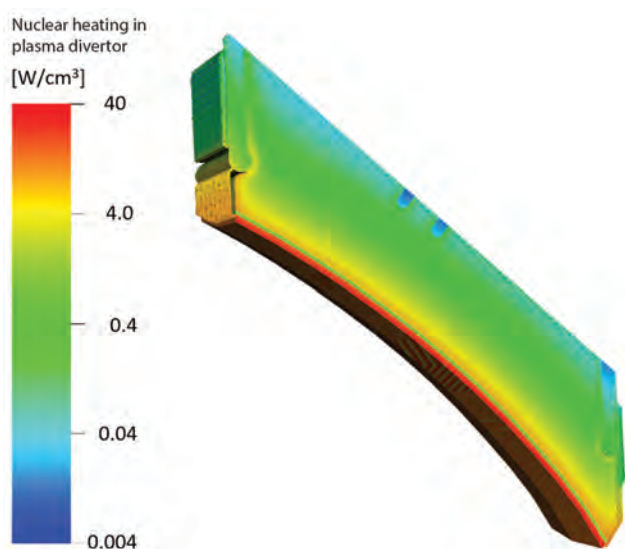
the calculated material damage due to uncertainties in the nuclear data, calculated the dose rates in the vicinity of the building where IFMIF-DONES is located, due to direct radiation and the sky-shine effect, and modelled the LIPAc accelerator, which is operating in Japan and testing the technologies we need for IFMIF-DONES.

In 2022 the F8 team, in collaboration with colleagues from multiple European institutes/laboratories/universities, analysed results from experimental work on the Joint European Torus – JET tokamak, currently the largest operational fusion reactor. The majority of our work was dedicated to calculations of the neutron field in various parts of the tokamak and comparisons of these values with experimentally obtained values. We simulated detector responses for various plasma sources (DD, DT, TT) and evaluated the possibility of experimentally determining the neutron spectrum of the TT plasma source. The main results were the calculations of the activation of the samples in JET for the tritium (TT) experimental campaign carried out in 2020–21, the comparison with the measurements at the Long Term Irradiation Station (O-LTIS) and the KN2 positions intended for the activation foils. We also simulated the detector response for different plasmas (DD, DT, TT) to prepare the irradiations for the final JET tritium plasma campaign in 2023. In 2022 the F8 team also completed the development of a calculation method for the source and transport of gamma rays in the JET tokamak to support the measurements as gamma ray measurements can complement neutron power measurements in the tokamak.

Within the EUROfusion framework we continued an international collaboration in the field of fusion, which started more than 20 years ago, specifically on 21–22 March 2000 when Slovenia joined the European fusion program. In 2022 we continued the development of a method for calculating the sensitivity of integral parameters to changes in nuclear data using the simultaneous sampling method and revealed the results at the M&C conference in Canada. We performed an analysis of the impact of the new nuclear data from the JEFF-4T test library for nuclides whose data were taken from the TENDL library to simulate fusion-relevant experiments. The results were presented at the ISFNT23 conference and an article on this topic is currently under review for publication in a special issue of the journal Fusion Engineering and Design. We have also continued our work on water activation in the TRIGA reactor, which is relevant to fusion.

In 2022 we also started the computational analysis of the sensitivity and uncertainty of the measured neutron reaction rates performed in the Water Cooled Lithium Lead (WCLL) reference experiment at the 14 MeV FNG neutron source facility in Frascati, Italy. The experiment consists of lead blocks containing dosimeters. These blocks have their own dimensional tolerances, estimated to be 1–2 mm. Initially, the sensitivities were estimated using deterministic neutron transport methods by calculating the so-called contribution field, which indicates which parts of the geometry have the greatest influence on the final results. Subsequently, a Monte Carlo method for particle transport was applied to calculate the reaction rates in the dosimeters inside the lead blocks, whose positions in all three directions were randomly sampled, having a normal distribution and a standard deviation of 2 mm. From the results, we extracted the measurement uncertainties and derived a first-order sensitivity equation.

We participated in the work of the Fusion Technology program group, which started in January 2019. This program group includes leading Slovenian experts in the field of fusion technologies and plasma physics from four departments of the Jožef Stefan Institute and two faculties of the University of Ljubljana. Four of thirteen researches in this group come from the F8 department.

In 2022 we actively participated in the JET3-NEXP streaming benchmark experiment. We continued the analysis of the experiments to determine the neutron streaming performed using thermoluminescent detectors and activation foils. The simulations of the neutron fluence and reaction rates were conducted using hybrid (deterministic/Monte Carlo) transport codes for several experimental locations positioned in the tokamak building. In 2022 we evaluated the measurements of the experimental campaign, during which the JET tokamak was operated with tritium plasma (TT) and made a comparison between measurements and calculations. The latter was particularly demanding due to a very low neutron flux at some of the detector locations and a complex geometry of JET. The results show that the discrepancy between the measurements and calculations is significant, reaching a factor of up to 3 for some of the detector locations. This discrepancy is not related to the statistical error of the calculations, which was small, but mainly to the complex geometry of the JET vacuum vessel surroundings, indicating that the modelling of this largest operating fusion reactor – the tokamak – is demanding.

In 2022, in the field of **medical physics**, specifically in the field of biomedical optics, we introduced a new optical coherence tomography imaging technique into the group workflow, which enables three-dimensional imaging of screening samples, using coherent light with a wavelength of around 1300 nm. The technique enables observing the morphology of samples and contrasts based on the movement of tissue components as well as determining the optical properties of samples. We continued international cooperation with the University of Rijeka, researching the use of machine learning methods for the analysis of hyperspectral images. With colleagues from the University of Bologna, we tested the developed system for infrared FTIR spectroscopy and made the necessary improvements. We have established cooperation with the Vanderbildt University in Nashville, Tennessee, USA, in the field of optical coherence tomography.

In 2022 the group's work in the field of hyperspectral microscopy was upgraded with the project Order Models for Optical Microscopy of Biological Tissues. The goal of the project is to develop new models that describe the organization of various healthy and diseased tissues. To achieve this, the work will involve the development and application of hyperspectral microscopy, colour microscopy and polarization-sensitive microscopy to create a database of images of various tissues. In 2022, as part of the project, we started capturing hyperspectral data and preparing the computational code for an analysis in Fourier space.

In addition, we continued our research in the field of positron emission tomography (PET) images. We focused on the use of FDG-PET imaging in neurology, in the differential diagnosis of neurodegenerative diseases. We resolved two issues, namely which FDG-PET images can be used for a network analysis and how many images are needed for a useful model. In our research, we found that for a successful differential diagnosis, it is necessary to use a sufficient number of reference images (at least 30 patients and 30 healthy controls). We also found that these images can have a relatively poor resolution (about 12–15 mm FWHM). The results were published in the scientific journal EJNMMI Research.

In 2022, F8 associates were involved in the RAPTOR project (Real-time adaptive particle therapy, https://raptor-consortium.com), aimed at introducing adaptive hadron therapy into the clinical environment. Within a project financed by the European Commission through the European Training Network, ETN under the Marie Skodlowska-Curie framework, we are examining algorithms used for transferring structure markings from computed tomography (CT) planning images onto anatomy images, investigating the role of artificial intelligence and the impact on therapy planning.

As in previous periods, we continued our close international cooperation with the University of Wisconsin, USA. Close cooperation continued through regular international research meetings, participation in internal reviews of articles, etc.

Some outstanding publications in the past year

1. Stergar, Jošt, Lakota, Katja, Perše, Martina, Tomšič, Matija, Milanič, Matija. Hyperspectral evaluation of vasculature in induced peritonitis mouse models. Biomedical optics express. 2022, vol. 13, no. 6, pp. 3461–3475, ISSN 2156-7085. DOI: 10.1364/BOE.460288.

2. Košťál, Michal, Evžen Losa, Stanislav Simakov, Martin Schulc, Jan Šimon, Vojtech Rypar, Martin Mareček, Trkov, Andrej, et al. Impact of reactor neutron spectrum on measured spectrum averaged cross sections. Annals of Nuclear Energy 2022, vol. 179, 109418.

3. Ćalić, Dušan, Kromar, Marjan. Spent fuel characterization analysis using various nuclear data libraries. Nuclear Engineering and Technology. 2022, vol. 54, issue 9, pp. 3260–3271. ISSN 1738-5733. DOI: 10.1016/j.net.2022.04.009.

4. Žohar, Andrej, Nocente, Massimo, Kos, Bor, Štancar, Žiga, Rebai, M., Rigamonti, S.D., Craciunescu, T., Gorelenkova, M., Kazakov, Y. O., Kiptily, V., Lengar, Igor, Čufar, Aljaž, Kodeli, Ivan Aleksander, Snoj, Luka, et al. Validation of realistic Monte Carlo plasma gamma-ray source on JET discharges. Nuclear Fusion. 2022, vol. 62, no. 6, 11 pp. ISSN 0029-5515. DOI: 10.1088/1741-4326/ac50c0.

Awards and Appointments

1. Domen Kotnik: Young Author Award, Portorož, 31st International Conference Nuclear Energy for New Europe – NENE 2022, September 2022, for the paper Analysis of water activation loop at the JSI TRIGA research reactor, co-authored by Anil Kumar Basavaraj and Igor Lengar

Organization of conferences, congresses and meetings

1. Participation at the KONFOR 2022 conference, Terme Čatež, Čatež ob Savi, Slovenia, 11 November 2022, dr Igor Lengar as a co-organizer and member of the Organizing Committee

INTERNATIONAL PROJECTS

1. Irradiation Services for the Rolls-Royce Civil Nuclear SAS Company
   Dr. Vladimir Radulović
   Rolls-Royce Civil Nuclear Sas
2. E-SiCure2 - Enhancing Security at Borders and Ports
   Prof. Luka Snoj
   Nato - North Atlantic Treaty Organisation
3. Kinetic Approach to Modelling and Measurements in SOL of Tokamak; Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research
   Dr. Jernej Kovačič
   IAEA - International Atomic Energy Agency
4. IAEA RC 24324 - Spent Fuel Characterization Uncertainties Due to Variations in Fuel Characteristics and Irradiation History; CRP T13018: Spent Fuel Characterization
   Asst. Prof. Marjan Kromar
   IAEA - International Atomic Energy Agency
5. H2020 - EURAD; European Joint Programme on Radioactive Waste Management
   Dr. Vladimir Radulović
   European Commission
6. H2020 - ENEEP; European Nuclear Experimental Educational Platform
   Dr. Vladimir Radulović
   European Commission
7. H2020 - SANDA; Supplying Accurate Nuclear Data for Energy and Non-Energy Applications
   Prof. Ivan Aleksander Kodeli
   European Commission
8. H2020 - ARIEL; Accelerator and Research Reactor Infrastructures for Education and Learning
   Prof. Ivan Aleksander Kodeli
   European Commission
9. H2020 - TOURR; Towards Optimized Use of Research Reactors in Europe
   Prof. Luka Snoj
   European Commission
10. Thermal Scattering Law from First Principles
    Dr. Aljaž Čufar
    Slovenian Research Agency
11. Thermal Scattering Law Analysis
    Prof. Andrej Trkov
    Slovenian Research Agency
12. Measurements and Simulations to support the Calibration of the Reactor Anti-Neutrino Detectors from the Chandler Series for Determination of the Isotopic Composition of a Reactor Core
    Dr. Klemen Ambrožič
    Slovenian Research Agency
13. Three-Dimensional Fuel Burnup Experimental Benchmark for Validation and Development of the bRAPID Nautronics and Burnup Code using the JSI TRIGA Mark-II Reactor
    Prof. Luka Snoj
    Slovenian Research Agency
14. Neutron Transport in Fusion and Fission Reactors by Coupling of Deterministic and Monte Carlo Methods
    Prof. Igor Lengar
    Slovenian Research Agency
15. Contribution to the improvement of nuclear data for higly reliable reactor shielding calculations
    Prof. Ivan Aleksander Kodeli
    Slovenian Research Agency
16. Absolute radiation measurements at very high neutron flux levels in reactor pulse mode
    Prof. Igor Lengar
    Slovenian Research Agency
17. Advances in Thermal Scattering Law Analysis
    Prof. Luka Snoj
    Slovenian Research Agency
18. Experimental Benchmark for validation of the modelling of neutron and gamma instrumentation
    Dr. Vladimir Radulović
    Slovenian Research Agency
19. New inelastic scattering nuclear reactions for epithermal neutron dosimetry
    Dr. Gašper Žerovnik
    Slovenian Research Agency
20. HE - EUROfusion; WP08: DES-1,2_HE-FU
    Dr. Aljaž Čufar
    European Commission
21. HE - EUROfusion; WP19: SAE-1_HE-FU
    Domen Kotnik
    European Commission
22. HE - EUROfusion; WP10: BB_HE-FU
    Dr. Gašper Žerovnik
    European Commission
23. HE - EUROfusion; WP06: PrIO-5_HE-FU; WPPrio-ITERneutronics&Safety
    Prof. Luka Snoj
    European Commission
24. HE - EUROfusion; WP01: WPTE - Tokamak Exploitation, HE - EUROfusion; WP01: WPTE-JET
    Dr. Jernej Kovačič
    European Commission
25. HE - EUROfusion; WP04: AC- TSVV-4,7_HE-FU
    Dr. Jernej Kovačič
    European Commission
26. HE - EUROfusion; WP25: PMU_HE-FU, RU-Mgmt-1_HE-FU
    Prof. Luka Snoj
    European Commission
27. HE - EUROfusion; WP24: TRED_HE-FU, EDU_HE-FU
    Prof. Luka Snoj
    European Commission
28. HE - EUROfusion; WP20: ENS_HE-FU
    Dr. Aljaž Čufar
    European Commission
29. HE - EURO-LABS; EUROpean Laboratories for Accelerator Based Science
    Prof. Luka Snoj
    European Commission
30. Activation Measurements for Dosimetry Data Validation Using Neutron Spectrum Filters
    Dr. Vladimir Radulović
    IAEA - International Atomic Energy Agency

RESEARCH PROGRAMMES

1. Medical physics
   Prof. Robert Jeraj
2. Reactor Physics
   Prof. Luka Snoj
3. Fusion technologies
   Prof. Igor Lengar

R&D GRANTS AND CONTRACTS

1. Unlocking the Selective Catalytic Conversion Processes of CO_2 to Ethanol – UliSess
   Prof. Luka Snoj
2. Electrocaloric elements for active cooling of electronic circuits
   Prof. Luka Snoj
3. Sensitivity of nuclear reactor physical parameters to thermal nuclear data
   Prof. Andrej Trkov
4. Nuclear radiation catalyzed chemistry
   Dr. Vladimir Radulović
5. Stability of nuclear reactors in load follow mode of operation
   Prof. Luka Snoj
   Machine learning-based optimization of fusion reactor neutronics performance
   Dr. Aljaž Čufar
6. Order models for optical microscopy of biological tissues
   Dr. Jošt Stergar
7. Irradiations on the TRIGA Reactor
   Prof. Luka Snoj
8. Neutron Transport and Criticality Calculations in Reactor Cores
   Dr. Vladimir Radulović
   Institut De Radioprotection Et De Surete Nucleaire
9. Irradiations of FT-TIMS Capsule on the TRIGA Reactor for Years 2020-2023
   Prof. Luka Snoj
   Cea-commissariat A Lʹ Energie Atomique Et Aux
10. SiC Campaign within the Frame of the Contract between CEA/AMU and FRAMATOME
    Dr. Vladimir Radulović
    Cea Saclay
11. MCNP Shielding Calculations for EPFL TCV Tokamak
    Dr. Andrej Žohar
    Epfl/sb/spc
12. Experimental Testing of the MONACO Acquisition System at the JSI TRIGA Reactor
    Dr. Vladimir Radulović
    Cea Saclay
13. MCNP Analysis of Proposed TCV Tokamak Neutron and Gamma Shield
    Dr. Andrej Žohar
    Epfl/sb/spc

NEW CONTRACTS

1. NPP Krško Cycle 33 Reload Safety Evaluation" (RSE)
   Asst. Prof. Marjan Kromar
   Krško Nuclear Power Plant
2. L2-2612 co-financing of L-project: Stability of nuclear reactors in load follow mode of operation
   Prof. Luka Snoj
   Gen Energija, d. o. o.
3. Reload Operational Core Analysis, Post Refuelling Nuclear Design Check Tests, PIS and KFSS Cycle Specific Data for Future Fuel Cycles (Cycle 32)
   Asst. Prof. Marjan Kromar
   Krško Nuclear Power Plant
4. NEK PSR3 Project Task „Safety Analyses"
   Prof. Luka Snoj
   Krško Nuclear Power Plant
5. Reload Operational Core Analysis, Post Refuelling Nuclear Design Check Tests, PIS and KFSS Cycle Specific Data for Future Fuel Cycles (Cycle 33)
   Asst. Prof. Marjan Kromar
   Krško Nuclear Power Plant
6. Support for reviews and calculations in the SFDS project for 2022 and 2023
   Prof. Luka Snoj
   Krško Nuclear Power Plant

VISITORS FROM ABROAD

1. Dr Loic Barbot, dr Gregoire de Izarra, Commissariat a l'Energie Atomique – CEA / DER / SPESI / LDCI, Cadarache, France, 17–28 January 2022
2. Dr Francois Trompier, IRSN – Institute de Radioprotection et de Surete Nuclear, External Dosimetry Dept., Fontenay-aux-Roses, France, 13–15 March 2022
3. Dr Loic Barbot, Hubert Carcreff, Damien Fourmentel, Elsa Dupin, Adrien Gruel, Vincent Chaussonet, Commissariat a l'Energie Atomique – CEA / DER / SPESI / LDCI, Cadarache, France, 8–25 March 2022
4. Dr Gilles Bignan, dr Christophe Destouches, dr Xavier Wohleber, dr Robert Jacqmin, CEA Cadarache, France, 2–4 May 2022
5. Dr Loic Barbot, Christophe Comergue, Herve Philibert, Commissariat a l'Energie Atomique – CEA / DER / SPESI / LDCI, Cadarache, France; Danilo Bisiach, Sebastjan Zorzut, Aleš Bardorfer, Instrumentation Tecnologies, Solkan, Slovenia, 16–27 May 2022
6. Dr Takahiro Makino, QST, Japan; Jose Coutinho, Universidade de Aveiro, Portugal; dr Ivana Capan, Robert Bernat, Tihomir Knežević, Institute »Rudjer Bošković«, Croatia, 30 May to 3 June 2022
7. Prof. dr Benoit Forget, Massachusetts Institute of Technology – MIT, Department of Nuclear Science and Engineering, Cambridge, MA, USA, 27 May 2022
8. Abdoulaye Sakho, The National School of Computer Science for Industry and Enterprise (ENSIIE), France, 30 May to 18 September 2022
9. Prof. dr Pierre-Jacques Dossantos-Uzarralde, ENSIIE (École nationale supérieure d'informatique pour l'industrie et l'entreprise), Évry-Courcouronnes, France, 3 August 2022
10. Samuel Henshaw, Virginiatech University, Virginia, USA, 1 October to 15 Decermber 2022
11. Prof. Henri Weisen, EPFL, Lausanne, Switzerland; dr Patrick Blaise, CEA, Cadarache, France; dr Branislav Vrban, Slovak University of Technology (STUBA), Bratislava, Slovakia, 12–15 September 2022
12. Prof. dr Piero Ravetto, Politecnico di Torino, Dipartimento Energia, NEMO Group, Torino, Italy, 23–29 October 2022
13. Dr Jakub Lüley, dr Branislav Vrban, Slovak University of Technology (STUBA), Bratislava, Slovakia, 24–28 October 2022

STAFF

Researchers
1. Dr. Dušan Čalič
2. Dr. Aljaž Čufar
3. Prof. Tomaž Gyergyek*
4. Prof. Robert Jeraj
5. *Prof. Ivan Aleksander Kodeli, on leave since 01.02.22*
6. Asst. Prof. Marjan Kromar
7. Prof. Igor Lengar
8. Asst. Prof. Matija Milanič*
9. Dr. Vladimir Radulović
10. Dr. Urban Simončič*
11. **Prof. Luka Snoj, Head**
12. Prof. Andrej Trkov
13. Dr. Gašper Žerovnik

Postdoctoral associates
14. Dr. Klemen Ambrožič
15. Stefan Costea, M. Sc.
16. Dr. Jernej Kovačič

17. Dr. Jošt Stergar
18. Dr. Andrej Žohar

Postgraduates
19. Tanja Goričanec, B. Sc.
20. Domen Kotnik, B. Sc.
21. Jan Malec, B. Sc.
22. Julijan Peric, B. Sc.
23. Anže Pungerčič, B. Sc.
24. Ingrid Švajger, B. Sc.

Technical officers
25. Sebastian Pleško, B. Sc.
26. Saša Škof, B. Sc.

Technical and administrative staff
27. Slavko Slavič, B. Sc.
28. Bojan Žefran

Note:
* part-time JSI member

DEPARTMENT OF EXPERIMENTAL PARTICLE PHYSICS F-9

Departmental research is devoted to experimental studies of elementary particles, to reveal the ultimate building blocks of matter and the nature of the interactions between them. Experiments are carried out within large collaborative programmes at international centres for particle physics at CERN near Geneva and at KEK in Tsukuba. The department is also engaged in developing and applying technologically advanced particle detectors, required for such measurements. Astroparticle physics is an emerging field applying the experimental techniques of particle physics to solve astrophysical problems. Slovenian researchers are participating in the measurements of ultra-high-energy cosmic rays at the Pierre Auger Observatory spread over a surface of 3000 km^2 near Malargue in Argentina.

With the aim of revealing the ultimate secrets of nature in the world of elementary particles, accelerators with higher and higher energies are needed. Their cost, both in terms of money and human resources, has grown to the level where they are affordable only as joint international enterprises. Thus, future accelerators will be unique facilities of their kind; an example is the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) near Geneva. Researchers exploit this facility to perform experiments in presently inaccessible regions of energy, which, though pushed higher and higher, still remain minute compared to that of the vast blast of the Big Bang that led to the creation of the Universe.

Together with colleagues from the Physics Department of the Faculty of Mathematics and Physics and the Faculty of Electrical Engineering of the University of Ljubljana, and from the Faculty of Chemistry and Chemical Technology of the University of Maribor, we are performing measurements at CERN and the Japanese centre KEK in Tsukuba. We are taking part in two experiments, each conducted as an international collaboration:

- ATLAS at the Large Hadron Collider (LHC) at CERN (3000 researchers, 182 institutions from 42 countries),
- Belle II at the asymmetric electron-positron collider (KEK-B) at KEK (1200 researchers, 130 institutions from 27 countries)

In the field of astroparticle physics we are part of the Pierre Auger collaboration (500 researchers, 91 institutions from 18 countries), which uses the giant scale (3000 km^2) observatory near Malargue in Argentina for detecting ultra-high-energy cosmic rays. This endeavour is carried out in collaboration with colleagues from the University of Nova Gorica.

A more detailed report on the 2022 activities follows, focused on the contributions of our researchers.

Head (until 30. 4. 2022):
Prof. Marko Mikuž

Head (since 1. 5. 2022):
Prof. Borut Paul Kerševan

ATLAS experiment at the Large Hadron Collider (LHC) at CERN

After three years of upgrades to the Large Hadron Collider (LHC) and its detectors, a new experimental period called Run 3 started at CERN in 2022. On 5 July 2022, the Large Hadron Collider (LHC) at CERN reached a new record proton collision energy of 13.6 TeV. Over the entire data-taking period last year, the ATLAS experiment recorded a large amount of exciting proton collisions with an integrated luminosity of 40 fb-1. Combined with the previously recorded data from the Run 2 period (2015–2018), these newly obtained data already allow the most accurate analyses ever in the search for New Physics processes beyond the Standard Model. Using state-of-the-art methods in data analysis, such as the use of graph neural networks in machine-learning methods, new frontiers have been set in the search for dark matter, along with the most precise measurements of the properties of the Higgs boson published in Nature on the tenth anniversary of the discovery of the Higgs boson by the ATLAS and CMS collaborators. Many interesting results were published on the search for rare Higgs boson decays as well as on probing the current theories related to the extensions of the Standard Model and predictions of new strange particles such as leptoquarks. Obviously, more data will be needed to make new discoveries and increase the precision of the measurements that the ATLAS experiment will record in the coming years of Run 3 – so the years ahead will also be full of challenges and expectations of ground-breaking events. In 2022, the ATLAS researchers published more than 60 scientific papers

- **On 5 July 2022 the Large Hadron Collider (LHC) at CERN reached a new record proton collision energy of 13.6 TeV.**
- **Using state-of-the-art methods in data analysis, such as the use of graph neural networks in machine-learning methods, new frontiers have been set in the search for dark matter, along with the most precise measurements of the properties of the Higgs boson published in Nature.**

Figure 1: Display of a collision event recorded by ATLAS on 7 July 2022 when stable beams of protons at the record energy of 6.8 TeV were delivered to ATLAS by the LHC. The red line shows the muon candidate with a transverse momentum of 15 GeV reconstructed using information from the inner tracking detectors and the muon spectrometer end cap, using the New Small Wheel (NSW) detector. The figure also sh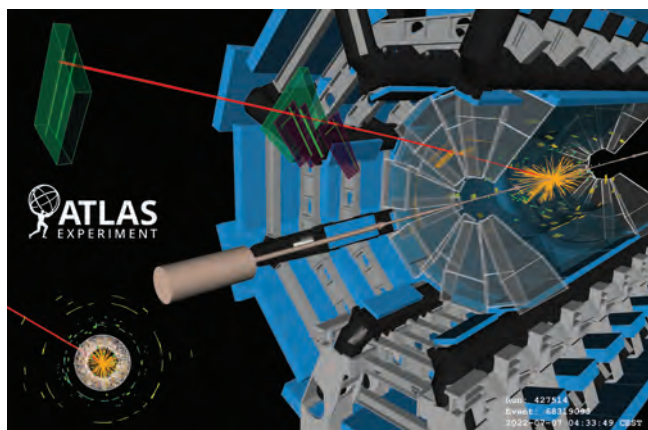ows the tracks of charged particles as they are reconstructed in the inner detector (orange tracks), as well as the energy deposits in the electromagnetic (green boxes) and hadronic (yellow/orange boxes) calorimeters.

- **A major upgrade of the ATLAS detector is needed for high-luminosity LHC (HL-LHC). A large part of the ATLAS collaboration, including the group from the F9 department, is working intensely on the development and building of detector systems for the upgrade.**
- **A High-Granularity Timing Detector is a part of an ATLAS upgrade for the High-Luminosity LHC upgrade. The JSI group has been heavily involved in the development and testing of suitable Low-Gain Avalanche Detectors (LGADs) for the HGTD. We contributed to the understanding of the LGAD performance and explained its response to different charge particles.**
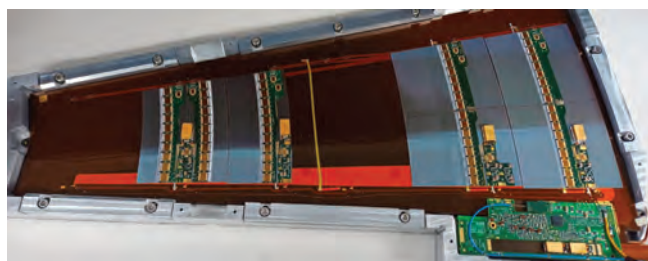

Figure 2: First silicon sensor modules mounted on flexible circuits produced by ELGOLINE Ltd., Podskrajnik. Such assemblies are the building blocks of the ATLAS Inner Tracker.

in the most distinguished scientific journals, bringing the total number of published papers to 1100, with more than 100 further papers in preparation.

The ATLAS Ljubljana group plays the leading role in designing, building and operating several beam- and radiation-monitoring systems: ATLAS Beam Condition Monitor (BCM), Beam Loss Monitor (BLM) and Radiation Monitor (RADMON). BCM was built to monitor conditions of the LHC beams and issue warnings about unexpected and potentially dangerous situations. In the first part of the LHC's operation it served as the main luminosity monitor of ATLAS. BLM, on the other hand, it is solely a safety system, protecting the ATLAS Inner Detector from potential damage due to imperfections or deviations of LHC beams. BLM operates independently in parallel with BCM. It fired a few times and successfully extracted LHC beams and prevented potential damage to the detectors. RADMON records the doses received by different parts of the ATLAS Inner Detector. In 2022 the readout electronics and control software of BCM and BLM were upgraded and integrated in the ATLAS data-acquisition system. They operated smoothly during data taking in 2022.

Atlas detector upgrade

In 2022, the LHC started the new data-taking period called Run 3, which will continue until the end of 2025. After Run 3 a major upgrade of the LHC to the High Luminosity LHC (HL-LHC) will start. The beginning of the HL-LHC operation is scheduled for 2029. To adapt to HL-LHC conditions a major upgrade of the ATLAS detector will be made during the shutdown period from 2025 to 2029. A large part of the ATLAS collaboration, including the group from the F9 department, is intensely working on the development and building of detector systems for the upgrade.

The F9 department's team has played a crucial role in developing an advanced system called BCM', which utilizes pCVD diamond sensors. This system will replace the current beam abort and luminosity monitor. To amplify and discriminate signals from segmented pCVD diamond sensors, the team has developed a dedicated rad-hard ASIC readout chip named Calypso. The chip's radiation hardness has been verified through several irradiation experiments in 2021 and 2022, and the performance of the diamond sensor readout by the new chip was successfully tested in the test beam. The system comprises several components that have been designed, manufactured, and functionally verified. BCM' is located near the interaction point and serves as a subsystem of the pixel detector. To comply with strict engineering and radiation-hardness constraints, the support structure, electrical and data connections must be harmonized with those of the pixel detector system.

The High-Granularity Timing Detector has officially become part of an ATLAS upgrade for the High-Luminosity LHC upgrade. The JSI group has played a large part in the development and testing of suitable Low-Gain Avalanche Detectors (LGADs) for the HGTD as documented in more than 10 publications in 2022. We tested sensors from different producers and demonstrated their suitability for use in the ATLAS experiment. The dependence of charge collection and timing properties of the sensors on the neutron fluence was systematically measured. We contributed to the development of different LGAD gain-layer designs and showed the beneficial effect of carbon co-implantation on the radiation hardness of the LGADs, particularly the reduced acceptor removal. Measurements of highly energetic particles in the beam showed that the use of LGADs is limited to voltages much lower than those in the laboratory, due to destructive events (single-event burnout), which make the use of carbon-enriched sensors mandatory in ATLAS. We demonstrated the stable operation of large LGAD arrays, irradiated and non-irradiated, over prolonged periods in similar conditions to those expected in the ATLAS experiment. We explained the LGAD response of different charge particles and proposed a model for the LGAD operation in the case of an enhanced concentration of free carriers.

In 2022 the ATLAS collaboration continued assembling components to upgrade the inner part of the tracking detector (Inner tracker – ITk). Slicon microstrip sensors will be used to track the path of charged particles. About

25% of 22000 sensors needed for the upgrade were manufactured by the end of 2022. The test structures made on silicon wafers together with the main sensors were irradiated with neutrons in the JSI Reactor Centre. For quality control regular irradiations of test structures are planned every month during the production period of four years. In a specially designed measurement system, the response of the sensors to electrons from a Sr^{90} source was measured. All the tested structures showed the expected degradation of the signals after irradiation. Irradiation with $1.6 \cdot 10^{15}$ n_{eq} cm^{-2} reduces the collected charge to 7500 el, which is one third of the pre-irradiation value.

In addition to the sensors development we took part in the development of special multilayer flexible circuits, working together with company Elgoline d.o.o. These radiation-hardened circuits connect sensors with the peripheral read-out electronics in the two end caps of ITk. Elgoline from Cerknica will produce more than 1000 of such large flexible circuits in the next years, and around 10% of the whole production has been already completed. Each circuit will be tested three times in different stages of the assembly process. For this purpose a robot was developed in collaboration with the Oxford University.

An upgraded system for online measurements of integrated doses (RadMon) will be installed in the ITk. The radiation arising from proton interaction creates a highly radioactive environment near the interaction point. This radiation damages sensors and readout electronics so it is important to monitor the dose levels to understand the detector performance. In 2022 our group designed and manufactured prototype readout electronics and prepared plans for the integration of the system into the ATLAS experiment. Near the end of 2022 the irradiation of the sensors for measuring the ionisation dose (RadFETs) with 24 GeV protons at CERN was made.

Belle and Belle II at the SuperKEKB electron-positron collider at KEK

Collaborators at the department continued activities within the Belle and Belle II experiments at the electron-positron collider KEKB (SuperKEKB) in Tsukuba, Japan. The main motivation of the two experiments, belonging to the so-called Intensity Frontier Experiments, is the search for so far unknown processes and particles beyond the theory of the Standard Model (SM) that are commonly addressed as New Physics (NP). The Intensity Frontier Experiments perform ultra-high precision measurements to compare the results to the equally precise predictions of the SM. The latter is the most successful and experimentally verified theory of elementary particles and their interactions at the currently achievable energies and precision. NP processes must be responsible, among other aspects, for the observed dominance of matter over antimatter in the Universe.

While the Belle detector finished data-taking in 2010, numerous analyses of the data are still in progress. Among the results of 2022 is a plethora of the studies of decays and properties of charmed baryons, searches for exotic tetraquark states, and measurements of the matrix elements of the quark mixing (so-called Cabibbo-Kobayashi-Maskawa) matrix, with the aim to resolve the still persistent tension observed in the value of $|Vub|$ and $|Vcb|$

Figure 3: During the tests with the accelerator at the Paul Scherrer Institute (PSI) in Switzerland, where we searched for the so-called Single Event Effect-e (SEE), two such events were recorded by the Calypso ASIC (left image). The right picture shows the set-up of the experiment where we used a laser to align the electronic circuit in the proton beam.

- **The Belle II experiment has so far collected 360 fb^{-1} of data, with the SuperKEKB breaking the instantaneous luminosity world record several times in 2022. Among the important results of the Belle II collaboration in 2022 is the world's most precise measurement of the charmed L_c baryon lifetime.**
- **Important research topics of Belle II are searches for dark matter candidates and possible interaction carriers between dark matter particles and ordinary matter.**
- **Results of the Pierre Auger Collaboration showed that the GZK effect cannot be the entire story behind the spectral cut-off and even the extent of its contribution remains unclear.**
- **In 2022, the SiGNET Tier-2 computing centre, with over 3072 cores and around 6 PB storage capacity, continued its involvement in international projects and organisations including WLCG, EGI, EGI/InSPIRE and Nordugrid.**
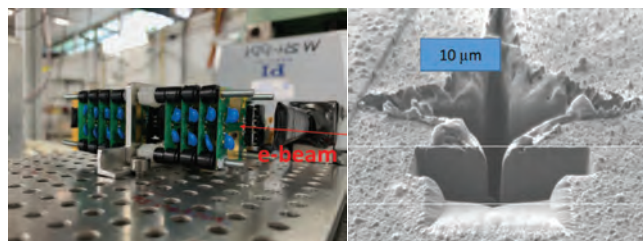
Figure 4: (left) Photo of the test beam set-up prepared by the JSI group to test the resilience of Low-Gain Avalanche Detectors to single event burnout. (right) A microscope picture of the single event burnout caused by a single beam particle crossing an LGAD.

matrix elements as determined from exclusive and inclusive determinations. A strong emphasis was also placed on searches for anomalies in B meson decays involving leptons in the final state. Searches were carried out for decays into two leptons of different flavours (tau and a light lepton), either alone or accompanied by a K meson.

The Belle II experiment has so far collected 360 fb^{-1} of data, with the SuperKEKB breaking the instantaneous luminosity world record several times in 2022. Among the important results of the Belle II collaboration in 2022 is the world's most precise measurement of the charmed L_c baryon lifetime (Figure 5). This measurement once again demonstrated the excellent vertexing capabilities of the Belle II detector, confirming a good understanding of systematic effects that will impact future analyses of neutral-meson mixing and mixing-induced CP-violation. Another prominent result comes from a combined analysis of the Belle and Belle II data; such an analysis has a double advantage: a larger data sample and the use of analysis tools that have been newly developed for the Belle II

experiment. The resulting measurement of f_3, one of the angles of the unitarity triangle, is an excellent starting point for the analyses of larger data samples that will become available during the SuperKEKB operation in 2023 and 2024.

Another set of important research topics at Belle II are the searches for dark-matter candidates and possible interaction carriers between dark-matter particles and ordinary matter. Among others, a search was carried out for a dark photon and an invisible dark Higgs boson in the final states with a μ+μ- pair and missing energy. The results of the measurement are the upper limits on the coupling of dark photons as a function of their mass (Figure 6).

Pierre Auger Observatory

The Pierre Auger Observatory is an international cosmic-ray observatory in Argentina designed to detect ultra-high-energy cosmic rays: sub-atomic particles traveling nearly at the speed of light and each with energies beyond 10^{18} eV. In Earth's atmosphere such particles interact with air nuclei and produce various other particles. Secondary particles forming the so-called "air shower" can be detected and measured in order to clarify the origin of the highest-energy primary particles and their properties like energy, arrival direction and the particle type (photons, protons, atomic nuclei). But since these high-energy particles have an estimated arrival rate of just 1 per km^2 per century for a particle with an energy of 10^{20} eV, the Auger Observatory has created a detection area of 3000 km^2 to be able to record a significant number of these events. It is located in the western Mendoza Province, Argentina, near the Andes.

The Pierre Auger Observatory combines two complementary techniques to measure the air showers. On their way through the atmosphere the secondary particles stimulate nitrogen molecules in the air to emit fluorescent light. This light is measured with large telescopes. In addition, secondary particles reaching the ground level are registered by an array of particle detectors. These are water Cherenkov detectors, measuring the light emitted by relativistic particles passing through a water tank.

Figure 5: Decay-time distributions of $L_c \to p\,K\text{-}\,\pi\text{+}$ events in the signal region (top) and the background control sample (bottom) with fit results overlaid.

The Pierre Auger Collaboration showed that the energy spectrum of cosmic rays exhibits a sharp drop of around 10^{20} eV. This drop is compatible with the Greisen-Zatsepin-Kuzmin (GZK) cut-off caused by the universe becoming opaque due to the resonant collisions between ultra-high-energy protons and the photons of the cosmic microwave 2.7-K background radiation. Past measurements by the Pierre Auger Collaboration already cast some doubt on this explanation, and this year's results further established that the GZK cut-off cannot be the entire story and even the extent of its contribution to the cut-off remains unclear.

One of the key goals of the observatory is to understand the origin of cosmic rays with energies of above 8×10^{18} eV. To this end, the observatory has been studying the dipolar anisotropy of the arrival directions of cosmic rays. The anisotropy is a measure of how likely it is for cosmic rays to arrive from a certain direction. The observatory found evidence for a dipolar anisotropy at the 99.8% confidence level, suggesting that cosmic rays may be coming from a preferred direction. Additionally, the observatory also detected a correlation between the arrival directions of ultra-high-energy cosmic rays and nearby galaxies.

Collisions of ultra-high-energy cosmic rays with atmospheric molecules provide hadronic interactions at an energy that exceeds the LHC centre-of-mass energy by one to two orders of magnitude. Although progress was made in incorporating LHC results, some mysteries were not solved. The number of muons in Monte Carlo simulations is significantly smaller than the number measured in experimental data. Also, the depth at which most muons that reach the Earth's surface are produced cannot be described by a Monte Carlo simulation for any reasonable composition mix of cosmic rays.

Figure 6: Observed 90% CL upper limits on the coupling of the dark photon A' to ordinary matter as a function of the dark photon mass for four different assumptions of the dark Higgs boson.

The Pierre Auger observatory is currently upgrading its detection capabilities. The key element of the upgrade is the installation of a plastic scintillator on the top of each of the 1660 existing surface detector stations. It will provide a complementary measurement of the showers, allowing the reconstruction of muons and electromagnetic particles. The surface scintillator detector stations (SSDs) are being deployed over the full 3000 km^2 area of the
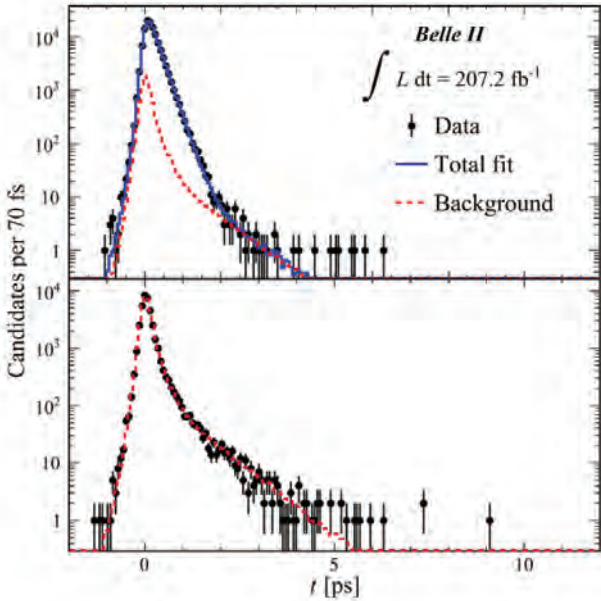
overall surface detector (SD). To enhance the capabilities of the surface detector, especially for composition measurements, it is being equipped with upgraded electronics that have a larger sampling rate and a larger dynamic range.

Commissioning of the AERA system (Auger Engineering Radio Array) is also under way. AERA is a new antenna system to measure short radio pulses emitted by cosmic-ray air showers of the highest energies. It consists of an array of antennas sensitive in the frequency range of 30 to 80 MHz with signal processing and electronics developed specifically for this purpose.

Distributed computing

In 2022 the SiGNET Tier-2 computing centre, with over 3072 cores and around 6 PB storage capacity, continued its involvement in international projects and organisations including WLCG, EGI, EGI/InSPIRE and Nordugrid. Furthermore, we worked together with other computing centres, such as the institute's own NSC and Arnes centre. As part of the European initiative EuroHPC and Slovenian national supercomputing network SLING, we participated in maintaining the Vega supercomputer at IZUM in Maribor. The resources of the SiGNET center were, in 2022, used mainly for the data analysis and production of international experiments ATLAS and Belle II, as well as for other department's projects. Some of the resources were also available for other institute members and external collaborators. We also continued with the cooperation in the Leonardo project, in setting up one of the three pre-exascale HPC systems in Cineca, Bologna. In 2022 we agreed to participate in the Leonardo Quantum Computer procurement and integration with HPC, starting the collaboration with Cineca and INFN. Apart from maintenance and administration, the department also collaborates in numerous projects related to the support, maintenance and planning of the computing infrastructure as well as the development, distribution and deployment of the distributed computing infrastructure, for example EuroHPC JU, EuroCC and Castiel 2.

- **A new LAPPD (Large Area Picosecond Photon Detector) sensor was added as a possible candidate for detecting Cherenkov light in RICH detectors.**
- **We designed a positron emission tomography (PET) device with flat-panel detectors, which, based on ultra-fast detection, enables PET imaging with a significantly smaller amount of detection crystals, thus allowing a lower cost and greater flexibility. We succeeded in the 2022 EIC Pathfinder Open Call of the European Innovation Council with our PetVision proposal to build and clinically test a flat-panel PET detector.**
- **We received the ERC Proof of Concept Lump Sum Grant 2022-2 from the European Research Council, for the CherPET project, to design the first larger-scale PET prototype using pure Cherenkov radiators.**
- **We are partners in the Horizon Europe project EURO-LABS with a budget of 14.5 M€ which started in September 2022.**

Detector development
Silicon and diamond detectors

Most of the work on the silicon detector development was performed in the framework of the ATLAS and CERN-RD50 collaborations. Our group is also active in the development of diamond tracking detectors within the RD42 collaboration.

Upgrading the ATLAS detector for the HL-LHC is the core activity within the silicon detector development. This includes the micro-strip silicon detector development and LGAD development for HGTD, as already described above.

We investigated the effect of irradiation with protons accelerated to very high energy on the strip detectors for ITk. We found that these particles damage them much more than we would expect. This was a surprising result, so we will continue our work in this area. Understanding the operation of detectors after proton irradiation is very important since high-energy protons contribute significantly to the radiation damage suffered by the detectors during data taking in the ATLAS experiment.

In 2022 we developed a system for measuring transients (Transient Current Technique, TCT) using the two-photon absorption effect (Two Photon Absorption), TPA-TCT. By exploring this effect we can release charge carriers in silicon in a limited volume in the detector and, in this way, measure the spatial dependence of the detector's response.

We dedicated a part of our research to the development of the so-called Silicon 3D detectors, which offer the best radiation resistance and, at the same time, excellent spatial and temporal resolution.

We studied the effect of exposure to high temperatures on the performance of highly irradiated LGADs. We found that it would be possible to improve the radiation resistance of LGADs by keeping them for a certain time at approximately 350°C. Of course, the exposure of a detector system to such a high temperature causes a series of practical problems that still need to be solved.

Our group is active in the detector development for next-generation hadron colliders such as Future Circular Collider – FCC_{hh}. This work includes measurements of the detector response after irradiation to extreme hadron fluences of 10^{17} n/cm^2 and beyond. In 2022 measurements with the detectors irradiated to an extreme fluence were made.

The development of diamond detectors in 2022 was focused on the BCM' system. We carried out several measurements with diamond detectors with electrons from a ^{90}Sr radioactive source as well as in the test beam. We used a diamond sensor with an area of 1 × 1 cm and a thickness of 500 μm. Several reading electrodes were made on the diamond surface, which were connected to the Calypso reading chip purpose built for BCM'.

In 2022, as part of a bilateral project with the NürDAM Institute, Bolu, Turkey, we developed FET dosimeters, in which a layer of boron (^{10}B) is made under the metal of the gate, greatly increasing the sensitivity to thermal neutrons. We irradiated the dosimeters with neutrons in the TRIGA reactor and the first results are encouraging so that we will continue with the measurements.

Photon detectors

Research of the photon sensors for the new generation of Cherenkov ring imaging detectors (RICH) continued in 2022. For the upgrade of the Belle II detector in the forward direction and the upgrade of the Cherenkov ring detectors of the LHCb spectrometer, we are developing a single-photon sensor that will be very fast, will have fine granulation, will be sensitive to the light of long wavelengths and will withstand radiation load, mainly due to the neutron flux. A new LAPPD (Large Area Picosecond Photon Detector) sensor was added as a possible candidate for detecting Cherenkov light in RICH detectors. The sensor was characterized with the lab set-up (Figure 7) to determine two important parameters for use in RICH detectors: position, and timing resolution.
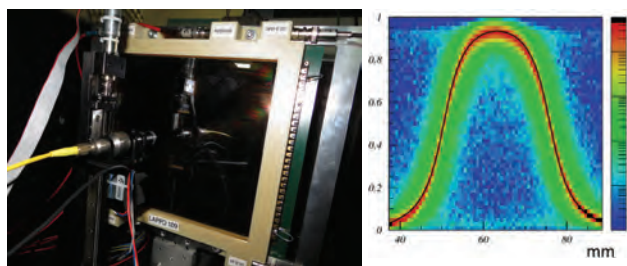

Figure 7: Characterisation of the new photosensor LAPPD (Large Area Picosecond Photon Detector). Left: photo of the sensor in the set-up for characterizing the position and timing resolution. Right: relative response of a 25.4 mm wide channel with respect to the light spot position.

Detectors for medical applications

Experimental particle physics strives to develop and master state-of-the-art technology. Innovations from our laboratories can be effectively transferred to other areas. Medical physics is a successful example of where we can introduce advances in photodetectors and reading electronics to improve the detector technology in nuclear medicine and imaging methods in biomedical optics.

We designed a positron emission tomography (PET) device with flat-panel detectors, which, based on ultra-fast detection, enables PET imaging with a significantly smaller amount of detection crystals, thus allowing a lower cost and greater flexibility (Figure 8). Through precise simulations, we have shown that such an approach achieves an image quality comparable to the best current commercial devices, while also enabling more affordable simultaneous imaging of the whole body. We succeeded in the 2022 EIC Pathfinder Open Call of the European Innovation Council with our PetVision proposal to build and clinically test a flat-panel PET detector. The project will be performed by a consortium of researchers from the Jožef Stefan Institute, the University of Barcelona, the Institute of Molecular Imaging Instrumentation in Valencia, Fondazione Bruno Kesler from Trento, Klinikum Rechst der Isar of the Technical University of Munich, the Massachusetts General Hospital from Boston and the company Oncovision from Valencia.

Based on our expertise in using Cherenkov light in experimental particle physics, we are developing another novel detection method for PET. By replacing traditionally used scintillators with radiators of Cherenkov light, PET detectors can be faster and more affordable. We received the ERC Proof of Concept Lump Sum Grant 2022-2 from the European Research Council, for the CherPET project, to design the first larger-scale PET prototype using pure Cherenkov radiators.

We also developed a system for fluorescence lifetime measurements, which uses the latest light detectors to enable a faster acquisition than the existing methods. We demonstrated the system to multiple national and international pharmaceutical and bio-tech companies and start-ups, and we are in talks with them to develop the system to higher TRL levels and their specific applications.

Figure 8: Use of flat-panel detectors enabling affordable and flexible positron tomography: same detectors can be configured for different types of imaging, e.g., cardiac (top) or brain (bottom) imaging.

Irradiations in the TRIGA reactor

A number of irradiations with neutrons, as well as with ionizing radiation of the reactor core when fission is stopped, was made for various institutions from around the world. The JSI reactor is the reference neutron irradiation site for the development of the silicon detectors and electronics for LHC and other particle physics experiments.

EURO-LABS

In 2022 the EURO-LABS project was approved and started in September as part of the Horizon Europe program. The project budget is 14.5 million euros; 33 institutions from 18 countries are participating. EURO-LABS funds ac-
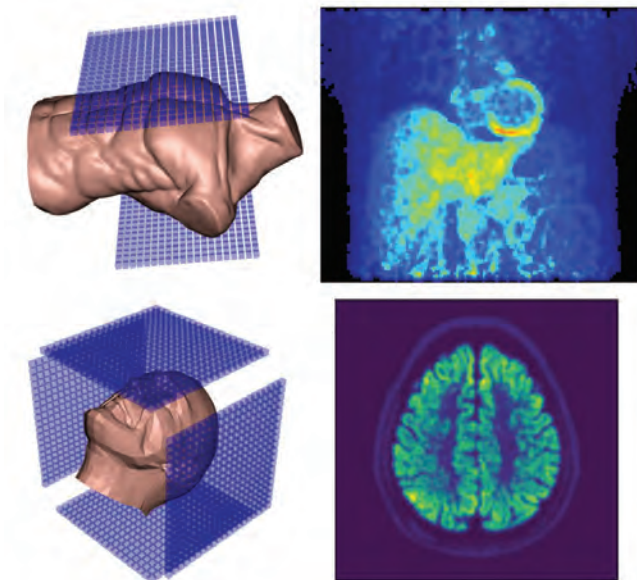
cess to the infrastructure for detector research; F9 department together with RIC coordinates this work package. EURO-LABS provides access to the irradiation of detectors at the TRIGA reactor of the JSI. In 2022 we carried out several irradiations from this program.

ERC project

1. H2020 - FAIME; Flavour Anomalies with advanced particle Identification Methods
   Prof. Peter Križan
   European Commission

Some outstanding publications in the past year

[1] ATLAS Collaboration, A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery, Nature 607 (2022) 7917, 52–59, DOI: 10.1038/s41586-022-04893-w

[2] ATLAS Collaboration, Search for invisible Higgs-boson decays in events with vector-boson fusion signatures using 139 fb^{-1} of proton-proton data recorded by the ATLAS experiment, JHEP 08 (2022), 104, DOI: 10.1007/JHEP08(2022)104

[3] ATLAS Collaboration, Direct constraint on the Higgs-charm coupling from a search for Higgs boson decays into charm quarks with the ATLAS detector, Eur. Phys. J. C 82 (2022), 717, DOI: 10.1140/epjc/s10052-022-10588-3 (publication)

[4] ATLAS Collaboration, Measurements of Higgs boson production cross-sections in the $H \to \tau^+\tau$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP 08 (2022), 175, DOI: 10.1007/JHEP08(2022)175

[5] ATLAS Collaboration, Search for long-lived charginos based on a disappearing-track signature using 136 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 82 (2022) 7, 606, DOI: 10.1140/epjc/s10052-022-10489-5

[6] A. Howard et al., Determination of impact ionization parameters for low gain avalanche detectors produced by HPK, JINST 17 (2022) P10036

[7] L. Diehl et al., Investigation of the signal amplitude decrease in subsequent detection in irradiated silicon sensors, Nucl. Inst. & Meth. A 1036 (2022) 166873

[9] A. Studen, N. Clinthorne, System resolution versus image uncertainty for positron emission tomography scanners, Journal of Medical Imaging 9 (2022) 3, 033501-033519, ISSN 2329-4310, https://caps.luminad.com:8443/stockage/stock/SPIE/LDL-SPIE-JMI-21032RR/JMI-21032RR_online.pdf, DOI: 10.1117/1.JMI.9.3.033501. [COBISS.SI-ID 107926019]

[10] G. Razdevšek et al., Multi-panel limited angle PET system with 50 ps FWHM coincidence time resolution: a simulation study, IEEE transactions on radiation and plasma medical sciences 6 (2022) 6, 721–730, ISSN 2469-7311, DOI: 10.1109/TRPMS.2021.3115704. [COBISS.SI-ID 89624579]

[11] Skomina, Petja, Hiti, Bojan, Cindro, Vladimir, Howard, Alissa, Mandić, Igor, Mikuž, Marko, Kramberger, Gregor, Studies of inter-pad distance in low gain avalanche detectors, Nuclear instruments and methods in physics research. Section A, Accelerators, spectrometers, detectors and associated equipment, [Print ed.]. 2022, vol. 1027, str. 166158-1-166158-7. ISSN 0168-9002. DOI: 10.1016/j.nima.2021.166158. [COBISS.SI-ID 151493123]

[12] Howard, Alissa, Cindro, Vladimir, Hiti, Bojan, Kramberger, Gregor, Kljun, Žan, Mandić, Igor, Mikuž, Marko, Determination of impact ionization parameters for low gain avalanche detectors produced by HPK, Journal of instrumentation. 2022, vol. 17, no. 10, str. p10036-1-p10036-13. ISSN 1748-0221, DOI: 10.1088/1748-0221/17/10/P10036. [COBISS.SI-ID 151161091]

Organization of Conferences, Congresses and Meetings

1. Belle International Masterclasses 2022, Jožef Stefan Institute, Ljubljana, Slovenia, 16 March 2022
2. ATLAS International Masterclasses 2022, Jožef Stefan Institute, Ljubljana, Slovenia, 4 April 2022
3. 10th anniversary of the Higgs boson discovery, Jožef Stefan Institute, Ljubljana, Slovenia, 4 July 2022
4. VII. Mediterranean Thematic Workshop in Advanced Molecular Imaging, Portorož, Slovenia, 5–7 September 2022
5. Researchers' Night, Jožef Stefan Institute, Ljubljana, Slovenia, 30 September 2022

INTERNATIONAL PROJECTS

1. H2020 - JENNIFER2; Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research 2
   Prof. Rok Pestotnik
   European Commission
2. H2020 - EUROCC; National Competence Centres in the Framework of EuroHPC

Prof. Marko Mikuž
European Commission
3. H2020 - AIDAinnova; Advancement and Innovation for Detectors at Accelerators
   Dr. Gregor Kramberger
   European Commission
4. H2020 - HITRIplus; Heavy Ion Therapy Research Integration

Asst. Prof. Andrej Studen
European Commission
5. H2020 - FAIME; Flavour Anomalies with advanced particle Identification MEthods
Prof. Peter Križan
European Commission
6. Fabrication and Qualification of NürFETs Dosimeters for use at Nuclear Reactors
Dr. Gregor Kramberger
Slovenian Research Agency
7. A Study of Lepton Anomalies
Prof. Peter Križan
Slovenian Research Agency
8. Fast Timing Detectors for Positron Emission Tomography
Prof. Rok Pestotnik
Slovenian Research Agency
9. HE - interTwin; An Interdisciplinary Digital Twin Engine for Science
Prof. Andrej Filipčič
European Commission
10. HE - EURO-LABS; EUROpean Laboratories for Accelerator Based Science
Prof. Marko Mikuž
European Commission

RESEARCH PROGRAMMES

1. Multimessenger astrophysics
Prof. Marko Zavrtanik
2. Experimental Particle Physics
Prof. Borut Paul Kerševan

R & D GRANTS AND CONTRACTS

1. Application of Machine Learning Methods in the Data Analysis at the Large Hadron Collider (LHC)
Dr. Andrej Gorišek
2. Atmospheric remote sensing for Cherenkov Telescope Array and its impact on science from large sky survey observations
Prof. Marko Zavrtanik
3. Development of High Granularity Timing Detector for ATLAS experiment
Dr. Gregor Kramberger

4. Advanced detector for Time-of-Flight PET based on Cherenkov radiation
Prof. Samo Korpar
5. ITk - Upgrade of the ATLAS Tracker for High-Luminosity LHC
Prof. Marko Mikuž
6. Ring Imaging Cherenkov detectors for the next generation of flavor physics experiments
Prof. Peter Križan
7. Development of the proton CT system based on Low Gain Avalanche Detectors
Dr. Gregor Kramberger
8. Belle II
Prof. Peter Križan
9. Collaboration CERN RD-39
Prof. Marko Mikuž
Cern
10. Collaboration CERN RD-50
Prof. Marko Mikuž
Cern
11. Collaboration DELPHI
Prof. Borut Paul Kerševan
Cern
12. Collaboration ATLAS
Prof. Marko Mikuž
Cern
13. Collaboration CERN RD-42
Prof. Marko Mikuž
Cern
14. Collaborations Belle in Belle II
Prof. Peter Križan
Kek - High Energy Accelerator Research
15. Irradiations in TRIGA Nuclear Reactor
Prof. Vladimir Cindro
16. MEDAMI 2022 - VII. Mediterranean Thematic Workshop in Advanced Molecular Imaging, Grand Hotel Portorož, Slovenia, 05 - 09 September 2022
Prof. Rok Pestotnik

NEW CONTRACT

1. QC analysis of the manufacturing quality of flexible PCB production
Dr. Andrej Gorišek
Elgoline d. o. o.

VISITORS FROM ABROAD

1. Dr Andrii Tykhonov, University of Geneva, Switzerland, 30 March 2022
2. Jovana Doknić, University of Montenegro, Faculty of Science and Mathematics, Podgorica, Montenegro, 4–9 June 2022
3. Ivona Božović, University of Montenegro, Faculty of Science and Mathematics, Podgorica, Montenegro, 4–9 June 2022
4. Fasih Zareef, AGH University of Science and Technology, Krakow, Poland, 4–14 July 2022

5. Dr Andrii Tykhonov, University of Geneva, Switzerland, 1 July to 31 August 2022
6. Dr Marcela Mikeštikov, Czech Academy of Sciences, Prague, Czech Republic, 24–25 October 2022
7. Dr Pavla Federičov, Czech Academy of Sciences, Prague, Czech Republic, 24–25 October 2022
8. Mag. Patrik Novotny, Czech Academy of Sciences, Prague, Czech Republic, 24–25 October 2022

STAFF

Researchers
1. Dr. Karol Mateusz Adamczyk
2. Asst. Prof. Marko Bračko*
3. Prof. Vladimir Cindro
4. Asst. Prof. Rok Dolenec*
5. Prof. Andrej Filipčič
6. Prof. Boštjan Golob*
7. Dr. Andrej Gorišek
8. **Prof. Borut Paul Kerševan*, Head (since 1. 5. 2022)**
9. Prof. Samo Korpar*
10. Dr. Gregor Kramberger
11. Prof. Peter Križan*
12. Dr. Boštjan Maček
13. Asst. Prof. Igor Mandić
14. **Prof. Marko Mikuž*, Head (until 30. 4. 2022)**
15. Prof. Rok Pestotnik
16. Asst. Prof. Tomaž Podobnik*
17. Dr. Andrej Seljak
18. Prof. Marko Starič
19. Asst. Prof. Andrej Studen*
20. Prof. Marko Zavrtanik
21. Prof. Danilo Zavrtanik*
22. Asst. Prof. Dejan Žontar*
Postdoctoral associates
23. Dr. Bojan Hiti
24. Dr. Luka Šantelj

Postgraduates
25. Dr. Dania Consuegra Rodriguez
26. Jernej Debevc, B. Sc.
27. Jan Gavranovič, B. Sc.
28. Alissa Shirley-Ann Howard, M. Sc.
29. Blaž Leban, B. Sc.
30. Andrej Lozar, B. Sc.
31. Miha Mali, B. Sc.
32. Jakob Novak, B. Sc.
33. Anja Novosel, B. Sc.
34. Ihor Prudiiev, M. Sc.
35. *Leonardo Benjamin Rizzuto, left 01.11.22*
36. *Luka Senekovič, B. Sc., left 15.10.22*
37. Krištof Špenko, B. Sc.
38. Valentina Igorevna Zhukova, M. Sc.
Technical officers
39. Jakob Merljak, B. Sc.
40. Brigita Novak, B. Sc.
Technical and administrative staff
41. Andreja Butina Čalič, B. Sc.
42. Jurij Eržen
43. Dejan Lesjak, B. Sc.
44. Erik Margan

Note:
* part-time JSI member

DEPARTMENT OF INORGANIC CHEMISTRY AND TECHNOLOGY K-1

The Department of Inorganic Chemistry and Technology is one of the world's leading groups for the synthesis of new inorganic compounds containing fluorine. The main research areas are: the synthesis of new coordination compounds with various ligands, the chemistry of noble gases, the chemistry of main-group elements, the synthesis of new hybrid materials and inorganic materials with special properties. A large part of the group's activities is devoted to technological, environmental and process safety issues in Slovenia. The group has been working closely with Slovenian industry for more than thirty years. It is also active in the field of education, promoting science among secondary and primary school students.

Head:
Asst. Prof. Gašper Tavčar

Research on the synthesis of new inorganic compounds including fluorine compounds with $[AuF_6]^-$ anions can be mentioned. Crystal growth from anhydrous hydrogen fluoride solutions of M^{2+} (M = Ca, Sr, Ba) and $[AuF_6]^-$ (molar ratio of 1:2) gave $[Ca(HF)_2](AuF_6)_2$, $[Sr(HF)](AuF_6)_2$ and $Ba[Ba(HF)]_6(AuF_6)_{14}$. $[Ca(HF)_2](AuF_6)_2$ exhibits a layered structure in which $[Ca(HF)_2]^{2+}$ cations are connected by AuF_6 units, while the crystal structure of $Ba[Ba(HF)]_6(AuF_6)_{14}$ exhibits a complex three-dimensional (3-D) network consisting of Ba^{2+} and $[Ba(HF)]^{2+}$ cations bridged by AuF_6 groups. When the initial Sr^{2+} : $[AuF_6]^-$ ratio was 1:1, single crystals of $[Sr(HF)](H_3F_4)(AuF_6)$ were grown. The crystal structure consists of a 3-D framework formed by $[Sr(HF)]^{2+}$ cations associated with $[AuF_6]^-$ and $[H_3F_4]^-$ anions. The latter exhibits a Z-shaped conformation, which has not been observed before. Single crystals of $M(BF_4)(AuF_6)$ (M = Sr, Ba) were grown when a small amount of BF_3 was present during crystallization. During prolonged crystallizations of $[AuF_6]^-$ salts, moisture can penetrate through the walls of the crystallization vessel. This can lead to partial reduction of Au(V) to Au(III) and the formation of $[AuF_4]^-$ by-products as shown by the single-crystal growth of $[Ba(HF)]_4(AuF_4)(AuF_6)_7$. Its crystal structure consists of $[Ba(HF)]^{2+}$ cations connected by AuF_6 octahedra and square-planar AuF_4 units. The synthesis and characterization of a compound with the trivalent metal main-group canter extended the diverse family of coordination compounds with XeF_2 as the ligand. Compound $[Bi(XeF_2)_3](BiF_6)_3$ can be prepared with the direct reaction between BiF_3, BiF_5 and XeF_2 in anhydrous HF as the solvent. In the compound, the same metal is present in two oxidation states, Bi(III) and Bi(V). The chemistry of silver continues to be a part of the research at the department. The research work was also presented on the cover of the journal *Zeitschrift für anorganische und allgemaine Chemie* (Figure 1).

> **The research area that covers organometallic compounds is getting more and more attention.**

Research continued under the ERC Starting Grant project, European Research Council, "Challenging the Oxidation-State Limitations of the Periodic Table via High-Pressure Fluorine Chemistry – HiPeR-F," 2021–2026. The HiPeR-F project focuses on the study of chemical reactions involving fluorine under extremely high pressure – from 10,000 bar to over 100,000 bar. The fluorine element, which can be called the tiger of the periodic table due to its extraordinary reactivity, will make it possible to test the limits of chemistry under extreme conditions. This research is thus a combination of two specialized experimental and extreme research areas – the study of substances under extremely high pressures and the study of extreme chemical reactivity.

Previously synthesized imidazolium-based fluorinating reagents [IPrH][F], [IPrH][(HF)F] and [IPrH][(HF)₂F] were studied for their reactivity in the organic chemistry. Fluorination of 4-*tert*-butylbenzyl bromide revealed that trifluoride $[IPrH][F(HF)_2]$ is the most selective reagent, especially when coupled with an addition of sterically hindered amine DIPEA or alkali metal fluorides, making it an excellent reagent for fluorination of various organic substrates. The scope of substrates that it successfully fluorinates includes benzyl bromides, iodides and chlorides, aliphatic halides, tosylates, mesylates, alpha-haloketones, silyl chlorides, acyl and sulfuryl chlorides and nitroarenes. Besides, it is also air-stable and *non*-hygroscopic and can be conveniently synthesised as well as regenerated after a reaction with hydrofluoric acid as a cheap fluoride source.

The same reagents were tested for reactivity with alkylaluminum compounds (AlR_3, R = Me, *n*-Bu) and led to the isolation of salts containing discrete triorganofluoroaluminate $([R_3AlF]^-)$, diorganodifluoroaluminate $([R_2AlF_2]^-)$ and organotrifluoroaluminate $([RAlF_3]^-)$
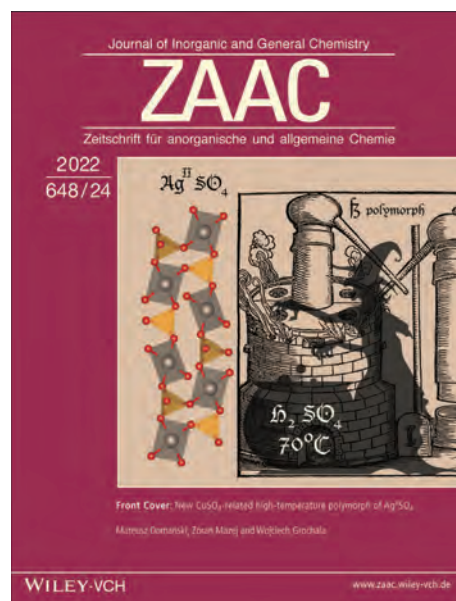

Figure 1: *Zeitschrift für anorganische und allgemaine Chemie, Issue 24, 2022, cover page presenting the scientific article New CuSO₄-related high-temperature polymorph of Ag^{II}SO₄ by Mateusz Domański, Zoran Mazej and Wojciech Grochala*

anions, respectively. The formation of the $[R_2AlF_2]^-$ and $[RAlF_3]^-$ anions was accompanied by a release of RH. The syntheses are effective, selective and straightforward. Related reactions of an arylaluminum compound ($AlPh_3$) led to a mixture of different phenylfluoroaluminate anions. NMR, Raman spectroscopy and single-crystal X-ray diffraction were used for the characterization and compared with DFT calculations.

In 2022 we focused on the synthesis of copper-cyanide-thiocyanate MOFs. We succeeded in obtaining a new anionic $\{[Cu_8(SCN)_4(CN)_6]^{2-}\}n$ network with infinite channels filled with solvated M^{2+} cations using the direct interaction of CuCN and CuSCN with the appropriate transition metal salt in the appropriate solvent. Moreover, using different original synthetic approaches and other metal cations, compounds with unknown anionic 2D fragments $\{[Cu_5(SCN)_3(CN)_5]^{3-}\}$, $\{[Cu_4(SCN)_2(CN)_5]^{3-}\}$ and $\{[Cu_2(SCN)_2(CN)]\}$ were synthesized.

We participated in the research on the preparation of phosphonate coatings to improve the stability of upconverting nanoparticles under physiological conditions, and we also participated in the research on the stability and vitality of these particles under physiological conditions. We started researching the possible toxicity of fluoride and aluminium, which are present in tea. The research was carried out in cooperation with the Institute of Microbiology and Immunology, Ljubljana.

Regarding the area of process safety, in 2022 we carried out research and published works on diverse topics. We concluded the work on the introduction of a safe use of liquefied natural gas (LNG) for ship propulsion (European project SUPER-LNG PLUS), continued the research on the relationship between leadership styles and safety management systems in industrial organizations, as well as our involvement in the EU Interreg project TRANSCPEARLYWARNING to improve the resilience of Adrion territories to natural and man-made risks. We started work on the Horizon Europe project ATLANTIS dealing with the safety and security (physical and cyber threats) of the European critical infrastructures at the system level and their relationships. In the applicative area, we led root-cause and consequence investigations of the major accident that occurred at Melamin d.d., Kočevje on 12 May 2022, and the incident at UNIOR d.d., Zreče, which occurred on 26 October 2022.

Figure 2: Crystal structure of [IPrH][AlF4] and [IPrH][Ph3F], the study was published in Organometallics, Issue 1, 2022

Together with our partners at NTF, we continued to reprocess secondary lead slag, utilizing different gravity- and magnetic separation techniques in order to obtain beneficiated streams for a further hydrometallurgical process.

We continued our activities in the field of education and promotion of science. Members of the department actively participated in the work of the Jožef Stefan International Postgraduate School as lecturers and mentors of M.Sc. and Ph.D. students. In addition, the School of Experimental Chemistry maintained very important relations with primary and secondary schools and even kindergartens through experimental courses conducted in the laboratory or direct demonstrations in schools. With demonstrations of chemical experiments, we participated at the Slovenian Science Festival, Festival Igraj se z mano ('Play with me' Festival) and Znanstival. Some of the activities of the School of Experimental Chemistry were carried out as part of a project funded by the JSI and the City of Ljubljana.

The promotion of science, research and non-formal education is also linked with the project Researchers' Night under the Horizon Europe programme. At the end of September 2022, we organised and carried out a series of activities within the framework of this EU project. The workshops of the School of Experimental Chemistry were presented in primary and secondary schools, in senior citizens' homes, in a library and in the centre of Ljubljana. In the evening, in cooperation with the research departments and centres of the Jožef Stefan Institute, we opened the doors of the Institute in Ljubljana and Podgorica. Visitors were able to see some of the departments and centres, visit the nuclear reactor TRIGA and participate in various workshops. Members of the department conducted more than 20 interactive workshops for primary and secondary school students as part of the "Researchers in Schools" activity. The aim of this activity was to bring researchers and science closer to the young generation. Within the H2020 CSA Athena project (https://www.athenaequality.eu/), a member of the Department of Inorganic Chemistry and Technology was involved in the work package related to monitoring and evaluating the activities required for the implementation of the Gender Equality Plan.
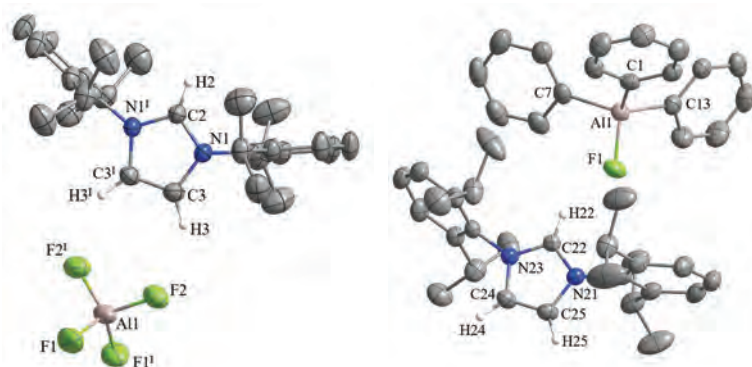
ERC project

1. H2020 - HiPeR-F; Challenging the Oxidation-State Limitations of the Periodic Table via High-Pressure Fluorine Chemistry
   Asst. Prof. Matic Lozinšek
   European Commission

Some outstanding publications in the past year

1. Z. Mazej, E. A. Goreshnik, Crystal growth from anhydrous HF solutions of M^{2+} (M=Ca,Sr,Ba) and $[AuF_6]^-$, not only simple $M(AuF_6)_2$ salts, *Inorganic Chemistry*, 2022, 61, 10587–10597.
2. B. Alič, J. Petrovčič, J. Jelen, G. Tavčar, J. Iskra, Renewable reagent for nucleophilic fluorination, *Journal of Organic Chemistry*, 2022, 87, 5987–5993.
3. E. Gruden, M. Tramšek, G. Tavčar, Discrete organofluoroaluminate anions: synthetic, structural, and spectroscopic aspects, *Organometallics*, 2022, 41, 41–51.
4. Z. Mazej, E. A. Goreshnik, Crystal structures of hexafluoridoantimonate(V) salts of d-block metals in oxidation state +2, *European Journal of Inorganic Chemistry*, 2022, e20210107-1-e202101076-8.
5. T. Pavčnik, M. Lozinšek, K. Pirnat, A. Vižintin, T. Mandai, D. Aurbach, R. Dominko, J. Bitenc, On the practical applications of the magnesium fluorinated alkoxyaluminate electrolyte in Mg battery cells, *ACS Applied Materials & Interfaces*, 2022, 14, 26766–26774.
6. M. Gerbec, O. Aneziris, Uncertainties in failure rates in the LNG bunkering risk assessment, *Safety Science*, 2022, 152, 105774-1-105774-13.

Awards and Appointments

1. Erik Uran, 3rd Place Prize at the Student Paper Contest, Slovenian Chemical Society Annual Meeting 2022, Sept. 2022, Portorož, Slovenia
2. Klemen Motaln, Best presentation by a young scientist, 28th Croatian-Slovenian Crystallographic Meeting, Sept. 2022, Poreč, Croatia
3. Erik Uran, Best Poster Award, 20th European Symposium on Fluorine Chemistry, Aug. 2022, Berlin, Germany
4. Erik Uran, Best Student Oral Presentation Award, 4th International Congress of Chemists and Chemical Engineers of Bosnia and Herzegovina, Jul. 2022, Sarajevo, Bosnia and Hercegovina
5. Klemen Motaln, Best abstract in the field of Nanosciences and Nanotechnologies, 14th Jožef Stefan International Postgraduate School Students' Conference, Jun. 2022, Kamnik, Slovenia
6. Melita Tramšek, Prometheus of Science Awards for Excellence in Communication for 2021
7. Melita Tramšek, Award for work in the editorial office of the journal Acta Chimica Slovenica, Slovenian Chemical Society Annual Meeting 2022, Sept. 2022, Portorož, Slovenia

Organization of conferences, congresses and meetings

1. Matic Lozinšek, member of the organizing committee, 28th Croatian-Slovenian Crystallographic Meeting, 7–11 September 2022, Poreč, Croatia
2. Matic Lozinšek, member of the organizing committee, Slovenski kemijski dnevi 2022, 21–23 September 2022, Portorož, Slovenia

Patents granted

1. Piotr J. Leszczyński, Adam Krzyszrof Budniak, Wojciech Marek Adamczyk, Jakub Henryk Gawraczyński, Tomasz Edward Gilewski, Piotr Połczyński, Rafał Jurczakowski, Wojciech Rafal Grochala, Zoran Mazej, Methods for obtaining salts of silver(II) and hydrates thereof, products obtained by the methods and use of the same, EP3347309 (B1), European Patent Office, 20. 07. 2022.
2. Piotr Połczyński, Rafał Jurczakowski, Piotr J. Leszczyński, Wojciech Rafal Grochala, Zoran Mazej, Method for electrosynthesis of silver (II) sulfate (VI) and the product obtained by this method, PL240270 (B1), Urząd Patentowy Rzeczypospolitej Polskiej, 07. 03. 2022.

INTERNATIONAL PROJECTS

1. Purifing of Tantalum Hydroxide and Niobium Hydroxide
   Asst. Prof. Gašper Tavčar
   Mining Mineral Resources S.a.r.l.
2. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Dr. Melita Tramšek
   European Commission
3. H2020 - HiPeR-F; Challenging the Oxidation-State Limitations of the Periodic Table via High-Pressure Fluorine Chemistry
   Asst. Prof. Matic Lozinšek
   European Commission
4. Silicon and Fluorine: A Swiss-Army-Knife Combination for New Mixed Polymerization Blocks, Protection of Ozone Layer and CF3 Transfer
   Asst. Prof. Gašper Tavčar
   Slovenian Research Agency
5. Supramolecular Assemblies of Vinyl Monomers as Matrices for Template Polymerization
   Asst. Prof. Evgeny Goreshnik
   Slovenian Research Agency
6. Noble-Gas Reactivity in Extreme Space Environments
   Dr. Kristian Radan
   Slovenian Research Agency
7. High-Pressure Structural Study of Framework-Forming Xenon Compounds
   Asst. Prof. Matic Lozinšek
   Slovenian Research Agency
8. HE - NOCMOC; (The Night has its Might), European Researchers' Night (NIGHT)
   Dr. Melita Tramšek
   European Commission
9. HE - ATLANTIS; Improved resilience of Critical Infrastructures AgainsT LArge scale transNational and sysTemic rISks
   Prof. Marko Gerbec
   European Commission

RESEARCH PROGRAMME

1. Inorganic Chemistry and Technology
   Asst. Prof. Gašper Tavčar

R & D GRANTS AND CONTRACTS

1. Holistic sustainability evaluation of critical raw materials - closing gaps and developing new methodological approaches
   Dr. Robert Kocjančič
2. The quest for high-temperature superconductvity and exotic magnetism in fluoridoargentates(II)
   Asst. Prof. Matic Lozinšek
3. Advanced reagents for (asymmetric) nucleophilic fluorination
   Asst. Prof. Gašper Tavčar
4. Structures of elusive noble-gas compounds elucidated by 3D electron diffraction
   Asst. Prof. Matic Lozinšek
5. High-pressure stabilization and phase transitions of elusive transition-metal fluorides
   Asst. Prof. Matic Lozinšek
6. Utilization of secondary lead slag as a secondary raw material for the production of lead
   Asst. Prof. Gašper Tavčar
7. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition)
   Asst. Prof. Gašper Tavčar
   Ministry of Education, Science and Sport
8. SUstainability PERformance of LNG-based maritime mobility PLUS- SUPER LNG PLUS
   Prof. Marko Gerbec
   Demokritos
9. Consultations and Analyses for Foreign Customers
   Prof. Maja Ponikvar-Svet
10. P.439148; Method of Oligomerization of Unsaturated Hydrocarbons
    Dr. Zoran Mazej
    University of Warsaw

NEW CONTRACTS

1. Investigation of the causes and consequences of the incident
   Prof. Marko Gerbec
   Melamin Kemična Tovarna d. d.
2. Utilization of secondary lead slag as a secondary raw resource for the production of lead
   Asst. Prof. Gašper Tavčar
   Th Re-mining d. d.
3. Threat assessment for the natural gas transmission system and updating the Security Vulnerability Plan
   Prof. Marko Gerbec
   Plinovodi d. o. o.

VISITOR FROM ABROAD

1. Vit Jenickek, Michal Trojan; cooperation on the project CZ-SI, VSCHT, Prague, Czech Republic, 22 January to 12 February 2022
2. dr Luka Fotović; working visit, laboratory work and training, Division of General and Inorganic Chemistry, Department of Chemistry, Faculty of Science, University of Zagreb, Zagreb, Croatia, 25 April to 31 July 2022
3. Xaver Hanushevsky; working visit, Universität Wien, Vienna, Austria, 1 June to 31 July 2022
4. Assoc. prof. dr Marko Rodić; establishment and initiation of scientific cooperation in the field of experimental determination of electron density, Faculty of Sciences, University of Novi Sad, Serbia, 20–29 June 2022
5. Assoc. prof. dr Vladimir Stilinović; Lecture and discussions on cooperation, Division of General and Inorganic Chemistry, Department of Chemistry, Faculty of Science, University of Zagreb, Zagreb, Croatia, 18 July 2022
6. Prof. Alain Tressaud; visit in the framework of cooperation in the field of fluorochemistry, CNRS, Bordeaux, France, 19–21 July 2022

STAFF

Researchers
1. Prof. Marko Gerbec
2. Asst. Prof. Evgeny Goreshnik
3. Dr. Robert Kocjančič
4. Asst. Prof. Matic Lozinšek
5. Dr. Zoran Mazej
6. Prof. Maja Ponikvar-Svet
7. Asst. Prof. Tomaž Skapin
8. **Asst. Prof. Gašper Tavčar, Head**
9. Dr. Melita Tramšek

Postdoctoral associates
10. Dr. David Levovnik
11. Dr. Svitlana Petrusenko
12. Dr. Kristian Radan
13. Dr. Miha Virant

Postgraduates
14. Jan Gnidovec, B. Sc.

15. Dr. Evelin Gruden
16. Jan Jelen, B. Sc.
17. Klemen Motaln, B. Sc.
18. Klara Ogorevc, B. Sc.
19. Anja Pavlovič, B. Sc.
20. Olha Sanko, B. Sc.
21. Erik Uran, M. Sc.

Technical officers
22. Tine Oblak, M. Sc.
23. *Tomaž Ogrin, M. Sc., retired 01.05.22*

Technical and administrative staff
24. Peter Frkal, B. Sc.
25. Marko Jeran, B. Sc.
26. Robert Moravec
27. Mira Zupančič

DEPARTMENT OF PHYSICAL AND ORGANIC CHEMISTRY K-3

The department is focused on investigating physicochemical processes on the surfaces of solids, such as corrosion and heterogeneous catalysis, and the synthesis of new compounds. The synergy of these fields is created with the studies of corrosion protection and functionalisation of materials by introducing an integrative experimental–modelling approach with a combination of experimental electrochemical and surface–analysis techniques and modelling and simulation based on first principles using methods of density-functional theory (DFT).

Head:
Prof. Ingrid Milošev

Corrosion is a widespread phenomenon with enormous economic and environmental impacts. The cost of corrosion damage is estimated at €2.5 trillion annually. Due to the enormous costs, protecting metals and alloys is essential. Corrosion protection, with the primary goal to prolong the lifetime of metallic materials, is one of the essential ways to reduce the need for steeply increasing production and thus preserve resources for the following centuries. Traditional ways of corrosion protection, such as conversion chromate coatings, can no longer be used due to ecological restrictions. The needs of industry, in particular transportation, construction, the machine and electronics industry, postulate the requirements for developing efficient, sustainable and environmentally friendly coatings, which also exhibit additional functional characteristics. Our research work in the field of corrosion protection is devoted to all major surface treatments, such as corrosion inhibitors, conversion coatings, organic coatings and inorganic coatings (Figure 1), for major metals and alloys, which are indispensable today, such as major lightweight (Al), energy efficient (Cu) and infrastructure (Fe and Zn) materials. Lightweight aluminium alloys and modern high-strength steels are used in various applications, especially in the transport industry, where there is a great need to reduce the weight of vehicles, consequently reducing emissions into the environment. Steels and alloys based on copper are indispensable materials in infrastructure, construction and other industries.

In our laboratory, we investigate the alternatives mentioned above (Figure 1) and even combine them, e.g., sol-gel coatings and inhibitors, to achieve barrier and active protection, where the coating after corrosion damage can self-heal. We also introduce modern methodologies in corrosion protection, such as atomic layer deposition (ALD).

We have achieved a major breakthrough in understanding the mechanism of corrosion inhibition with organic compounds by introducing an integrative experimental–modelling approach with the combination of experimental electrochemical and surface analysis techniques, and modelling and simulations based on first principles using methods of density-functional theory (DFT). This approach results in a more rational and ecologically oriented use of chemicals, which is in line with the European Union's directives on sustainable development and circular economy.

In the field of heterogeneous electrocatalysis, we investigated, using DFT modelling, supported metal catalysts for oxygen (OER) and hydrogen evolution (HER) reactions to scrutinize the effect of the metal–support interaction on the stability and activity of OER and HER catalysts. These two reactions are the fundamental reactions involved in water electrolysis, a feasible route for hydrogen production.

Prof. Ingrid Milošev joined the *Journal of The Electrochemical Society* (JES) Editorial Board as an Associate Editor of the Corrosion Science and Technology section. JES is the flagship journal of the Electrochemical Society. Published continuously from 1902 to the present, JES remains one of the most highly cited journals in electrochemistry and solid-state science and technology.
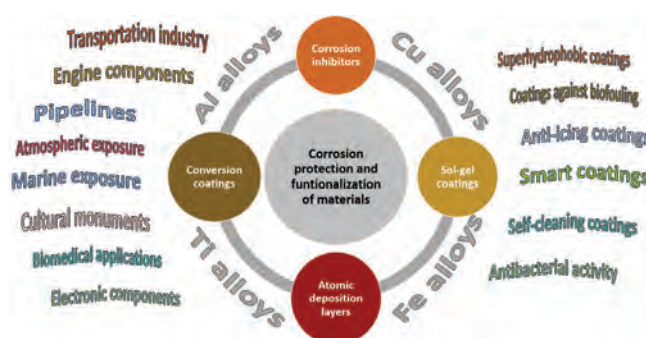
Figure 1: Types of corrosion protection and functionalisation of materials

1. Integrative experimental–modelling approach of novel corrosion inhibitors

In-depth fundamental knowledge of surface processes is needed to design effective corrosion protection because our understanding of the mechanism of corrosion inhibition at the atomic level is still very limited. To overcome this, we introduced a synergistic iterative approach that consists of the following three research directions: (1) inorganic and organic synthesis, (2) electrochemical and surface-analysis techniques, and (3) modelling and simulations based on DFT.

1.1. Organic molecules as corrosion inhibitors

We investigated how the pretreatment of a substrate surface affects the performance of organic compounds acting as corrosion inhibitors. Aluminium and copper were used as substrates, and 2-mercaptobenzimidazole (MBI) and octylphosphonic acid (OPA) were used as potential corrosion inhibitors (Figure 2). For this purpose, mechanical and chemical pretreatments were used, including grinding and polishing or chemical etching. Organic films were prepared using liquid phase deposition from an ethanolic or aqueous solution with MBI and OPA. The mechanisms of the formation and degradation of films on Cu and Al samples in 3 wt.% NaCl were investigated with electrochemical methods, and the morphology and binding of the inhibitors were investigated with scanning electron microscopy (SEM) in conjunction with energy-dispersive X-ray spectroscopy (EDS) and X-ray photoelectron spectroscopy (XPS). It was shown that the surface pretreatment did not significantly affect the chemical composition of the Cu and Al surfaces, but the key method was the procedure of a film formation. Organic films on Cu and Al were not formed in an ethanolic solution, but only when deposited from an aqueous solution. A significant reduction in the corrosion current density showed that MBI is an effective inhibitor for Cu but not for Al. Conversely, OPA behaves differently and is an effective inhibitor only for Al. Using the XPS method, we have shown that a layer is formed on a copper surface that is a compound of Cu(I) and MBI, the latter being in the deprotonated thiolate form (MBI can exist in two tautomers: thiol and the more stable thione; deprotonation of thione results in a thiolate, which binds to the copper surface via S and N atoms). An Al phosphonate layer forms on an aluminium surface in an OPA solution.

With this study, we have shown that the method for preparing an inhibitor film is crucial for achieving its optimal efficiency.

1.2. Effect of pre-adsorbed species on the adsorption of corrosion inhibitor molecules

Metal surfaces are usually either oxidized or at least covered with species such as O and OH under ambient conditions. For this reason, we investigated how adsorbed species, such as O, OH, H and Cl (labeled as $X_{(ads)}$), affect the adsorption bonding of imidazole and benzotriazole used as archetypal models of azole corrosion inhibitors on copper surfaces. To this end, we performed a systematic high-throughput DFT study by considering several hundred different adsorption configurations, where the effects of the coverage, type of $X_{(ads)}$ species and distance between the inhibitor molecule and $X_{(ads)}$ were scrutinized. Our calculations indicate that O and Cl enhance the adsorption bonding of imidazole, H has almost no effect, whereas the effect of OH is more intricate. The effect of the $X_{(ads)}$ species on the inhibitor adsorption typically diminishes with the increasing inhibitor–$X_{(ads)}$ distance and with decreasing $X_{(ads)}$ coverage. Four co-adsorption effects of $X_{(ads)}$ on inhibitor adsorption were identified, three pertaining to non-dissociative and one to dissociative adsorption.

The first stabilizing effect, relevant for O and Cl, is due to the $X_{(ads)}$-induced enhancement of the N–Cu bond between the nearby adsorbed inhibitor and the surface (Figure 3a); this effect intensifies with the increasing coverage of $X_{(ads)}$. The second effect is related to the $X_{(ads)}$ induced work-function change and can be stabilizing (for O and Cl), negligible (for H), or destabilizing (for OH) for the adsorption of imidazole, explaining why the impact of $X_{(ads)}$ on the adsorption bonding diminishes with the $X_{(ads)}$ coverage. The third effect, operative for O and OH, is due to the hydrogen bond formation with the nearby adsorbed inhibitor molecule (Figure 3a). This effect leads to the fourth effect, the deprotonation of adsorbed azole molecules (Figure 3b). Deprotonation involves an N–H bond cleavage, but imidazoles can also deprotonate via the C–H cleavage. Calculated deprotonation activation energies are considerably smaller for the cleavage of an N–H bond (below 0.1 eV) than for the cleavage of a C–H bond (0.6–0.9 eV), although the cleavage of the C–H bond is thermodynamically preferred for imidazoles. Deprotonation reaction energies do not depend strongly on the surface coverage of O and OH. Molecular deprotonation upon adsorption is important because of the higher stability of the resulting adsorption states, which increases the persistence of chemisorbed molecules. In particular, deprotonated benzotriazole molecules are by about 1 eV more stable on O/Cu(111) and OH/Cu(111) compared to an adsorbed intact molecule on bare Cu(111). For imidazole, the magnitude of such stabilization is weaker but still sizable (0.3–0.7 eV).
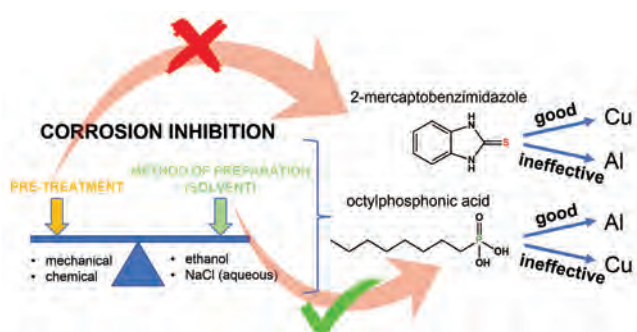
Figure 2: Influence of the pretreatment of a surface and the type of organic compound on the degree of corrosion inhibition of copper and aluminium was studied using electrochemical and surface analysis methods. If the two metals were immersed in an ethanolic solution of organic compounds, no corrosion inhibition for the metal occurred. However, if they were immersed in an aqueous solution, 2-mercaptobenzimidazole was an effective inhibitor for copper and octylphosphonic acid for aluminium.

We also addressed the widely used fundamental premise that the standard Gibbs energy of adsorption can be used to distinguish between physisorption and chemisorption. This premise is based on the fact that a physisorption interaction is weak and a chemisorption interaction is strong. To this end, we formulated several arguments to show that the standard Gibbs energy of adsorption is not a reliable criterion for distinguishing between the two adsorption modes. The most notable feature is the fact that chemisorption may involve bond-breaking and bond-making, resulting in a rather "weak" standard Gibbs energy of adsorption. For this reason, we recommended more reliable criteria, which are readily available in first-principle computational modelling studies, two of them being the molecule–surface distance and the electronic structure analysis of the molecule–surface bonding.

2. Hybrid sol-gel coatings used for corrosion protection
2.1. Silane-siloxane coatings

The sol-gel synthesis process is a versatile method used to produce a wide variety of materials and is increasingly used as a surface-modification method to alter porosity, wettability, catalytic activity, biocompatibility and corrosion performance of underlying substrates. Sol-gel coatings remain one of the important fields of our research work.

New hybrid sol-gel-acrylic coatings were synthesised by combining two sols, leading to polycondensation: Sol 1, prepared with copolymerisation between MAPTMS (3-(trimethoxysilyl)propyl methacrylate) and acrylate monomers, and Sol 2 of hydrolysed TEOS (tetraethyl orthosilicate). We used seven monomers with different alkyl chain lengths: E ethyl, M methyl, B

Figure 3: (a) Electron charge density difference of imidazole adsorbed on Cu(111) [left] and O/Cu(111) [right]. Electron accumulation regions are red while electron depletion regions are blue. Imidazole adsorbs more strongly to O/Cu(111) due to the enhanced N–Cu bond and the formed H-bond with $O_{(ads)}$. (b) The so-formed H-bond can lead to the deprotonation of an adsorbed molecule, resulting in a more stable adsorbed state.

butyl, H hexyl, O octyl and D dodecyl. Siloxane coatings siloxane-P*X*MA, where *X* stands for the acrylate monomer derivative, can be divided into two groups: coatings with short-chain monomers (M1, E2 and B4) with up to four carbon atoms and coatings with long-chain monomers (H6, O8 and D12) with up to twelve carbon atoms. A fluoro acrylate monomer with an ethyl chain length (FE) was additionally used. Derivatives of different lengths of alkyl and perfluoroalkyl chains were characterised in terms of copolymerisation kinetics during the sol synthesis; the composition, structure, wettability, thermal properties and porosity of the coatings were investigated using real-time Fourier transform infrared spectroscopy (ATR FTIR), XPS, time-of-flight secondary ion mass spectrometry (ToF-SIMS), charge-discharge optical emission spectroscopy (GDOES) and photothermal laser beam deflection spectroscopy (PTBD). The degree of copolymerisation between MAPTMS and the acrylate derivative (i.e., the organic moiety) depends on the type of derivative: it increases from methyl to butyl and then reaches a plateau. For derivatives with a longer chain, the steric effect prevents a further increase in copolymerisation kinetics and leads to uneven polycondensation. The same trend is observed in the hydrophobicity of the coatings: it increases for the derivatives with alkyl chains up to four carbon atoms, but longer chains show no further changes in hydrophobicity. Replacing hydrogen with fluorine in a chain improves the kinetics of copolymerisation of the sol and increases the hydrophobicity of the coating.

The surface and depth chemical composition were investigated using XPS, ToF-SIMS and GDOES techniques. Coatings consist mainly of an organic part, while the inorganic part with siloxane bonds is essential for achieving good adhesion to the substrate. Positive and negative TOF-SIMS fragments characteristic of the alkyl chains in acrylate derivatives were identified, and their intensity depended on the type of derivative. GDOES depth profiles confirmed a homogeneous depth composition of the coatings with a sharp coating/substrate interface. Photothermal deflection spectrometry results showed that the coatings with alkyl chains between hexyl and dodecyl have higher porosity compared to those with shorter chains. This is also reflected in the level of corrosion protection. Siloxane-polyacrylic sol-gel coatings were deposited on 7075-T6 aluminium alloy. The Si-PBMA coating showed the highest impedance after 18 months in a 5 wt.% NaCl solution and, therefore, the most effective anti-corrosion protection. Replacing hydrogen with fluorine does not significantly affect corrosion resistance.

Another important result concerns the thermal conductivity and diffusivity of these coatings. Compared to organic polymethyl methacrylate coatings, inorganic-organic hybrid sol-gel Si-P*X*MA coatings achieve approximately 50% higher thermal conductivity and diffusivity. We explained this with the favourable effect of the siloxane phase in a coating. The study was conducted in collaboration with the researchers from the CNRS, Chimie ParisTech, France and the University of Nova Gorica.
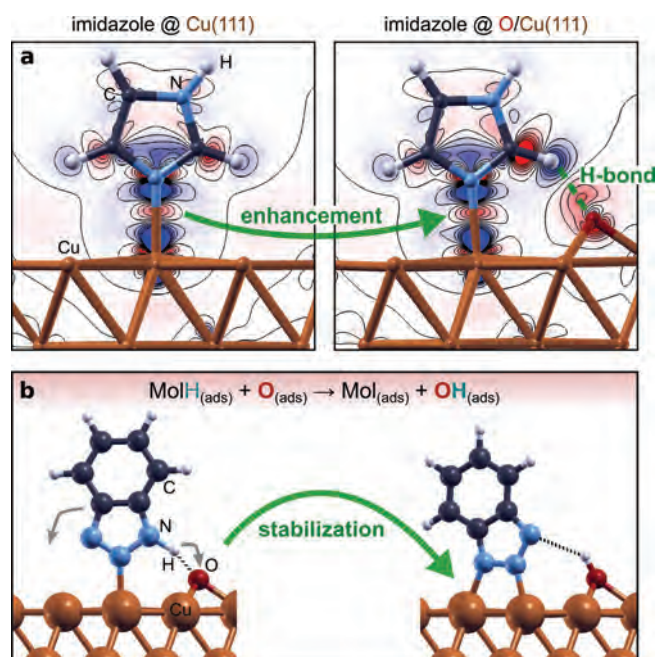
2.2. Silane-based coatings with zirconia

We prepared hybrid sol-gel coatings from TEOS and MAPTMS by adding zirconium(IV) tetrapropoxide crosslinked with methacrylic acid (TMZ). The coatings were prepared by adding zirconium(IV) tetrapropoxide crosslinked with methacrylic acid. Two series of samples were investigated: the first series included TMZ-I, TMZ-II and TMZ-III with different amounts of zirconium and the second series included TMZ-I/Ce, TMZ-II/Ce and TMZ-III/Ce, with an addition of cerium nitrate. We analysed the influence of the zirconium and cerium content on the thermal parameters of sol-gel coatings. For this purpose, two non-destructive and photothermal techniques were used: photothermal radiometry (PTR) and photothermal laser beam deflection spectroscopy (PTBD). A two-layer model was used to interpret the photothermal spectra. The results obtained with these two techniques were compared and discussed.

Different amounts of Zr in the siloxane network and the addition of Ce to the Si/Zr sol resulted in different thermal properties of the coatings. It was demonstrated that it is possible to simultaneously determine the thermal diffusivity and thermal conductivity of the samples by fitting the theoretical to the experimental frequency amplitude and phase of the PTR and PTBD characteristics. Thermal diffusivity values obtained with the PTR method are in a range of $(1.838–2.404) \times 10^{-3}$ cm^2/s; on the other hand, thermal conductivity values are in a range of $(1.710–2.730) \times 10^{-3}$ W/(cm·K). Thermal diffusivity values obtained with PTBD are in a range of $(1.75–2.53) \times 10^{-3}$ cm^2/s, and thermal conductivity values are in a range of $(1.8–2.6) \times 10^{-3}$ W/(cm·K). Using two methods made it possible to determine the obtained thermal parameters of the tested coatings accurately. In both cases, thermal diffusivity decreased with an increasing amount of Zr in the coating. The thermal conductivity had the same tendency as the thermal diffusivity. It was also shown that adding Ce to the sol-gel coating further reduced the thermal conductivity and diffusivity. The study was conducted in collaboration with the researchers from the University of Nova Gorica and University of Technology in Koszalin, Poland.

2.3. Superhydrophobic sol-gel coatings

An attractive way of modifying a metal surface is by obtaining a superhydrophobic surface. A surface modified in this way has a water droplet contact angle greater than 150° and a sliding angle lower than 10°. Such a surface exhibits high water-repellent properties, reflected in improved anti-corrosion protection, as it creates contact between the metal substrate and corrosive medium. At the same time, the surface also acquires other highly desirable properties, such as self-cleaning and extended durability against freezing. These properties make the surface treatment attractive for many academic and industrial fields.

A two-step process was used to obtain a hydrophobic or superhydrophobic surface. In the first step, the surface of aluminium was ground and then etched in a solution of hydrochloric acid and water peroxide (HCl/H$_2$O$_2$). Etching is a very exothermic and vigorous reaction, in which metal dissolves at 1.2 %/min. The surface, therefore, becomes very rough, on average around 5-7 μm (Figure 4). An additional property is that the roughness is hierarchical and consists of micro- and nanostructures. Such a topography enables the maintenance of air, which is essential for obtaining superhydrophobic properties.

In the second step, the rough surface was modified and dissolved in an ethanol (1 wt.%) solution of silane compounds *n*-octyltrimethoxysilane (AS-8) or 1H,1H,2H,2H-perfluorooctyltrimethoxysilane (FAS-8) for 30 minutes at room temperature. The unmodified and salinized aluminium surfaces were characterised with regard to the surface roughness, wettability, morphology and surface composition (Figure 5). Furthermore, we also tested the durability of the salinized surface against temperature and UV exposure. Corrosion properties were evaluated using potentiodynamic measurements and standard salt spray chamber testing (ASTM B117-19 standard). Finally, the self-cleaning and anti-icing abilities were evaluated.

Modification with silane compounds AS-8 and FAS-8 resulted in nanometer-thin films formed on the aluminium surface, which are covalently bonded to the substrate. The salinized surface exhibited high hydrophobicity (AS-8, a water droplet angle of 132°) and superhydrophobicity (FAS-8,
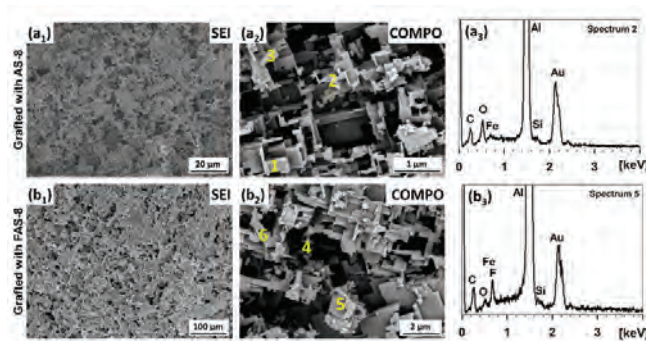
Figure 4: Scanning electron microscope images of an aluminium surface etched for 20 minutes in 1 M HCl/H$_2$O$_2$ and treated for 30 minutes in 1 wt.% n-octyltrimethoxysilane (AS-8) and 1H,1H,2H,2H-perfluorooctyltrimethoxysilane (FAS-8) solutions. The images were taken with secondary electrons (SEI) and backscattered electrons (COMPO). Numbers 1-6 indicate the places where the chemical analysis was performed using the EDS method. Spectra 2 and 5 are shown as representatives.

a water droplet angle of 156°). Durability tests confirmed that the surface modified with FAS-8 has greater thermal and UV stability. Aluminium salinized with FAS-8 also showed excellent self-cleaning performance and anti-icing performance.

Modified aluminium surfaces, especially those treated with FAS-8, provide very effective corrosion resistance during immersion in 0.1 M NaCl solution. A surface treated with FAS-8 remains unchanged even after 2 weeks of exposure in a salt spray chamber. These results reflect the influence of the composition of a silane compound, as the addition of fluorine in FAS-8 results in the formation of a more reflective surface, which also affects all the other properties. The presented surface etching and salinization process can be further used to produce large superhydrophobic aluminium surfaces for various industrial applications, as their usage is relatively simple and involves commercially available chemicals.

2.4. Conversion coatings

Corrosion protection of aluminium alloys is a significant area of research, as these materials are among the most important technological

Figure 5: Process of preparing a hydrophobic and superhydrophobic aluminium surface includes two stages: the formation of a hierarchically rough surface by etching it in an HCl/H_2O_2 solution and immersion in an ethanolic solution of n-octyltrimethoxysilane (AS-8) or 1H,1H,2H,2H-perfluorooctyltrimethoxysilane (FAS -8). The modified (super)hydrophobic surface improves the corrosion resistance and exhibits self-cleaning properties.

metals nowadays, used in many applications. Aluminium alloys are heterogeneous alloys that consist of an aluminium matrix and many intermetallic particles (IMPs) based on iron, copper, zinc, silicon, magnesium or manganese, added to improve the strength and mechanical properties. On the other hand, these particles show different electrochemical activities than aluminium; therefore, an alloy is subject to local forms of corrosion, especially galvanic and pitting corrosion. This process is reduced by the formation of a conversion coating, i.e., a protective layer on the surface, thus reducing the electrochemical activity of the matrix and IMPs. The most effective conversion coatings are based on zirconium or rare earths, especially cerium. The latter is prepared from cerium(III) salts, where the inhibition effect is based on the precipitation of $Ce(OH)_3$. This process, which is only possible at a pH of around 8.5, follows a local increase in pH during the oxygen reduction reaction at IMP cathodic sites, so the deposition starts at these sites and then gradually spreads to the alloy matrix. Cerium ions react with hydroxyl ions to form $Ce(OH)_3$. Ce(III) hydroxide can be partially oxidised to $Ce(OH)_4$ in neutral solutions. Therefore, Ce(III) and Ce(IV) are responsible for the corrosion inhibition on an aluminium alloy surface.

In our laboratory, we have already considered the influence of various mechanical and chemical pretreatments on the morphology, composition, wettability and corrosion properties of the AA7075-T6 alloy. We also studied how the type of Ce(III) salt affects the formation of the conversion cerium layer and found that Ce(III) acetate forms the most effective layer. The focus of this study was the correlation between different surface pretreatments before and after immersion in sodium chloride with added Ce(III) acetate. The main hypothesis is that even the most effective inhibition can be achieved with appropriate surface pretreatment. We chose two types of mechanical pretreatment (grinding and polishing) and two types of chemical pretreatment (alkaline cleaning with commercial etch SurTec® (pH = 8.3) or with sodium hydroxide (pH = 11.6); in both cases, the surface was further rinsed with nitric acid (HNO_3) to remove alkaline etching products from the surface).

The finding that chloride ions can stabilize the adsorption of azole corrosion inhibitors is surprising and counterintuitive in view of the well-known experimental fact that chlorides are aggressive corrosion activators.

The surface of the alloy was analysed in terms of composition, topography, morphology and electrochemical properties, even during long-term testing (up to 1 month). Figure 6 shows images of aluminium alloy 7075-T6 samples treated with different surface treatments: a) grinding, b) grinding and polishing; and grinding and chemical treatment with c) $NaOH/HNO_3$ and d) $SurTec/HNO_3$ and then immersed for 1 month in a solution of 0.1 M NaCl with an addition of 3 mM $Ce(OAc)_3$. Significant differences between surface pretreatments were reflected in the properties of the resulting cerium layer. Among the mechanical pretreatments, polishing gave better results than grinding, as the layer was more homogeneous. The pretreatment with $NaOH/HNO_3$ had a negative effect on the formation of the cerium layer as, after 3 days of immersion, a large part of the sample was covered with corrosion products, confirming that the added cerium compound cannot effectively protect the surface from corrosion. After 1 month, a thick layer of corrosion products covered almost the entire surface of the alloy. After the chemical pretreatment with $SurTec/HNO_3$, the cerium layer formed evenly over the entire surface and there were no corrosion products.

Figure 7 shows the dependence of the magnitude of the impedance on the immersion time in 0.1 M NaCl with the addition of 3 mM $Ce(OH)_3$. Since the magnitude of impedance is proportional to the degree of corrosion protection, we conclude that pretreatment affects the degree of protection. An adequate chemical treatment improves local corrosion protection even after a long-term immersion. An important finding of this study is the fact that the effectiveness of corrosion protection is also highly dependent on surface pretreatment.
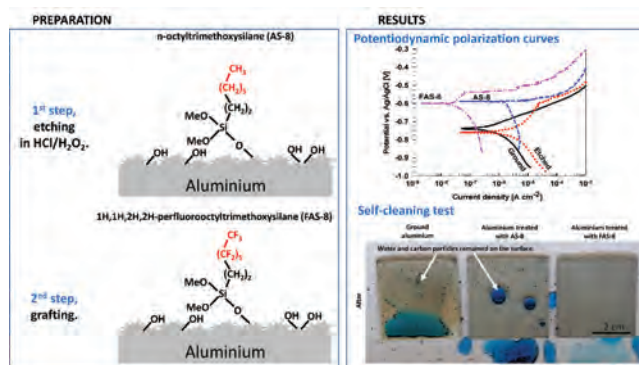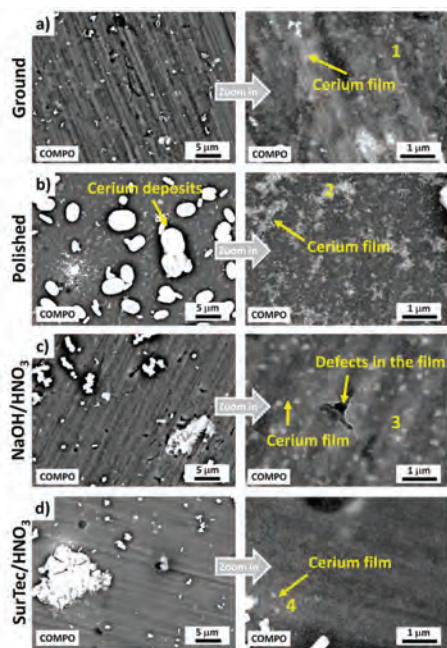
Figure 6: Scanning-electron-microscope images of the surfaces of 7075-T6 aluminium-alloy samples treated with different surface treatments: a) grinding, b) grinding and polishing, and grinding and chemical treatment with c) NaOH/HNO₃ and d) SurTec/HNO₃ and immersed for 1 month in a solution of 0.1 M NaCl with the addition of 3 mM Ce(OAc)₃. The images were made with backscattered electrons.

With DFT modelling, we helped explain why Pt nanoparticles supported by titanium oxynitride outperform the benchmark Pt catalysts for hydrogen evolution reaction.
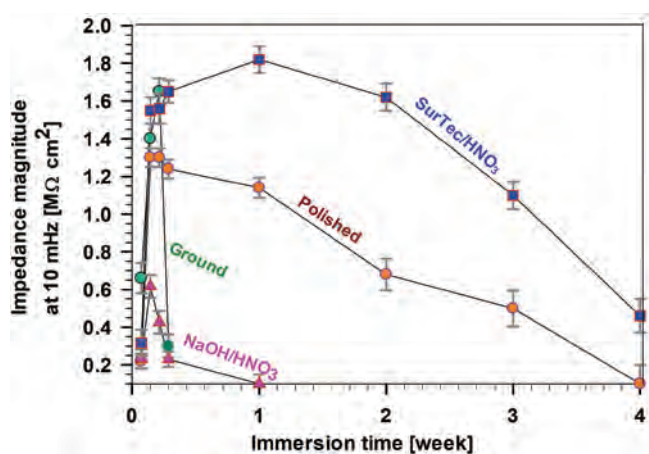

Figure 7: Dependence of the magnitude of the impedance at 10 mHz on the immersion time in 0.1 M NaCl with the addition of 3 mM Ce(OAc)₃ for differently pretreated samples: ground, polished and ground and chemically treated with NaOH/HNO₃ and SurTec/HNO₃

In the next study, we investigated the relationship between the microstructure of AA7075-T6 aluminium alloy and the type of cerium(III) salt. The study aimed to investigate two key relationships: (i) how the type of cerium salt used for conversion affects the composition, thickness and electrochemical properties of the layer and (ii) how the deposition depends on the microstructure or type of intermetallic particles. The application of the cerium conversion layer to 7075-T6 aluminium alloy was made via a simple dipping process. Four series of samples were prepared with immersion in 0.1 M NaCl with and without the addition of 3 mM Ce(III) salts: chloride, nitrate and acetate. Samples were analysed using scanning electron microscopy with a chemical analysis at the same site before and after immersion. Therefore, this study was site-specific, focusing on the corrosion mode and deposition of the cerium layer depending on the type of intermetallic particles.

In the NaCl solution, all IMPs were susceptible to selective dissolution. In the S-phase of Al_2CuMg, the dissolution of Mg and Al caused an enrichment of the particles with Cu and intense dissolution of the surrounding matrix, forming cracks. Also, in IMP Al(Fe,Cu)Si, the dissolution of Al resulted in an enrichment with Cu, which contributed to a stronger cathodic activity of the IMP and, with time, a strong dissolution of the surrounding matrix.

Adding Ce(III) chloride and NaCl nitrate significantly reduced the corrosion attack on AA7075-T6. The surface was covered with cerium-rich deposits. The deposition of Ce-rich layers started at large Al(Fe,Cu)Si IMPs and proceeded laterally across the surface, depending on the electrochemical character of individual IMPs. Therefore, some IMPs were slower than others in the deposition process, which also took place on the matrix, but slower than on the IMPs.

A cross-sectional analysis of larger deposits yielded new details on the operative mechanism of cerium hydroxide deposition. Al dissolution from IMPs Al(Fe,Cu)Si leaves particles highly enriched with Cu. We, therefore, concluded that the selective dissolution mechanism applies not only to the S-phase but also to the IMPs containing Fe and Cu. Another new finding was the presence of Cl inside the deposit, indicating that chloride ions promote the selective dissolution of Al. An IMP surface, which remains enriched with Cu, becomes a strong cathode where oxygen reduction occurs, leading to the local alkalisation (pH = 8.5) necessary for the Ce-hydroxide precipitation. For large IMPs, the process can be so intense that a burst of electrochemical activity results in a precipitation of micrometre-sized deposits of cerium hydroxide (Figure 8). The latter contained cerium from the solution and metal ions that dissolved from the alloy. Therefore, the conversion layer formation is a dynamic process with a selective dissolution of Al to the outside and precipitation of Ce-hydroxide to the inside. Because of this "two-way street" dynamics, the interior of the deposit above the IMPs is complex. It comprises (a) a mixed Cu-rich/Al-poor boundary layer at the top of the IMPs containing Fe, some O and also Cl, (b) an intermixed Ce-Cu-Al-Fe layer with lower Cu and Fe contents and a higher O content than in the lower layer and (c) a Ce-Al-hydroxide layer that forms most of the interior of the deposit.

On the alloy matrix covered with a spontaneously formed nanometer layer of aluminium oxide, the mechanism of chloride-assisted selective dissolution was not operative. The cerium hydroxide layer formed only slowly due to a much lower electrochemical activity and, consequently, a longer time required to generate the alkaline conditions necessary for the conversion of cerium ions from the solution into cerium deposits. The difference in the thickness of the Ce-conversion layer was 50-100 times smaller than that of large IMPs.

The behaviour of Ce(III) acetate is completely different from that of Ce(III) chloride and nitrate. Large Ce-rich deposits were observed on the IMPs or matrix surface. The whole surface was covered with a thin Ce-hydroxide layer, which prevented IMP selective dissolution, including the S-phase. This study verifies that the Ce hydroxide deposition on an aluminium alloy surface from an aqueous solution of cerium ions is a complex process, in which the dealloying of intermetallic particles plays an essential role.

2.5. Catalysis: DFT modelling of metal–support interaction and hydrogen adsorption

Titanium oxynitride (TiON) has been recently recognized as a promising support material for electrocatalytic applications. In particular, Pt nanoparticles supported by TiON were shown to exhibit improved stability and activ-

ity for a hydrogen evolution reaction (HER) compared to the benchmark HER catalyst composed of Pt nanoparticles on a high-surface-area carbon support. To help explain this experimental finding, we performed a detailed DFT study and verified that the adhesion of Pt nanoparticles to TiON is considerably stronger than to a carbon support (Figure 9b). The stronger adhesion provides two benefits for HER. First, it reduces the detachment and coalescence of Pt nanoparticles, thus keeping them well dispersed and maintaining a high surface area of platinum during the reaction. Secondly, it is known that the supports that bind metal nanoparticles more strongly affect their reactivity so that nanoparticles bind covalently-bonded adsorbates more weakly. According to the Sabatier principle, Pt binds chemisorbed H atoms slightly too strongly; hence, a reduced H–Pt binding due to the strong metal–support interaction should improve the catalyst's activity. DFT calculations confirm that Pt nanoparticles supported by TiON systematically bind H atoms more weakly than those supported by carbon (Figure 9a), irrespective of the H coverage.

Some outstanding publications in the past year

1. Milošev I, Hamulić D, Rodič P, Carrière C, Zanna S, Budasheva H, Korte D, Franko M, Mercier D, Seyeux A, Marcus P, Siloxane polyacrylic sol-gel coatings with alkyl and perfluoroalkyl chains: Synthesis, composition, thermal properties and long-term corrosion protection. *Appl. Surf. Sci.*, 2022, **574**, 151578

2. Milošev I, Rodič P, The effect of surface pretreatment of aluminum alloy 7075-T6 on the subsequent inhibition by cerium(III) acetate in chloride-containing solution, *J. Electrochem. Soc.,* 2022, **169**, 011504

3. Rodič P, Kapun B, Milošev I, Superhydrophobic aluminium surface to enhance corrosion resistance and obtain self-cleaning and anti-icing ability. *Molecules*, 2022, **27**, 1099

4. Kozlica DK, Milošev I, Corrosion inhibition of copper and aluminium by 2-mercaptobenzimidazole and octylphosphonic acid: surface pre-treatment and method of film preparation. *Electrochim. Acta*, 2022, **431**, 141154

5. Dlouhy M, Kokalj A, How adsorbed H, O, OH and Cl affect plain adsorption of imidazole on copper. *Corros. Sci.,* 2022, **205**, 110443

6. Kokalj A, Corrosion inhibitors: physisorbed or chemisorbed? *Corros. Sci.*, 2022, **196**, 109939

7. Smiljanić M, Panić S R, Bele M, Ruiz-Zepeda F, Pavko L, Gašparič L, Kokalj A, Gaberšček M, Hodnik N. Improving the HER activity and stability of Pt nanoparticles by titanium oxynitride support. *ACS Catal.,* 2022, **12**, 13021–13033

Awards and Appointments

1. Veronika Bračič (student of the Faculty of Chemistry and Chemical Technology, University of Ljubljana) received a commendation at the 52nd Krka Awards. Her contribution entitled "Corrosion protection of aluminium alloy by conversion and sol-gel coating" was prepared under the supervision of Asst. Prof. dr Peter Rodič.

Organization of conferences, congresses and meetings

1. Prof. dr I. Milošev, together with S. Virtanen, J. Locke and C. Dong, was a guest editor of the focus issue Women in Electrochemistry published by the Journal of The Electrochemical Society. The issue aimed to celebrate and promote many achievements of women investigating the myriad aspects of electrochemistry and reduce gender inequality in science and engineering.
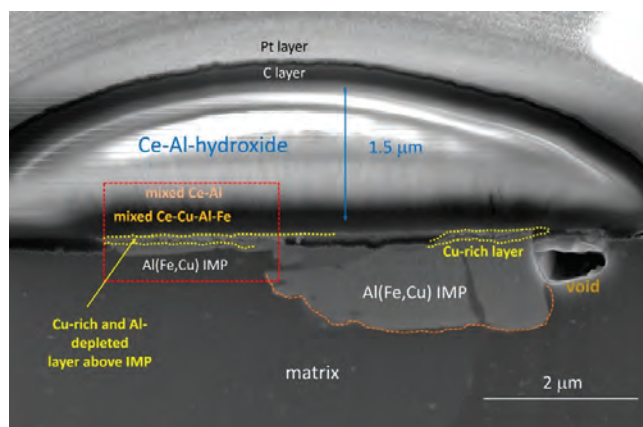
Figure 8: Cross-section of the cerium conversion layer on intermetallic particle (IMP) Al(Fe,Cu) of aluminium alloy 7075-T6. The layer was formed during the 24 h immersion in 0.1 M NaCl with added 3 mM CeCl₃. The red rectangle denotes a detail of the interface with IMP covered with a Cu-rich and Al-depleted layer, followed by a mixed Ce-Cu-Al-Fe layer and a thick layer of Ce-Al-hydroxide. The latter also contains some chlorine.
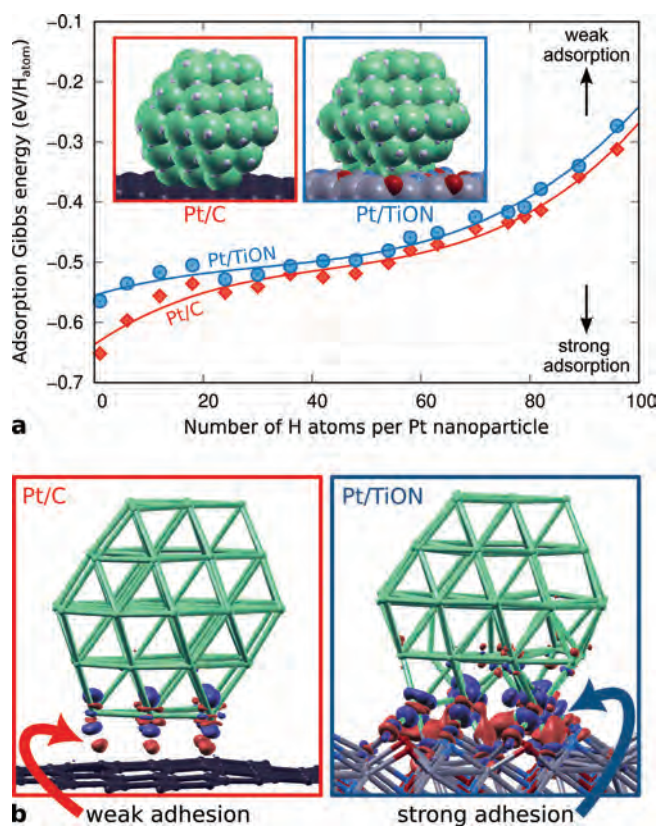
Figure 9: Pt nanoparticles supported by carbon (Pt/C) and titanium oxynitride (Pt/TiON): (a) Pt nanoparticles supported by TiON systematically bind H atoms more weakly than those supported by carbon; (b) electron charge density difference reveals that Pt nanoparticles adhere weakly to carbon and strongly to TiON.

INTERNATIONAL PROJECTS

1. COST CA17126: Towards Understanding and Modelling Intense Electronic Excitation
   Prof. Anton Kokalj
   Cost Association Aisbl
2. H2020 - MAMI; Magnetics and Microhydrodynamics - From Guided Transport to Delivery
   Prof. Ingrid Milošev
   European Commission
3. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Ingrid Milošev
   European Commission
4. DCOIN: Disentagling COrrosion and its INhibition
   Dr. Matic Poberžnik
   Slovenian Research Agency
5. The Role of Corrosion Protection of Metals in Sustainable Development
   Prof. Ingrid Milošev
   Slovenian Research Agency

RESEARCH PROGRAMMES

1. Chemistry for sustainable development
   Asst. Prof. Peter Rodič

2. Advanced materials for low-carbon and sustainable society
   Prof. Ingrid Milošev

R & D GRANTS AND CONTRACTS

1. Development of advanced nanostructured catalysts for hydrogenation of carbon dioxide to methanol
   Prof. Anton Kokalj
2. Structures of elusive noble-gas compounds elucidated by 3D electron diffraction
   Prof. Anton Kokalj
3. 4D STEM of energy related materials down to quantum level
   Prof. Anton Kokalj
4. Antibacterial alloys: development by additive 3D manufacturing, characterization and clinical applications
   Prof. Ingrid Milošev
5. Photocatalytic water treatment - development of immobilized catalysts and compact reactor systems
   Asst. Prof. Peter Rodič
6. Ecology laboratory with mobile unit
   Asst. Prof. Peter Rodič
   Ministry of Defence

VISITORS FROM ABROAD

1. Dr Njomza Ajvazi, College of Medical Sciences "Rezonanca", Priština, Republic of Kosovo, 5 July to 30 September 2022
2. Dr Dominique Costa, Physical Chemistry and Surfaces, Chimie ParisTech, France, 5–8 December 2022
3. Prof. dr Philippe Marcus, Physical Chemistry and Surfaces, Chimie ParisTech, France, 5–7 December 2022

STAFF

Researchers
1. Prof. Anton Kokalj
2. **Prof. Ingrid Milošev, Head**
3. Asst. Prof. Peter Rodič

Postdoctoral associates
4. Dr. Dževad Kozlica
5. *Dr. Matic Poberžnik, on leave since 01.01.21*
6. Dr. Ivan Spajić

Postgraduates
7. Matjaž Dlouhy, B. Sc.
8. Lea Gašparič, B. Sc.
9. Erik Gregori, B. Sc.
10. Ana Kraš, M. Sc.
11. *Nikolina Lešić, M. Sc., left 01.03.22*

Technical officer
12. Barbara Kapun, B. Sc.

ELECTRONIC CERAMICS DEPARTMENT

K-5

The Electronic Ceramics Department is active in the research of the synthesis, properties and applications of ceramic materials for electronics and energetics, mainly complex multifunctional materials and structures. The materials of interest include piezoelectrics, ferroelectrics, relaxors, multiferroics, conductive oxides, low-dimensional magnets and cuprate superconductors. The emphasis is on the creation of properties by the synthesis and structure on the nano-, micro- and macro-levels. The group also works on the principles of basic technologies of ceramic pressure sensors, ceramic MEMS and flexible electronics.

Head:
Prof. Barbara Malič

We continued the work on **lead-free ferroics**. Sodium niobate ($NaNbO_3$) is an end member of the lead-free piezoelectric $KNbO_3$–$NaNbO_3$ solid solution (KNN)-based formulations and a prototypical antiferroelectric. In collaboration with colleagues from Technical University Darmstadt we studied the undoped and donor-doped sodium niobate (1 mol % Ca or Sr) to elucidate the role of dopants on the Fermi energy, electrical conductivity and energy gap of sodium niobate. The average grain size of sodium niobate is strongly reduced upon doping, from about 90 mm to about 1 mm , a phenomenon commonly observed in alkali-niobate ceramics and attributed to reduced grain-boundary migration. Both donor-doped materials exhibit good insulating behaviour, i.e., room-temperature conductivity of up to 10×10^{-10}S/cm, which is only slightly higher than that of the undoped material, suggesting that the energy gap of $NaNbO_3$ is substantially higher than the gap of 3.4 eV to 3.5 eV determined from optical spectroscopy reported in the literature.

We continued our investigations on the electric-field-induced microstrain mechanisms in **polycrystalline $BiFeO_3$**. Using in-situ X-ray diffraction analysis we discovered an unexpected decrease in the lattice strain with increasing field amplitude at sub-Hz driving frequencies. The response was assigned to a coupled effect of local domain-wall conductivity and elastic intergranular coupling, leading to an extensive redistribution of electric fields inside individual grains that ultimately results in the peculiar lattice-strain field dependence.

Together with colleagues from the National Institute of Chemistry in Ljubljana, Ecole Polytechnique Fédérale de Lausanne and Université Paris-Saclay, CentraleSupélec we performed an in-situ scanning-transmission electron microscopy study in which the response of domain walls in a $BiFeO_3$ single crystal in a capacitor-like configuration was directly observed. The dynamics of domain walls, in the presence of defects, revealed unique and complex phenomena at the atomic level (Figure 1). The study published in Nano Letters provides insight into the dynamic, atomistic processes at domain walls in ferroelectric materials.

Based on its efficiency in the mechanochemical synthesis of lead-based perovskites, we tested the so-called seeding approach in the synthesis of lead-free $BiFeO_3$–$BaTiO_3$ ceramics. The procedure involved the use of $BaTiO_3$ powder particle seeds during mechanochemical activation, which should promote the perovskite formation. In contrast to expectations, the use of $BaTiO_3$ seeds resulted in core-shell structured ceramics likely due to chemical segregation of the $BaTiO_3$-rich regions. Homogeneous ceramics were obtained by a conventional technique in which seeds were not used. While the homogeneous $BiFeO_3$-$BaTiO_3$ ceramic was characterized by larger, weak-field piezoelectric coefficients, the heterogeneous ceramics exhibited pronounced high-field strains due to greater reversibility in the response, which was correlated with the presence of chemical heterogeneities. The study was performed with colleagues from Denmark.

In collaboration with colleagues from the Department of Condensed Matter Physics, JSI, and the Department of Advanced Materials, JSI, as well as with colleagues from Morocco, France, and Ukraine, we studied the dielectric and piezoelectric properties of **barium-titanate-based ceramics**. Different compositions of the

Barbara Malič received the Ferroelectrics Recognition Award 2022 from the IEEE Ultrasonics, Ferroelectrics and Frequency Control (UFFC) Society for her outstanding contribution to the elucidation of the relationships between chemical and physical properties of ferroelectric ceramics.
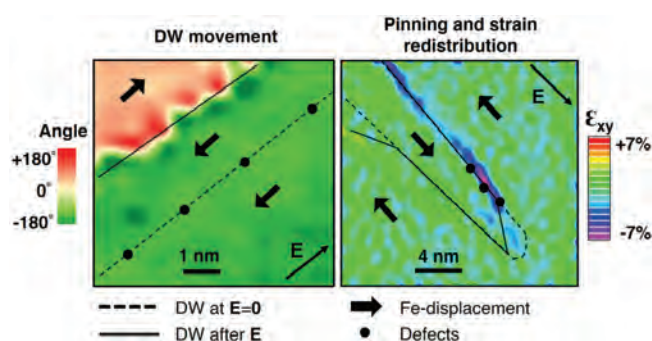

Figure 1: Response of domain walls (DWs) investigated with in-situ bias scanning transmission electron microscopy. Fe-displacement orientation (left) and strain distribution (right) were evaluated from the HAADF atomic resolution images. Defect segregation, changes in strain and the bound charge distribution at domain walls under electrical stimuli were observed.

$(1-x)Ba_{0.85}Ca_{0.15}Zr_{0.10}Ti_{0.90}O_3–xBaTi_{0.89}Sn_{0.11}O_3$ (xBTSn, x = 0.2, 0.4 and 0.6) solid solution were prepared. Ceramics with composition x = 0.2 exhibited the highest piezoelectric coefficient d_{33} = 228 pC·N^{-1}.

We further investigated the origins of the large piezoelectric response of **lead-based relaxor-ferroelectric ceramics** based on the $(1-x)Pb(Mg_{1/3}Nb_{2/3})O_3–xPbTiO_3$ (PMN-PT) solid solution. A systematic analysis of the piezoelectric nonlinear harmonic response of the relaxor-based PMN-PT ceramics and non-relaxor $Pb(Zr,Ti)O_3$ (PZT) samples across a great part of the respective phase diagrams revealed fundamental differences in the dynamic domain-wall contributions to the properties in these two systems. Although indirectly, we were able to identify for the first time the key nonlinear features related to the low-angle domain-wall dynamics and contrasted this behaviour with the dynamics of conventional domain walls in ferroelectrics such as PZT. The results were published in the form of a feature paper in J. Am. Ceram. Soc.

In collaboration with colleagues from the Reactor Physics Department, JSI, we investigated the feasibility of using $(1-x)Pb(Mg_{1/3}Nb_{2/3})O_3–xPbTiO_3$ (PMN–100xPT) **electrocaloric materials** in applications where the material is exposed to high neutron and γ radiation. For this purpose, PMN–100xPT ceramics (x = 0, 0.1, and 0.35) were irradiated with a neutron fluence of 10^{15} to 10^{17} neutrons/cm^2, which exceeds the largest expected neutron irradiation in the European Council for Nuclear Research (CERN) and simultaneously exposed to γ irradiation. The neutron and γ radiation partially affect the functional properties of the PMN–35PT. In contrast, the functional properties of the irradiated PMN and PMN–10PT samples are similar to those of the pristine samples; therefore, we concluded that these materials can be used as working materials in electrocaloric coolers exposed to such harsh environments.

Part of our research was focused on **single-crystal growth and magnetic studies of low-dimensional and frustrated magnetic materials** such as $SrCu_2(BO_3)_2$ and $NdTa_7O_{19}$.

We first synthesised polycrystalline $SrCu_2(BO3)_2$ and then developed a flux method to grow mm-sized, blue single crystals of $SrCu_2(BO_3)_2$ and doped-$SrCu_2(BO_3)_2$ (Figure 2a), which allowed us to investigate their magnetic properties further. On the other hand, we also performed the single-crystal growth of the Ising triangular-lattice antiferromagnet neodymium heptatantalate, $NdTa_7O_{19}$ (Figure 2b), which will be used to obtain a more complete understanding of the magnetic ground state of this compound. In collaboration with the Condensed Matter Physics Department, JSI, these crystals will be used for a series of measurements such as magnetization, heat capacity, μSR and inelastic neutron scattering.

The other part of our research focused on silver(II) compounds. Fluoride phases containing spin ½ $4d^9$ Ag^{2+} were predicted to have exotic magnetic properties similar to cuprates. Since Ag^{2+} is a very powerful oxidant, its synthesis techniques are limited to those that use F_2 or anhydrous HF. In addition, the thermal decomposition of the main Ag^{2+} precursor, AgF_2, further limits the methods for preparing these compounds. We therefore focused our efforts on developing an alternative synthesis technique to obtain new silver(II) phases.

In the quest for alternative piezoelectric materials to lead-based perovskites such as PZT, the large piezoelectric effect of $Ba(Zr,Ti)O_3$-$(Ba,Ca)TiO_3$ or BZT-BCT in a bulk form has been reported. The Chemical Solution Deposition (CSD) of BZT-BCT thin films is a cost-effective approach for the miniaturization of devices. In general, CSD of $BaTiO_3$ (BT) or BT-based thin films such as BZT-BCT, alkaline-earth carboxylates, and transition-metal alkoxide are dissolved and diluted, respectively, in carboxylic acid and alcohol solvents. The reactions of the solvents led to the formation of water and eventually the progressive hydrolysis of transition-metal alkoxide and precipitation. In order to resolve these problems, we developed a new synthesis route in which ethylene glycol (EG) is used as the solvent for alkaline-earth carboxylates. The EG-based BT coating solutions are stable for at least a few months. The films deposited from the EG-ethanol-based solution yield perovskite films with columnar microstructures and good dielectric and ferroelectric properties (Figure 3).

> **PhD students Oana-Andreea Condurache, Katarina Žiberna and Barbara Repič won awards for presenting their dissertation results at international conferences.**
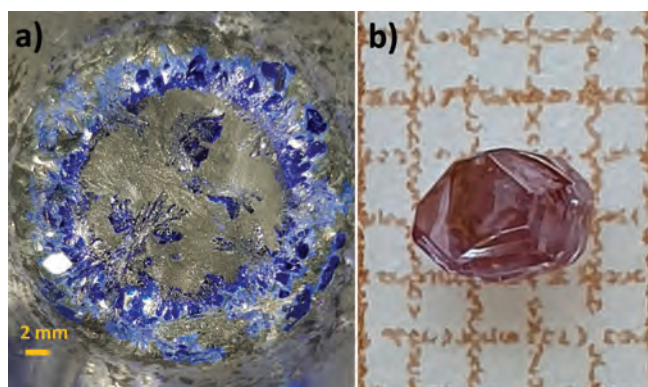
Figure 2: a) Milimeter-sized, blue $SrCu_2(BO_3)_2$ single crystals as grown by the flux method in a platinum crucible. b) A lilac single crystal of the quantum-spin-liquid candidate $NdTa_7O_{19}$ grown at K5.

> **Since 2022, Andreja Benčan Golob has been leading a three-year large interdisciplinary ARRS project, the purpose of which is to establish a platform for the development of a new methodology of scanning transmission electron microscopy (4D STEM) for characterizing the properties of energy-efficient materials down to the quantum level. The project connects scientists involved in the development of microscopy, the synthesis of various energy-efficient materials, computational methods and artificial intelligence methods from two leading Slovenian research institutions, the Jožef Stefan Institute and the National Institute of Chemistry.**

In collaboration with colleagues from the Department of Condensed Matter Physics, JSI, and the Department of Advanced Materials, JSI, as well as colleagues from Morocco, France, and Ukraine, we studied piezoelectric properties of $H_2(Zr_{0.1}Ti_{0.9})_3O_7$ nanowires. Piezo-response force microscopy (PFM) was used to determine the piezoelectric coefficient $d_{33} \sim 25$ pm·V^{-1} of a single nanowire. Furthermore, in collaboration with colleagues from the Department for Materials Synthesis, JSI, we investigated the functional properties of $Bi_4Ti_3O_{12}$ nanoplatelets and nanowires. Observations of the ferroelectric domains by PFM indicated the piezoelectric/ferroelectric nature of both nanostructures.

We continued research on **thick films** of environmentally benign piezoelectrics based on $K_{0.5}Na_{0.5}NbO_3$ (KNN) on ceramic substrates for energy-harvesting and ultrasound-transducer applications. The multilayer structure consists of a KNN substrate with a high attenuation coefficient of 0.5 dB/mm/MHz and a **screen-printed** KNN thick film. The electroacoustic response of the multilayer structure in water provides a central frequency of 15 MHz and a very large fractional bandwidth (BW) of 127% at -6dB. The multilayer structure is a candidate for imaging applications operating above 15 MHz. The research was conducted as part of the Proteus project in collaboration with researchers from the University of Tours, France.

We continued research on materials and technologies to realise an electrochemical sensor system (MES) for neonicotinoid pesticide detection. The miniature three-electrode systems on alumina substrates were fabricated by **screen printing**. We confirmed the electrochemical response of pure carbon-based working electrodes for neonicotinoid detection. In collaboration with the Faculty of Chemistry and Chemical Technology, University of Ljubljana, we improved the response by modifying the carbon-based working electrode with metal oxide particles.

We continued with the preparation of **thick films by aerosol deposition**. The aerosol deposition facility is a part of the Laboratory for the Ultracool Preparation of Complex Oxides, for which financial support was granted by **the Director's fund ULTRACOOL project**. In collaboration with colleagues from Friedrich-Alexander-University Erlangen-Nürnberg, Germany, and the University of Tours, France, we focused on the preparation and characterization of multifunctional $0.65Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.35PbTiO_3$ (PMN–35PT) thick films deposited on stainless steel. The films annealed at 500 °C withstand electric fields of 1350 kV·cm^{-1} and exhibited promising room-temperature energy-storage properties; the recoverable energy density reached 15 J·cm^{-3}, and an electric-field cycling stability of 5 million cycles. Macroscopic displacement measurements revealed a maximum relative strain of 0.38% at 1000 kV·cm^{-1}, corresponding to an inverse effective piezoelectric coefficient of $\sim$40 pm·V^{-1}.

Furthermore, we developed a procedure to study films in the cross-section by PFM. In this way, we investigated the relaxor-ferroelectric domain structure of **screen-printed and aerosol-deposited** PMN–35PT films. Due to the different preparation methods used for these two groups of films, the grain size and, thus, the relaxor-ferroelectric domain structures differ. Micron-scale domains are observed in the screen-printed films, while sub-micrometer-scale domains are found in the aerosol-deposited films. However, no change in the ferroelectric domain structures was observed across the thicknesses of the films.

Using aerosol deposition, we also prepared $0.9Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.1PbTiO_3$ (PMN-10PT) thick films on polymer substrates (Figure 4). After annealing at 400 °C, the films exhibit high polarization (38 µC·cm^{-2}) and low hysteresis losses, leading to a recoverable energy density of 10 J·cm^{-3} at 1000 kV·cm^{-1}. The excellent stability of energy-storage properties was confirmed after bending to a radius of 3 mm (1.1% bending strain) and after repeating 100,000 bending cycles. Such an energy-storage operation makes these thick-film structures promising for integration into a wide range of flexible electronic devices.

We progressed in our research on the **cold sintering** of functional oxides in our ULTRACOOL laboratory, expanding the sintering from $BiFeO_3$ ceramics to $(K,Na)NbO_3$ perovskites and composites with piezoelectric polymers (PVDF). While optimization of all parameters for successful cold sintering of the ceramic compounds is still an ongoing process, the first measured electromechanical properties of the sintered ceramics are very promising and show a great perspective of cold-sintered oxides for actuator and energy-storage applications. Preliminary studies
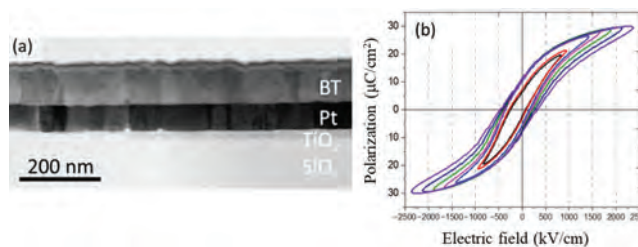
Figure 3: a) Cross-section transmission electron microscopy micrograph of a barium titanate (BT) thin film revealing a predominantly columnar microstructure. The ethylene glycol-ethanol-based coating solution was spin-coated on a platinized silicon substrate, dried, pyrolysed and annealed at 800°C four times to reach a thickness of approximately 130 nm. b) Polarization vs. electric field hysteresis loops of the BT film with a gold top electrode.

A European patent entitled "A vibration system and a filtering plate for filtering substances" has been granted, co-authored by Danjela Kuščer, Tadej Rojac and Darko Belavič.
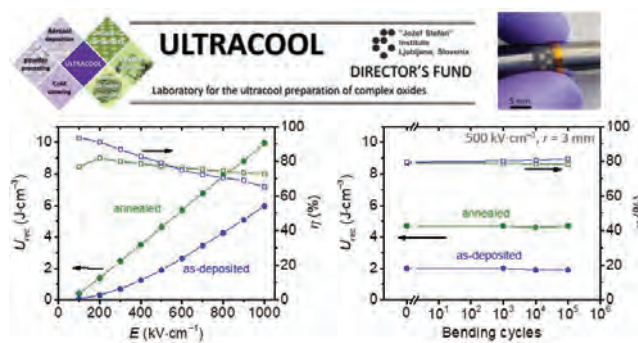
Figure 4: Room-temperature energy-storage properties of PMN-10PT thick films deposited on polymer substrates; (left) recoverable energy density (U_{rec}) and efficiency (η) as a function of electric field (E), (right) U_{rec} η as a function of mechanical bending cycles.

Mojca Otoničar and Tadej Rojac organized, with the help of colleagues and support of the MIDEM society, the 57ᵗʰ International Conference on Microelectronics, Devices and Materials with the workshop on Energy Harvesting: Materials and Application, which was held in Maribor. Invited lecturers from foreign and Slovenian institutions presented the state of the art in the field, followed by more than 30 regular contributions.

show that the main benefits of the cold sintering of ceramics are, besides the energy savings due to the low-temperature processing, their dielectric breakdown strength that allows high voltages applied to the materials without their disintegration, as well as high dielectric permittivity and low dielectric losses.

In collaboration with the National Institute of Chemistry from Ljubljana and RC eNeM we investigated the integration of transparent electronics on an industrial glass product for the next generation of transparent electronics. The project focuses on realising solution-manufactured indium-free conductors through a low-cost, environmentally friendly industrial process.

Some outstanding publications in the past year

1. Šadl, Matej, Lebar, Andrej, Valentinčič, Joško, Uršič Nemevšek, Hana. Flexible energy-storage ceramic thick-film structures with high flexural fatigue endurance. ACS applied energy materials, ISSN 2574-0962, 2022, vol. 5, no. 6, str. 6896-6902, doi: 10.1021/acsaem.2c00518. [COBISS.SI-ID 110882307]
2. Uršič Nemevšek, Hana, Prah, Uroš, Rojac, Tadej, Jazbec, Anže, Snoj, Luka, Drnovšek, Silvo, Bradeško, Andraž, Mirjanić, Anja, Vrabelj, Marko, Malič, Barbara. High radiation tolerance of electrocaloric $(1-x)$ Pb(Mg1/3Nb2/3)O3–xPbTiO3. Journal of the European ceramic society, ISSN 0955-2219. [Print ed.], 2022, vol. 42, iss. 13, str. 5575-5583, ilustr., doi: 10.1016/j.jeurceramsoc.2022.05.051. [COBISS.SI-ID 111403011]
3. Kuščer, Danjela, Kmet, Brigita, Drnovšek, Silvo, Bustillo, Julien, Levassort, Franck. Lead-free sodium potassium niobate-based multilayer structures for ultrasound transducer applications. *Sensors*, ISSN 1424-8220, 2022, vol. 22, no. 9, str. 3223-1-3223-13, doi: 10.3390/s22093223. [COBISS.SI-ID 105730563]
4. Otoničar, Mojca, Dragomir, Mirela, Rojac, Tadej. Dynamics of domain walls in ferroelectrics and relaxors. Journal of the American Ceramic Society. Nov. 2022, vol. 105, iss. 11, str. 6479-6507, ilustr. ISSN 1551-2916. DOI: 10.1111/jace.18623. [COBISS.SI-ID 114034947] (pregledni članek)

Awards and Appointments

1. Oana-Andreea Condurache: Student Award for the contribution: Monitoring Bismuth Ferrite Domain Walls Behavior Under Electric Field With Atomic Resolution by In Situ Scanning Transmission Electron Microscopy, Organization board of the conference: Microscopy & Microanalysis 2022
2. Barbara Malič, Ferroelectric Recognition Award 2022 of the IEEE Ultrasonics, Ferroelectrics and Frequency Control Society (UFFC-S) for the outstanding contributions to the elucidation of the relationships between chemical and physical properties in ferroelectric, Ultrasonics, Ferroelectrics and Frequency Control Society (UFFC-S) in the frame of Institute of Electrical and Electronics Engineers (IEEE)
3. Barbara Repič, Best Contribution in Sensor Technology Award for the presentation entitled: Preparation and Electrochemical Characterization of Screen-Printed Graphite Electrodes, Organization Board of 14th Student Conference of Jožef Stefan Postgraduate School
4. Katarina Žiberna, Best Poster Award among the top three in the Materials Science section, Organization Board at 16ᵗʰ Multinational Congress on Microscopy

Organization of conferences, congresses and meetings

1. MIDEM 2022: 57ᵗʰ International Conference on Microelectronics, Devices and Materials with the Workshop on Energy Harvesting: Materials and Application, Maribor, Slovenia, September 14-16, 2022

Patent granted

1. Mirko Faccini, Morillo Martín, David Amantia, Danjela Kuščer, Darko Belavič, Tadej Rojac, A vibration system and a filtering plate for filtering substances, EP3454977 (B1), European Patent Office, 09. 02. 2022.

INTERNATIONAL PROJECTS

1. Hot Stage Microscope Measurements
   Prof. Barbara Malič
   Meggitt Sensing Systems
2. Laboratory Measurements for TDK
   Prof. Hana Uršič Nemevšek
   TDK Electronics GmbH & Co Og
3. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Barbara Malič
   European Commission
4. H2020 - QMatCh; Towards Quantum States of Matter via Chemistry under Extreme Conditions
   Asst. Prof. Mirela Dragomir
   European Commission
5. Environment-Friendly Ferroelectric Oxide Thin Films for Energy Harvesting and Energy Storage Applications
   Prof. Barbara Malič
   Slovenian Research Agency
6. Realizing In-Situ Studies of Dynamic Mechanisms in Ceramic Oxides in the Reducing Environment in a Transmission Electron Microscope
   Prof. Andreja Benčan Golob
   Slovenian Research Agency
7. Engineering the Microstructure and Performance of Lead-Free Piezoelectrics for Energy Harvesting
   Prof. Barbara Malič
   Slovenian Research Agency
8. Environment-Friendly Processing of Lead-Free Functional-Oxide Thin Films for Micro-Electro-Mechanical Systems (MEMS) Applications
   Prof. Barbara Malič
   Slovenian Research Agency
9. Smart Design of New Multifunctional Composites with Optimized Energy Transfer Across Interfaces between the Components (SoMwOT)
   Prof. Barbara Malič
   Slovenian Research Agency
10. ABO3-Type Perovskite Structured Ferroelectric Ceramics for Future Sensors, Actuators and Solid-State Refrigerators
    Prof. Hana Uršič Nemevšek
    Slovenian Research Agency
11. Low Temperature Processing of Piezoelectric Thick Films for Medical Imaging and Energyharvesting Applications
    Prof. Hana Uršič Nemevšek
    Slovenian Research Agency
12. Ferroelectric and Antiferroelectric Ceramic Materials
    Prof. Hana Uršič Nemevšek
    Slovenian Research Agency
13. Single-Crystal Growth and High-Pressure Studies of Low-Dimensional Quantum Magnets
    Asst. Prof. Mirela Dragomir
    Slovenian Research Agency

RESEARCH PROGRAMME

1. Multifunctional materials and devices: from quantum to macroscale
   Prof. Barbara Malič

R & D GRANTS AND CONTRACTS

1. In situ atomic level Quantitative Scanning Transmission Electron Microscopy of Functional Materials
   Prof. Andreja Benčan Golob
2. TCCbuilder: An open-source simulation tool for thermal control circuits
   Prof. Barbara Malič
3. Electrocaloric elements for active cooling of electronic circuits
   Prof. Barbara Malič
4. Advanced inorganic and organic thin films with enhanced electrically-induced response
   Prof. Barbara Malič
5. The quest for high-temperature superconductvity and exotic magnetism in fluoridoargentates(II)
   Asst. Prof. Mirela Dragomir
6. Designing functionality of lead-free ferroelectrics through domain wall engineering
   Prof. Andreja Benčan Golob
7. The cool way to polarize
   Asst. Prof. Mojca Otoničar
8. Engineering of relaxor ferroelectric thin films for piezoelectric and energy storage applications
   Prof. Tadej Rojac
9. Structures of elusive noble-gas compounds elucidated by 3D electron diffraction
   Asst. Prof. Mirela Dragomir
10. All in One: Multi-caloric and Multi-scavenging Elements for Green Future
    Prof. Hana Uršič Nemevšek
11. High-pressure stabilization and phase transitions of elusive transition-metal fluorides
    Asst. Prof. Mirela Dragomir
12. Enhanced piezoelectricity via structural disorder in polycrystalline relaxor ferroelectrics
    Prof. Tadej Rojac
13. MIcrofluidic Sensor System for PESticides detection (MISS PES)
    Prof. Danjela Kuščer Hrovatin
14. Flexible elements with multi-physical properties
    Prof. Hana Uršič Nemevšek
15. Antiferroelectric materials for cooling and high power electronic applications
    Prof. Andreja Benčan Golob
16. 4D STEM of energy related materials down to quantum level
    Prof. Andreja Benčan Golob
17. Process intensification for the continuous synthesis of high purity hydrogen peroxide using a micro-scale electrocatalytic reactor
    Prof. Barbara Malič
18. Advanced materials and technologies for the sustainable printed electronics on glass
    Prof. Danjela Kuščer Hrovatin
19. Battery Thermal Management System Based on High Power Density Digital Microfluidic Magnetocaloric Cooling
    Prof. Hana Uršič Nemevšek
    University of Ljubljana
20. Minor Services - Foreign Customers
    Prof. Barbara Malič

NEW CONTRACT

1. Advanced materials and technologies for the sustainable printed electronics on glass
   Prof. Danjela Kuščer Hrovatin
   Razvojni Center Enem Novi Materiali d. o. o.

VISITORS FROM ABROAD

1. Nikola Tutić, University of Bjelovar, Bjelovar, Croatia, January 16 - April 15, 2022
2. Prof. Dragan Damjanovic, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, March 8 – April 2, 2022
3. Matheiu Fricaudet, CentraleSupelec, Paris, France, March 20 – June 6, 2022
4. Dr Ilona Zamaraite, Vilnius University, Vilnius, Lithuania, April 1 - 30, 2022
5. Justine Breuzard, Tours University, Tours, France, April 5 - June 24, 2022
6. Jeanne Gonzales, Tours University, Tours, France, April 5 - June 24, 2022
7. Meryem Lachhab, University Limoges, Limoges, France, April 19 - July 8, 2022
8. Longfei Song, Luxembourg Institute of Science and Technology, Luxembourg, Luxembourg, May 16 – June 15, 2022
9. Ivica Grgić, University of Bjelovar, Croatia, May 16 – July 14, 2022
10. Christine Farmer, Institute of Technology Blois, Blois, France, May 20, 2022
11. Prof. Marco Deluca, Materials Center Leoben Forschung GmbH, Leoben, Austria, May 24, 2022
12. Dr Xi Shi, Friedrich-Alexander-Universität Erlangen-Nürnberg. Nürnberg, Germany, May 29 – June 8, 2022
13. Marah Alqedra, Faculty of Science, Ankara University, Ankara, Turkey, July 5 – September 26, 2022
14. Matheiu Fricaudet, CentraleSupelec, Paris, France, August 23 – October 13, 2022
15. Dr Julian Walker, Norwegian University of Science and Technology, Trondheim, Norway, September 19 – 20, 2022
16. Prof. Jacob L. Jones, North Carolina State University, Raleigh, USA, September 23, 2022
17. Prof. dr Geoff Brennecka, Colorado School of Mines, Golden, USA, October 1, 2022 - February 28, 2023
18. Matheiu Fricaudet, CentraleSupelec, Pariz, France, October 25 – December 9, 2022
19. Alexander Kobold, Materials Leoben Forschung GmbH (MCL), Leoben, Austria, November 7 – 11, 2022
20. Luka Čubrilo, Faculty of Sciences, University of Novi Sad, Novi Sad, Serbia, November 7, 2022 – February 7, 2023

21. Prof. Vera Gradišnik, Prof. Duško Čakara, University of Rijeka, Rijeka, Croatia, November 22, 2022
22. Dr Jaroslaw Kita, Faculty of Engineering Science, University of Bayreuth, Bayreuth, Germany, December 15 – 16, 2022
23. Dr Yongli Wang, Albertus Sutanto, Kyosuke Nakamura, TDK Electronics GmbH & Co OG, Deutschlandsberg, Austria, December 22, 2022

STAFF

Researchers
1. Prof. Andreja Benčan Golob
2. Asst. Prof. Mirela Dragomir
3. Prof. Goran Dražić*
4. Prof. Danjela Kuščer Hrovatin
5. Dr. Kostja Makarovič*
6. **Prof. Barbara Malič, Head**
7. Asst. Prof. Mojca Otoničar
8. Prof. Tadej Rojac
9. Prof. Hana Uršič Nemevšek
Postdoctoral associates
10. Dr. Andraž Bradeško*
11. Dr. Antonio Iacomini
12. Dr. Soukaina Merselmiz
13. *Dr. Uroš Prah, on leave since 15.06.21*
Postgraduates
14. Matic Belak Vivod, B. Sc.
15. Oana Andreea Condurache, M. Sc.
16. Ivana Goričan, B. Sc.
17. Maja Koblar, B. Sc.

18. Sabi William Konsago, M. Sc.
19. Victor Regis De Moraes, M. Sc.
20. Barbara Repič, B. Sc.
21. Samir Salmanov, M. Sc.
22. Ankita Sarkar, M. Sc.
23. Dr. Matej Šadl
24. Lia Šibav, B. Sc.
25. Blaž Velkavrh, B. Sc.
26. Katarina Žiberna, B. Sc.
Technical officers
27. Silvo Drnovšek, B. Sc.
28. Brigita Kmet, B. Sc.
29. Izabela Stojanoska, B. Sc.
Technical and administrative staff
30. Andrej Debevec
31. Tina Ručigaj Korošec, B. Sc.

Note:
* part-time JSI member

DEPARTMENT FOR NANOSTRUCTURED MATERIALS K-7

The research and development at the Department for Nanostructured Materials are focused on the leading-edge areas of nanotechnology and advanced materials, addressing the most difficult societal challenges that Europe and the world are currently facing. This includes clean and efficient energy, health, environment remediation and critical-raw-materials resource efficiency. A versatile team with synergies across a variety of complementary basic and applied expertise in combination with state-of-the-art research methods enables us to respond promptly to various emerging challenges. The basic and applied research of the Department for Nanostructured Materials includes permanent magnets and intermetallic alloys, engineering and functional ceramics, minerals, sensors, materials for a sustainable and ecologically built environment, biomimetic materials and biomaterials.

Head:
Prof. Sašo Šturm

Magnetic materials

We are tackling one of Europe's most pressing social challenges, closely aligned with the objectives of the European Green Deal. We aim to achieve climate-neutral, resource-efficient and environmentally friendly mobility and energy production while promoting greater circularity in material use and reducing the EU's dependence on critical raw materials from foreign sources. Of particular concern are rare-earth-element-based permanent magnets such as Nd-Fe-B and Sm-Co. Nd-Fe-B permanent magnets exhibit the highest maximum energy product $(BH)_{max}$. They are in high demand for critical applications in electric mobility, traction and energy conversion motors, and wind turbines. To address this challenge, we are conducting extensive research aimed at improving the design and manufacture of resource-efficient Nd-Fe-B magnets with enhanced magnetic properties. Through our work, we seek to advance knowledge and create new solutions to contribute to a more sustainable and resilient future for Europe and beyond.

For that purpose, we exploit the electrochemical and chemical procedures for treating end-of-life magnets, proposing a new paradigm of selective extraction of magnetic phases. The paper "Electrochemical routes for environmentally friendly recycling of rare-earth-based (Sm–Co) permanent magnets" explains a new environmentally-friendly electrochemical process for recycling $Sm_2(Co, Fe, Cu, Zr)_{17}$ permanent magnets, published in *Journal of Applied Electrochemistry* (https://doi.org/10.1007/s10800-022-01696-9). The presented paired electrochemical process of anodic oxidation and cathodic reduction serves as the starting point for the recycling and recovery of critical raw materials without any acid usage and waste generation (Figure 1). The work was continued to include the recycling of Sm-Co grinding swarf in the frame of the **MSCA IF GYROMAGS project**. Our efforts were also focused on the reprocessing of Sm-Co PMs, as reported in the paper "Effects of Ni and Cu Residuals on the Magnetic Properties and Microstructure of $SmCo_5$ Magnets" published in *MDPI Materials* (https://www.mdpi.com/1996-1944/15/22/8226). We concluded that sintered $SmCo_5$ magnets could be successfully recycled with up to 2 wt.% Ni/Cu as the residual from a coating.

In the segment of Nd-Fe-B permanent magnets, our major breakthrough lies in an innovative preparation of single-crystalline feedstock from recycled and fresh materials, which allows a new form of grain-boundary engineering to overcome the $(BH)_{max}$ limitations of the current sintering technology. This is realised with selective chemical leaching of the Nd-rich secondary phase out of Nd-Fe-B feedstocks via citric acid, which is considered an environmentally friendly approach. The magnetic properties of the $Nd_2Fe_{14}B$ matrix grains were intact, and a successful extraction was realised. The developed selective leaching of the Nd-rich phase was successfully applied to an end-of-life sintered Nd-Fe-B magnet by obtaining pure $Nd_2Fe_{14}B$ matrix grains (**MSCA PF OCARINA Project**). By exploring the possibilities of re-engineering the Nd-Fe-B magnets starting from the pre-obtained single crystalline $Nd_2Fe_{14}B$ phase, new intergranular recourse efficient phases were designed and consolidated via spark plasma sintering. Sintered magnets made from an extracted single-crystalline $Nd_2Fe_{14}B$ phase had extremely poor magnetic properties as per an inadequate microstructure. Magnets with 2.5, 5 and 10 wt. % $Nd_{70}Cu_{30}$ were prepared, and the results showed high coercivity and remanence values, H_{ci} = 500 kA/m and B_r = 1.1 T, which were further optimised. The effects of this work are multifaceted as it aims at recycling
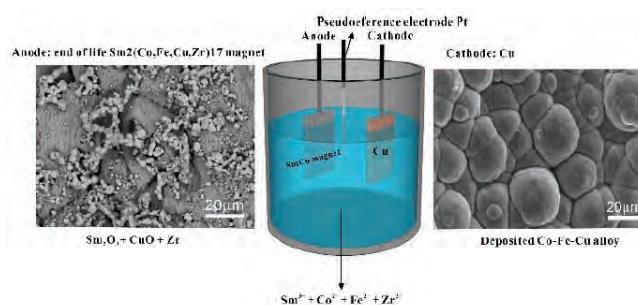

Figure 1: Paired electrochemical process for recycling rare-earth-based magnets (Sm-Co), without acid consumption and waste generation

and upgrading the Nd-Fe-B magnets to obtain improved performance and better recourse efficiency. The work has been carried out under the ongoing **Horizon EU project 101058598 – REEsilience**.

By further developing a novel sintering approach to Nd-Fe-B magnets in the frame of the **ARRS project Z2-2645**, we investigated sintering based on intense thermal radiation, for which a contemporary spark-plasma sintering (SPS) furnace is used. Rapid heating cycles result in insufficient grain-boundary wetting. However, intrinsic coercivity (H_{ci}) doubles upon low-temperature ($\approx 520\ °C$) post-sinter annealing and reaches values comparable to conventionally sintered samples.

The new rapid-sintering paradigm opens up new possibilities of redesigning the microstructure of Nd-Fe-B magnets for a potential breakthrough in the magnetic performance.

The radiation-sintering approach was also adopted to sinter recycled powders that conventional sintering routes cannot densify. Novel recycled magnets retain 94 % of H_{ci} value of the corresponding end-of-life (EOL) magnets (1495 kA/m, grade N35SH), opening up new possibilities for environmentally-friendly reprocessing of magnet waste that could replace the hydro- and pyrometallurgical approaches. The obtained knowledge of the Nd-Fe-B processing was also successfully implemented during the **EIT RAW Materials project 21043 RECO2MAG**. The work was initiated with the advanced characterisation of the current Nd-Fe-B feedstock and final magnets from the Magneti Ljubljana factory. Guidelines were developed to improve the magnet grades by several classes, reaching N45-48 grades (N 48 ˜ 385 kJ/m³).

Following the fast consolidation processing opportunities, i.e., sintering with intense thermal radiation, the research activities in the field of strengthening ferrite-based ceramic magnets were continued. Here, our research path was following the successful method of strengthening engineering ceramics using cellulose nanofibers (CNFs) developed in collaboration with colleagues from the Materials Science Institute (CSIC) of Madrid. We were able to prepare Sr-ferrite magnets reinforced with CNFs, which displayed pseudo-ductile behaviour. On the other hand, consolidation plays an important role in fast consolidation of functional materials, thus we are exploring the possibilities of consolidating Sr-ferrite-based ceramic magnets.

In 2022 we continued our research within the **H2020 SUSMAGPRO and EIT RAW Materials INSPIRES projects**. In addition to the characterisation of magnets, the focus of our research topic within the SUSMAGPRO project is the development of new coatings for corrosion protection. The goal is to make coatings that are of high quality and, at the same time, easily removable during a recycling process. Within the INSPIRES project, we achieved excellent results in the densification of powders from recycled waste magnets using the rapid densification method and a small addition of a low-melting Nd-Cu alloy. We reached a coercivity above 1200 kA/m. For the pilot line at the Kolektor KFH factory, we started the process of degassing powder obtained with the hydrogen processing of magnetic scrap – the HPMS process – from magnets obtained from household appliances. In addition to degassing, the powder must also be coated with a silane protective layer, enabling work under atmospheric conditions in the factory.

In 2022 we successfully obtained funds from **EIT Manufacturing**, for the **aProMag project**. Within the framework of this project, we will focus on developing a 3D printing technology for Nd-Fe-B powders in a magnetic field for a rapid production of rotor prototypes for brushless DC motors or actuators. The technology can significantly reduce the time it takes to make finished products by testing design concepts up to 5 times, drastically reducing the cost of injection moulding tools. In this process, we will use powders obtained by recycling waste magnets using the technology we developed for our industrial partner Kolektor KFH (**a patent was granted in 2022**), with which we improved the coercivity of commercial MQP B+ powders (Magnequench) by 30% and which uses an addition of a low-melting NdCu alloy (**SI 26141 A, 2022 -07-29**),

https://worldwide.espacenet.com/patent/search/family/082607918/publication/SI26141A?q=pn%3DSI26141A. Thus, the improved quality of the initial powder for producing bonded magnets enables them to be placed in a higher quality class.

As an alternative approach towards reducing the consumption of critical materials containing rare-earth elements, we explored the possibility of making custom-shaped magnets, which would yield the same performance at lower volumes. An additional advantage of this solution is the ability to match the properties of complex magnet assemblies by applying uniformly magnetised samples, which might lead to a simplified production at lower costs. The idea was, within the frame of the finite-element modelling, demonstrated for a magnetic harvester – a device for automated charging of portable electronic equipment (Figure 2) (***Materials Today 65, 3642 (2022)***).

The study and applications of magnetic skyrmions in quantum technology have the potential to revolutionise information processing and sensing. Upon that, we are developing the methodologies for their modelling and
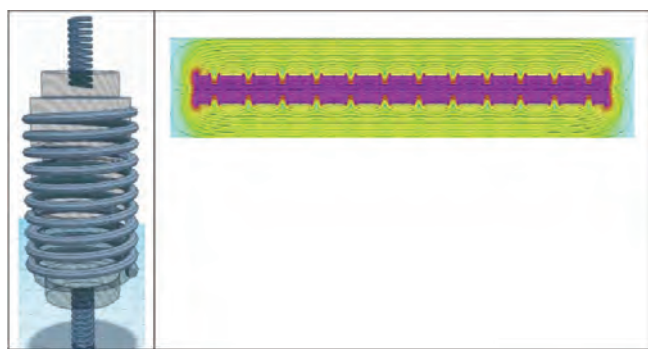

Figure 2: Magnetic harvester – a device (left); calculated flux lines around a single curve shape magnet in the equilibrium position (right)

characterisation. Skyrmions can be found isolated in a material or they can form hexagonal lattices as shown in the image (Figure 3). Such a hexagonal lattice of skyrmions was obtained with micromagnetic simulations where the Landau-Lifshitz-Gilbert equation was solved with the Runge-Kutta evolution in an object-oriented micromagnetic framework. Further study of magnetic skyrmions will involve further computational investigation of magnetic ground states and direct magnetic imaging through transmission electron microscopy.

In 2022 we started the M-Era.Net project **AddMag** (Additive manufacturing of permanent magnet materials) where the goal is to use the additive manufacturing process to precisely shape and miniaturise permanent magnets of two magnetic materials, Nd-Fe-B and Fe-Cr-Co.

In the frame of the ARRS project "Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology", we are continuing to develop complex-shape, multi-component, permanent magnets using additive manufacturing for the company Kolektor d.d. By successfully printing magnetic materials in a magnetic field we explored the effect of the external magnetic field on the printed part. It was shown that the printed part acts as an additional magnet, together with the permanent magnet increasing the range of the magnetic field used to orientate the particles for a higher anisotropy of the printed part, increasing the size of the parts that can be printed, thus making this technology viable also for larger prints.

Figure 3: Skyrmions can be isolated in a material or can form a hexagonal skyrmion lattice in the FeGe alloy on a permalloy substrate simulated in the frame of micromagnetism

Complex intermetallic alloys

In the frame of a collaboration within IRP PAC2, a new binary phase with the chemical composition Al4Ir was discovered in the Al-Ir binary system. The results were published in the journal *Inorganic Chemistry* (https://pubs.acs.org/doi/full/10.1021/acs.inorgchem.2c00816).

This structure is derived from the structure type Ni_2Al_3 and has a supercell due to the ordering of the aluminium atoms, which replace the nickel atoms in the prototype structure. The crystal structure was imaged by atomic-scale high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM). It evidenced the misalignment of the Al site responsible for the superstructure ordering. Single-crystal X-ray diffraction revealed a trigonal space group P3c1 with unit cell parameters a = 12.8802(2) Å and c = 9.8130(2) Å. The density functional theory with structural optimisation confirmed that the lattice parameters and atomic positions agree with the experimental ones. This phase is only observed in the as-cast sample and disappears after a short annealing time. Experimental techniques XRD, DTA, and the COHP calculation also confirmed metastable behaviours of the phase.

Figure 4: (a) Experimental atomic-scale HAADF-STEM image; (b) low-frequency filtered image with Ir atomic planes highlighted with higher intensity (marked by an arrow); (c) crystal structure of Al4Ir showing the Ir polyhedron in the (ab) plane (height) and in the (ac) plane (down)

Structural materials

Plasma-facing structural materials are currently one of the bottlenecks for a successful and economical implementation of fusion as an energy source. Development of novel materials within the framework of the European fusion program EUROfusion (2021-2025) is therefore of utmost importance for technological progress. During this period, we shall have continued our research in the field of W-W_2C composites with varying compositions with the aim of improving the long-term resistance of plasma-facing tungsten-based materials. Additionally, additive manufacturing of W-W_2C is being investigated as a prospective path toward more complex shaped and functionally graded components.

The composition and preparation process of W-W_2C composite materials was optimised based on the study of interdependent relationships between the initial and final composition of the material, which directly affect its temperature-dependent (up to 1000°C) mechanical and thermal properties. The main criterion for selecting the optimal composition is the resistance of the material to thermal shocks during a high-heat flux test (HHFT). In continuation of the HHFT of our materials, new monoblock components were fabricated and tested in the actively cooled divertor mock-up set-up at the GLADIS facility at the Karlsruhe Institute of Technology, Germany (Figure 5).
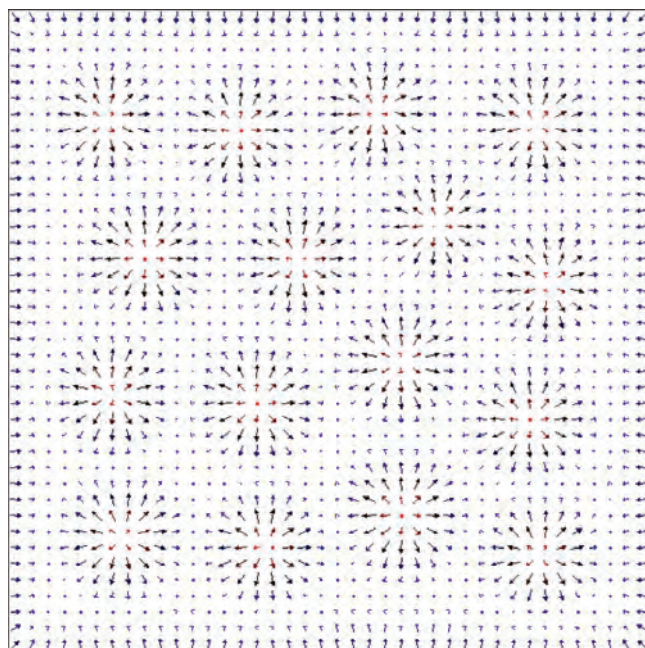
Figure 5: Composite monoblocks joined to a CuCrZr cooling tube and subjected to HHF tests in an actively cooled divertor model

The W-W$_2$C composite with 4 at.% C in the initial composition exhibited a brittle-ductile transition temperature as much as 200°C lower in comparison to the current state-of-art tungsten materials designed for the divertor application.

Future development will be focused on an in-depth investigation of the microstructure-property relationship of this material and on up-scaling its capabilities, demonstrating its use in industrial-scale manufacturing.

Within the scope of the fusion materials research, a master's thesis was completed, entitled "Improving the oxidation resistance of tungsten carbide composite with an addition of chromium and yttrium". The aim of the work was to study the influence of chromium and yttrium additions on the high-temperature oxidation resistance of W-W$_2$C composites. An addition of chromium increased the onset temperature, at which oxidation of samples was observed from 700 to 900°C. However, it could not suppress active oxidation of the samples.

Catalysis

Photo(electro)catalysis is a relatively well-established approach towards degrading organic pollutants from water and air. However, commonly recognized photocatalysts (such as TiO$_2$) have many disadvantages including low efficiency under visible light and fast recombination of electron/holes. Therefore, developing novel, high-efficient photo(electro)catalysts for pollutant degradation in the field of the photo(electro)catalysis is necessary. The main goals that the Group for Catalysis is trying to attain in the research work are rigid adherence of the catalyst to the active parts in the reactor (published in the *Journal of Cleaner Production*, https://www.sciencedirect.com/science/article/pii/S0959652622006941?via%3Dihub), high(er) photoactivity of the catalyst in the visible part of solar spectrum (published in the journal *ACS Omega,* https://pubs.acs.org/doi/10.1021/acsomega.1c02862), structural stability of a catalyst (published in the journal *Catalysts*, https://www.mdpi.com/2073-4344/10/7/803), versatility in degrading different pollutants (published in *The Journal of Physical Chemistry*, https://pubs.acs.org/doi/10.1021/acs.jpcc.9b09522), low-cost catalysts (published in the journal *Nano Energy*, https://www.sciencedirect.com/science/article/pii/S2211285522010369?via%3Dihub) and easily achievable high-technology readiness levels (TRLs) (published in the journal *Angewandte Chemie,* https://onlinelibrary.wiley.com/doi/10.1002/anie.202109212). Apart from the knowledge gained on the TiO$_2$, TiON and BDD materials"ISSN":"19327455","abstract":"TiO2 nanotubular films prepared using the anodic oxidation process applied to various forms of metal titanium are promising materials for photocatalytic applications. However, during successive anodizations in batch-anodization cells, the chemical composition of the NH4F-and water-based ethylene glycol electrolyte changes with each subsequent anodization, which greatly affects the final photocatalytic properties of the annealed TiO2 nanotubular films. In the present study, 20 titanium discs (φ 90 mm, the Catalysis Group successfully continued the research on the use of high-entropy alloys (HEAs) for catalytic applications.

According to the maximum entropy principle, HEAs consist of a mixture of five or more elements in equal or proportional amounts (5–35 at.%). HEAs have unique structural and physical properties that result in many catalytically driven processes. The catalytic properties of HEAs arise from the random atomic positions of different elements in a defined crystalline structure.

The past knowledge of anodic oxidation was used to grow high-entropy oxides (HEOs) on a HEA substrate. While numerous new catalytic properties of HEAs are being investigated, very few reports exist on the catalytic properties of high-entropy oxides (HEOs).

Anodic oxidation was implemented on the HEAs to address the kinetics and thermodynamics conversion to the corresponding HEOs and vice versa. Preliminary conversion was tested on a Cantor alloy (CoCrFeNiMn) and refractory TiNbZrHfTa composition. Our group successfully grew fully formed and uniform nanotubes, rigidly attached to the substrate of TiNbZrHfTa HEA. This material was tested during the photo(electro)catalytic degradation of the antibiotic tetracycline.

The results were compared with TiO$_2$ and TiON catalysts and they showed that anodized TiNbZrHfTa degraded tetracycline faster than the commonly used TiO$_2$. Meanwhile, the Cantor alloy showed promising results in the process of oxygen evolution reaction.

Furthermore, the group successfully designed a reactor system, in which the new HEAs/HEOs materials will be tested for the photo(electro)
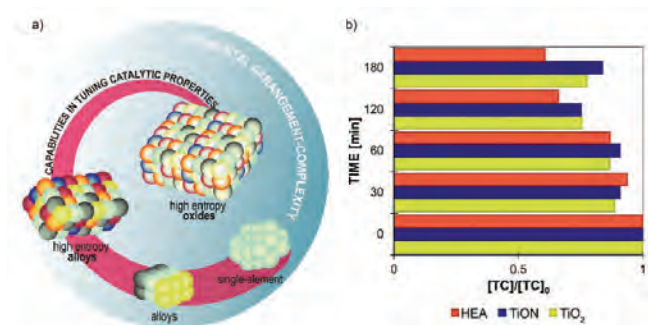

Figure 6: (a) Schematic comparison of conventional photo(electro) catalysts and high-entropy oxides; and (b) experimental results of tetracycline photocatalytic degradation using HEA, TiON and TiO$_2$ substrate

catalytic activity and compared with the already established materials (e.g., TiO_2, TiON and BDD). The continuous reactor system will allow an upscale process (1 cm² to 10 cm² of an active catalytic surface) and precision analysis of the degradation process with the fully established UPLC analysis.

Sensors

We are developing receptor elements for the detection of a variety of toxic organic components (TOC) and biomolecules. In the field of biomolecules, we are developing electrochemical biosensor platforms for rapid diagnosing of pathogens (e.g., viruses) with portable units. Due to the current worldwide outbreak, our research activities have recently been centred on the SARS-CoV-2 virus. However, the developed biosensor platforms may be modified to detect similar pathogens emerging in the future. The biosensor platform for the SARS-CoV-2 detection is based on a highly conductive matrix (fabricated polystyrene/polyaniline-Au nanocomposite) that enables immobilisation of representative antibodies (Ab), specific to the SARS-CoV-2 spike (S)-protein (Figure 7).

The biosensor platform is able to translate specific covalent interactions between antibodies and their corresponding binding viral S-protein into a measurable, concentration-dependent electrochemical signal. It can also monitor the electrochemical responses in phosphate-buffered saline, without using hazardous chemicals such as $K_3[Fe(CN)]_6$. By creating cyclic voltammetry, differential pulse voltammetry and electrochemical impedance spectroscopy-based electrochemical readout, the data enables a qualitative and quantitative interpretation of results.

Additionally, it exploits outstanding conductivity and biocompatibility, thus resulting in high analytical sensitivity and a low detection limit of 15.6 µg/mL, which is within the physiologically relevant concentration range. Hence, the feasible design of the proposed biosensor platform represents a good starting point for an inexpensive and practical diagnosis of asymptomatic patients or people before the symptom onset.

We continued to study the PANI behaviour due to the ammonia (NH_3) presence. NH_3 is a part of the natural nitrogen cycle and a toxic, neurotoxic compound indicating a disease state in the human body. Therefore, detecting and monitoring NH_3 concentrations in physiological fluids present a field of high scientific interest. The developed sensing mechanism is based on the chronoamperometric setup conditions and results. The calculated detection limit for NH_3 detection in phosphate-buffered saline on the PANI electrode (25 µM) was lowered three times by introducing Au nanoparticles on the PANI surface (8 µM). The recovery of PANI after each aliquot addition and reversibility of measurements indicate further potential application in a flow injection system. The research was published in *Electrochimica Acta* (https://doi.org/10.1016/j.electacta.2022.141034).

Volatile toxic organic compounds, namely catechol (CC), resorcinol (RS) and hydroquinone (HQ) are isomers of benzenediols, which are known to pose problems to living beings. For example, CC is banned from the cosmetic industry while HQ is its replacement. Benzendiols are electrochemically active molecules, meaning they are subject to redox processes. Detection can be performed using screen-printed electrodes (SPEs) where the working electrode is modified with a thin layer of a carbon-supported catalyst such as Pt/C or Au/C.

These modified SPEs were then subjected to CV for the qualitative detection of single isomers, DPV for the qualitative detection of multiple isomers in the same analyte, and chronoamperometry for the quantitative detection of single isomers, all performed in acidic media to boost the electrical conductance of the electrolyte. A comparison of the potentiostats used was the next task as the availability of the novel analogy hardware provides a noticeable merit over the standard digital hardware used in conventional devices.

Further steps were taken to analyse the degradation of the modified surface of the SPE using electrochemical impedance spectroscopy and the efficacy of modified vs. unmodified SPEs when used for detection. The modified SPEs detected 3 isomers selectively, reaching a detection limit of 1 µM for catechol and hydroquinone and 100 nM for resorcinol with good reproducibility in laboratory conditions. Future goals are to improve the detection limits even further, lower rise times and modify the system for detecting gaseous analytes.

A new area of research is dedicated to developing receptor elements for portable and miniaturised sensors with selective and sensitive detection of persistent and mobile chemicals (PMCs) in water. PMCs are a result of the development of modern organic chemistry, which has been found in tens of thousands of everyday products.

> **We are developing receptor elements for the detection of toxic organic compounds such as acrylamide (AA) (national project J2-1739), persistent and mobile chemicals (PMCs) (national project J2-3051) and benzenediols. We are also developing receptor elements for electrochemical detection of SARS-CoV-2 (national project Z2-3206).**
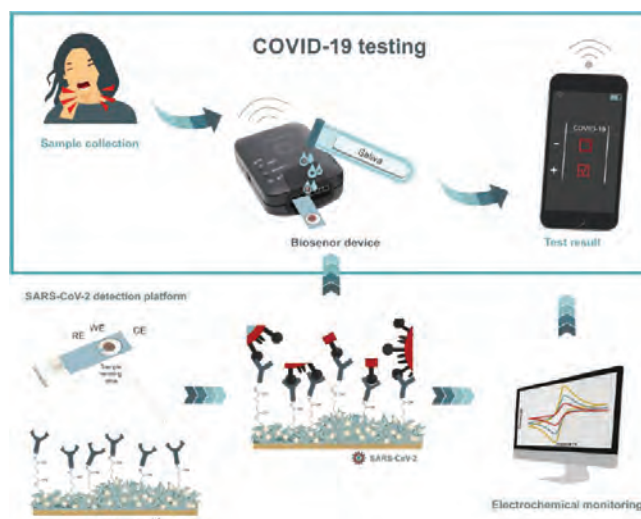

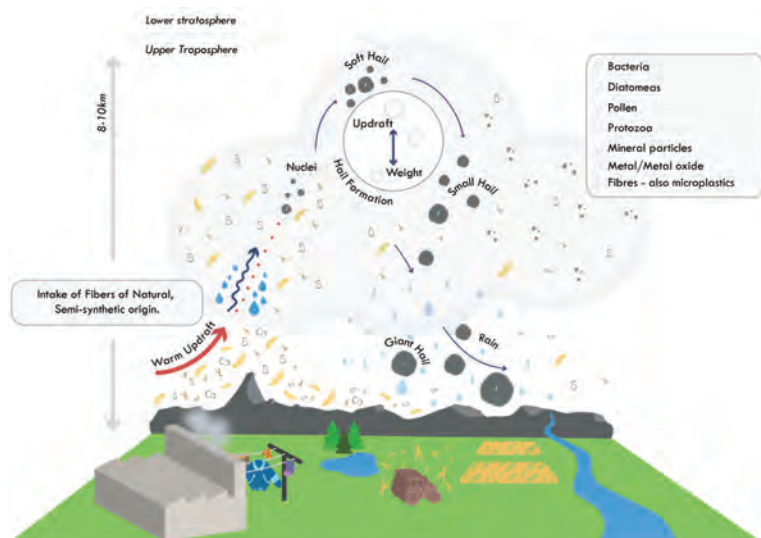*Figure 7: Concept of COVID-19 testing*

Figure 8: In our view, a strong updraft pushes light fibres even higher into the atmosphere while heavier sand particles, which are usually higher-density minerals, remain lower. Higher than usual and with lower moisture concentrations, hail is thus formed, growing on its way to the ground.

In the journal *Science of the Total Environment* (IF for 2022 10.753, https://doi.org/10.1016/j.scitotenv.2022.158786) we published the article *Dissecting giant hailstones: A glimpse into the troposphere with its diverse bacterial communities and fibrous microplastics.* We were the first in the world to discover fibres of polymer origin in the core of a large hailstone.

Although modern chemicals have been around for many years their negative effects on human and animal health are only beginning to be understood. At the top of the priority list of PMCs are bisphenols. Bisphenol S (BPS) is one of the most common phenols in the environment. In plastics, it is used as a substitute for bisphenol A (BPA), which is a known endocrine disruptor. The electrochemical detection of bisphenols is possible due to the irreversible oxidation of the phenol group leading to different oxidation peaks for each bisphenol (e.g., BPS at 0.7–1.0 V). By applying carbon-based SPEs and conducting CV measurements, we could qualify and quantify analytes. From the calibration curve, we obtained high sensitivity and a low detection limit (0.7 µM for BPS and 0.09 µM for BPA). Finally, the selective detection of BPS, BPA and BPF was observed using DPV on the same carbon-based working electrode with a solution containing all three isomers.

Microplastics

With interdisciplinary research, we outlined details of the biotic and abiotic components of large hailstones that fell down on 11 June 2019, in Bela Krajina.

With a detailed insight into the distribution of various fragments throughout the layers of the entire hail volume, we were able to draw conclusions about the dynamics of the formation of such large samples (Figure 8). The core of the largest hailstone had a higher concentration of fibres than the outer layers. The population of other fragments was the opposite. More than 90% of the fibres consisted of lignocellulose, lignin and/or cellulose. It was concluded that they are of natural origin. Cotton is also made of pure cellulose, but the addition of an artificial dye indicates that it was produced industrially. We were the first in the world to find fibres of polymer origin in the core of a large hailstone. It was an unnaturally smooth fibre made of polyethene terephthalate (PET), 500 µm long and 12 µm in diameter. A fragment of polyethene vinyl acetate (PEVA) copolymer was found in the core of a smaller hailstone.

Materials for health and a clean environment

We are developing nanocarriers for innovative cancer treatments and diagnostics in collaboration with Queen's University Belfast, United Kingdom, and the Medical Faculty of the University of Ljubljana.

We developed temperature-sensitive liposomes for prostate-cancer treatment containing a prodrug consisting of doxorubicin (Dox), conjugated to a peptide substrate for a prostate-specific antigen (PSA), which can be cleaved by enzymatically active PSA at the tumor site (Figure 9). As-prepared liposomes combined with hyperthermia significantly inhibited tumor growth and metastasis in mice. The study was published in *Acta Biomaterialia* (IF = 10.633, https://doi.org/10.1016/j.actbio.2021.12.019).

Erythrocyte membranes have been used as carriers for nucleic acids for gene-silencing cancer therapy. We found that as-prepared carriers protect siRNA from enzymatic degradation. They also enable efficient gene silencing *in vitro*, comparable to commercially available transfection reagents. *In vivo* studies are currently underway to confirm the system's effectiveness and safety.

In collaboration with the Faculty of Medicine of the University of Maribor, we have developed multi-layered nanofilms for the treatment of skin cancer. We used a combination of polyhydrohiethyl methacrylate (PHEMA), polyhydroxylpropyl methacrylate (PHPMA), sodium deoxycholate (NaDOC) with incorporated FePt superparamagnetic nanoparticles and an anticancer drug (5-fluorouracil). The efficacy of drug release was tested *in vitro,* and the safety of the formulation was evaluated on fibroblasts obtained from human skin.

In the field of nanocarriers, we have taken a step forward and moved from synthetic liposomes towards cell-based nanocarriers to reduce the possibility of side effects.
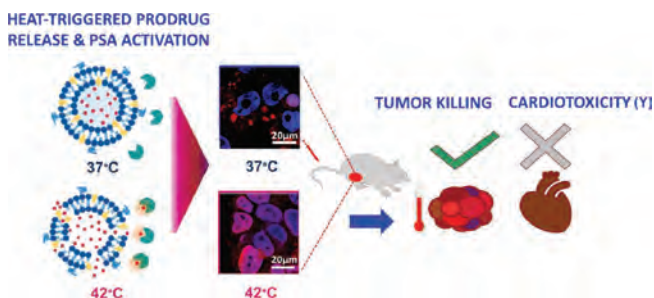

Figure 9: DOX-PSA loaded, low-temperature-sensitive liposomes combined with hyperthermia significantly delayed the tumor growth at a rate similar to the one found for the mice treated with free Dox-PSA in both solid and metastatic prostate cancer tumor models.

The study was published in the journal *Pharmaceutics* (FV = 6.525, https://doi.org/10.3390/pharmaceutics14040689).

Biomaterials

A postdoctoral fellow, a member of our department, was awarded an international research fellowship in Japan, which he commenced in April 2022 at the renowned University of the Ryukyus, in Okinawa. The project aims to produce ceramic bio-interactive substrates for marine habitat restoration prepared by additive manufacturing. Bioresorbable materials that promote coral settlement and calcification through the release of Ca^{2+} ions into the microenvironment in 3D structures will be installed in designated spots around the Okinawa archipelago at a gradient down to 25 meters of depth (Figure 10). Settled corals will be assessed for their skeletons' calcification kinetics, porosity, ion and gene expression, and structural changes.

Figure 10: Deployed 3D-printed settlement tiles near Onna-son, Okinawa, Japan

Highly hierarchical structures of layered double oxide (LDO) photocatalyst microparticles with strong radial lamellar orientation were prepared in collaboration with the University of Szeged, Hungary. LDO particles with rough surfaces can be incorporated in a fluoropolymer solution, resulting in a composite layer with dual superhydrophobic and photocatalytic properties, high bacterial adhesion and inactivation ability. The study was presented in *Applied Clay Science (*https://doi.org/10.1016/j.clay.2022.106587).

Polymethyl methacrylate (PMMA) is often used in restorative dentistry where non-toxicity, biocompatibility and good mechanical properties are crucial. We showed that an increased addition of TiO_2 nanoparticles into PMMA induces a morphological change of bacterial cells and hinders biofilm propagation. The results of this work were published in *Coatings (*https://doi.org/10.3390/coatings12111757).

We previously used polyelectrolyte multilayers to modify the surfaces to inhibit bacterial adhesion and hinder biofilm formation. The continuation of the research with the Faculty for Health Sciences, University of Ljubljana, focused on the inhibition of biofilm formation on coated urinary tract catheters as well as the study of the formation and thickness of multilayers. It was found that the thickness of multilayers on titanium is three times higher than on silicon.

Moreover, the multilayers formed on silicon display a grain-like structure. Finally, it was shown that, in addition to the electrostatic interactions, the hydrophobicity of the substrate also plays an important role in the polyelectrolyte multilayer formation process and influences its thickness and properties. These studies were published in *Polymers* (https://doi.org/10.3390/polym14132566) and *Coatings* (https://doi.org/10.3390/coatings11121469).

Engineering ceramics

In 2022 a senior researcher from our department successfully concluded a six-month ARRS-funded Visiting Research Fellow position, working with prof. Raul Bermejo, an ERC grantee at Montanuniversität Leoben, Austria. Despite his ERC consolidator grant application, entitled "Rapid Radiation Sintering of 3D Printed Ceramics," not getting approved, he managed to secure the ARRS project N2-0301 thanks to the threshold achieved within the ERC complementary scheme. In the scope of the mobility project including Leoben, a joint publication was published in *Additive Manufacturing (IF – 11.63)* (https://doi.org/10.1016/j.addma.2022.103141) on the rapid sintering of high-strength lithography-based additive manufacturing of complex-shaped ceramic components with refined microstructures (Figure 11).

A member of our department was invited to join the board of senior editors of Elsevier`s scientific journal covering the field of ceramic materials, *Journal of the European Ceramic Society*.

As a Guest Editor at *Advances in Applied Ceramics* he published a commentary article as a Foreword to a collection of papers published within the scope of the 4th (online) work-
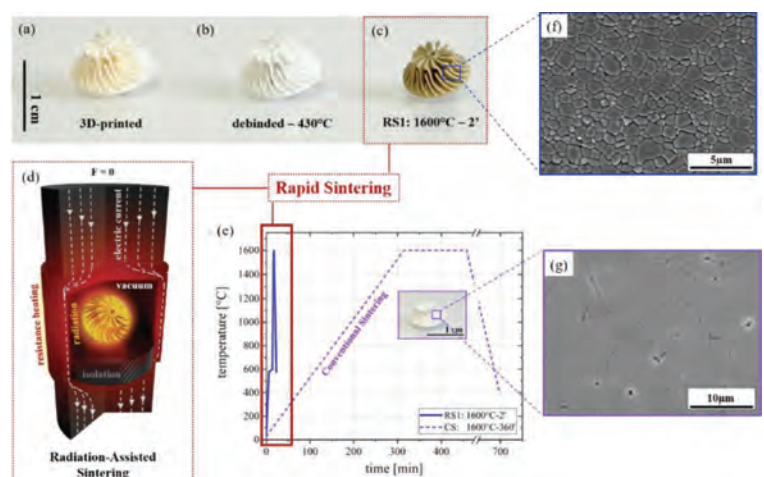
Figure 11: Radiation-assisted sintering (RAS) vs. conventional sintering (CS): (a–c) Processing of a turbocharger engine rotor: (a) after LCM 3D-printing; (b) after binder removal at ~430°C and (c) after RAS sintering at 1600°C with a 2-min dwell time (RS1); (d) set-up of the RAS technique where thermal radiation, induced through Joule heating, due to electric current resistance, is the only heat transfer used for densifying the ceramic component; (e) sintering protocol for rapid (RS1) and conventional sintering (CS); (f, g) resulting microstructures of (f) rapid (RS1) and (g) conventional sintering protocol (CS)

shop Advanced Ceramics and Technologies for Dentistry (ACT4D) 2020 and in memory of recently deceased Zhijian (James) Shen for his devotion in taking care of and preparing the ACT4D, while also contributing extensively to his favourite field of zirconia for dentistry.

In collaboration with the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, we studied the recycling potential of solid waste alumina powder (WAP), collected as the industrial scrap after a machining process, using the two-step sintering (TSS) process.

Slip-cast green samples containing various commercial and scrap alumina amounts were sintered at optimised TSS conditions. Similar mechanical properties were achieved in comparison to conventionally sintered commercial alumina, showing the potential of TSS as a sintering strategy for the recycling of ceramic waste powders. The work was published in *Materials* (https://doi.org/10.3390/ma15217840).

In the scope of a successfully completed master's thesis and in collaboration with the Materials Science Institute of Madrid, ceramic matrix composites (CMCs) based on an ionic-conducting 8 mol.% yttria-stabilized zirconia (8YSZ) matrix and cellulose nanofibers (CNFs) were consolidated with spark plasma sintering (SPS) in order to study the in-situ CNF graphitisation process, which in turn functionalises the oxide ceramic matrix. Significantly improved electrical properties and refined microstructures make the CNF an interesting sustainable carbon nanofiller for the preparation of CMCs that are suitable as anode-material candidates in solid oxide fuel cells (SOFC), a possible replacement for the benchmark Ni/8YSZ system, which is currently used. The work was published in the *Journal of the European Ceramic Society,* the leading scientific journal in the field of ceramic materials.

Dental ceramics

In the field of dental ceramics, we have been traditionally involved in the interdisciplinary translational research of zirconia dental ceramics in collaboration with the Department for Prosthetic Dentistry, Medical Faculty, University of Ljubljana (DPD-MF-UL) where numerous *in vitro* and *in vivo* clinical studies have been conducted. In 2022, a thorough study of the effect of airborne-particle abrasion of yttria-containing zirconia dental ceramics on mechanical properties before and after regeneration firing was performed and published in the *Journal of the European Ceramic Society* (https://doi.org/10.1016/j.jeurceramsoc.2022.05.010). This study represented one of the last results achieved within the successfully concluded ARRS project J2-9222 Towards reliable implementation of monolithic zirconia dental restorations (2018-2021). In 2022, in collaboration with the DPD-MF-UL, the execution of another project (granted at the end of 2021) began. It will deal with preclinical and clinical investigations of zirconia dental ceramics fabricated with additive manufacturing technologies. In addition, a clinical evaluation of monolithic zirconia multiunit posterior fixed dental prostheses was published in the *Journal of Prosthetic Dentistry* (https://doi.org/10.1016/j.prosdent.2021.02.034).

Figure 12: Self-glazed Y-TZPSG-FDPs (A, B) and conventionally milled Y-TZPC-FDPs (C, D)

Within a fruitful collaboration with the Department of Prosthetic Dentistry, Center for Dental Medicine, Faculty of Medicine, University of Freiburg, Germany, we provided expertise on the zirconia ceramics and advanced characterisation in a joint study, entitled "Zirconia fixed dental prostheses fabricated by 3D gel deposition". These prostheses demonstrate a higher fracture strength than conventionally milled counterparts (Figure 12). The study was published in the *Journal of the Mechanical Behaviour of Biomedical Materials* (https://doi.org/10.1016/j.jmbbm.2022.105456).

Functional ceramics: semiconducting ZnO-based ceramics (varistors, thermoelectrics)

Semiconducting oxide ceramic materials exhibit stability in an oxidising atmosphere at high temperatures. As they also have a high potential for improving their thermoelectric properties, they are used in thermoelectric technologies for harvesting electricity from waste heat at temperatures above 650°C. For most oxide thermoelectric materials, improving the thermoelectric properties requires a significant increase in their electrical conductivity (s), which is a consequence of too low a concentration of charge carriers, and at the same time maintaining a high Seebeck coefficient (S), which is a major challenge due to the correlation between the two parameters. At the same time, it is necessary to lower their high thermal conductivity (k), mainly due to their simple crystal structure and their simple chemical composition of mostly light elements. This is also true for semiconducting ZnO, which is highly interesting as an n-type thermoelectric material due to its high Seebeck coefficient (S) of -400 μV/K. The advantages of ZnO are also its low cost, environmental neutrality, biocompatibility and high amenability for doping, which can be used to tailor its physical properties according to the specific requirements of different applications. The aim of our research is to understand the influences of donor dopants (M^{3+}) on the charge carrier concentration and mobility, and of structural and microstructural elements on the charge carrier and phonon transport. Thus,

we study the influences of interfaces such as grain boundaries (GBs) and specific inversion boundaries (IBs) in grains on the charge and heat transport.

Our research focuses on the role of multiple IBs, induced by dopants such as In^{3+} and Ga^{3+} and act as an energy filter where phonon and electron pathways split. Electrons along a planar defect, which is limited in width to one layer of atoms and practically infinite in the other two dimensions, switch to the ballistic transport mode (σ_b). At the same time, the 2D structural and chemical anisotropy of IBs induces the scattering of phonons transversely crossing the planar defect, lowering the thermal conductivity of ZnO ceramics. The research is carried out in collaboration with the National Institute for Materials Science (NIMS), Tsukuba, Japan, and the CRISMAT Laboratory, Caen, France.

We have also collaborated with the Institute for Multidisciplinary Research, University of Belgrade, Serbia, to investigate the influence of the synthesis and doping process on the microstructural, mechanical and thermoelectric properties of p-type $NaCo_2O_4$ ceramics.

Electrostatic Schottky barriers at grain boundaries critically affect the electrical conductivity of thermoelectric ZnO ceramics, while in the case of varistor ZnO ceramics used for surge protectors, they are essential for their current-voltage (I-U) nonlinearity.

In collaboration with the Shanghai Institute of Ceramics, Chinese Academy of Science (SICCAS), we study the influence of selected dopants and process parameters (temperature and sintering atmosphere) on the formation of electrostatic Schottky barriers at grain boundaries and on the electrical/thermoelectric characteristics of ZnO ceramics. In the framework of this research, we discovered a new type of ZnO-based varistor ceramics which, compared to the currently known standard varistor ceramics based on ZnO, do not contain volatile (Bi_2O_3), expensive (Pr_6O_{11}) and toxic (V_2O_5) dopants, and have the advantage of a simple and significantly cheaper chemical composition. In the novel ZnO-Cr_2O_3-based varistor ceramic, the formation of electrostatic Schottky barriers is induced by an addition of Cr_2O_3, while an addition of small amounts of Ca, Co and Sb oxides further improves the I-U nonlinearity. Having elucidated the role of Cr_2O_3 in the formation of electrostatic Schottky barriers and the mechanism of their formation, we focused on the influence of individual dopants on the grain growth, microstructural development and I-U characteristics. We found that within the limits of solid solubility in ZnO, due to the deformation of the crystal structure, CaO accelerates the diffusion processes and, thus, the grain growth, allowing the control of the breakdown voltage in a broader range. At the same time, CaO doping positively affects the height of the electrostatic Schottky barriers so that the nonlinearity coefficient a is increased and the leakage current IL is lowered.

Figure 13: Electron-backscattered diffraction (EBSD) local misorientation map of ZnO-Cr2O3-based varistor ceramics with CaO: (a) 0 mol.% and (b) 3 mol.%, indicating a higher degree of lattice distortion in the Ca-doped sample (i.e., more misorientations ranging from 1° to 2°, marked as green regions) than in the Ca-free one; (c) levels of Ca and Co solubility (as Ca:Zn and Co:Zn atomic ratios) measured with EDS in individual grains of ZnO-Cr2O3-based varistor ceramics with different CaO contents (x = 0, 0.5, 1, 2, 3, 4 and 6 mol.%)

We worked with the Bourns company on the development of multilayer varistors (MLVs) with an improved temperature stability. We studied the influence of trace elements and clarified the critical amount of Fe and negative influence on the electrical and energy characteristics of different types of MLVs and the positive influence of Al on their improvement. In collaboration with the Faculty of Mechanical Engineering of the University of Ljubljana and Raycap, we studied the surface characteristics of varistor ceramics and their processing procedures to optimise the finalisation of varistors and thus improve their properties. We also collaborated with the Raycap company in monitoring the processes involved in the fabrication of varistors for their optimisation.

Semiconductors

The formation of inversion boundaries (IBs) with different dopants in ZnO was studied in the framework of density functional theory (DTF) calculations in collaboration with the Atomistic Modelling Group of the Materials Center in Leoben (MCL), Austria.

We are developing a new theoretical approach to calculating the stability of chemically-induced domain walls across different chemistries, which has not yet been attempted before for interfaces. Spontaneous formation of IBs has been so far predicted for Sb–, In– and Fe–doped ZnO, whereas full screening of the complete periodic system of elements is underway.

Mineralogy

Collaboration with the Department for Litospheric Research of the Vienna University in the frame of FWF–ARRS bilateral Project N1–0115 (GInA): 'Mineral inclusions in garnets from macroscopic to atomic scale – opening the petrogenetic archive' was continued in the studies of crystallographic orientation relations of rutile in garnet.

In addition, the replacement of apatite central inclusions in garnets was studied using advanced methods of transmission electron microscopy. With the University of Pannonia in Veszprém, Hungary, we started a newly funded bilateral Project N1–0230: 'Aragonite: Structure and formation', The project deals with one of the most important

Figure 14: High-resolution FEGSEM image of a PS/PANI/Au nanohybrid composite consisting of a polystyrene spherical core covered with a polyaniline layer and decorated with dispersed 20-nm gold nanoparticles; the inset shows a schematic model of this PS/PANI/Au nanohybrid structure.

questions in geology – the stability of aragonite in low-pressure conditions. In the past year, studies were focused on the unexplained Hiragi-Makovicky reflections and their relation to the twinning of aragonite. The University of Novosibirsk is included as an external partner.

Advanced electron microscopy

For the microstructural characterisation of materials, we use scanning electron microscopy (SEM), transmission electron microscopy (TEM), light optical microscopy (LOM) and atomic force microscopy (AFM). Among SEM techniques we use high-resolution FEGSEM imaging, qualitative and quantitative electron-probe microanalysis (EPMA: EDXS, WDXS) and electron-backscatter diffraction (EBSD). Among TEM techniques, high-resolution scanning transmission electron microscopy (STEM, HAADF-STEM), electron-energy-loss spectroscopy (EELS) and EDXS are used for structural and chemical analysis of materials at the atomic scale. Recently, *in-situ* liquid-cell TEM has been employed to observe dynamical processes during electrochemical processes of metal deposition from liquid media.

The ESTEEM consortium (Enabling Science and Technology through European Electron Microscopy) continued its activities within the ESTEEM3 project in the field of materials characterisation using state-of-the-art transmission electron microscopy techniques.

The research group of the Department for Nanostructured Materials is strongly connected with the activities within the Center for Electron Microscopy and Microanalysis (CEMM), mainly through the implementation of various electron microscopy analytical techniques and the possibility for the researchers to access research infrastructure for electron microscopy.

In the frame of a collaboration within IRP PAC2, a new fabrication approach was proposed to investigate new ultrathin-oxide (UTO) two-dimensional perovskites. The results were published in journal *Physical Chemistry Chemical Physics* (https://pubs.rsc.org/en/content/articlelanding/2022/cp/d1cp05296a).

The formation of two-dimensional oxide dodecagonal quasicrystals as well as the related complex approximant phases was recently observed in thin films derived from $BaTiO_3$ or $SrTiO_3$ perovskites deposited on (111)-oriented Pt single crystals. In our study, we used an all-thin-film approach, according to which the single crystal is replaced by a 10-nm-thick Pt(111) buffer layer grown by molecular beam epitaxy on an Al_2O_3(0001) substrate. An ultrathin film of $SrTiO_3$ was subsequently deposited by pulsed laser deposition. The film stacking and structure were fully characterised by diffraction and microscopy techniques (Figure 15). We reported on the discovery of two new complex UTO phases obtained with the reduction of this system through high-temperature annealing under ultrahigh vacuum conditions: a square-like approximant with a giant unit cell (44.4 Å) and a complex hexagonal phase.
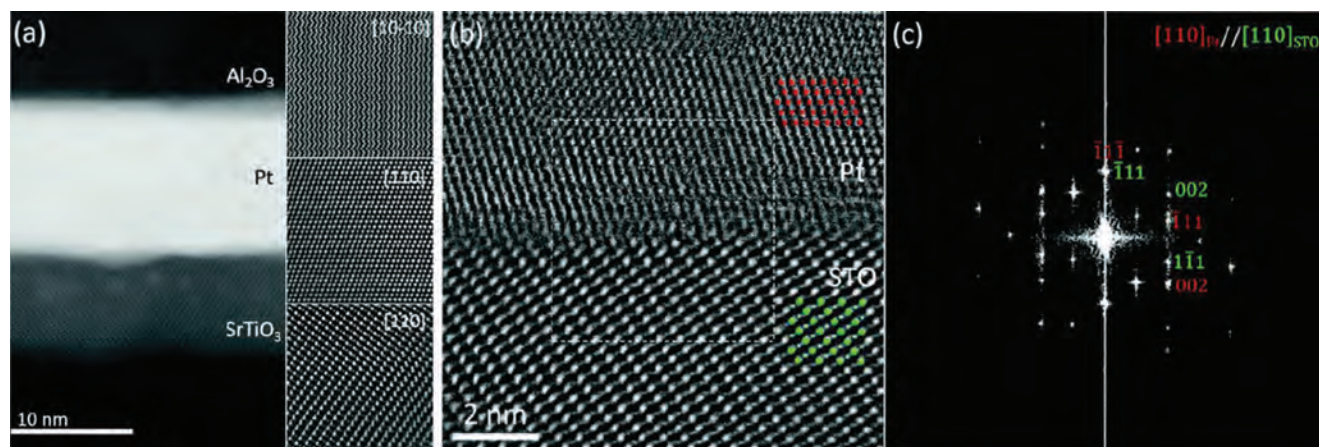
Figure 15: (a) HAADF-STEM image shows the thin film stacking, consisting of an Al_2O_3 substrate, ~12 nm Pt buffer layer and ~10 nm $SrTiO_3$ thin film. The all-thin-film approach was used to form two-dimensional oxide quasicrystal approximants of $SrTiO_3$ on the Pt buffer layer grown by molecular beam epitaxy on the Al_2O_3(0001) substrate. Atomically resolved HAADF-STEM images of each layer are shown on the right at their corresponding zone axes of $[210]_{Al2O3}$, $[110]_{Pt}$ and $[110]_{STO}$ respectively. (b) Atomically resolved ABSF-filtered HAADF-STEM image shows the Pt/STO interfacial region with superimposed structural models viewed in the $[110]_{Pt}$ and $[110]_{STO}$ zone axes, respectively. Pt, Sr and Ti atoms are shown in red, green and blue, respectively. (c) The corresponding FFT pattern obtained from the marked area in (b).

In cooperation with the Institute for Multidisciplinary Research in Belgrade, we investigated the self-organization and microstructure of fast-response humidity sensors based on SnO_2. Materials produced with the infiltration of SnO_2 into a KIT-5 mesostructured silicate lattice were synthesized by colleagues from Serbia, whereas TEM investigations of the mesostructure formation with controlled pore size were performed at the Department of Nanostructured Materials. We have shown that after infiltration, SnO_2 completely replaces and replicates the cubic KIT-5 lattice, whereas larger idiomorphic SnO_2 cyclic twins are formed on the surface of the particles. The SnO_2 mesostructure is stable and does not collapse during thermal treatment (Figure 16). Preparation of SnO_2 based sensors according to this procedure enables the production of mesostructures with a large specific surface, enabling a fast response and regeneration of the semiconducting element. The article 'KIT-5 assisted synthesis of mesoporous SnO_2 for high-performance humidity sensors with a swift response/recovery speed' was published in *Molecules* (https://www.mdpi.com/1420-3049/28/4/1754).

In-situ liquid TEM (LTEM): Recent development of liquid-cell TEM holders allows for *in-situ* studying of materials reactions. Such specialised holders contain liquid cells that can withhold liquid in a confined environment, facilitating the imaging and spectroscopy of samples in reaction media. Combining the capabilities of liquid-cell TEM holders with micro-size electrodes printed on a chip enables us to study dynamic phenomena during electrochemical reactions at high spatial and temporal resolution with the *in-situ* electrochemical liquid transmission electron microscopy (*in-situ* EC-LTEM). One of the most studied chemical processes in liquid TEM is related to studies of nucleation, growth and dissolution processes of nanoparticles and nanostructures. This is also the subject of a SLO-FWO joint project where we use the EC-LTEM to investigate the dynamics of the electrochemical deposition and dissolution of metallic nanoparticles such as Au, Ag, Pt and Pd by directly visualising them during the process. Figure 17 shows the holder tip structure (a) in the exploded view, (b) the EC e-chip containing the three electrodes including the reference electrode (RE), working electrode (WE) and counter electrode (CE), and (c) the deposited Au nanoparticles on the working electrode of the e-chip.

Figure 16: Microstructural study of a fast-response humidity sensor based on mesostructured SnO_2 synthesized with its infiltration into a KIT-5 silicate lattice: (a) KIT-5 with visible mesocrystalline porosity replaced by SnO_2 in the interior and large cyclic twins on the surface; (b) FFT of KIT-5 silicate after infiltration, showing characteristic diffraction rings corresponding to the SnO_2 phase; (c) the unfilled part of the KIT-5 mesostructure in the [111] projection indicating a cubic pore arrangement; (d) arrangement of SnO_2 nanoparticles following the KIT-5 pore structure
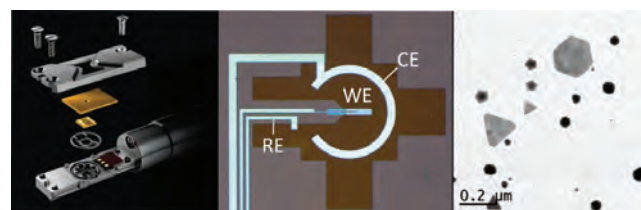
Figure 17: (a) Liquid-cell TEM tip structure in the exploded view showing the chips and other parts; (b) EC e-chip containing the RE, CE and WE; (c) Au nanoparticles deposited on the glassy carbon working electrode of the EC-LTEM e-chip

Education and outreach activities

For the tenth year, the members of the department participated in the science-promotion activities within the framework of the Science on the Street project.

We organized 15 live and/or virtual popular-science lectures. On the ZnC website we published 7 blogs of researchers and one photo competition, "The beauty of biomedicine". At the invitation of the EIT "Raw Materials" and JA Slovenia (Institute for the Promotion of Youth Entrepreneurship), we co-organised the Innovation Camp 2022, for the fourth time. 150 students from 17 high schools from all over Slovenia participated in the Innovation Camp.

Strategic Research and Innovation Partnership of the Factories of the Future (SRIP ToP) activities, vertical value chain New Materials

In 2022, SRIP ToP restructured its five separate value chains into two primary areas of focus. As part of this reorganisation, the value chain previously known as 'New Materials' has been renamed 'Advanced Green Technologies.' This newly named focus area now includes various fields, such as sensors and magnetic materials, among others. In 2022 we focused on the preparation of documents for the activities of the new focus areas, meetings with other SRIPs, and the organisation of an expert group together with the focus area covering modern production technologies for materials.

Awards and Appointments

1. Prof. Miran Čeh is the recipient of the "Spiridion Brusina" award for the cooperation with Croatian scientists in the field of natural history and promoting Croatian science around the world. The award is given by the Croatian Society of Natural Sciences from Zagreb, Croatia.
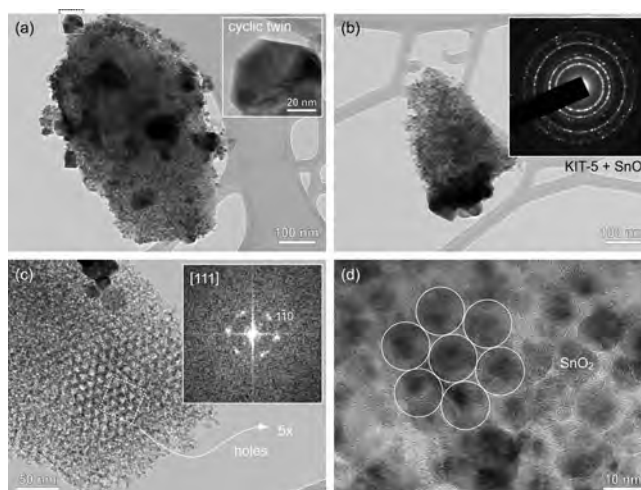
2. Prof. Jean-Marie Dubois is the recipient of the Stoddart International Science Award (named after Sir Frazer Stoddart, Nobel Laureate in Chemistry) for lifetime achievement in materials science. The award was presented by Flogen Star Outreach (a non-profit organization) at the SIPS 2022 Congress in Phuket, Thailand.

3. Prof. Saša Novak Krmpotič is the recipient of the honorary annual title "Science Communicator 2022" in the field of the importance of scientists' communication to the public, awarded by the Slovenian Science Foundation.

4. Prof. Aleksander Rečnik is the recipient of an honorary award for long-term cooperation and assistance within the doctoral program at the University of Pannonia in Veszprém. The prize is awarded by the Senate of the University of Pannonia, Veszprém, Hungary.

5. Dr Sorour Semsari Parapari is the recipient of the 2nd-best oral presentation award at the ELMINA international conference for the presentation entitled Heterogeneous Electrochemical Dissolution of Gold Nanoparticles Observed via In-Situ Liquid TEM, awarded by the Serbian Academy of Sciences and Arts and the Faculty of Technology and Metallurgy of the University of Belgrade, Serbia.

6. Dr Sorour Semsari Parapari is the recipient of the European Society for Microscopy scholarship at the 16th MCM (Multinational Microscopy Congress) conference in Brno, Czech Republic.

7. Dr Vesna Ribić is the recipient of the award for the best article entitled New inversion boundary structure in Sb-doped ZnO predicted by DFT calculations and confirmed by experimental HRTEM (published in the journal Acta Materialia), awarded by the Scientific Council of the Institute for Multidisciplinary Research in Belgrade, Serbia.

Organization of conferences, congresses and meetings

1. International Workshop on Sustainable Remediation of Toxic Compounds (SusRemTOC), Goriška Brda, 5–6 May 2022

2. Annual meeting within the international laboratory LIA PACS2: Push-Pull AlloyS and Complex Compounds (PACS2): from bulk properties to surface functions, Ljubljana and Goriška Brda, 20–21 September 2022

3. International workshop and project meeting ReCement: Re-generating (raw) materials and end-of-life products for re-use in cement/concrete, Ljubljana and Dobrovo in Brda, 21–24 November 2022

4. Project meeting group for the development of 4D microscopic techniques: 4D STEM Meeting, Ljubljana, 9 December 2022

Patent granted

1. Matic Korent, Marko Soderžnik, Urška Ročnik, Karla Kosmač, Zoran Samardžija, Boris Saje, Spomenka Kobe, Procedure for improving the magnetic properties of MQP-B+Nd-Fe-B magnetic powders with a small proportion of intergranular phase and aprocess for making polymer-bonded magnets from these magnetic powders, SI26141 (A), Slovenian Intellectual Property Office, 29. 07. 2022.

INTERNATIONAL PROJECTS

1. Microwave Ferrites
   Dr. Petra Jenuš
   Antistat GmbH

2. COST CA17140 - Nano2Clinic; Cancer Nanomedicine - From the Bench to the Bedside and COST Action 2nd CA17140 Training School (Institute of Oncology Research (IOR), Bellinzona, Switzerland), From 13 March 2023 to 14 March 2023
   Asst. Prof. Nina Kostevšek
   Cost Association Aisbl

3. H2020 - ESTEEM3; Enabling Science and Technology through European Electron Microscopy
   Prof. Miran Čeh
   European Commission

4. H2020 - SUSMAGPRO; Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy
   Prof. Spomenka Kobe
   European Commission

5. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Spomenka Kobe
   European Commission

6. H2020 - ORACLE; Novel Routes and Catalysts for Synthesis of Ammonia as Alternative Renewable Fuel
   Prof. Andraž Kocjan
   European Commission

7. H2020 - PASSENGER; Pilot Action for Securing a Sustainable European Next Generation of Efficient RE-Free Magnets
   Prof. Kristina Žužek
   European Commission

8. H2020 - OCARINA; Novel Recycling and Reprocessing of Permanent Magnets
   Prof. Kristina Žužek
   European Commission

9. Nanostructured Metal Oxide-Based Materials for Applications in Photocatalytic Processes
   Dr. Matejka Podlogar
   Slovenian Research Agency

10. INSPIRES - Intelligent and Sustainable Processing of Innovative Rare-Earth Magnets
    Prof. Spomenka Kobe
    Eit Rawmaterials E.v.

11. HE - EUROfusion; WP18: MAT_HE-FU, IREMEV-MAT-1_HE-FU, IREMEV-MAT-2_HE-FU, IREMEV-MAT-3_HE-FU
    Dr. Petra Jenuš
    European Commission

12. HE - EUROfusion; WP21: PRD-1,2_HE-FU
    Dr. Aljaž Iveković
    European Commission

13. RECO2MAG; Grain Boundaries Engineered Resource Efficient Nd-Fe-B Permanent Magnets (PMs)
    Prof. Kristina Žužek
    Eit Rawmaterials E.v.

14. HE - EUROfusion; WP24: TRED_HE-FU, EDU_HE-FU

Prof. Saša Novak Krmpotič
European Commission
15. HE - REESilience; Resilient and Sustainable Critical Raw Materials REE Supply Chains for the E-Mobility and Renewable Energy Ecosystems and Strategic Sectors
Prof. Kristina Žužek
European Commission
16. HE - GYROMAGS; Green Recycling Route for Sm-Co Permanent Magnet Swarf
Prof. Kristina Žužek
European Commission
17. HE - HEO4CAT; Development of New High-Entropy Oxide Catalysts by the Anodic Oxidation of High-Entropy Alloys
Belisa Alcantara Marinho
European Commission

RESEARCH PROGRAMMES

1. Nanostructured Materials
   Prof. Sašo Šturm
2. Ceramics and complementary materials for advanced engineering and biomedical applications
   Prof. Andraž Kocjan
3. Fusion technologies
   Prof. Saša Novak Krmpotič

R & D GRANTS AND CONTRACTS

1. Development of a new reactor concept for microkinetic studies and its use for selective oxidative dehydrogenation of alkanes and methane coupling
   Dr. Luka Suhadolnik
2. Selective extraction of high value molecules from forest products processing residues in the speciality chemicals sector
   Dr. Petra Jenuš
3. Molybdenum geobiochemical Cycle in modern environments
   Prof. Sašo Šturm
4. Advanced 3D cell models: Bridging the gap between in vitro and vivo experimental systems (hep3DGenTox)
   Prof. Saša Novak Krmpotič
5. Post-radiation caries in head and neck cancer patients: Understanding and prevention
   Prof. Andraž Kocjan
6. Degradation of plastics with polyextremotolerant fungi
   Dr. Matejka Podlogar
7. Modulation of fruit polyphenolic profile by sustainable postharvest physical treatments
   Dr. Anže Abram
8. Preclinical and Clinical Investigations of Zirconia Dental Ceramics Fabricated by Additive Manufacturing Technologies (ZIRAMDENT)
   Prof. Andraž Kocjan
9. Development of novel multifunctional metal-oxide-based nanozymes and their toxicological characterisation (NaNoZymSafe)
   Dr. Petra Jenuš
10. Fundamental understanding of the hydrogen formation reaction for a new generation of nickel-based electrocatalysts in alkaline and chloralkali electrolysis
    Prof. Sašo Šturm
11. Mineral inclusions in garnet from macroscopic to atomic scale: Opening the petrogenetic archive
    Prof. Aleksander Rečnik
12. High performance nanostructured acrylamide sensors
    Asst. Prof. Kristina Žagar Soderžnik
13. Designing functionality of lead-free ferroelectrics through domain wall engineering
    Asst. Prof. Matej Andrej Komelj
14. Prediction of the initial stages of electrochemical phase formation by multi-scale modelling and insitu transmission electron microscopy
    Prof. Sašo Šturm
15. Extended defects in natural and synthesized perovskite oxides: nanogeochemcial indicators and functional interfaces
    Prof. Aleksander Rečnik
16. Development of High Performance Sensors for Detection of Persistent and Mobile

Chemicals in the Environment (SENSE-PMC)
Asst. Prof. Kristina Žagar Soderžnik
17. Aragonite: structure and formation
    Prof. Aleksander Rečnik
18. Functionally Graded Materials with Interpenetrating Phases made of Immiscible Alloys
    Dr. Aljaž Iveković
19. Nuclear radiation catalyzed chemistry
    Prof. Sašo Šturm
20. 4D STEM of energy related materials down to quantum level
    Prof. Sašo Šturm
21. Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology
    Prof. Spomenka Kobe
22. Degradation of textile microplastic for domestic wastewater treatment
    Dr. Matejka Podlogar
23. Novel Flow Photoelectrocatalytic Reactors for Degradation of Pharmaceuticals in Waste Water
    Prof. Miran Čeh
24. Development of rapid radiation-sintering technique for net-shape manufacture of advanced multicomponent Nd-Fe-B permanent magnets with reduced use of critical raw materials
    Dr. Tomaž Tomše
25. Portable, highly sensitive and selective nanostructured biosensors for viral rapid detection
    Dr. Špela Trafela
26. RECEMENT:Re-generating (raw) materials and end-of-life products for re-use in Cement/Concrete
    Prof. Sašo Šturm
    Ministry of Education, Science and Sport
27. AddMag - Additive manafucturing of permanent magnet materials
    Asst. Prof. Matej Andrej Komelj
    Ministry of Education, Science and Sport
28. Characterization of surface structure of machined ceramic materials
    Prof. Slavko Bernik
    University of Ljubljana
29. External Services
    Prof. Andraž Kocjan

NEW CONTRACTS

1. Degradation of textile microplastic for domestic wastewater treatment
   Dr. Matejka Podlogar
   Gorenje Gospodinjski Aparati, d.d.
2. Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology
   Prof. Spomenka Kobe
   Kolektor Group, d. o. o.
3. Novel Flow Photoelectrocatalytic Reactors for Degradation of Pharmaceuticals in WasteWater
   Prof. Miran Čeh
   Arhel Projektiranje in Inženiring, d. o. o.
4. Cooperation in the performance of measurements - Performance of VSM, XRD, TEM and CoNiP measurements
   Prof. Sašo Šturm
   Rls Merilna Tehnika, d. o. o.
5. Development and optimization of varistor ceramics and volume and multilayer (MLV) varistors
   Prof. Slavko Bernik
   Bourns, d. o. o., Žužemberk
6. Material characterization of biopharmaceutical products and primary packaging
   Prof. Sašo Šturm
   Lek, d. d.
7. Monitoring the manufacturing process of varistor ceramics and varistors
   Prof. Slavko Bernik
   Raycap, d. o. o.
8. Ceramic nozzle manufacturing
   Prof. Andraž Kocjan
   Trimo, d. o. o.

VISITORS FROM ABROAD

1. Prof. Andreja Gajović, Institut Rudjer Bošković, Zagreb, Croatia, 8–11 February 2022
2. Lucie Pejchalova, Brno University of Technology, Czech Republic, 21 March–19 June 2022
3. Daria Jardas and Assoc. Prof. Aleš Omerzu, Sveučilište u Rijeci, Rijeka, Croatia, 8 April 2022
4. Alexandra Maegli, Olliver Pujol and Alain Semoroz, Rolex, Plan-les Quartes, Switzerland, 12 April 2022
5. Justine Boutbien and Dr Vincent Fournee, Institut Jean Lamour – Universitet dé Lorraine, Nancy, France, 18–23 April 2022
6. Prof. Peter Fantke, Technical University of Denmark (DTU), Copenhagen, Denmark, 5–8 May 2022
7. Dr Goran Branković and Jelena Vukašinović, Institute for Multidisciplinary Research (IMSI), Belgrade, Serbia, 6–15 May 2022
8. Ece Günay, Sabancy University, Istanbul, Turkey, 17 May–10 June 2022

9. Martina Kocijan, University of Zagreb, Croatia, 22–27 May 2022
10. George Alameel and Tomaž Bojko, Bourns d. o. o., Žužemberk, Slovenia, 31 May 2022
11. Prof. Hasan Göcmez, Kütahya Dumlupinar University, Küthaya, Turkey, 2 June 2022
12. Juan Anat Gomez Belenguer, University of Zaragoza, Spain, 9 June to 5 August 2022
13. Zoran Goljuf and Tomaž Petan, Trimo d. o. o., Trebnje, Slovenia, 22 June 2022
14. Prof. Nina Bednarsek, National Institute of Biology, Ljubljana, Slovenia and Oregon State University, Corvallis, United States of America, 30 June 2022
15. Anna Katharina Hofer and Tobias Prötsch, Chair of Structure and Functional Ceramics, Montanuniversität Leoben, Austria, 4–7 July 2022
16. Prof. Andreja Gajović, Institut Rudjer Bošković, Zagreb, Croatia, 1–4 September 2022
17. Prof. Marian Janák, Geological Institute, Bratislava, Slovakia and Prof. Mirijam Vrabec, University of Ljubljana, Slovenia, 16 September 2022
18. Dr Pascal Boulet, Dr Vincent Fournee and Dr Julian Ledieu, Institut Jean Lamour – Universitet dé Lorraine, Nancy, France, 19–21 September 2022
19. Dr Nadezda Radmilović, University of Belgrade, VINČA Institute for Nuclear Science, Belgrade, Serbia and Prof. Vuk Radmilović, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, 20 October 2022
20. Assoc. Prof. Aleš Omerzu, University of Rijeka, Croatia, 6–13 November 2022
21. Tobias Prötsch, Chair of Structure and Functional Ceramics, Montanuniversität Leoben, Austria, 8–11 November 2022
22. Anna Katharina Hofer, Chair of Structure and Functional Ceramics, Montanuniversität Leoben, Austria, 21–23 November 2022
23. Dr Pavel Gavryushkin, Sobolev Institute of Geology and Mineralogy, SB RAS, Novosibirsk, Russia, 22–25 November 2022
24. Dr Matjaž Rozman, Bourns d. o. o., Žužemberk, Slovenia, 24 November to 7 December 2022
25. Dr Cristian Fàbrega Gallego, University of Barcelona, Department of Electronic and Biomedical Engineering, Spain, 5–9 December 2022
26. Prof. Carlo Burkhardt, Pforzheim University – University of Applied Sciences with the faculties of design, technology, economics and law, Pforzheim, Germany, 11–13 December 2022
27. Fabian Burkhardt, University of Birmingham, School of Metallurgy and Materials, Birmingham, United Kingdom, 16 December 2022
28. Martina Kocijan, University of Zagreb, Croatia, 17–23 December 2022

STAFF

Researchers
1. Prof. Slavko Bernik
2. Prof. Miran Čeh
3. Prof. Jean Marie Dubois
4. Dr. Aljaž Iveković
5. Dr. Petra Jenuš
6. Prof. Spomenka Kobe
7. Prof. Andraž Kocjan
8. Asst. Prof. Matej Andrej Komelj
9. Prof. Saša Novak Krmpotič
10. Dr. Matejka Podlogar
11. Dr. Benjamin Podmiljšak
12. Prof. Aleksander Rečnik
13. Dr. Zoran Samardžija
14. **Prof. Sašo Šturm, Head**
15. Asst. Prof. Kristina Žagar Soderžnik
16. Prof. Kristina Žužek

Postdoctoral associates
17. Dr. Anže Abram
18. Dr. Belisa Alcantara Marinho
19. Dr. Maja Antanasova*
20. Dr. Nataša Drnovšek*
21. Dr. Sina Khoshsima
22. *Dr. Matic Korent, left 01.03.22*
23. Dr. Nina Kostevšek
24. Dr. Amit Mishra
25. Dr. Vesna Ribić
26. Dr. Sorour Semsari Parapari
27. *Dr. Luka Suhadolnik, left 12.04.22*
28. Dr. Tomaž Tomše
29. Dr. Špela Trafela
30. Dr. Jelena Vujančević

Postgraduates
31. Giulia Della Pelle, M. Sc.
32. Diana Knyzhnykova, B. Sc.
33. *Anja Korent, B. Sc., left 01.10.22*
34. Abhilash Krishnamurthy, M. Sc.
35. Monika Kušter, B. Sc.
36. Barbara Ljubec Božiček, B. Sc.
37. Dr. Živa Marinko
38. Ipeknaz Özden, M. Sc.
39. Mihaela Rebernik, B. Sc.
40. Layrton Jose Souza Da Silva, M. Sc.
41. Vinko Sršan, M. Sc.
42. Aleksander Učakar, B. Sc.
43. Anubhav Vishwakarma, M. Sc.

Technical officers
44. Sanja Fidler, B. Sc.
45. Nik Gračanin, B. Sc.
46. Klara Laura Konda, B. Sc.
47. Kaja Križman, B. Sc.
48. Tina Radošević, B. Sc.
49. Dr. Boris Saje*
50. Kseniia Vyshnevska, B. Sc.

Technical and administrative staff
51. Sabina Cintauer, B. Sc.
52. Darko Eterović
53. Tamara Matevc, B. Sc.
54. *Tomislav Pustotnik, retired 04.07.22*
55. Marija Šebjan Pušenjak, B. Sc.

Note:
* part-time JSI member

DEPARTMENT FOR MATERIALS SYNTHESIS K-8

The research of the Department for Materials Synthesis is mainly related to the synthesis of various advanced materials, especially magnetic materials. Special attention is given to nanostructured materials, such as ferrofluids, functionalized nanoparticles for use in biomedicine, multifunctional nanocomposites, catalysts, and fluorescent nanoparticles.

Head:
Prof. Darko Makovec

A large part of the research at the Department for Materials Synthesis is devoted to the engineering of nanoparticles' surface properties. The control of surface properties is of key importance for the applications of nanoparticles, the preparation of their colloidal suspensions and their assembly into composite materials. The surface properties are engineered either by coating surfaces with inorganic shells and/or by bonding different functionalization molecules onto the nanoparticles' surfaces, known as functionalization. The layer of molecules has to be bonded by forming stable covalent bonds, not to be desorbed or exchanged with other ligands from the medium. Despite the high stability of covalent bonds, the coordinative interaction between a metal-oxide surface and organic molecules is often exploited for the surface functionalization. This is because of the ionic nature of metal-oxide crystals, in which the constituent ions are bonded electrostatically via the so-called ionic bonds, whereas organic molecules comprise covalently bonded atoms. The main problem of a coordinative bond is its dependence on the system's properties. Nevertheless, very strong coordinative bonding can be achieved between surface metal ions and some organic moieties (e.g., carboxylates, catechols, phosphonates). Our results showed that by coating superparamagnetic maghemite nanoparticles with some catechols the saturation magnetization of the nanoparticles increased. This was opposite to the expected decrease because of the nonmagnetic shell. Previous studies proposed two possible explanations: (1) reduction of the surface layer to magnetite with a higher saturation magnetization than that of maghemite, or (2) improved magnetic order at the surface by the catechol chelates.

> **Elucidation of the interactions in ferromagnetic liquids resulted in the development of the first room-temperature liquid magnets and miniature contactless sensors of the magnetic field.**

Our experiments did not confirm any of the proposed explanations but showed that the saturation-magnetization increase resulted from the size separation during the processing. In contrast to the above, a much larger decrease in the saturation magnetization of barium hexaferrite nanoplatelets was measured than expected after coating them with phosphonic acids. Among all the studied phosphonate ligands (mono-, bis-, di- and tetraphosphonates), only the di- and tetraphosphonate ligands showed such an effect. To elucidate the unexpected behaviour, a detailed spectroscopic study was carried out in collaboration with the University of Nova Gorica (prof. Iztok Arčon) and theoretical calculations were done by CNR, Trieste (dr Layla Martin Samos, dr Matic Poberžnik and Gabriela Herrero).

The control of surface properties of nanoparticles enables the preparation of their colloidal suspensions. In the forefront of our research is the preparation of suspensions of permanently magnetic barium hexaferrite nanoplatelets (in cooperation with the Department of Complex Matter). At sufficiently high concentrations such suspensions become ferromagnetic, i.e., they exhibit a spontaneous magnetic ordering and represent liquid magnets (in contrast to well-known superparamagnetic ferrofluids). We focused on the understanding of colloidal interactions in the suspensions of hexaferrite nanoplatelets. The conditions for the formation of ferromagnetic fluids in isotropic solvents and the stability range of ferromagnetic liquid crystals were determined. Based on these results, we also developed the first room-temperature liquid magnets.

A new research direction evolved from our background on the hexaferrite nanoplatelets and ferromagnetic fluids. Our aim is to add to the magnetic and shape anisotropy of those special materials by introducing additional functionality only on one basal surface of the nanoplatelets, thus making Janus nanoplatelets. The national project J2-2495, carried out in cooperation with the Faculty of Chemistry and Chemical Technology, University of Ljubljana, is focused on the development of hybridization technology for
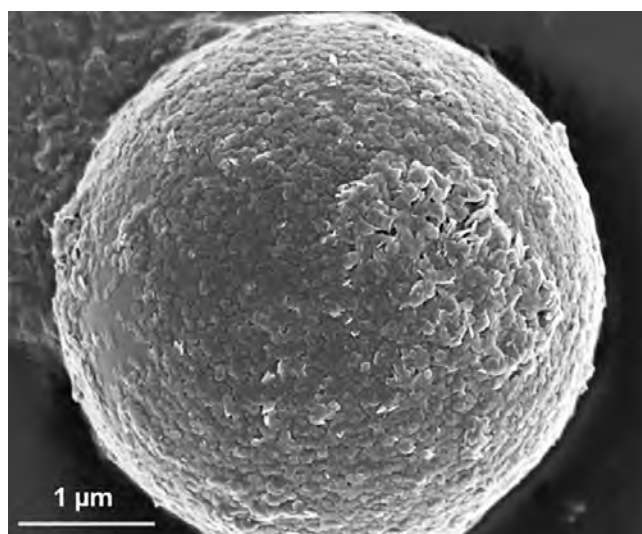

Figure 1: Barium hexaferrite nanoplatelets chemically assembled on a silica sphere

1 µm

making the magneto-electric Janus nanoplatelets based on the immobilization of hexaferrite nanoplatelets on a solid substrate. An immobilized monolayer of nanoplatelets (Figure 1) allows for their hybridization with electrically polar ligands only on one basal surface of the nanoplatelets. A major focus in 2022 was directed to the optimization of amino-functionalization of nanoplatelets, glass-substrate functionalization, and the Pickering-emulsion method for producing Janus nanoplatelets. Our advancement was related to the improved stability of the surface amine groups that lose their activity by bonding excessive ligands via hydrogen or electrostatic bonds and also via condensation reaction.

We were also very active within the FET-OPEN MAGNELIQ project where we cooperate with the University of Maribor, CNR Trieste, Czech Academy of Sciences and a SME Prensilia from Pisa. In the project we aim to develop a magneto-electric liquid based on magneto-electric Janus nanoplatelets. We studied the coordinative interaction of complexing ligands with hexaferrite nanoplatelets. Our aim was to identify conditions ensuring stable magneto-electric hybrids. Experimental studies run in parallel with theoretical calculations of basic interaction potentials. In addition, a variety of ferromagnetic liquids with a strong magneto-optic response was prepared and characterized.

Silica-coated gold nanoparticles with different morphologies were synthesized for the use in electroporation.

During the year, we developed a miniature sensor of the magnetic field (strength and direction) with colleagues from the University of Maribor.

A large part of our research remains devoted to the synthesis of nanomaterials for application in biomedicine. In 2022 we continued our study on drug delivery systems based on magnetic nanoparticles in cooperation with the group from the Faculty of Pharmacy, University of Ljubljana (prof. Petra Kocbek). We developed partially hollow magnetic nanostructures that have nanoscale voids available for drug loading while they preserve sufficient magnetic responsiveness. Furthermore, we also developed an electrospinning method for the preparation of a re-dispersible dry product with a high content of magnetic nanoparticles.

In 2022 we started the research, with which we tried to understand the mechanisms of cellular internalization of nanoparticles with different surface roughnesses while the overall size and composition of the nanoparticles remained unchanged. This interdisciplinary collaborative work was performed with researchers from the equivalent research group at the Faculty of Pharmacy. In the frame of this project we developed nanoparticle clusters coated with mesoporous shells of silica with different pore morphologies.

In the national project J2-3040, where we are cooperating with the Department of Molecular and Biomedical Sciences (asst. prof. Toni Petan), Biotechnical Faculty, University of Ljubljana (prof. Nataša Poklar Ulrih), and the Institute of Cell Biology, University of Ljubljana (prof. Mateja Erdani Kreft), we are developing new nanocarriers mimicking endogenous lipid particles. The nanocarriers will enable the delivery of a large amount of hydrophobized nanoparticles and lipophilic drugs into cells. The nanocarriers will be assembled from hydrophobized nanoparticles and lipophilic molecules in an emulsion, where the phospholipids and proteins (apolipoprotein or albumin) will be used as the surfactants. We aim to deliver: (i.) magnetic hexaferrite nanoplatelets for destruction of cancer cells with the actuation of the nanoplatelets with a low-frequency magnetic field (i.e., magneto-mechanical actuation), (ii.) different Fe-containing nanoparticles (hexaferrite nanoplatelets and magnetite nanoparticles) in a combination with polyunsaturated fatty acids to enable ferroptosis, and (iii.) fluorescent fluoride nanoparticles. The fluoride nanoparticles will be protected from dissolution in biological fluids during delivery. After delivery into cells, the cytotoxic species released by their nanoparticle dissolution will be used to possibly kill the cancer cells. The hexaferrite nanoplatelets will also be used to trigger the release of the cargo with the magneto-mechanical actuation of the nanoplatelets. In 2022 we were focused mainly on the development of the assembling method. First, the nanoparticles (hexaferrite nanoplatelets and isotropic maghemite nanoparticles) ware hydrophobized with a fatty acid and suspended in a hydrophobic solvent. The preparation of concentrated suspensions of hydrophobized, permanently magnetic nanoplatelets represented a large challenge since they tend to agglomerate due to magnetic interactions. We managed to prepare colloidally stable, concentrated nanoplatelet suspensions with our original method. The suspensions were then used to assemble the nanoparticles with lipophilic molecules, glyceryl trioleate, lecithin and different fluorophores, into the nanocarriers in the emulsion. In this initial stage, we used Tween 80 and Triton X100 as the biocompatible surfactants instead of phospholipids because of their much lower price. The nanocarriers contain magnetic nanoparticles dispersed in lipid droplets with a hydrodynamic size of around 200 nm.

In collaboration with scientists from the Faculty of Electrical Engineering, University of Ljubljana (the group of prof. Damijan Miklavčič), we continued research in the framework of a national project devoted to selective electroporation using gold nanoparticles as targeted nanoelectrodes. In 2022 we developed methods for silica coating of gold nanoparticles with relatively thick silica shells. The coating of gold proved to be very challeng-
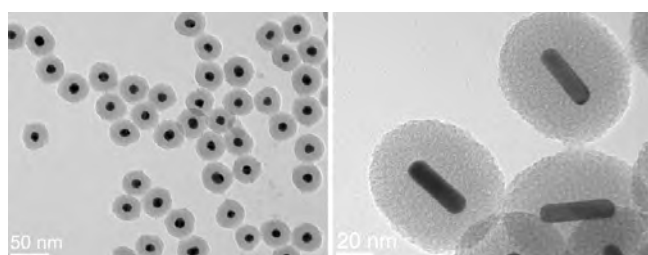

Figure 2: TEM images of silica-coated gold nanoparticles: spherical nanoparticles (left-hand image) and nanorods (right-hand image)

ing because of the inert metallic surface of the nanoparticles, which is not compatible with silica. Currently, our silica coating method allows the coating with relatively thick silica shells, with a thickness exceeding 20 nm (Figure 2). For our future needs, we are investigating new pathways for making silica shells thinner, preferably close to 2 nm.

We also continued our collaboration with researchers from the Department of Chemical and Pharmaceutical Sciences, University of Trieste, Italy (prof. Silvia Marchesan). We successfully synthesized a set of novel hybrid nanomaterials made of self-assembled di- and tripeptides. The hierarchical supramolecular assemblies allow for time- and space-controlled, selective chemical segregation by means of guest encapsulation. The gel nanostructure is influenced by the presence of cages, thus providing new means for time control over diffusion and, as a consequence, uptake of small molecules. Our future efforts will focus upon the extension of this chemical platform to biocompatible materials able to perform time-controlled guest release. In addition, our fruitful collaboration with the University of Trieste was also dedicated to the development of magnetic nanostructures conjugated with short peptides and self-assembled fibrillar peptide nanostructures.

Phosphonate coatings improve the viability of endothelial cells in the presence of fluorescent nanoparticles based on rare-earth fluorides.

In 2022 we started a new collaboration with researchers from the Laboratory of General Biochemistry and Physical Pharmacy, University of Ghent, Belgium (prof. Kevin Braekmans). We successfully developed larger superparamagnetic nanoparticle clusters with a mean size of 400 nm, which are suitable for light-triggered vapour nanobubble generation used for intracelular delivery of functional macromolecules. In the frame of the project we prepared a composite nanoparticle called "nanobomb", which consists of photothermal core particles of 400 nm (e.g., iron oxide nanoparticles), to which smaller polystyrene nanoprojectiles of 100–200 nm are attached. Our aim is to develop the protocols for a homogeneous coverage of the core particles with nanoprojectiles.

We continued with our research of fluorescent optical materials. Fluorescent nanoparticles with up-conversion emission can be applied in various optical elements and are also proposed as alternative bio-markers in imaging diagnostic techniques for medicine. After our previous discovery of the significant dissolution of fluoride-based up-converting nanoparticles (UCNPs, e.g., lanthanide-doped rare-earth fluorides) we focused on the prevention/minimization of their dissolution. We studied the efficiency of some phosphonate coatings to prevent the dissolution of the UCNPs. We showed that the phosphonate structure and coating-synthesis conditions are very important for the definition of the density of phosphonic coatings. The dissolution studies were made in cooperation with the Department of Inorganic Chemistry and Technology (dr Maja Ponikvar-Svet) and Czech Academy of Sciences (dr Uliana Kostiv). All the studies were supported with optical characterization in cooperation with the Department of Complex Matter (prof. Boris Majaron) and with cell-viability studies at the Faculty of Medicine, University of Ljubljana (dr. Lovro Žiberna).

We continued our research on the application of magnetic heating in catalysis. The catalysis by magnetic heating (also referred to as induction heating) is based on selective magnetic heating of the catalyst surface in a high-frequency (usually 200–600 kHz) magnetic field. The catalytic nanoparticles are deposited onto a catalyst support containing magnetic nanoparticles. When such a magnetic catalyst is exposed to an AC magnetic field, the catalyst is selectively heated due to magnetic losses of the magnetic nanoparticles dispersed in its interior. The main advantages of this electrified technology are its potential energy

Synthesis of magnetic catalysts for electrified ammonia production.

efficiency and very large flexibility as magnetic heating enables very fast heating and cooling rates of the catalyst (almost instant when compared to the conventional processes). This new heating methodology solves general problems encountered in industrial plants where start-up times under conventional radiation, convection and conduction heating schemes typically require several days to bring a plant under the regime conditions safely.

In the forefront of our research is the synthesis of magnetic catalysts. For the synthesis of nanostructured carbon-based magnetic catalyst supports, iron-oxide magnetic nanoparticles were coated with a carbonaceous material using hydrothermal carbonization of carbohydrates followed by a thermal treatment. The synthesis procedure for nanostructured magnetic alumina was developed in cooperation with the Department for Nanostructured Materials (prof. Andraž Kocjan), based on deposition of AlOOH onto superparamagnetic iron-oxide nanoparticles, with the hydrolysis of AlN in a colloidal suspension followed by a thermal treatment.

In cooperation with the Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry (dr Blaž Likozar and dr Miha Grilc), we studied the AC field-mediated catalytic hydrotreatment of levulinc acid using Ru-bearing carbon-coated magnetic nanoclusters. An in-depth analysis and modelling of the hydrogenation and deoxygenation processes showed that the surface of a catalyst rapidly heats to 137 °C, while the bulk of the medium remains at a significantly lower temperature of 85 °C. Such a thermal imbalance increased the rate of conversion of isopropyl levulinate (formed by a competing reaction) to γ-valerolactone, thus increasing the yield.

We have also been very active in the H2020 Oracle project, which aims to develop a scalable and flexible electrified production of NH_3 for fuel applications. Here, we collaborate with several European institutions focusing on
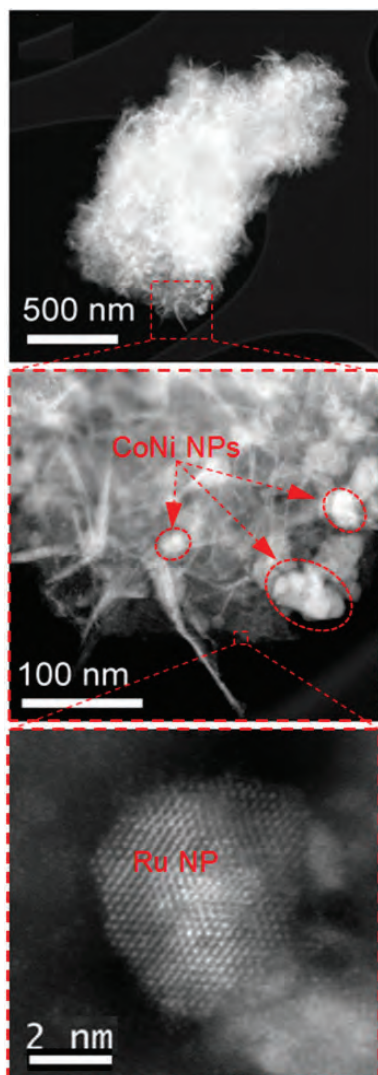
Figure 3: HAAHF STEM images of a Ru catalyst supported by a nanostructured alumina matrix containing CoNi magnetic nanoparticles

developing catalysts and their integration within reactor units, utilizing the magnetic heating of coated magnetic nanoclusters for a flexible and on-demand production. We have developed a scalable aqueous method for the preparation of Co_xNi_{1-x} precursor particles based on co-precipitation. Such nanoparticles were successfully embedded within an alumina matrix using our method based on the hydrolysis of AlN (Figure 3). During high-temperature reduction, the precursor nanoparticles reduce to Co_xNi_{1-x} nanoparticles. The research was focused on the influence of reduction conditions, such as temperature, temperature ramp and H_2 gas flow, on the size of Co_xNi_{1-x} nanoparticles. The size has a major impact on their heating ability. We have developed a process yielding several gram quantities per batch of Co_xNi_{1-x} dispersed in high-surface-area alumina. The product demonstrated superior heating already under a low AC magnetic field in an environment relevant for the ammonia synthesis.

In 2022 we have strengthened our research collaboration with the Department of Green Technologies, University of Southern Denmark (prof. Shuang Ma Andersen and prof. Raghunandan Sharma). We contributed to the development of a method for recycling Pt from end-of-life proton-exchange-membrane fuel-cell stacks. The recycling processes involved the dissolution of Pt from fuel-cell electrodes in diluted HCl. The recycled material was then used for a polyol synthesis of platinum supported by carbon (Pt/C). The electrochemical performances of the Pt/C electrocatalysts synthesized using the recycled Pt were found to be comparable to the commercial product. We also contributed to an important study where determination of the electrochemical surface area (ECSA) of Pt/C electrocatalysts through the hydrogen adsorption/desorption region was revisited. Our study showed the importance of considering an appropriate baseline correction, taking into account the oxidation of the support carbon during catalyst durability tests, such as the accelerated stress test (AST).

We continued our research of the materials exhibiting a positive temperature coefficient of resistivity (PTCR). The focus was on composite materials containing a mixture of a conducting phase (metal) and non-conducting phase ($BaTiO_3$ ceramic). Due to dimensional changes during the phase transformation in the non-conducting phase, disconnections occur in the conductive phase that lead to a PTCR anomaly.

Some outstanding publications in the past year

1. Gyergyek, Sašo, Grilc, Miha, Likozar, Blaž, Makovec, Darko. Electro-hydrogenation of biomass-derived levulinic acid to γ valerolactone via the magnetic heating of a Ru nanocatalyst. Green Chemistry [in press]. 2022, 8 pp., doi: 10.1039/D2GC00102K.

2. Makovec, Darko, Kosi Križaj, Nina, Meden, Anton, Dražić, Goran, Uršič Nemevšek, Hana, Kostanjšek, Rok, Šala, Martin, Gyergyek, Sašo. Ferroelectric bismuth-titanate nanoplatelets and nanowires with a new crystal structure. Nanoscale. ISSN 2040-3364, 2022, vol. 14, iss. 9, pp. 3537–3544, doi: 10.1039/d2nr00307d. [COBISS.SI-ID 101065219]

3. Hribar, Patricija, Gregorin, Žiga, Sebastián Ugarteche, Nerea, Osterman, Natan, Lisjak, Darja, Mertelj, Alenka. Isotropic to nematic transition in alcohol ferrofluids of barium hexaferrite nanoplatelets. Journal of Molecular Liquids [Print ed.]. 2022, vol. 348, 118038-1-118038-9

Awards and Appointments

1. Sebastjan Nemec: Dean's Award for the publication of the research article entitled *A versatile interfacial coassembly method for fabrication of tunable silica shells with radially aligned dual mesopores on diverse magnetic core nanoparticles* in high impact factor scientific journal *ACS Applied Materials & Interfaces*. The award was given on 30 November 2022, on the Research Day at the Faculty of Pharmacy, University of Ljubljana.

INTERNATIONAL PROJECTS

1. Maghon - Feasibility Study for Preparation of Magnetically Heatable Honeycombs
   Asst. Prof. Sašo Gyergyek
   Ceram Austria GmbH

2. Microwave Ferrites
   Prof. Darja Lisjak
   Antistat Gmbh

3. COST CA18132; Functional Glyconanamaterials for the Development of Diagnostics and Targeted Therapeutic Probes
   Asst. Prof. Slavko Kralj
   Cost Association Aisbl

4. H2020 - BeMAGIC; Magnetoelectrics Beyond 2020: A Training Programme on Energy-Efficient Magnetoelectric Nanomaterials for Advanced Information and Healthcare Technologies
   Prof. Darja Lisjak
   European Commission

5. H2020 - ORACLE; Novel Routes and Catalysts for Synthesis of Ammonia as Alternative Renewable Fuel
   Asst. Prof. Sašo Gyergyek
   European Commission

6. H2020 - PASSENGER; Pilot Action for Securing a Sustainable European Next Generation of Efficient RE-Free Magnets
   Prof. Darko Makovec
   European Commission

7. H2020 - MAGNELIQ; A Magneto-Electric Liquid - Better Sensing
   Prof. Darja Lisjak
   European Commission
8. Investigation of Ferrimagnetic Vortex Iron Oxide (FVIO) Based Nanoparticles for Magnetic Hyperthermia Applications
   Prof. Darko Makovec
   Slovenian Research Agency

RESEARCH PROGRAMME

1. Advanced inorganic magnetic and semiconducting materials
   Prof. Darko Makovec

R&D GRANTS AND CONTRACTS

1. Bactericidal nanoblades: a proof-of-concept approach for bimodal chemo-mechanicaleradication of persistent biofilms
   Asst. Prof. Slavko Kralj

2. Selective electroporation by distributed nanoelectrodes
   Asst. Prof. Slavko Kralj
3. The development of a highly sensitive electrochemical method for trace determination of antibiotic compounds based on magnetic polymericnanocomposites in environmental systems
   Asst. Prof. Sašo Gyergyek
4. Liquid Magnets: fundamental studies of ferromagnetic order in liquids
   Prof. Darja Lisjak
5. Surface-selective hybridization technology for magneto-electric hybrids
   Prof. Darja Lisjak
6. Magneto Responsive Surfaces for Manipulation of Light and Liquids
   Prof. Darko Makovec
7. Magnetically-controllable nanocarriers mimicking endogenous lipid particles for improved drug/nanoparticle delivery
   Prof. Darko Makovec
8. Exploitation of the magneto-mechanical effect in the treatment of neurodegenerative diseases
   Asst. Prof. Slavko Kralj
9. Selective mechanical removal of bacterial biofilms by conjugated magnetic nanoparticles
   Asst. Prof. Slavko Kralj
10. Different Services
    Prof. Darko Makovec

VISITORS FROM ABROAD

1. Nina Popov, Inštitut Ruđer Bošković, Zagreb, Croatia, 17 November 2022
2. Mario Schweiger, Ceram Austria Gmbh, Schamberg, Austria, 16 December 2022
3. Roland Nilica, Ceram Austria Gmbh, Schamberg, Austria, 16 December 2022
4. Georg Kogler, Ceram Austria Gmbh, Schamberg, Austria, 16 December 2022
5. Fauland Gernot, Ceram Austria Gmbh, Schamberg, Austria, 16 December 2022

STAFF

Researchers
1. Asst. Prof. Sašo Gyergyek
2. Asst. Prof. Slavko Kralj
3. Prof. Darja Lisjak
4. **Prof. Darko Makovec**, Head
5. Dr. Igor Zajc

Postdoctoral associates
6. Dr. Stanislav Čampelj
7. *Dr. Jelena Papan Djaniš, left 01.11.22*
8. *Jelena Papan Djaniš, B. Sc., left 01.11.22*
9. Dr. Janvit Teržan*
10. Dr. Ali Tufani

Postgraduates
11. Maja Caf, B. Sc.

12. Katja Drobež, B. Sc.
13. Nina Križaj Kosi, B. Sc.
14. Sebastjan Nemec, B. Sc.
15. Žiga Ponikvar, B. Sc.
16. Anja Sedminek, B. Sc.
17. Luka Skubic, B. Sc.

Technical officer
18. Tina Černič, B. Sc.

Technical and administrative staff
19. Bernarda Anželak, B. Sc.
20. Tamara Matevc, B. Sc.

Note:
* part-time JSI member

DEPARTMENT FOR ADVANCED MATERIALS

K-9

At the Advanced Materials Department we investugate novel materials through an understanding of the mutual dependence of their structural, microstructural and functional characteristics. We use modern technologies to control the synthesis of materials with atomic and microscale precision and prepare pre-designed structural 3D materials, thin films and nanoparticles with the desired crystal structure, chemical composition and morphology. Among our important objectives is the development of novel functional oxide materials for electronic applications and energy conversion, antibacterial and piezoelectrical biocompatible materials, and heat-insulation materials with improved properties and sustainability.

Head:
Prof. Matjaž Spreitzer

Novel functional oxides

Photocatalysis has been one of the fastest-growing segments of science. Despite the development and evaluation of several photocatalytic systems that have brought progress in the understanding of the phenomena, considerable advancement is still needed to increase the photoconversion efficiencies to the levels that would make these processes economically viable for practical application (e.g., for the production of H_2 with photocatalytic water splitting). In engineering new and even better photocatalysts it is important to exploit the existing knowledge pool and innovatively combine several design strategies that contribute to the enhancement of photocatalytic efficiency. In our research, together with project partners, we attempt to contribute to the progress in the field of photocatalytic water splitting used for the production of H_2. We are focused on the development of new photocatalysts based on graphitic carbon nitride (g-C_3N_4) with cobalt boride (CoB) as the co-catalysts and on perovskites, particularly on two-dimensional (2D) $SrTiO_3$/$Bi_4Ti_3O_{12}$ epitaxial nanoheterostructures, 2D $SrTiO_3$ nanoplatelets and $SrTiO_3$ particles with partial substitution of Ti with Al (Al-doped $SrTiO_3$). We showed that an optimized CoB-gC_3N_4 composite exhibits a ∼60-times-higher hydrogen-generation rate compared to bare g-C_3N_4 nanosheets, with good stability. For the preparation of 2D $SrTiO_3$/$Bi_4Ti_3O_{12}$ and 2D $SrTiO_3$ nanoplatelets, we developed a new method of hydrothermal topochemical conversion. We determined the mechanism of the transformation and experimental strategies for tuning the platelet composition ($SrTiO_3$:$Bi_4Ti_3O_{12}$ ratio, bismuth remains), surface roughness and surface area, whereby all of these influence the platelet functional properties to a great extent. A photocatalytic evaluation revealed that without any addition of noble-metal co-catalyst $SrTiO_3$/$Bi_4Ti_3O_{12}$ platelets show (under AM 1.5G irradiation) more than a 35 times higher photocatalytic H_2 production (2950 mmol×g⁻¹×h⁻¹) compared to the commercial $SrTiO_3$ nanopowders (81 mmol×g⁻¹×h⁻¹). The reason for the enhancement can be ascribed to the 2D morphology, $SrTiO_3$/$Bi_4Ti_3O_{12}$ epitaxial heterojunction (Figure 1), favorable charge transfer via a direct Z-scheme and surface plasmon resonance effect of the captured and *in-situ* reduced Bi^{3+} ions ($Bi°$). The understanding of this particular topochemical conversion is of broader importance as it provides guidelines for designing other defined-shaped epitaxial heterostructures, anisotropic nanostructures, or nanostructures with pre-defined exposed facets that otherwise cannot be formed.

Another research area was devoted to the preparation of H_2 evolution photocatalysts based on Al-doped $SrTiO_3$, grown in different molten salts (NaCl, KCl, $SrCl_2$). In addition, to study the effect of Al on the photocatalytic H_2 evolution, we were interested in how the combination of salt, Al and temperature (900–1000 °C) influences the particle morphology and Al incorporation. We found that, compared to pure, rather well-defined cubes of $SrTiO_3$ with dominant (100) exposed facets, Al-doped $SrTiO_3$ particles adopt more irregular morphologies with less defined facets and a much broader particle size distribution, whereby dislocations and planar defects are also more frequently present. We believe that all these influence the photoinduced electron-hole recombination and consequently the photocatalytic properties but, most probably, the intrinsic contribution of Al-doping prevails over these extrinsic effects. It was confirmed experimentally that the greatest improvement in the photocatalytic efficiency after Al^{3+} doping was achieved for Al-doped $SrTiO_3$ grown (2 at. Al) in molten KCl at 1000 °C (apparent quantum yield (AQY) of 15.7% at 365 nm), which rendeed this molten salt system a cheaper alternative to the much more studied $SrCl_2$ molten salt method. First-principles calculations, performed by the project partner from the Institute of Solid State Physics at the University of Latvia, indicated that the doping leads to photostimulated mobile hole trapping at local energy levels close to the valence band top, which is is likely to prevent the electron-hole recombination, thus stimulating the H_2 formation.

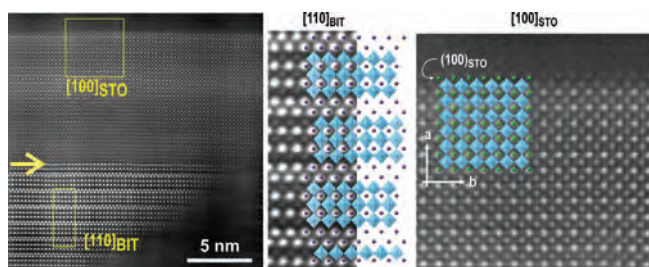*Figure 1: High-resolution (HR) STEM micrographs of a heterostructural SrTiO₃/Bi₄Ti₃O₁₂ platelet (edge-on oriented and thinned to electron transparency). Left: HR image indicating (100) SrTiO₃ growth on the Bi₄Ti₃O₁₂ platelet where the yellow arrow denotes the SrTiO₃/Bi₄Ti₃O₁₂ interface. The magnified HR images of the marked areas of the SrTiO₃ near the surface and Bi₄Ti₃O₁₂ in the interior are shown on the right-hand side together with the overlaid structural models. BIT Bi₄Ti₃O₁₂, STO SrTiO₃, (Z-J. Gong, J. C. S. Wu, N. Daneu, M. Maček Kržmanc, Wen-Yueh Yu, et al., J. Catal. 416 (2022) 222–232).*

Several research projects at our department are dedicated to tailoring the properties of thin films based on functional oxides by controlling the growth of complex relaxor ferroelectric thin films. We continued our studies on the (1-x) Pb($Mg_{1/3}Nb_{2/3}$)O_3 – xPbTiO₃ (PMN–PT) solid solution. In our study, published in the Journal of Materials Chemistry C (doi:10.1039/D2TC04070K) we showed that the material transfer from the pulsed-laser deposition (PLD) target is not fully stoichiometric. The largest deviations were found for the Mg and Pb concentrations. We showed that it is possible to tune the stoichiometry of the films with the use of custom-made ceramic targets, emphasizing their advantage over single-crystal targets in the PLD growth of complex metal oxides. The functional response, however, is the result of complex interactions between the crystal structure, microstructure and chemical composition of the films. The sample with the largest deviations from the nominal stoichiometry exhibited the highest longitudinal piezoelectric coefficient.

We also continued our research on the epitaxial strain in PMN-33PT thin films using different rare-earth scandates as the substrates. We obtained PMN-33PT thin films with extremely low rocking curves (FWHM < 0.05°) on ScSmO₃ (SSO) and DyScO₃ (DSO) substrates buffered with SrRuO₃ (SRO). On the SSO substrate, which allows a smaller mismatch, the film exhibits enhanced tetragonality compared to the bulk, whereas on the DSO substrate, which causes a higher mismatch, the film exhibits reduced tetragonality. The fully strained film displays typical ferroelectric *P-E* hysteresis loops, while the relaxed sample shows a relaxor-like behavior (Figure 2a). The samples exhibit large negative imprints, induced by the alignment of defect dipoles with the polarization and are tuned by the epitaxial strain (Figure 2b). This allows for the stabilization of a robust polarization state and low dielectric permittivity. These characteristics, along with the enhanced $d_{33,eff}$, present the key factors for designing micro-electromechanical devices with an enhanced figure of merit. More details can be found in the scientific paper published in Applied Physics Letters (doi:10.1063/5.0115777).
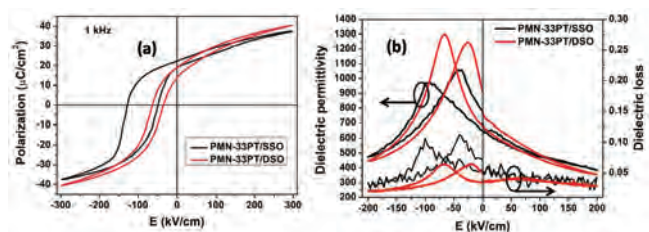

Figure 2: (a) Polarization hysteresis loops and (b) dielectric permittivity and losses as a function of DC bias of PMN–33PT/SRO heterostructures grown on DSO and SSO substrates. The samples exhibit a large negative imprint, beneficial for energy harvesting applications.

Relaxor ferroelectrics thin films have found applications in energy storage, conversion and harvesting based in large part on the inherent interrelationships between electrical, mechanical and thermal properties of solids. In this context, using PLD, we deposited Sm-doped Pb($Mg_{1/3}Nb_{2/3}$)O_3–30PbTiO₃ (PMN–30PT) thin films on SrTiO₃ (STO) substrates using LaNiO₃ as the bottom electrode. Based on the recorded polarization-electric field (*P–E*) hysteresis loops, slim hysteresis loops with a high maximum polarization were observed. Besides, this film showed a giant energy density of 82 J/cm³ (equivalent to 2.8 Wh/kg), accompanied by a high energy efficiency of 78% at a 3.2 MV/cm electric field, excellent fatigue resistance (>10⁹ cycles) and high thermal stability from −40 to 200 °C. Also, the designed capacitor can release a giant power density of 67.7 MW/cm³ (8.4 10⁹ W/kg) within 0.9 μs, which is far beyond the state-of-the-art power capacitors (10⁷–10⁸ W/kg) (Figure 3a). For environment-friendly solid-state cooling (*via* the electrocaloric effect) and heat-waste harvesting (*via* the pyroelectric effect), the deposited thin film exhibited outstanding electrocaloric and pyroelectric energy harvesting properties where the adiabatic temperature change, pyroelectric energy density, pyroelectric energy efficiency

Figure 3: (a) Ragone plot, (b) thermal evolution of the adiabatic temperature change (ΔT) at different applied electric fields, and (c) the temperature span (ΔT_span) dependent pyroelectric energy density (N_d) using the Olsen cycle, the efficiency's figure of merit (η_p) and the relative efficiency (η_r) with respect to the Carnot cycle of Sm-PMN–30PT thin film.

(η_p) and scaled efficiency (η_r) reached large values of 60 K, 39 J/cm³ 9.81% and 32.1% at 2 MV/cm, respectively (Figures 3b,c). These results indicate that the designed thin film could be used in energy storage and waste-heat energy harvesting applications.

Our research also extended into the field of photoelectrochemical (PEC) water splitting, especially the integration of a perovskite metal oxide protective layer with a semiconductor substrate using the PLD technique for PEC applications. Specifically, on the surface of an Si substrate, a few layers of reduced graphene oxide (rGO) nanosheets, enabling van der Waals epitaxy, were tactically coated, which significantly improved the crystallinity of the over-grown protective layer SrTiO₃ (STO). The PEC behavior of the STO/rGO/Si heterojunction photocathode showed a

remarkable enhancement in terms of onset potential and saturation current density, compared to the case where STO was directly prepared on Si without rGO that gave rise to a relatively poor crystallinity and thereby lower charge transfer efficiency and PEC performance. Moreover, a long-term stability test validated the efficacy of the STO protection capability over the easily corroded Si substrate against PEC operational environments.

STO epitaxial thin films deposited with PLD were also studied for integration on semiconductors, specifically on a germanium substrate. The epitaxial growth of STO on Ge resembled the growth of STO on Si, except that the STO unit cell on Ge was larger than that on Si. Further application possibilities for the use of a STO/Ge stack lie in the production of transistors and other electronic components as in photoelectrochemical applications.

In the field of a new type of lithium-ion batteries, we continued with the research of the solid-state ceramic electrolyte $Li_{0.33}La_{0.56}TiO_3$ (LLTO) prepared with the conventional solid-state sintering method. We found that in compositions with an initial La:Ti ratio of > 0.6, Ruddlesden-Popper (RP)-type planar defects nucleate in perovskite LLTO grains and contain structural elements of the $Li_2La_2Ti_3O_{10}$ phase. The formation of planar defects results in an exaggerated grain growth of some LLTO grains and the formation of a bimodal microstructure consisting of large elongated LLTO grains embedded in a matrix of smaller grains (Figure 4a). All grains contain lamellae (Figure 4b) with a predominantly non-periodically modulated structure consisting of perovskite sequences of different thicknesses separated by Li-rich RP defects (Figure 4c). At lower temperatures these defects trigger an exaggerated grain growth of LLTO grains, while at higher temperatures they recrystallize into the perovskite phase, forming a ceramic microstructure consisting of LLTO grains with sizes up to 100 microns and larger (Figure 4d). With this approach, we were able to reduce the volume fraction of grain boundaries and prepare LLTO ceramics with high ionic conductivity in a range of 10^{-4} S/cm. The results were published in the Journal of the European Ceramic Society (doi:10.1016/j.jeurceramsoc.2022.11.004).

Using the PLD method, we prepared $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ (NMC) and $Li_4Ti_5O_{12}$ (LTO) epitaxial thin films to be used as a solid-state cathode and anode for a microbattery. The use of NMC as the cathode material was motivated by its ubiquitous presence in commercial state-of-the-art Li-ion battery systems as well as its high specific capacity, whereas spinel LTO was chosen as the anode due to its high electrochemical stability and low volume change exhibited during lithiation/delithiation. The thin films were deposited on Nb-doped $SrTiO_3$ conductive single-crystal substrates where we studied the effects of substrate orientation and deposition parameter change on the quality of grown films using various structural as well as electrochemical characterization techniques. We have also deposited Ba- and Sr-doped LLTO solid electrolyte thin films on STO substrates, with the optimal stoichiometries determined based on the bulk conductivity meas-

Figure 4: (a) Thermally etched microstructure exhibiting a bimodal grain size distribution of a sample sintered at 1250 °C. (b) HAADF-STEM image of a lamella taken at a higher magnification along the [100] zone axis of the LLTO matrix. (c) Lamella with a non-periodic modulated structure with structural elements of the $Li_2La_2Ti_3O_{10}$ phase. (d) Thermally etched microstructure of a sample sintered at 1350 °C with a larger LLTO grain size (a smaller magnification of the image).

urements on sintered pellets. The deposited LLTO thin films exhibited similar properties as the bulk ceramics. After the optimization of each individual component, different layers will be deposited epitaxially on top of each other to create a bottom-up assembled LTO | LLTO | NMC all-solid-state thin-film microbattery, which will require an additional cross-optimization approach as the optimal deposition parameters vary strongly between different materials.

Within the basic research project J1-9177 we studied the formation mechanism of contact and multiple cyclic twins of cassiterite, which commonly form during the sintering of SnO_2 with a small addition of Co- and Nb-oxides (Figure 5). In this work, we show that the formation of twins is a two-stage process that starts with an epitaxial growth of SnO2 on the particles of two secondary phases, $CoNb_2O_6$ and $Co_4Nb_2O_9$ seeds (the twin nucleation stage; <1300 °C), and continues with a fast growth of (101) twin contacts (the twin growth stage; > 1300 °C). Both secondary phases form below the temperature of enhanced densification and SnO_2 grain growth; $CoNb_2O_6$ forms at ~700 °C and $Co_4Nb_2O_9$ at ~900 °C. While the oriented growth of cassiterite on columbite-type $CoNb_2O_6$ grains can only result in the formation of contact twins, the $Co_4Nb_2O_9$ grains with a structure comparable with that of corundum, represent suitable sites for the nucleation of contact and multiple cyclic twins with the coplanar or alternating morphology. The twin nucleation stage is followed by a fast densification accompanied by a significant SnO_2 grain growth above 1300°C. The twin nuclei coarsen into large twinned grains as a result of the preferential and fast growth of low-energy (101) twin contacts. The solid-state diffusion processes during densification and SnO_2 grain growth are controlled by the formation of point defects and result in a dissolution of the twin nuclei and incorporation of Nb^{5+} and Co^{2+} ions into the SnO_2 matrix in the form of a solid solution. In this process, the twin

nuclei are erased and their role in the formation of twins is evidenced only by irregular segregation of Co and Nb at the twin boundaries and inside the cassiterite grains, and Co, Nb-enrichment in the cyclic twin cores. The results are published in the journal Acta Crystallographica (doi:10.1107/S2052520622006758).
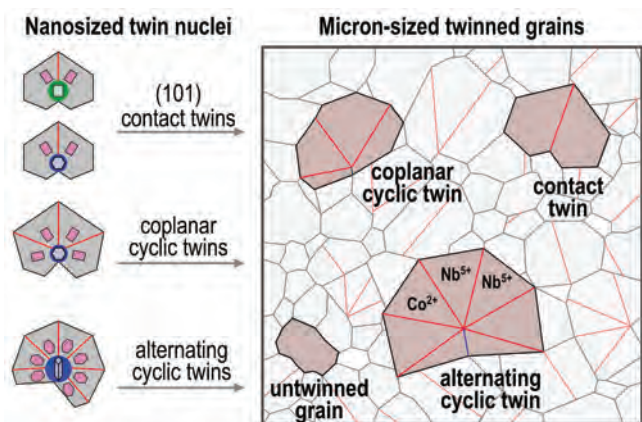
Figure 5: Nanosized twin nuclei for the formation of different types of cassiterite twins recrystallize into micro-sized SnO_2 grains after high-temperature sintering.

In the scope of the investigation of phase relations in ternary oxide systems where new compounds and solid solutions form and exhibit interesting electric properties, we determined, in the ternary system La_2O_3-TiO_2-Nb_2O_5, together with colleagues from the Faculty of Chemistry and Chemical Technology, University of Ljubljana, the crystal structure of the solid solution $La_{3-x}Ti_{5-3x}Nb_{10-2x}O_{39.5-12.5x}$. The structure was studied using neutron and high-resolution synchrotron powder X-ray diffraction. In the same system, we determined the range of solid solubility and crystal structure along the tie line $LaTiNbO_6$-$La_4Ti_9O_{24}$. In the ternary system La_2O_3-TiO_2-Ta_2O_5 we determined the temperature stability of two compounds, $La_{4.67}Ta_{22}O_{62}$ and $LaTa_5O_{14}$. In the field of the study of cold sintering of selected clay minerals, preliminary experiments confirmed that some clay minerals can be sintered at temperatures below 300 °C and at other strict conditions.

Our research of materials for passive electronic components includes the densification of ceramic composites at room temperature based on a high loading of an $SrTiO_3$ filler combined with a suitable binder. In the so-called upside-down composite system, we utilized different binders such as Li_2MoO_4, Na_2SiO_3, Na_2MoO_4, Na_2WO_4 and $MgSO_4$. Composite samples were prepared using the room temperature fabrication (RTF) method, which utilizes a water-soluble ceramic curable at room temperature and presents an alternative to the time- and energy-consuming high-temperature sintering of ceramics. This method shows promising application potential for the production of electronic components with enhanced dielectric properties. We studied the effects of various physical parameters on the densification process, the nature of the contact between the $SrTiO_3$ ceramic particles and the binder, and the mechanical properties as a function of a varied composition. Experimental results for the composites show a relative permittivity of 65–145 and dielectric losses from 0.002 to 0.05 in a radio-frequency range of 1 MHz. With the RTF method, we prepared composites exhibiting a relative permittivity of 20–50% of that of conventionally sintered $SrTiO_3$ ceramics. In addition, we investigated the impact of porosity and changing composition on the microstructure, dielectric and mechanical properties. Further, we compared experimental results with the modeled values obtained with the Lichtenecker mixing rule and OOF2 simulations (Figure 6). To reduce the residual porosity, we impregnated the prepared composite samples with Ti-isopropoxide, which improved the dielectric constant by up to 50%.

Figure 6: Simulation of dielectric properties (energy of electric field and polarization) of LMO-ST composites with OOF2

ZnO nanoparticles (NPs) are multifunctional materials with unique physical and chemical properties, such as high chemical stability, high electrochemical coupling coefficient, high photostability, doping amenability, and others. Controllable synthesis of ZnO nanostructures with different morphologies and sizes has attracted considerable attention from the standpoint of basic research and the realization of advanced devices. The stability of ZnO NPs depends on the type of capping agents used during their synthesis. Moreover, capping agents also act as structure-directing agents and, hence, play a significant role in the formation of various ZnO nanostructures. In our research of ZnO NPs, we studied the influence of fructose, a capping-structure directing agent that is environmentally safe and sustainable. We obtained different morphologies from rods, plates and blocks made of nanoparticles (Figures 7a,b,c). Investigation of their photocatalytic properties revealed a very high degradation of methyl blue dye under the influence of UV light in an aqueous solution of over 80% in 90 min for plates and blocks made of nanoparticles, whereas rods degraded by only 68% in the same time frame (Figure 7d).

Figure 7: SEM images of ZnO morphologies: (a) rods, (b) plates, and (c) blocks of nanoparticles. (d) Methyl blue dye degradation for different ZnO morphologies.

Antibacterial and piezoelectric biocompatible materials

In the area of biomaterials, our work was focused on designing new approaches in healing and tissue regeneration. We were developing organic piezoelectric biomaterials and novel antimicrobial technologies. Within the project "Mechano-chromic, voltage-sensitive electro-stimulators: innovative piezoelectric biomaterials for electro-stimulated cellular growth", which is a bilateral collaboration with a Swiss partner from the Institute of Robotics and Intelligent Systems (ETH), we were designing new piezoelectric biomaterials based on poly(l-lactide) (PLLA). During the study, we observed that PLLA modified with a small amount (1 wt.%) of crystalline filler particles, characterized by high morphological anisotropy, acts as a nucleating agent during melting crystallization, promoting the formation of highly crystalline and oriented PLLA structures. The most effective fillers were either barium-titanate nanotextured rods (BT NTRs) (Figure 8a) or non-piezoelectric apatite nanorods (HAp NRs) (Figure 8b). Fillers induce an increase in PLLA piezoelectricity, which is evidenced based on the increase in the voltage output from film surfaces during their ultrasound (US)-assisted deformation. In the case of US- assisted cell stimulation (human skin keratinocytes), PLLA films modified with high-aspect-ratio fillers (BT NTRs and HAp NRs) were observed to promote the cytoskeleton formation (which was not detected without the US stimulation or in case of fillers with a lower morphological anisotropy). The differences were particularly detected when directly comparing non-drawn (DR1) films, which were not piezoelectric, with their drawn (DR5) piezoelectric pairs. The cells directly adhered to the PLLA film surface were oriented in a specific direction that matched the direction of PLLA dipoles in the case when their piezoelectricity was enhanced by high-aspect-ratio fillers (Figure 8c). This type of orientation was not pronounced for the cells on the surfaces of non-modified PLLA films (Figure 8d).

We continued to develop composites of PLLA with Ga NPs to obtain smoother homogeneous sheets that were evenly coloured due to the surface plasmon resonance of Ga NPs (Figures 9a,b). We discovered that 0.8 wt.% of Ga in the composite fully inhibited the growth of *P. aeruginosa* bacteria on the composite, while a Ga amount that was twice as high already exhibited a bactericidal effect (Figure 9c) that caused severe damage to bacterial integrity (Figures 9d,e). The addition of Ga also increased Young's modulus and hydrophobicity of the material, but the nanoparticles got exposed on the surface and released from the composite already within one day under physiological conditions.

Figure 8: (a,b) Filler-modified poly(l-lactide) (PLLA) films: SEM morphology of barium-titanate nanotextured rods (BT NTRs) and apatite nanorods (HAp) as filler particles and their filler-modified PLLA films. (c) Actin filaments orientation at the surfaces of filler-modified and (d) non-modified PLLA films.

Materials for heat-insulation applications

A large part of the total energy used in the EU is used for the heating and cooling of buildings. Their energy efficiency is thus essential for an efficient and sustainable use of energy. With the development of thermal insulation materials, buildings are becoming increasingly energy efficient, while an increasing part of the energy input is represented by the materials used for their construction. Improving various aspects of the sustainability of these materials, such as recyclability and embodied energy, is an important part of the research. Foamed glass is a building thermal insulation material that can be characterized as a product with a high added value where the main input in its production is waste glass. The current weak point of the synthesis of foamed glass with superior insulation properties is its high embodied energy associated with the use of the energy-intensive process of melting waste glass.

Figure 9: (a) Nanogallium/PLLA composites. The appearance of a film/ sheet of this composite with the characteristic colour due to the surface plasmon resonance of Ga NPs. (b) Magnified detailed morphology observed under SEM. (c) Growth of P. aeruginosa bacteria on the composite films with different Ga amounts and their morphologies after 24 hours on (d) PLLA and (e) nanogallium-PLLA film.

In our work, we continued to search for a process not requiring the re-melting phase. With a direct use of waste glass, without adjusting its chemical composition, the foaming process becomes more complex, among other factors, due to the difficulty of controlling glass crystallization, which significantly increases the proportion of open porosity in foamed glass and thus reduces its efficiency as a building insulation material.

Therefore, the primary purpose of the research is to control unwanted crystallization during the foaming of waste glass. We focused on a process performed in air atmosphere, which is more sustainable compared to the processes carried out in controlled atmospheres. We have shown that fluxing agents (B_2O_3 and borax) and

phosphates successfully suppress the crystallization of container glass during a foaming process, in a temperature range of 800–860 °C. By properly selecting the quantity and type of additives we produced foams with densities below 150 kg m⁻³ and improved the homogeneity of the porous structure. With the aforementioned adjustment of the additives, we managed to prepare samples with thermal conductivities in a range of 57–66 mW (m K)⁻¹. Further research showed that an addition of water glass allows the process to be transferred from an oxygen-free to air atmosphere, leading to a reduction in the crystalline phases. The samples prepared in this way have a low density (130 kg m⁻³) and thermal conductivity (53 mW (m K)⁻¹).

The use of hydrated silicates (water glass) has proven to be effective for the transfer of the foaming process to air atmosphere. For this reason, we also devoted part of our research to the hydrothermal treatment of waste glass, which can then be directly used for foaming in air atmosphere, without the need to add water glass. We demonstrated the ability of various hydrothermally treated waste glass powders to foam in air atmosphere. A FTIR analysis showed the presence of carbonates after the processing of waste glass, and an analysis of the gas within the pores of the foam showed a high proportion of carbon dioxide, confirming the assumption that this foaming mechanism is similar to the mechanism in the case of using water glass through a reaction with the carbon dioxide from the atmosphere. With the following research, we showed that waste glass treated in this way enables foaming in an atmosphere also in the case of using carbonaceous foaming additives. Evaporation of water during the heating displaces the air from a sample and prevents a premature oxidation of the carbonaceous foaming agents. The knowledge gained from the above research helps us understand the foaming process, enabling an improved sustainability, which is one of the focuses of the green transition.

Some outstanding publications in the past year

1. Vukomanović, Marija, Gazvoda, Lea, Aničić, Nemanja, Rubert, Marina, Suvorov, Danilo, Müller, Ralph, & Hofmann, Sandra (2022). Multi-doped apatite: strontium, magnesium, gallium and zinc ions synergistically affect osteogenic stimulation in human mesenchymal cells important for bone tissue engineering. *Biomaterials Advances*, *140*, 213051-1-213051–11. doi:10.1016/j.bioadv.2022.213051

2. Hanani, Zouhair, Mezzane, Daoud, Amjoud, M'barek, Lahcini, Mohammed, Spreitzer, Matjaž, Vengust, Damjan, Jamali, Arash, El Marssi, Mimoun, Kutnjak, Zdravko, & Gouné, Mohamed (2022). The paradigm of the filler's dielectric permittivity and aspect ratio in high-K polymer nanocomposites for energy storage applications. *Journal of Materials Chemistry*, *10*(30), 10823–10831. doi:10.1039/d2tc00251e

3. Chen, Binbin, Gauquelin, Nicolas, Strkalj, Nives, Huang, Sizhao, Halisdemir, Ufuk, Nguyen, Minh Duc, Jannis, Daen, Sarott, Martin F., Eltes, Felix, Abel, Stefan, Spreitzer, Matjaž, Fiebig, Manfred, Trassin, Morgan, Fompeyrine, Jean, Verbeeck, Johan, Huijben, Mark, Rijnders, Guus, & Koster, Gertjan (2022). Signatures of enhanced out-of-plane polarization in asymmetric $BaTiO_3$ superlattices integrated on silicon. *Nature Communications*, *13*(1), 265-1-265–268. doi:10.1038/s41467-021-27898-x

4. Trstenjak, Urška, Daneu, Nina, Rafalovskyi, Iegor, Belhadi, Jamal, Vengust, Damjan, Hlinka, Jiri, & Spreitzer, Matjaž (2022). Polarization in pseudocubic epitaxial relaxed PMN-PT thin films. *Applied Physics Letters*, *120*(4), 042901-1-. doi:10.1063/5.0067531

5. Gazvoda, Lea, Perišić, Milica, Spreitzer, Matjaž, & Vukomanović, Marija (2022). Antimicrobial activity of piezoelectric polymer: piezoelectricity as the reason for damaging bacterial membrane. *Biomaterials Science*, *10*(17), 4933–4948. doi:10.1039/d2bm00644h

Organization of conferences, congresses and meetings

1. Co-organization of the International Postgraduate School Students' Conference (IPSSC), Kamnik, 1–3 June 2022

2. Workshop within the ATHENA project: Gender equality in career progression and recruitment, Ljubljana, 11 November 2022

INTERNATIONAL PROJECTS

1. Development and Characterisation of Mineral Wool Fibres and Binder Systems
Prof. Matjaž Spreitzer
Knauf Insulation S.p.r.l.

2. Noveon - JSI; Investigation of NdDyCoCuFe Rare Earth Alloys and Related Compounds
Prof. Matjaž Spreitzer
Noveon Magnetics Inc.

3. COST CA17140; Cancer Nanomedicine - From the Bench to the Bedside (NANO2CL)
Marija Vukomanović
Cost Association Aisbl

4. COST CA20116; OPERA - European Network for Innovative and Advanced Epitaxy
Prof. Matjaž Spreitzer
Cost Association Aisbl

5. H2020 - AMULET; Advanced Materials and Manufacturing Technologies united for LightwEight
Dr. Jakob König
European Commission

6. HE - INDUSAC; Quick Challenge-driven, Human-centered Co-Creation mechanism for INDUStry-Academia Collaborations
Prof. Matjaž Spreitzer
European Commission

7. EDA - AMALIA; Additive Manufacturing of Metallic Auxetic Structures and Materials for Lightweight Armour
    Prof. Matjaž Spreitzer
    European Defence Agency (EDA)

RESEARCH PROGRAMMES

1. Advanced inorganic magnetic and semiconducting materials
    Prof. Mihael Drofenik
2. Contemporary Inorganic Materials and Nanotechnologies
    Prof. Matjaž Spreitzer

R & D GRANTS AND CONTRACTS

1. Multiscale modeling of photocatalytic CO_2 reduction with computer intensive simulations
    Dr. Marjeta Maček Kržmanc
2. Model system based interface design for enhancement of the electrochemical performance of Ni-rich NMC for Li-ion batteries
    Prof. Matjaž Spreitzer
3. Subglacial carbonate deposits - a new source for studying the presence of glaciers in a glaciokarstic environment
    Prof. Srečo Davor Škapin
4. Mineral inclusions in garnet from macroscopic to atomic scale: Opening the petrogenetic archive
    Prof. Nina Daneu
5. Strain and domain structure engineering in epitaxial relaxor ferroelectric thin films
    Prof. Matjaž Spreitzer
6. Mechano-chromic, voltage-sensitive electrostimulators: innovative piezoelectric biomaterials for electro-stimulated cellular growth
    Marija Vukomanović
7. Engineering of relaxor ferroelectric thin films for piezoelectric and energy storage applications
    Prof. Matjaž Spreitzer
8. Photoelektrochemical Hydrogen Evolution from Graphene Oxide Enabled Epitaxial Silicon-Oxide Heterostructures
    Prof. Matjaž Spreitzer
9. Semiconductor - dielectric heterostructures for photoelectrochemical hydrogen evolution, SeDiHe
    Prof. Matjaž Spreitzer
10. Extended defects in natural and synthesized perovskite oxides: nanogeochemcial indicators and functional interfaces
    Prof. Nina Daneu
11. Applicability of the cold sintering process to clay minerals
    Prof. Srečo Davor Škapin
12. Innovative procedures for advanced surface properties of medical stainless steel
    Asst. Prof. Marija Vukomanović
13. Novel Surface Modification of Dental Prosthetic Replacements by Gaseous Plasma
    Asst. Prof. Marija Vukomanović
14. On-demand Contact Based Antimicrobial Surfaces: Human and Environmental Safe Infection Control Strategy
    Asst. Prof. Marija Vukomanović
15. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
    Asst. Prof. Marija Vukomanović
    Ministry of Education, Science and Sport
16. Control of crystallization in glass materials for thermal insulation
    Dr. Sonja Smiljanić
    Ministry of Education, Science and Sport
17. ANTISOLVO - Antisolvent precipitation to extract the value from end-of-life Nd-Fe-B magnets
    Prof. Srečo Davor Škapin
    Ministry of Education, Science and Sport
18. XRD Analysis
    Prof. Matjaž Spreitzer

NEW CONTRACTS

1. Determination of potential structural changes of proteins using the following analytical techniques: UV-Vis-NIR spectrometry, fluorescence spectrometry, X-ray diffraction and circular dichroism
    Prof. Matjaž Spreitzer
    Lek d. d.

VISITORS FROM ABROAD

1. Dr Jamal Belhadi, Dr Manal Benyoussef, Laboratoire de Physique de la Matière Condensée, Université de Picardie Jules Verne, Amiens, France, 19 December 2021 to 21 January 2022
2. Prof. Dr Gertjan Koster, University of Twente, Enschede, Netherlands, 7–13 May 2022
3. Prof. Eugene Kotomin, Dr Leonid Rusevich, Institute of Solid State Physics, University of Latvia, Riga, Latvia, 17–20 May 2022
4. Dr Federico Baiutti, Catalonia Institute for Energy Research, Barcelona, Spain, 30 May to 12 June 2022
5. dr Jamal Belhadi, Laboratoire de Physique de la Matière Condensée, Université de Picardie Jules Verne, Amiens, France, 3–21 July 2022
6. Prof. Dr Mladenka Malenica, Vera Tomas, MD, Hrvoje Križan, MLS, Faculty of Medicine of Rijeka, Croatia, 5–9 September 2022 and 12–16 September 2022
7. Prof. Dr Heli Jantunen, University of Oulu, Finland, 24 September to 1 October 2022
8. Prof. Dr Gertjan Koster, University of Twente, Enschede, Netherlands, 23–28 October 2022
9. Dr Matej Baláž, Dr Martin Stahorský, Institute of Geotechnics of the Slovak Academy of Sciences, Košice, Slovakia, 20–26 November 2022

Visiting Researchers

10. Dr Suraj Gupta, School of Engineering, University of Liverpool, United Kingdom, 21 June 2021 to 20 June 2023Dr Zouhir Hanani, Cadi Ayyad University, Marrakesh, Morocco, 21 December 2021 to 30 June 2023
11. Dr Hsin-Chia Ho, National Taiwan University, Taipei City, Taiwan, 7 June 2021 to June 2023
12. Dr Sonja Smiljanić, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, 1 June 2019 to 30 June 2023

STAFF

Researchers
1. Prof. Nina Daneu
2. Dr. Suraj Gupta
3. Dr. Heli Maarit Jantunen
4. Dr. Jakob König
5. Dr. Gertjan Koster
6. Dr. Špela Kunej
7. Dr. Marjeta Maček Kržmanc
8. **Prof. Matjaž Spreitzer**, Head
9. Prof. Srečo Davor Škapin
10. Dr. Marija Vukomanović
Postdoctoral associates
11. *Dr. Roxana-Mihaela Apetrei, left 07.01.22*
12. Dr. Zouhair Hanani
13. Dr. Hsin-Chia Ho
14. Dr. Mario Kurtjak
15. *Dr. Tjaša Parkelj Potočnik, left 14.03.22*
16. Dr. Sonja Smiljanić
17. Dr. Urška Trstenjak
Postgraduates
18. Petruša Borštnar, B. Sc.
19. Alja Čontala, B. Sc.
20. Lea Gazvoda, B. Sc.
21. Uroš Hribar, B. Sc.
22. Blaž Jaklič, B. Sc.
23. Nina Kuzmić, B. Sc.
24. Jan Žuntar, B. Sc.
Technical officers
25. Lucija Bučar, B. Sc.
26. Vesna Butinar, B. Sc.
27. David Fabijan, B. Sc.
28. Tina Radošević, B. Sc.
29. Damjan Vengust, B. Sc.
Technical and administrative staff
30. Silvo Zupančič

DEPARTMENT OF BIOCHEMISTRY, MOLECULAR AND STRUCTURAL BIOLOGY

B-1

The B1 department's research predominantly revolves around investigating the physiological functions of proteases and their native protein inhibitors in both typical and aberrant physiological conditions. This includes in-depth explorations of the mechanisms governing protease activity, alongside an examination of the structural and functional attributes of proteases, their inhibitors, and a selection of other enzymes. While we have made strides in comprehending the molecular intricacies of protease activity and control, a substantial portion of this landscape still eludes us. Consequently, there is a body of work ahead, particularly in the pursuit for additional physiological substrates and the elucidation of the signalling pathways under their purview.

In the last decade, protease research has witnessed an expansion, largely propelled by the swift development of innovative technologies like quantitative proteomics and in-vivo imaging. These advances have facilitated the discovery of physiological substrates, fundamentally altering our perspective on proteases. They are now seen not only as protein-degrading enzymes but also as central signalling molecules. Their catalytic activities are meticulously regulated, chiefly through mechanisms like zymogen activation and inhibition by endogenous protein inhibitors. Any perturbation in the regulation of proteases can lead to a spectrum of diseases, spanning from auto-immune, cardiovascular, neurologic, and neurodegenerative disorders to cancer. Consequently, proteases are seen as important targets for therapeutic intervention.

Head:
Prof. Boris Turk

In our research on the therapeutical inhibition of cysteine cathepsins, cathepsin X has emerged as a potential candidate due to its involvement in the critical steps of cancer progression. In collaboration with prof. Janko Kos, we developed a selective reversible inhibitor called Z9 targeting cathepsin X. Our findings show that Z9 significantly inhibits tumour progression both in vitro and in vivo using distinct breast-cancer mouse models. Cathepsin X com-

pensates for the loss of cathepsin-B activity, a mechanism contributing to cancer progression. The simultaneous inhibition of both cathepsins B and X exhibits a synergistic effect, impairing tumour-progression processes. This study suggests that Z9, used in combination with other peptidase inhibitors, presents an innovative strategy to overcome resistance to anti-peptidase therapy (Mitrovic et al., 2022).

Researchers in our department continued with their collaborative work on the multifunctional role of SARS-CoV-2 papain-like protease (PLpro). In addition to its cysteine protease activity, crucial for viral polypeptide cleavage, PLpro plays a vital role in evading the host's immune response by removing

Figure 1: Presentation of pathological roles of extracellular and intracellular cysteine cathepsins. Main extracellular roles of cysteine cathepsins are extracellular matrix degradation, cleavage of cell receptors, cell-adhesion molecules and bacterial proteins. Intracellular cysteine cathepsins are involved in the processing of viral and bacterial proteins.

ubiquitin and ISG15 from host-cell proteins. They identified three phenolic compounds from a natural compound library that bind to PLpro, disrupting essential interactions with ISG15. These compounds demonstrated the clear inhibition of PLpro in deISGylation activity assays. Two of them showed antiviral activity in Vero cell- line assays, and one exhibited a cytopathic effect inhibition at non-cytotoxic concentrations. Given the increasing PLpro mutations in new SARS-CoV-2 variants, these natural compounds could potentially enhance the host's antiviral immune response, which is often suppressed in COVID-19 infections (Srinivasan et al., 2022).

Renko et al. discovered a new family of fungal protease inhibitors, named cocaprins, found in Coprinopsis cinerea mushrooms. These cocaprins effectively inhibit both cysteine and aspartic proteases. They identified two

Figure 2: Presentation of most commonly conducted clinical trials in the case of cysteine cathepsins. Cysteine cathepsins are mostly being investigated in interventional studies, where they are either being targeted directly or used for the activation of diagnostic or therapeutic agents. Far more rarely, their concentration or activity is being detected in observational studies for either monitoring purposes or with the goal of biomarker discovery and validation.

genes responsible for cocaprin production, each showing distinct expression patterns in different fungal tissues. Cocaprins are small proteins (15 kDa) that form dimers and possess an acidic isoelectric point. The three-dimensional structure of cocaprin 1 resembles fungal β-trefoil lectins. These inhibitors target specific proteases, demonstrating their potential role in regulating proteolytic activities or acting as a defence against fungal antagonists. This discovery sheds light on the versatile functionality of fungal proteins with a β-trefoil fold (Renko et al., 2022).

Mikhaylov et al. utilized magnetic cobalt ferrite spinel (MCFS) nanoparticles to create a versatile drug-delivery system with MRI capabilities for cancer treatment. The MCFS nanoparticles demonstrated exceptional contrast-MRI properties and were employed to develop a targeted drug-delivery platform with simultaneous MR contrast capabilities for cancer therapy. In-vivo experiments using a breast-cancer mouse model confirmed both the therapeutic effectiveness in systemic chemotherapy and the unique MRI double-contrast properties. This study lays the foundation for a new multimodal composite drug-delivery system for effective anticancer therapy combined with non-invasive MRI capabilities (Mikhaylov et al., 2022).

In a different study, we addressed the need for efficient assessment of nanomaterial toxicity in biomedical applications. Traditional methods rely on lab experiments, but in silico approaches utilizing computer modelling and data science have gained traction. A novel in-silico method, CIN2D, employing free-energy analyses and molecular-dynamics simulations for rapid cytotoxicity evaluation of two-dimensional nanomaterials was proposed. This approach was successfully applied to five commonly used nanosheets, validating its predictive capability in nanotoxicity assessment (Tsukanov et al., 2022).

In collaboration with Asst. Prof. Režen, we focused on circRNAs' role in hepatocellular carcinoma (HCC). Transcriptome analysis and enrichment studies revealed an upregulated circRNA hsa_circ_0062682 and potential downstream targets (Razpotnik et al., 2022).

Prof. **Žerovnik** wrote a review exploring the role of human stefin B (cystatin B) mutations in progressive myoclonic epilepsy type 1 (EPM1), a neurodegenerative condition. Dodecamer repeats, missense, and frameshift mutations, are identified as the most common mutations. Stefin B primarily functions as a cysteine cathepsin inhibitor, but it also plays roles in oxidative stress protection, inflammation regulation, and transcriptional control. Additionally, it exhibits functions in synaptic physiology and vesicular transport. The review suggests that stefin B may have a chaperone-like role in proteostasis regulation. The author discusses interaction partners of stefin B and other gene mutations contributing to EPM1-like conditions, highlighting common pathways (**Žerovnik**, 2022).

Biasizzo et al. highlighted the significance of cysteine cathepsins in inflammation-related diseases in a review of their clinical potential. Their dysregulation can shift normal physiological processes towards pathological outcomes. Overexpression and secretion of these proteases are closely linked to disease development, making them attractive targets for pharmaceutical intervention. Beyond their negative role in diseases, cysteine cathepsins play vital roles in maintaining homeostasis and responding to stimuli. The review addressed challenges in translating research findings into clinical applications and examined the clinical potential of targeting cysteine cathepsins for disease management and diagnosis (Biasizzo et al., 2022).

Some outstanding publications in the past year

1. Mikhaylov, G., Mikac, U., Butinar, M., Turk, V., Turk, B., Psakhie, S., & Vasiljeva, O. (2022). Theranostic applications of an ultra-sensitive T[sub]1 and T[sub]2 magnetic resonance contrast agent based on Cobalt ferrite spinel nanoparticles. Cancers, 14(16), 4026-1-4026–14. doi:10.3390/cancers14164026

2. Mitrović, A., Završnik, J., Mikhaylov, G., Knez, D., Pečar Fonović, U., Matjan-Štefin, P., Butinar, M., Gobec, S., Turk, B., & Kos, J. (2022). Evaluation of novel cathepsin-X inhibitors in vitro and in vivo and their ability to improve cathepsin-B-directed antitumor therapy. Cellular and molecular life sciences, 79(1), 14. https://link.springer.com/article/10.1007/s00018-021-04117-w

3. Razpotnik, R., Vidmar, R., Fonović, M., Rozman, D., & Režen, T. (2022). Circular RNA hsa_circ_0062682 binds to YBX1 and promotes oncogenesis in hepatocellular carcinoma. Cancers, 14(18), 1–25. https://www.mdpi.com/2072-6694/14/18/4524

4. Renko, M., Zupan, T., Plaza, D. F., Schmieder, S. S., Perišić, M., Kos, J., Turk, D., Künzler, M., & Sabotič, J. (2022). Cocaprins, [beta]-trefoil fold inhibitors of cysteine and aspartic proteases from coprinopsis cinerea. International journal of molecular sciences, 23(9), 4916-1-4916–15. doi:10.3390/ijms23094916

5. Srinivasan, V., & Turk, D. (2022). Antiviral activity of natural phenolic compounds in complex at an allosteric site of SARS-CoV-2 papain-like protease. Communications biology, 5(1), 805-1-805–812. doi:10.1038/s42003-022-03737-7

6. Biasizzo, M., Javoršek, U., Vidak, E., Zarić, M., & Turk, B. (2022). Cysteine cathepsins: a long and winding road towards clinics. Molecular aspects of medicine, 88, 101150-1-101150–24. doi:10.1016/j.mam.2022.101150

7. Cioca, A.-A., Langerholc, T., & Tušar, L. (2022). Implementation of food matrix effects into chemical food contaminant risk assessment. EFSA journal, 20(2), 1–11. https://dk.um.si/IzpisGradiva.php?id=85894

8. Tsukanov, A. A., Turk, B., Vasiljeva, O., & Psakhie, S. (2022). Computational indicator approach for assessment of nanotoxicity of two-dimensional nanomaterials. Nanomaterials, 12(4), 650-1-650–19. doi:10.3390/nano12040650

9. Žerovnik, E. (2022). Human stefin B: from its structure, folding, and aggregation to its function in health and disease. Frontiers in molecular neuroscience, 15, 1–13. doi:10.3389/fnmol.2022.1009976

Organization of conferences, congresses and meetings

1. FEBS-ICGEB Workshop 2022 – Proteolysis: at the interface between health and disease, Bled, Slovenia, 17–21 September 2022, organizer
2. 39th Winter School on Proteinases and their Inhibitors, 16–18 February 2022 (hybrid), co-organizer

INTERNATIONAL PROJECTS

1. EFSA - EU-FORA; Implementation of Matrix Effects into Chemical Food Contaminant Risk Assessment;
   Asst. Prof. Livija Tušar
   European Food Safety Authority - Efsa
2. COST CA20117; Converting Molecular Profiles of Myeloid Cells into Biomarkers for Inflammation and Cancer (Mye-InfoBank)
   Prof. Nataša Kopitar – Jerala
   Cost Association Aisbl

RESEARCH PROGRAMMES

1. Structural biology
   Prof. Dušan Turk
2. Proteolysis and its regulation in health and disease
   Boris Turk

R & D GRANTS AND CONTRACTS

1. Structural insight into the mechanism of Clostridium difficle surface formation
   Prof. Dušan Turk
2. Cathepsins B and X in breast cancer stem cells – molecular targets and relevance for antitumor therapy
   Prof. Marko Fonović

3. Aptamers and hydrodynamic cavitation, an accessible tool for the analysis of organic residuals in archaeological pottery
   Prof. Marko Fonović
4. Role of cysteine cathepsins in complement activation in cancer
   Boris Turk
5. Mineral inclusions in garnet from macroscopic to atomic scale: Opening the petrogenetic archive
   Boris Turk
6. Cathepsin-based non-invasive diagnostics and theranostics of cancer
   Boris Turk
7. Human cathepsin F: An unusual cysteine protease involved in neurodegeneration
   Prof. Veronika Stoka
8. Dissecting cancer activome to develop new generation of antibody-drug conjugates
   Boris Turk
9. Systemic determination of legumain physiological roles
   Prof. Marko Fonović
10. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition)
    Boris Turk
    Ministry of Education, Science and Sport
11. Conference FEBS-ICGEB Proteolysis: At the Interface between Health abd Disease; Bled, Slovenia, from 17 September 2022 to 21 September 2022
    Boris Turk
    IUBMB - International Union Of Biochemistry And

NEW CONTRACT

1. Collaboration on quantification of cellular proteins by LC-MS/MS based proteomic analysis

Prof. Marko Fonović
Lek d. d.

VISITORS FROM ABROAD

1. Gian Pietro Pietri, Center for Proteomics, Medical Faculty, University of Rijeka, Croatia, 23 January to 23 March 2022
2. Dr Katarina Trajković, Mediterranean Institute for Life Sciences (MedILS), Split, Croatia, 13–24 December 2022
3. Dr Ana-Marija Vučković, Mediterranean Institute for Life Sciences (MedILS), Split, Croatia, 13–17 December 2022

STAFF

Researchers
1. Dr. Iztok Dolenc
2. Prof. Marko Fonović
3. Prof. Nataša Kopitar - Jerala
4. Prof. Jure Pražnikar*
5. Prof. Veronika Stoka
6. Dr. Andrej Šali
7. **Prof. Boris Turk, Head**
8. Prof. Dušan Turk
9. Asst. Prof. Livija Tušar
10. Prof. Olga Vasiljeva
11. Prof. Eva Žerovnik

Postdoctoral associates
12. Dr. Monika Biasizzo
13. Dr. Katarina Karničar
14. *Dr. Nežka Kavčič, left 01.11.22*
15. Dr. Andreja Kozak
16. Dr. Nataša Lindič
17. Dr. Georgy Mikhaylov
18. Dr. Metka Stantič
19. Dr. Aleksandra Usenik
20. Dr. Robert Vidmar

Postgraduates
21. Klemen Dretnik, B. Sc.
22. Ana Ercegovič Rot, B. Sc.
23. Marija Grozdanić, M. Sc.
24. Sara Ivanovski, B. Sc.
25. *Urban Javoršek, B. Sc., left 01.06.22*
26. Matej Kolarič, B. Sc.
27. Ana Kump, B. Sc.
28. Ernestina Lavrih, B. Sc.
29. Jure Loboda, B. Sc.
30. Petra Matjan Štefin, B. Sc.
31. Matej Novak, B. Sc.
32. Andreja Novak, M. Sc.
33. Tilen Sever, B. Sc.
34. Tea Sinožić, M. Sc.
35. Mojca Trstenjak Prebanda, B. Sc.
36. Eva Vidak, B. Sc.
37. Miki Zarić, B. Sc.
38. *Viktor Zupančič, B. Sc., left 01.04.22*

Technical officers
39. Marinka Horvat, B. Sc.
40. Maja Orehek, B. Sc.
41. *Tjaša Peternel, B. Sc., 01.09.22, transferred to Department B3*
42. Andreja Sekirnik, B. Sc.
43. Ivica Štefe, B. Sc.

Technical and administrative staff
44. Dejan Pelko
45. Polonca Pirš
46. Vahida Suljić

Note:
* part-time JSI member

DEPARTMENT OF MOLECULAR AND BIOMEDICAL SCIENCES B-2

The research programme of the Department of Molecular and Biomedical Sciences is focused mainly on basic research in protein biochemistry, molecular and cellular biology, and genetics. The primary goal of our investigations is the acquisition of a new understanding of mammalian pathophysiology with the aim of improving human and animal health.

Head:
Prof. Igor Križaj

Toxinology

One of our traditional research topics in the field of toxinology is the study of molecular mechanisms of the toxic action of secreted phospholipases A_2 (sPLA_2s) from animal venoms. In particular, we are focused on those endowed with presynaptic neurotoxicity (β-neurotoxins). The knowledge that we are gaining by studying toxic sPLA_2s is helping us to discover the pathophysiological roles of orthologous mammalian sPLA_2s, for example, their role in the development of neurodegenerative diseases such as Alzheimer's disease (AD).

In a proof-of-concept study, we showed that the IIA sPLA_2 (GIIA) rat group acted on the rat neuronal mitochondria in the same way as the snake venom β-neurotoxic GIIA. Moreover, the GIIA rat inhibited the activity of the cytochrome c oxidase (CCOX) also *ex vivo*, in the rat's brain-tissue sections (Figure 1), additionally supporting the engagement of extracellular excessive GIIA in neurodegeneration, such as AD, with a similar molecular mechanism as observed with the snake-venom β-neurotoxic GIIA at its poisoning of the motoneuron (A. Ivanušec et al., *Int. J. Mol. Sci.* 23 (2022), 12368). We monitored the intracellular trafficking of derivatives of recombinant ammodytoxin (Atx), rat GIIA and their enzymatically inactive (D49S) mutants in PC12 cells with transmission electron and fluorescence confocal microscopy, and concluded that sPLA_2 molecules do not require an enzymatic activity to enter and move within the cell, including entering the mitochondria (A. Ivanušec et al., *Toxins* 14 (2022), 375). Using ^{125}I-GIIA, we determined the binding affinity of GIIA to a mitochondrial protein with an apparent molecular mass of 20 kDa (R20). Given that GIIA, like Atx, inhibits the CCOX activity, we hypothesized that R20 is a subunit of CCOX IV (CCOX-IV). As we were not able to confirm this with the help of anti-CCOX-IV antibodies, we attempted to identify R20 following its isolation from porcine mitochondria by means of GIIA-affinity chromatography. We have been optimizing conditions for the isolation of the receptor. A precise description of the action of GIIA on CCOX is crucial for the use of our findings in medicine, both for the treatment of AD as well as for an early diagnosis of this severe neurodegenerative disease. Namely, it has been shown that GIIA in AD is overexpressed and becomes toxic to mitochondria, which is similar to the effects observed in Atx poisoned nerve endings.

It has been demonstrated that certain sPLA_2s bind specifically to nicotinic acetylcholine receptors (nAChRs). The binding of ACh or other agonists, such as nicotine and its derivatives, to nAChRs has been linked to uncontrolled cell division, prevention of apoptosis and induction of angiogenesis, ultimately supporting tumour growth and metastasis. The nAChR antagonists, however, showed opposite effects on cells, suggesting their potential value in cancer therapy. Among the naturally occurring nAChR antagonists, found in various venoms, snake venom sPLA_2s were also shown to suppress ACh-elicited ion currents. For this reason, we investigated the anti-cancer effect of an array of human sPLA_2s and their single-point enzymatically inactive mutants to assess their lung cancer therapeutic potential. In collaboration with the pharmacologists from the University of Leuven, Belgium, we were determining the effect of these proteins on α7 and muscle-type nAChRs. The most interesting result was obtained with GV(H48Q), which was absolutely selective for α7-nAChR. We then used GV(H48Q) to assess its effects on the viability, cytotoxicity, proliferation and apoptosis of various lung-cancer-cell lines as well as one non-cancerous lung-cell line. We demonstrated that GV and GV(H48Q) are able to prevent the ACh-induced cell proliferation and viability. In parallel, we were also involved in a similar study of another group of α7-nAChR antagonists, 3-alkylpyridinium salts (APSs). A paper describing the effects of APS7, either free or packed

> **Animal venoms are a rich source of new substances and molecular tools to improve human and animal health.**
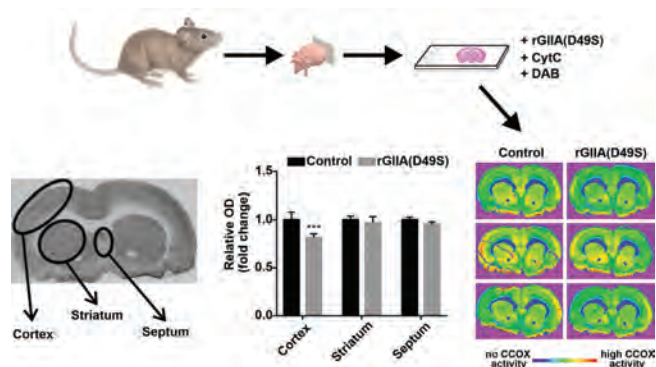
Figure 1: Ex-vivo experiment on the rat brain tissue sections showed a slight but significant inhibition of the CCOX activity in the cerebral cortex in the presence of rat GIIA protein. A trend towards a decreased CCOX activity was detected also in the striatum and septum. Tissue sections were histochemically stained for the CCOX activity in the absence or presence of rat GIIA protein, imaged and analysed for the relative optical density (OD) corresponding to the CCOX activity in different brain regions of interest.
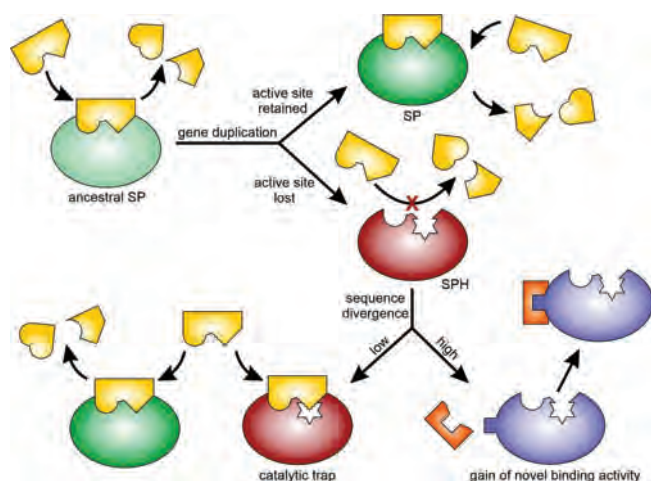
Figure 2: Evolution of novel biological functions in serine pseudoproteases. Duplication of the ancestral serine protease (SP) gene was followed by a loss in the catalytic activity in SP homologues (SPHs) due to mutations in the active site. The gain of novel functions (e.g., novel binding interface) in SPHs is the consequence of the specific pattern of amino acid substitutions. SPHs with low sequence divergence from their enzymatically active paralogues can no longer cleave polypeptide chains, but some of them can still bind to these chains and act as 'catalytic traps'. By retaining their binding to substrates, SPHs affect the function of cognate SPs by reducing the availability of the substrate to be processed. The figure is from N. Zupanič et al., FEBS J. (2022), doi: 10.1111/febs.16355.

Figure 3: Kity Požek with the Krka Award in the company of her co-mentor Dr Adrijana Leonardi at the 52nd Krka Awards Ceremony. Kity Požek received the Krka Award for her Master's degree work on a detailed description of VaaMPIII-3, the first member of the P-IIIe subclass proteins. For the same work she also received the University of Ljubljana Prešeren Award.

in gelatine nanoparticles, on human lung cancer cells is almost finished (V. Kononenko et al., in preparation). In this area of our research, we also prepared two review papers, one has already been published (V. Kononenko et al., *Acta Biol. Slov.* 65 (2022), 5–17), the other is to be submitted (T. Bele et al., in preparation).

Linked to sPLA$_2$s, we published a survey on pathophysiological actions of sPLA$_2$ molecules due to their binding to protein receptors, i.e., acting as ligands and not as enzymes, a scarcely studied area of increasing significance (A. Ivanušec et al., *Int. J. Biol. Sci.* 18 (2022), 873–888).

In 2022, we continued the study of snake-venom proteins that affect the process of blood coagulation – haemostasis. In the scope of the research project J1-2475, funded by the Slovenian Research Agency (ARRS), we have been investigating a unique anticoagulant homologue of a serine protease from the venom of the nose-horned viper (*Vipera a. ammodytes*, *Vaa*), VaaSPH-1, with the aim of developing completely new and safe drugs with the anticoagulant activity. We searched for the best possible conditions for the expression of VaaSPH-1 as well as its binding protein, blood coagulation factor VIIIa (FVIIIa), in mammalian HEK293-F cells. In parallel, we have been designing low-molecular-mass FIX antagonists. We have a promising peptide candidate to test its action *in vitro*. We wrote an invited review article on serine pseudoproteases (N. Zupanič et al., *FEBS J.* (2022), doi: 10.1111/febs.16355), exposing and discussing a profoundly neglected possibility of nonenzymatic functions of these SP molecules (Figure 2).

After publishing a detailed description of the serine protease VaaSP-VX, which promotes blood clotting by activating both FV and FX, we isolated a structurally very similar VaaSP-6 molecule from the *Vaa* venom. Since the entire cDNA sequence of VaaSP-6 is known, we will produce this protein recombinantly to characterize it. Hopefully, the recombinant VaaSP-6 will exhibit the same unique procoagulant activity as VaaSP-VX so that it could replace the unreliable dilute Russell's viper venom (dRVV) that is currently used in clinics for determining lupus anticoagulants (the LA test).

We completed and published an extensive genetic, biochemical and physiological characterization of the VaaMPIII-3 protein from the nose-horned viper venom (K. Požek et al., *Toxins* 14 (2022), 232). By analysing its gene structure, we unequivocally proved its structural exclusivity, and we proposed the introduction of a new subclass of metalloproteinases from snake venoms, subclass P-IIIe. For her Master's degree work dedicated to VaaMPIII-3, the first P-IIIe subclass protein, Kity Požek received the Krka Award (Figure 3) and the University of Ljubljana Prešeren Award.

Within our large international project on the *Vaa* genome sequencing and analysis with the Technical University of Denmark and Beijing Genomics Institute, we estimated that the size of the *Vaa* genome is about 1.61 Gb. More than 47% of the nose-horned -viper genome was annotated as transposable elements, and close to 22,000 protein-coding genes were predicted.

Together with the colleagues from the Centre for Clinical Toxicology and Pharmacology, University Medical Centre Ljubljana (UMCL), we investigated an interesting clinical effect in patients envenomed by the nose-horned viper, namely a profound, transient and reversible thrombocytopenia of functional platelets, as part of the ARRS research project J3-2534. In thromboembolic diseases, such as myocardial infarction and ischemic stroke, platelets play a central role. The existing antiplatelet drugs have one common side effect – a reduced number of platelets whose activity is inhibited. This condition carries a high risk of bleeding (haemorrhage), especially in interventional cardiology and angiology that use an antithrombotic approach. Our findings may pave the way for the development of a new group of antiplatelet agents that would reduce the risk of dangerous bleeding in interventional cardiology and angiology, and increase the efficacy of vasodilation and clot removal. We demonstrated that the reversible thrombocytopenia in patients envenomed by the *Vaa* is induced by proteins similar to type C lectins (snaclecs). In the past year, we isolated several snaclecs from the *Vaa* venom and showed that snaclec 3/2 is a particularly strong inducer of thrombocytopenia through its interaction with the GPIb platelet receptor. In collaboration with our partners from the Faculty of Veterinary

Medicine, University of Ljubljana (VF/UL), we initiated an *in-vivo* study of a mouse model of arterial thrombosis to validate the potential of snaclec 3/2 to prevent the clot formation and arterial occlusion after experimentally induced vascular injury and to determine its potential for medical applications. Two papers on this topic are currently in preparation (M. Dobaja-Borak et al., in preparation; M. Žužek et al., in preparation).

Within the research network, comprising experts from the UMCL, University Hospital and University of Split, University of Zagreb (UZ) and our group, we analysed samples of patients who were envenomed by the *Vaa* and treated with different antidotes. A publication is underway (T. Kurtović et al., in preparation).

Lipid metabolism and signalling

Our research in the field of lipid metabolism and signalling is focused on the role of lipid droplets in inflammatory signalling, autophagy and ferroptosis. Our work was focused on the following fundamental questions in lipid biology: (1) What is the role of the lipid droplet organelle in fatty acid trafficking and the regulation of membrane oxidation?, (2) How does autophagy cooperate with lipolysis in a lipid droplet breakdown during nutrient stress (Figure 4)? and (3) Are lipid droplets required for the production of lipid mediators of inflammation?

Cells carefully control the oxidation of lipids to balance the desired oxidative conversion of polyunsaturated fatty acids into lipid signalling molecules with unwanted peroxidation reactions that lead to membrane dysfunction, inflammation and potentially cell death. Oxidized lysophospholipids are emerging as novel damage-associated molecular patterns that promote sterile inflammation and contribute to the pathology of chronic and aging-related diseases. In a review paper (T. Petan & M. Manček-Keber, *Free Radic. Biol. Med.* 188 (2022), 351–362), we gathered and critically evaluated the current knowledge on their biosynthesis and release from cells, the cellular processes that drive their formation as well as their (patho)physiological roles. Additionally, we discussed the potential use of phospholipase and oxidative enzyme inhibitors in the prevention of oxidized lysophospholipid formation, which might revive the clinical research with the existing inhibitors and foster the development of new strategies for treating inflammatory diseases.

In 2022, we completed our experimental work on the role of lipid droplets in the production of lipid signalling molecules. We were able to show that lipid droplets cause the formation of mitogenic lipid mediators in cancer cells observed not only in the cell culture but also in xenograft tumor models. This work was recently submitted and is under review (E. Jarc Jovičić et al., *bioRxiv* (2022), 2021.11.25.470010). In collaboration with colleagues from the Biotechnical Faculty, University of Ljubljana (BF/UL), we studied the possible role of lipid droplets in the protection of endothelial cells from iron oxide nanoparticles (N. Repar et al., *Int. J. Mol. Sci.* 23 (2022), 6972). We found that the induction of lipid droplet biogenesis is not required for the ability of exogenous monounsaturated fatty acids, such as oleic acid, to protect cells from nanoparticle-induced stress. We also collaborated in a study focused on the subcellular trafficking of herpesviruses (M. Mavri et al., *Front. Endocrinol.* 13 (2022), 862940).

Targeting lipid droplets as the central managers of metabolic processes and membrane function to control cellular life and death.

Figure 4: Colocalization between lipid droplets and autophagosomes in starving cancer cells. Live-cell confocal microscopy imaging of lipid droplets stained with BODIPY 493/503 (green) and autophagosomal structures labelled with marker protein LC3 fused with a red fluorescent protein (red). The overlapping signals (yellow) of the two organelles suggest that lipid droplets are broken down via autophagy. The image was taken by our PhD student Špela Koren.

We presented our work at numerous international conferences and workshops, including invited talks at the 17th GERLI Lipidomics Meeting, Nice, France and the Training School in Lipid Metabolism, TU Dresden, Germany.

High-throughput genetics and functional genomics in yeast *Saccharomyces cerevisiae*

The budding yeast *Saccharomyces cerevisiae* is a well-established model organism for basic research and a cell factory in biotechnology. Recently, it has also become an important feature in synthetic biology for the homology recombination-based *in yeasto* assembly of DNA fragments. Following our development of the techniques for polygenic trait analysis of yeast, we started assembling a toolbox for hierarchical DNA assembly by combining *in vitro* and *in yeasto* approaches.

Yeast genetics, functional genomics and synthetic biology for basic research and biotechnology.

Within the ARRS project L4-3181, *Hierarchical DNA assembly for advanced applications in biopharmaceuticals production and cell therapy*, we developed a toolbox for the assembly of combinatorial variants of plasmids and smaller genomes. This approach can also be combined with multiplex CRISPR-Cas systems for further genome editing. We published a research paper in which we describe our study to evaluate precise targeting of multiple loci simultaneously using multiplex CRISPR-Cas9 (G. Žun et al., *Yeast* (2023), doi: 10.1002/yea.3833; accepted in 2022). One of the features of this work is a CRISPR-Cas9 system that enables simultaneous edits of up to 5 genomic loci (Figure 5). In addition to multiplex CRISPR-Cas9, we started developing, in 2022, methods for epigenome engineering and genome editing

Figure 5: Multiplex CRISPR-Cas9 for up to five successful simultaneous genome edits. Constructs expressing gRNAs individually were assembled as BioBricks and then the evaluation of single and multiplex CRISPR-Cas9 gRNA systems was performed (G. Žun et al., Yeast (2023), doi: 10.1002/yea.3833).

Evolutionary, genomic and structure-function analysis of proteases and their homologues. Genome and transcriptome analysis of cave adaptations, chemosensory system and repetitive DNA.

whereby specific cellular DNA repair mechanisms are selected. Our expertise in genome editing with CRISPR-Cas9 methods featured also in a collaborative research project lead by Dr Gianni Liti (CNRS, France), which resulted in a joint publication entitled Domestication reprogrammed the budding yeast life cycle, published in the prestigious journal *Nature Ecology & Evolution* (M. De Chiara et al., *Nat. Ecol. Evol.* 6 (2022), 448–460).

In the field of biotechnological research, we screened more than 1400 non-conventional yeast strains for the ability to store a high lipid amount from short-chain fatty acids as the main carbon source, and identified some potentially biotechnologically interesting strains. This work was done in collaboration with our partners in the ERACoBioTech project OLEOFERM (https://oleoferm.eu/).

Natural habitats are the most important source of yeast strains with biotechnologically interesting traits and within this line of research we participated in a consortium of authors of a review paper Yeasts from Temperate Forests (S. Mozzachiodi et al., *Yeast* 39 (2022), 4–24), whereby we contributed to the part describing the isolation of biotechnologically promising yeast strains.

Evolutionary genomics

The proteus (*Proteus anguinus*) exhibits exceptional morphological and physiological adaptations to the subterranean environment, with a regenerative ability, high resistance to prolonged starvation, and a lifespan that may exceed 100 years. The international Proteus Genome Research Consortium (http://proteusgenome.com) was established to tackle the challenge of sequencing the proteus genome and its transcriptomes. In the scope of the ARRS project J1-2469, led by our colleagues at BF/UL, we have been participating with an analysis of genomic and transcriptomic data. The first paper on this subject provides the scientific and biomedical rationale for exploring the proteus genome and outlines potential outcomes, challenges, and methodological approaches required to analyze and annotate the genome of this unique amphibian (R. Kostanjšek et al., *Ann. NY Acad. Sci.* 1507 (2022), 5–11). In the middle of 2022, the first draft assembly of the huge Proteus genome was made at the Beijing Genomics Institute, which is, with its 34 Gb, among the largest genomes ever sequenced, more than 10-fold larger than the human genome. Besides the analysis of transposable elements (TEs) we participate in the investigations of diverse cave adaptations, the analysis of the chemosensory system of this blind animal, its G-protein-coupled receptors repertoire (GPCRome) and the genome defense systems against TEs (*APOBEC*, *SCAN-ZNF* and *KRAB ZNF* genes). With the genome data, we also updated some of our previous findings based on the transcriptome data (e.g., olfactory receptors, V1R and V2R vomeronasal receptors and taste receptors).

We also performed a comprehensive analysis of the papain superfamily of cysteine peptidases, using the extensive proteomic, transcriptomic and genomic data for Archaea, Bacteria and Eukaryota. It has provided new insights into their origin, evolution and classification. A publication is underway (D. Kordiš & V. Turk, in preparation).

Other subjects

In 2022 we also participated in different projects outside the thematic framework of our department, funded by the ARRS or other funders. Mentioned below are only those projects, on which publications have been already prepared.

In the scope of the ARRS project J1-2482 (leading institution: BF/UL), we have been determining the impact of environmentally relevant nano- and microplastics on terrestrial vertebrates using mass spectroscopy. We also performed a proteomic analysis of the haemolymph of the terrestrial crustacean *Porcellio scaber* and revealed components of its innate immunity under baseline conditions (A. Jemec Kokalj et al., submitted).

As partners in the ARRS project J2-3040 on magnetically controllable nanocarriers that mimic endogenous lipid particles, aiming to improve drug/nanoparticle delivery, we participated in analysing the effects of barium-hexaferrite nanoplatelets in a low-frequency magnetic field on cancer cells (T. Goršak et al., in preparation).

We also collaborated informally with several groups at home and abroad. Colleagues from the Ruđer Bošković Institute and UZ were assisted in researching the mechanism of the formation and morphogenesis of biomineral nanostructures of the *Archa noae* shell. We performed a structural identification of protein components of the shell that are potentially involved in the biomineralization process (I. Sondi et al., in preparation).

In the study led by colleagues from the Faculty of Electrical Engineering UL (FE/UL), we analysed the protein corona composition of nanoparticles using a proteomic approach to explain their toxic impact on the human immune system (M. Pavlin et al., *Int. J. Mol. Sci.* 23 (2022), 6197).

Invited by the Editor-in-Chief of *Acta Biologica Slovenica*, a review paper on mass spectrometry used in the snake venom research was prepared (A. Leonardi, *Acta Biol. Slov.* 65 (2022), 5–25).

We came to the aid of our colleagues from the MF/UL performing a confocal microscopic analysis for a functional validation of an α-FREM2 nanobody as a molecular tool to target specifically glioblastoma stem cells (N. Šamec et al., submitted). In the same area, we joined our colleagues from the National Institute of Biology in Ljubljana to prepare an extensive analysis of bioactive peptides from venoms against glioma progression (B. Majc et al., *Front. Oncol.* 12 (2022), 965882).

Some outstanding publications in the past year

1. De Chiara, M., Barré, B.P., Persson, K., Irizar, A., Vischioni, C., Khaiwal, S., Stenberg, S., Chioma Amadi, O., Žun, G., Doberšek, K., Taccioli, C., Schacherer, J., Petrovič, U., Warringer, J. and Liti, G.: Domestication reprogrammed the budding yeast life cycle. Nature Ecology & Evolution, 6 (2022), 448–460

2. Požek, K., Leonardi, A., Pungerčar, J., Rao, W., Gao, Z., Liu, S., Laustsen, A.H., Trampuš Bakija, A., Reberšek, K., Podgornik, H. and Križaj, I.: Genomic confirmation of the P-IIIe subclass of snake venom metalloproteinases and characterization of its first member, a disintegrin-like/cysteine-rich protein. Toxins, 14 (2022), 232

3. Ivanušec, A., Šribar, J., Leonardi, A., Zorović, M., Živin, M. and Križaj, I.: Rat group IIA secreted phospholipase A_2 binds to cytochrome c oxidase and inhibits its activity: A possible episode in the development of Alzheimer's disease. International Journal of Molecular Sciences, 23 (2022), 12368

4. Zupanič, N., Počič, J., Leonardi, A., Šribar, J., Kordiš, D. and Križaj, I.: Serine pseudoproteases in physiology and disease. FEBS Journal, (2022), doi: 10.1111/febs.16355

5. Kostanjšek, R., Diderichsen, B., Recknagel, H., Gunde-Cimerman, N., Gostinčar, C., Fan, G., Kordiš, D., Trontelj, P., Jiang, H., Bolund, L. and Luo, Y.: Towards the massive genome of *Proteus anguinus*, illuminating longevity, regeneration, convergent evolution and metabolic disorders. Annals of the New York Academy of Sciences, 1507 (2022), 5–11

6. Petan, T. and Manček-Keber, M.: Half is enough: Oxidized lysophospholipids as novel bioactive molecules. Free Radical Biology and Medicine, 188 (2022), 351–362

Awards and Appointments

1. Špela Koren, Krka Pharmaceutical Commendation Prize, Krka, d.d., Novo mesto, Master's thesis entitled Links between lipid droplets and autophagy in stressed cancer cells, Novo mesto, Slovenia

2. Kity Požek, Krka Award, Novo mesto, Krka, d.d., Novo mesto, Master's thesis entitled Isolation and characterization of the VaaMPIII-3 protein from the venom of the nose-horned viper

3. Kity Požek: Prešeren Prize for Students of the University of Ljubljana, Master's thesis entitled Isolation and characterization of the VaaMPIII-3 protein from the venom of the nose-horned viper

INTERNATIONAL PROJECTS

1. COST CA19144 - EUVEN; European Venom Network
   Prof. Igor Križaj
   Cost Association Aisbl

2. COST CA19105 - LipidNET- Pan-European Network in Lipidomics and Epilipidomics
   Prof. Toni Petan
   Cost Association Aisbl

RESEARCH PROGRAMME

1. Toxins and biomembranes
   Prof. Igor Križaj

R&D GRANTS AND CONTRACTS

1. Protein complexes from the fungal genus Pleurotus, new biopesicides for controlling Colorado potato beetle and western corn rootworm
   Prof. Igor Križaj

2. Exploitation of a virus-borne small protein to combat antibiotic resistance in Staphylococcus aureus
   Prof. Igor Križaj

3. Genomic and transcriptomic insights into the exceptional biology of proteus (Proteus anguinus)
   Prof. Dušan Kordiš

4. Impact of environmentally relevant nano- and micro-plastics on soil invertebrates
   Prof. Igor Križaj

5. Inflammatory process in interstitial cystitis and evaluation of the influence of cannabinoid receptor agonists in urinary bladder - from cells to patients
   Prof. Igor Križaj

6. Reversibility of transient thrombocytopenia induced by a snake venom component offers asafe antithrombotic prevention in interventional angiology and cardiology
   Prof. Igor Križaj

7. Parasitic-like modulation of Bacillus thuringiensis development and larvicidal activity by a bacteriophage
   Prof. Igor Križaj

8. Adaptation of wine yeasts to climate change
   Prof. Uroš Petrovič

9. Targeting lipid droplets to reduce cancer cell resistance to stress
   Prof. Toni Petan

10. Development of an innovative drug to treat venous thromboembolism based on a unique viper venom anticoagulant
    Prof. Igor Križaj

11. Magnetically-controllable nanocarriers mimicking endogenous lipid particles for improved drug/nanoparticle delivery
    Prof. Igor Križaj

12. Development of medical chestnut honey quality control and technology
    Prof. Igor Križaj

13. Hierarchical DNA assembly for advanced applications in biopharmaceuticals production and cell therapy
    Prof. Uroš Petrovič

14. Lipid droplets as sources of inflammatory lipid mediators in cancer
    Dr. Eva Jarc Jovičić

15. The interplay between lipolysis and lipophagy in the modulation of ferroptosis in

cancer
Dr. Mauro Danielli
16. OLEOFERM - Sustainable oleochemicals biopreoduction from carboxylates via oleaginous fermentation
Prof. Uroš Petrovič
Ministry of Education, Science and Sport

NEW CONTRACTS

1. Hierarchical DNA assembly for advanced applications in biopharmaceuticals production and cell therapy
Prof. Uroš Petrovič
Jafral d. o. o.

VISITORS FROM ABROAD

1. Prof. dr Charles Boone, University of Toronto, Canada, 25 September to 2 October 2022

STAFF

Researchers
1. Prof. Dušan Kordiš
2. **Prof. Igor Križaj, Head**
3. Asst. Prof. Adrijana Leonardi
4. Prof. Toni Petan
5. Prof. Uroš Petrovič*
6. Prof. Jože Pungerčar
7. Dr. Jernej Šribar
Postdoctoral associates
8. Dr. Mauro Danielli
9. Dr. Eva Jarc Jovičić
10. Dr. Nina Mikec
Postgraduates
11. Tadeja Bele, M. Sc.
12. Adrijan Ivanušec, B. Sc.

13. Špela Koren, B. Sc.
14. Kity Požek, B. Sc.
15. Mia Žganjar, B. Sc.
16. Gašper Žun, B. Sc.
Technical officers
17. Katja Doberšek, B. Sc.
18. Leja Perne, B. Sc.
Technical and administrative staff
19. Igor Koprivec
20. Vahida Suljić
21. Maja Šimaga, M. Sc.

Note:

* part-time JSI member

DEPARTMENT OF BIOTECHNOLOGY
B-3

At the Department of Biotechnology we investigate biological molecules of animal, plant microbiological and fungal origin using modern biotechnological methods. We would like to apply them for diagnostic and therapeutic purposes in human and veterinary medicine, for plant protection, the preparation of high-quality and safe food and for the protection of the environment, contributing to an improvement in peoples' health and the environment in which we live. Our research work is focused on processes of cancer progression and immune response, neurodegenerative processes, the biology of fungi and on the search for new biotechnological approaches and products.

Head:
Prof. Boris Rogelj

Regulation of anti-tumour immune response

In 2022 we continued our studies on the role of cysteine peptidases and their inhibitors in the regulation of anti-tumour immune response. We focused our work on the endogenous inhibitor cystatin F. It is an important modulator of the cell cytotoxicity of natural killer cells (NK) and cytotoxic T cells (CTL). In a tumour micro-environment various cells express and secrete inactive dimeric cystatin F, which can be internalized to cytotoxic cells and activated within endo/lysosomal vesicles, impairing the cytotoxic action against tumour cells and cancer stem cells. The results were published in *Biomedicines*. Together with co-workers from UCLA, Los Angeles, we used the humanized BLT mouse model to test the action of cystatin F in supercharged NK cells, evaluating its expression in tumour and immune cells with proteomics. Supercharged NK cells were also used in sequential therapy with either chemotherapy drug cisplatin or anti-PD-1 antibody and we found that the combination significantly decreased the tumour size and enhanced the NK function in Hu-BLT mice. The results were published in *Frontiers in Immunology.*

Since cystatin F represents an important mediator of antitumor immune response and a target for an improvement of cancer immunotherapy, we developed inhibitors of cathepsin V, a peptidase that activates cystatin F from an inactive dimeric form to an active monomer. Compound 7 significantly inactivated cathepsin V activity and reduced the cytotoxicity of NK cells, improving their antitumor activity. A research paper was published in *Computational and Structural Biotechnology Journal.*

Antitumor activity was also determined for the inhibitors of cathepsins B and X, peptidases involved in tumour migration, invasion and metastasis. Their synergistic action was confirmed in vitro and in vivo on mice models. We demonstrated that tumour progression can be prevented with a simultaneous application of specific inhibitors of both peptidases. Results were published in *Cellular and Molecular Life Sciences*. Additionally, we demonstrated the action of cathepsin X to gamma enolase regulating its pro-survival function in patients with colorectal cancer. Results were published in *Journal of Biotechnology and Biomedicine*.

Endogenous and exogenous inhibitors of lysosomal cysteine peptidases are key regulators of the antitumor immune response

Molecular neurodegeneration

With an aging population and the lack of a useful therapy, neurodegenerative diseases are increasing and becoming one of the leading causes of death worldwide. In this field our main focus is on selected genes and their protein products (TDP-43, FUS, C9orf72, SFPQ, MATR3, etc.) associated with amyotrophic lateral sclerosis (ALS), frontotemporal dementia (FTD) and Alzheimer's disease (AD). The majority of them are in some way associated with RNA biogenesis, processing, transport and turnover. We study their nuclear transport, cellular stress response and macromolecular interactions leading to mislocalization and aggregation.

We continued our studies with protein interactors of FUS, potentially responsible for its cytoplasmic toxicity, identified with BioID2 proximity labelling in 2021. To functionally evaluate their effect on the FUS or FUSdNLS (without NLS) proteins in cells, we generated stable cell lines Flp-In HEK293 and Flp-In SH-SY5Y expressing fluorescently tagged proteins: mScarlet-FUS (NeonGreen-FUS) and mScarlet-FUSdNLS (NeonGreen-FUSdNLS) or only

Figure 1: New inhibitors of cathepsin V, capable to enhance cytotoxicity of NK cells and their antitumor immune response

mScarlet (NeonGreen). Our bioinformatic analyses previously identified NUDT21 (Nudix hydrolase 21, a cleavage factor subunit), RBMX (RNA-binding motif protein X-linked) and STAU2 (Staufen double-stranded RNA binding protein 2) where the last one is completely sequestered from the nucleus into the aggregates in the cytoplasm by FUSdNLS, suggesting that FUS mutations and post-translational modifications in the dNLS region disrupt the vital processes of the STAU2-mediated mRNA transport in cells and neurons, possibly leading to silenced translation at distal sites (synapses), and overall contributing to the process of

Dipeptide repeat polyGA from the C9orf72 mutation impairs the autophagy pathway.

neurodegeneration. As for the post-translational modification of FUS NLS, particularly its C-terminal tyrosine phosphorylation (FUS^{p-Y526}), which, as we have confirmed, contributes to the cytoplasmic localization of FUS, we examined the effect of FUS^{p-Y526} on the formation of cytoplasmic aggregate formation in various non-differentiated (HEK293T) and differentiated (SH-SY5Y and NCS34) cell lines expressing constitutively active Src family kinases. For Abl and Src kinase, co-localization with FUS^{p-Y526} was subsequently confirmed *in vivo* in the mouse brain where the cytoplasmic localization pattern appeared kinase type-specific. To determine the changes in the interactome of TDP-43 during a stress granule formation and dissolution, we evaluated four stable cell lines expressing different forms of TDP-43 in fusion with ascorbate peroxidase (APEX2). The localization of fusion proteins with APEX and localization of interactors (SFPQ, NONO, ATXN2L and PUM1) were determined with an immunocytochemical

Figure 2: Active kinases of Src family (pSrc and pAbl) phosphorylate C-terminal tyrosine of FUS (FUSp-Y526) and co-localize with it in the cytoplasm of hypocampal neurons in the mouse brain as confirmed by immunohistochemical staining.

analysis. In addition, we prepared nuclear and cytoplasmic fractions and determined the differences between the distributions of interacting proteins PUM1, ATXN2L, MAML, SFPQ and NONO in both fractions in the presence of dNLS-TDP43 or wtTDP-43. In our study published in *Brain*, we focused on the poly-dipeptide repeats resulting from the translation of mutant repeat expansions in the C9orf72 gene that accumulate in cells as aggregates and cause cell death in neurodegenerative diseases.

We continued with the investigation of the C9orf72 mutation and effect of C4G2 repeat on phenylalanine-tRNA synthetase (FARS). We showed that this interaction affects the charging of tRNAphe and observed a reduction in phenylalanine-rich proteins in lymphoblasts with the C9orf72 mutation compared to controls. We also showed a global reduction in phenylalanine containing proteins with the developed Click-chemistry protocol. Additionally, we showed that a reduced expression of FARSA, when using the knock-down technology, also results in a reduced expression of these proteins in non-differentiated HEK293 cells. We are now exploring this effect also in IPSC-derived motor neurons and human brain tissue.

We continued with the preparation of new constructs for the expression of proteins involved in the paraspeckle formation (SFPQ, NONO, FUS, TDP-43, HNRNPH1, RBM14, PABPC1, SMARCA4, DAZAP1, HNRNPK). We made test expressions for proteins SFPQ, FUS, NONO in TDP-43 and obtained a decent amount of proteins. We successfully isolated enough protein HNRNPH1 to conduct further experiments. Using microscale thermophoresis, we showed that protein binds G4C2 repeat DNA found in C9orf72 ALS/FTD and observed the effect of the protein on the linearization of the DNA strand.

Prader Willi syndrome and RNA biology

We additionally optimised the COMRADES protocol to detect interactors of SNORD116 RNA. As with the previous protocol, we could not get enough quality RNA to conduct further experiments, we used another method to enrich SNORD116 RNA. We have added another step to the protocol where we will pull down SNORD116 RNA crosslinked to the interactors from SHSY5Y lysate using DNA primers that anneal to RNA. We will observe the enrichment using Qpcr. We have optimised the protocol and will use it for the generation of RNA for further experiments with mass spectrometry.

Probiotics

The dysregulated production of cytokines plays an important role in the pathogenesis of intestinal inflammatory diseases and cancer, and neutralization of cytokines represents an important treatment strategy. Our approach toward this goal involves safe lactic acid bacteria as hosts for the delivery of cytokine binders to the mucosal surfaces. We engineered *Lactococcus lactis* to display, on its surface, anti-IL-6 affibodies (designated

Engineered *L. lactis* sequestered by up to 99% of recombinant human cytokine IL-6 from the solution in a concentration-dependent manner.

as ZIL). ZIL-displaying *L. lactis* sequestered recombinant human IL-6 from a solution in a concentration-dependent manner by up to 99% and showed no binding to other pro-inflammatory cytokines, thus proving to be highly specific. The removal was equally efficient across different IL-6 concentrations (150–1200 pg/mL) that were found to be clinically relevant
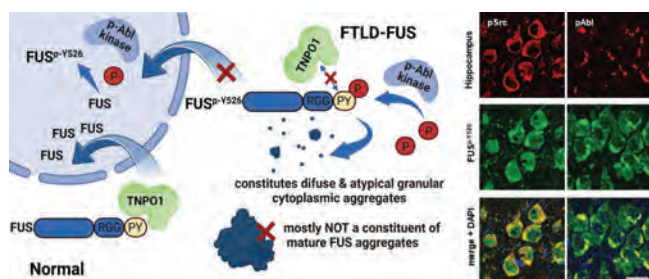
for inflammatory bowel disease patients. The ability of engineered bacteria to capture IL-6 from the cell-culture supernatant was assessed using immunostimulated human monocytic cell lines (THP-1 and U-937) differentiated into macrophage-like cells. In the next step, we upgraded bacteria with dual functionality for a selective delivery of cytokine-binding proteins to tumours by targeting specific receptors on cancer cells. We engineered *L. lactis* to co-display, on its surface, a protein ligand for tumour antigens (EpCAM-binding affitin; HER2-binding affibody) and a ligand for pro-inflammatory cytokines (IL-8-binding evasin; IL-6-binding affibody). We confirmed the removal of IL-8 and IL-6 by the engineered bacteria by establishing inflammatory cell models by stimulating cytokine secretion in human colon adenocarcinoma cells (Caco-2; HT-29) and monocyte-like cells (THP-1; U-937). The tumour-targeting properties of the engineered bacteria were confirmed in human embryonic kidney epithelial cells HEK293 transfected to overexpress EpCAM or HER2 receptors. These results confirm the concept that *L. lactis* can be efficiently modified to simultaneously display two proteins on a surface and exert a physiologically meaningful effect.

Figure 3: Functionality of surface-displayed IL-6-binding affibody ZIL. Confocal immunofluorescence microscopy images (a) and flow cytometric analysis (b) show the binding of ZIL-flag-displaying L. lactis to human biotin-conjugated IL-6. ZIL-flag: L. lactis cells containing pSD-ZIL-flag plasmid. Cont: L. lactis control cells containing empty plasmid pNZ8148. ***: P <0.001 (unpaired t-test). Bar scale: 20 μm. MFI: mean fluorescence intensity.

Lactic acid bacteria are also important as probiotics in the treatment of vaginal infections; however, their use is limited by the lack of appropriate delivery systems. We incorporated three vaginal lactobacilli, i.e., *Lactobacillus crispatus*, *Lactobacillus gasseri* and *Lactobacillus jensenii*, into nanofibers using electrospinning. Polyethylene oxide (PEO) was used as a carrier polymer to produce nanofibers, and was supplemented with alginate and sucrose due to their growth-promoting effect on lactobacilli. Sucrose improved the survival in polymer solutions and preserved the viability of *L. crispatus* and *L. jensenii* immediately after electrospinning, and *L. gasseri* and *L. jensenii* during storage. The three lactobacilli in the nanofibers retained some viability after 56 days, indicating that composite multifunctional nanofibers can be used as a potential solid delivery system for vaginal administration of probiotics.

Glycobiology

In the field of fungal bioactive proteins, in 2022 we continued with their characterization and described an interesting new family of proteins from the mushroom *Coprinopsis cinerea* and named them cocaprins. They are inhibitors of cysteine and aspartic peptidases with a beta-trefoil fold. This is the fourth new family of peptidase inhibi-tors that we have described in our research group and is found exclusively in fungi. Cocaprins are the first described inhibitors of aspartic peptidases with a beta-trefoil fold in fungi and, at the same time, they surprise us with a new mode of inhibition of cysteine peptidases that differs from the mode

Fungi are an inexhaustible source of new proteins with interesting properties.

of the other families of fungal inhibitors of cysteine peptidases, clitocypins and macrocypins. In addition, we have shown with mutagenesis that the inhibition sites for both peptidase types are located at different sites in the protein. Cocaprins confirm a remarkable plasticity of the surface functionalization of the beta-trefoil fold. Furthermore, in collaboration with foreign researchers, we described new representatives of mycocypins in a model mushroom *Laccaria bicolor* and showed that their role is related to a mycorrhizal development as they exhibit a strong increase in expression during symbiosis and, at the same time, diverse localization of individual representatives of the family in different tissues of the fungus during developmental stages and during its interaction with a plant. In addition, we showed that they are toxic to nematodes and have a deterrent effect on hypha-feeding Collembolas. Thus, mycocypins have a defense function of great importance to the soil food web.

Figure 4: Three-dimensional structure of cocaprin, the peptidase inhibitor form Coprinopsis cinerea

In the field of glycobiology and the application of bioactive proteins, we continued the research on the molecular mechanisms of action of fungal lectins and described the mechanism of action of CNL (*Clitocybe nebularis* lectin) on cancer cells. The toxicity of CNL is restricted to leukemic T lymphocytes where we showed that it induces atypical cell death that does not follow the known pathways of programmed cell death and exhibits features of apoptosis and necroptosis. An important feature of this effect is the specific interaction with glycosylated receptors on the cell surface. A similar effect, which was not restricted to leukemic T lymphocytes, was also shown for the plant lectin WFA (*Wisteria floribunda* lectin), which has a similar specificity for glycan binding as CNL. We also continued with the analysis of fungal peptidase inhibitors and lectin toxicity to invasive pests within the FunContrAPest project (Novel fungal

proteins as biopesticides for control of challenging invasive alien agricultural pests), co-funded by the Slovenian and Hungarian research agencies. In this context, we also organized a mini-symposium on alternative strategies for crop protection against invasive pests.

COVID-19 research

We completed our research on the role of cysteine peptidases in the replication and infection of the SARS-CoV-2 virus. For compounds from our peptidase inhibitor library we found the most promising antiviral effect for cathepsin B inhibitors, including antibiotic nitroxoline. The virus uptake to host cells uses two main mechanisms, membrane fusion and endocytosis; Omicron predominantly utilizes endocytosis with the key function of host lysosomal cysteine peptidases. In particular, the uptake of Omicron depends on cathepsin B. The inhibitors of cathepsin B could be crucial for the prevention of viral uptake and proliferation. The results, obtained in collaboration with colleagues from ICGEB in Trieste, Italy, are in press, and two international patent applications have also been filed. With colleagues from the University of Debrecen, Hungary, we tested derivatives of teicoplanin with a dual antimicrobial and antiviral role, exhibiting a strong antiviral activity against SARS-CoV-2. The results were published in *Scientific Reports*.

The results of the research work at the Department of Biotechnology in 2022 were published in 24 scientific papers in journals with an impact factor. We also published six reviews. We received four new research grants from the Slovenian Research Agency. This year we also started work on our new multi-institute research programme where our department is led by dr Sabotič. The following awards and recognitions were received: dr Ana Mitrović and prof. Janko Kos were among the recipients of the awards of the Slovenian Biochemical Society; dr Tina Vida Plavec received the big Krka Prize for her doctoral dissertation; our publications by Božič et al., Mitrovič et al., and Breznik et al. received Excellent in Science 2022 recognitions. Members of the department were also very active in pedagogical work as lecturers and mentors to students preparing diploma and doctoral theses at universities in Slovenia and abroad. In 2022 two doctoral theses were completed at the department.

Some outstanding publications in the past year

1. Božič, Janja, Motaln, Helena, Pucer Janež, Anja, Markič, Lara, Rogelj, Boris, et al. Interactome screening of C9orf72 dipeptide repeats reveals VCP sequestration and functional impairment by polyGA. *Brain : journal of neurology*, ISSN 0006-8950, 2022, vol. 145, no. 2, pp. 684–699, illustr., doi: 10.1093/brain/awab300. [COBISS.SI-ID 76933379] **IF 15, 3.**
2. Mitrović, Ana, Završnik, Janja, Mikhaylov, Georgy, Knez, Damijan, Pečar Fonović, Urša, Matjan-Štefin, Petra, Butinar, Miha, Gobec, Stanislav, Turk, Boris, Kos, Janko. Evaluation of novel cathepsin-X inhibitors in vitro and in vivo and their ability to improve cathepsin-B-directed antitumor therapy. *Cellular and Molecular Life Sciences*, ISSN 1420-682X, 2022, vol. 79, no. 1, 14 pp. https://link.springer.com/article/10.1007/s00018-021-04117-w, doi: 10.1007/s00018-021-04117-w. [COBISS.SI-ID 92443651] **IF 9, 2.**
3. Zahirović, Abida, Berlec, Aleš. Targeting IL-6 by engineered *Lactococcus lactis* via surface-displayed afbody. *Microbial Cell Factories*. 2022, vol. 21, pp. 143-1-143-15, ISSN 1475-2859, doi: 10.1186/s12934-022-01873-7. [COBISS.SI-ID 115689987] **IF 6, 4.**
4. Mitrović, Ana, Senjor, Emanuela, Jukič, Marko, Bolčina, Lara, Prunk, Mateja, Proj, Matic, Perišić, Milica, Gobec, Stanislav, Kos, Janko. New inhibitors of cathepsin V impair tumor cell proliferation and elastin degradation and increase immune cell cytotoxicity. *Computational and Structural Biotechnology Journal*. 2022, vol. 20, 4667–4687, [COBISS.SI-ID 119687939] **IF 6, 2.**
5. Perišić, Milica, Žurga, Simon, Konjar, Špela, Prunk, Mateja, Kos, Janko, Sabotič, Jerica. The fungal Clitocybe nebularis lectin binds distinct cell surface glycoprotein receptors to induce cell death selectively in Jurkat cells. *The FASEB Journal*. [Online ed.]. 2022, vol. 36, no. 4, pp. e22215-1-e22215-20. ISSN 1530-6860, doi: 10.1096/fj.202101056RR. [COBISS.SI-ID 99060227] **IF 5, 8.**

Awards and Appointments

1. Aleš Berlec, Recognition of the work in the editorial board of the journal Acta Chimica Slovenica, Slovenian Chemical Society
2. Ana Mitrović, Lapanje, Recognition for outstanding scientific research and professional achievements in the field of biochemical sciences, Slovenian Biochemical Society, Ljubljana, Slovenia

3. Ana Mitrović, Excellent in Science 2022, Ljubljana, Slovenia, Slovenian Research Agency, for paper Evaluation of novel cathepsin X inhibitors in vitro ter and vivo and their ability to improve cathepsin B-directed antitumour therapy

4. Tina Vida Plavec, Krka Prize for doctoral dissertation, Krka d.d., Novo mesto, Slovenia, Surface display of tumour antigen binders on *Lactococcus lactis* NZ9000 and evaluation of their binding to selected human tumour cell lines

5. Emanuela Senjor, Excellent in Science 2022, Ljubljana, Slovenia, Slovenian Research Agency, for paper Infiltrating natural killer cells bind, lyse and increase chemotherapy efficacy in glioblastoma stem-like tumorospheres, B. Breznik et al., Communications Biology

6. Spase Stojanov, Alessandro de Vita Award, Trieste, Italy, CrossNano workshop, Recognition of a high-level scientific multidisciplinarity

7. Abida Zahirović, The Second Best Short Oral Presentation Award, Paris, France, International Society of Microbiota, Recombinant Lactic Acid Bacteria for the Therapy of Inflammatory Bowel Disease

Organization of conferences, congresses and meetings

1. Jerica Sabotič, Alternative strategies of plant protection against invasive insect pests, mini-symposium, Ljubljana, 28 September 2022

INTERNATIONAL PROJECTS

1. COST CA18238; Ocean4Biotech - European Transdisciplinary Networking Platform for Marine Biotechnology
   Dr. Jerica Sabotič
   Cost Association Aisbl
2. COST CA19123 - PHOENIX; Protection, Resilience, Rehabilitation of Damaged Environment
   Prof. Aleš Berlec
   Cost Association Aisbl
3. Crosstalk of Proteinopathy and Inflammation in Amyotrophic Lateral Sclerosis
   Prof. Boris Rogelj
4. Increasing NK Cell Cytotoxicity Through Modulation of Cystatin F
   Dr. Milica Perišić Nanut

RESEARCH PROGRAMMES

1. Pharmaceutical Biotechnology: Knowledge for Health
   Prof. Janko Kos
2. Marine and microbial biotechnology
   Dr. Jerica Sabotič

R & D GRANTS AND CONTRACTS

1. Bactericidal nanoblades: a proof-of-concept approach for bimodal chemo-mechanicaleradication of persistent biofilms
   Dr. Jerica Sabotič
2. Cathepsins B and X in breast cancer stem cells – molecular targets and relevance for antitumor therapy
   Asst. Prof. Ana Mitrović
3. Intra-biofilm dynamics of Campylobacter with other bacteria: effects on biofilm formation and composition with a view to the design of innovative control strategies
   Dr. Jerica Sabotič
4. Recombinant probiotics as bio-alternative antimicrobial approach against Clostridioides difficile
   Prof. Aleš Berlec
5. Molecular mechanisms of specificity in regulation of secretion and action of muscle-derived cytokines
   Prof. Boris Rogelj
6. Nanofibers for codelivery of selected microbiota cocktails and antimicrobials for local treatment of vaginal infections
   Prof. Aleš Berlec

7. Microplastics as a vector of microbial contamination, infection and resistance: the case of Campylobacter bacteria in poultry meat production
   Dr. Jerica Sabotič
8. New antimicrobial strategies in prevention of biofilm formation by using lectins that inhibit bacterial adhesion
   Dr. Jerica Sabotič
9. Improvement of immunotherapeutic potential of NK cells through modulation of cystatin F
   Prof. Janko Kos
10. Nuclear transport defects in frontotemporal dementia
    Prof. Boris Rogelj
11. Cystatin f as a mediator of immunosuppression in glioblastoma microenvironment
    Dr. Milica Perišić Nanut
12. FunContrAPest: Novel Fungal Proteins as Biopesticides for Control of Challenging Invasive Alien Agricultural Pests
    Dr. Jerica Sabotič
13. Small protein blockers of IL-23/IL-17 axis as intestinal inflammation inhibitors secreted by probiotic bacteria
    Prof. Aleš Berlec
14. Targeting protein phase separation and aggregation in neurodegenerative TDP-43 proteinopathies
    Prof. Boris Rogelj
15. Translational irregularities underlying C9orf72-associated amyotrophic lateral sclerosis and frontotemporal dementia
    Prof. Boris Rogelj
16. On-demand Contact Based Antimicrobial Surfaces: Human and Environmental Safe Infection Control Strategy
    Dr. Milica Perišić Nanut
17. Exploring the biofilm phenotype and surfactome of Listeria monocytogenes to predict its persistence and pathogenicity potential using machine learning
    Dr. Jerica Sabotič
18. Selective mechanical removal of bacterial biofilms by conjugated magnetic nanoparticles
    Prof. Aleš Berlec
19. Antibacterial alloys: development by additive 3D manufacturing, characterization and clinical applications
    Asst. Prof. Helena Motaln
20. Plasma VUV and UV radiation – a method for successful deactivation of Aflatoxins
    Asst. Prof. Helena Motaln
21. Engineering lactic acid bacteria for tumour targeted delivery of anticancer agents
    Dr. Abida Zahirović
22. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
    Prof. Boris Rogelj
    Ministry of Education, Science and Sport
23. Cell4Chem: Engineering microbal communities for the conversion of lignocellulose into medium-chain carboxylates
    Prof. Aleš Berlec
    Ministry of Education, Science and Sport

VISITORS FROM ABROAD

1. Dr Stefan Toepfer, Dr Szabolcs Toth, MATE University, Godollo, Hungary, 23 February 2022
2. Prof. Stéphanie Perret, Laboratory of Chemical Biology, CNRS-AMU, Marseille, France, 10 May 2022
3. Prof. Hélène Gaussier, Mediterranean Institute of Oceanology, Marseille, France, 10 May 2022
4. Dr Petr Maly, BIOCEV Research Center, Vestec, Czech Republic, 19 August 2022
5. Prof. Milan Raška, Faculty of Medicine and Dentistry, Palacky University, Olomouc, Czech Republic, 19 August 2022

STAFF

Researchers
1. Prof. Aleš Berlec
2. Prof. Janko Kos*
3. Asst. Prof. Helena Motaln
4. Dr. Milica Perišić Nanut
5. Prof. Boris Rogelj, Head
6. Dr. Jerica Sabotič
7. Prof. Borut Štrukelj*
Postdoctoral associates
8. Dr. Maruša Bizjak, left 01.09.22
9. Dr. Nikolaja Janež
10. Asst. Prof. Ana Mitrović
11. Dr. Tina Vida Plavec
12. Dr. Emanuela Senjor
13. Dr. Spase Stojanov
14. Dr. Abida Zahirović

Postgraduates
15. Urša Čerček, B. Sc.
16. Jerneja Nimac, B. Sc.
17. Petra Štravs, B. Sc.
Technical officers
18. Manca Černila, B. Sc.
19. Tjaša Peternel, B. Sc.
20. Nika Zaveršek, B. Sc.
21. Tanja Zupan, B. Sc., left 22.08.22
Technical and administrative staff
22. Vahida Suljić
23. Maja Šimaga, M. Sc.
24. Tadeja Tumpej, B. Sc.

Note:

* part-time JSI member

DEPARTMENT OF ENVIRONMENTAL SCIENCES O-2

The Department of Environmental Sciences focuses on the interweaving of the physical, chemical and biological processes that shape our environment as well as humans and their activities. Our research is interdisciplinary and multidisciplinary and takes place in several areas, such as environmental analytical chemistry, biogeochemical cycles, microbial ecology and colloid biology, environment and health, environmental technologies, risk and environmental assessment, and environmental monitoring. We also work on the development of technical solutions for environmental problems and environmental management. The department hosts the "ISO-FOOD" ERA Chair for isotope techniques in food safety, quality and traceability, the infrastructural Centre of Mass Spectrometry (CMS), the Infrastructural Centre for Measurements of Ionising Radiation (ICMIS) and the Mobile Ecological Laboratory Unit (ELME).

Head:
Prof. Milena Horvat

Analytical chemistry of the environment and biological systems

Inorganic analysis and speciation

The role of trace elements and their impact on the environment and living organisms depend on both their total concentration and the chemical forms in which they are present. Our research is focused on the development of new analytical procedures for the speciation of elements in environmental, food and biological samples.

In the field of *elemental speciation*, the behaviour of Cr(III) and Cr(VI) was followed using enriched ^{50}Cr(VI) and ^{53}Cr(III) stable isotopic tracers added to wine and beer samples, applying a speciation analysis based on anion-exchange HPLC-ICP-MS. Results revealed that wine and beer do not contain toxic Cr(VI) as the concentrations were below 0.06 ng/mL. It was also demonstrated that, due to the presence of antioxidants, the added ^{50}Cr(VI) was reduced to ^{50}Cr(III). Our investigation refuted the statements of some researchers who reported that wine and beer contain toxic Cr(VI). Moreover, we optimized the analytical procedure for a simultaneous speciation of chromate, molybdate and arsenate in lysimetric water from geotechnical composites installed in field lysimeters. The main advantages of a multielement speciation analysis over the commonly used single-speciation procedures are its speed and cost-effectiveness.

A new method for the speciation of copper (Cu) in human serum was developed. Separated Cu species were quantified with isotope dilution (ID)-ICP-MS. The technique was successfully applied in the determination of Cu-Cp, Cu-HSA and Cu-LMM species in the human serum of healthy individuals, kidney-transplant patients and cancer patients. Our research provides an important new analytical tool that can be used to assess Cu metabolic disorders in many other diseases.

In the field of bioimaging of metal ions we continued with the optimization of the parameters for LA and the quantification of an ablated sample with ICP-MS in tumour spheroids and plant tissue, with the aim to achieve a high spatial resolution and low limits of detection.

Using laser ablation with inductively coupled plasma mass spectrometry (LA-ICP-MS), we obtained high-resolution and sensitive images that enabled the pharmaco-kinetic monitoring of the Pt distribution in mouse tumours and the optimization of the dose of chemotherapeutic cisplatin using different modalities of its application (intravenous or intratumorally) in cancer therapy. The work was carried out in cooperation with the Oncology Institute in Ljubljana.

Figure 1: Quantitative Pt distribution in B16F10 mice tumours, 10 min after the treatment with 4 μg of cisplatin per body mass

In the field of archeology and paleontology we optimized analytical methods for determining the ^{87}Sr/^{86}Sr isotopic ratio in solid samples (transverse and longitudinal sections of cave bear teeth) using laser ablation coupled to multi-collector ICP-MS and for determining the elemental composition of the same samples using laser ablation coupled to QQQ-ICP-MS. In cooperation with the Ivan Rakovec Institute of Paleontology, ZRC SAZU, we will use optimized methods to study the life and environment of cave bears in Slovenia. In collaboration with the Stefan cel Mare University of Suceava, Romania, we began to study the connection between the elemental analysis and the

^{87}Sr/^{86}Sr isotopic ratio in water, soil and wood samples with the aim of using them in determining the provenance of wooden artifacts.

In the framework of the MSCA fellowship STROMASS we are developing a rapid method for determining Sr-90 in water and milk samples with ICP-MS. The initial results are promising, showing that the developed method might significantly decrease the time needed for the analysis and increase the sample throughput. This is of particular importance in the case of emergency situations.

A method for the pre-concentration of Hg from low-content biological matrix (tree leaves) for a Hg stable isotope analysis was developed. The validated method was successfully applied for the determination of Hg stable isotopes in leaves from the Iskrba station, Ljubljana, and Idrija region.

Organic analytical chemistry

A molecularly imprinted polymer (MIP) aimed for an extraction of an active pharmaceutical substance bupivacaine from blood-derived samples was optimized. While at higher concentrations this material showed promising results, leaching the template from the material makes the method ill-suited at lower levels. This was solved by replacing the template with a structurally similar analogue as a part of the MIP synthesis procedure.

A reference solid-phase extraction method was developed and validated for the local anaesthetic drug bupivacaine and sedative dexdemetomidine in plasma samples. The method was then used for pharmacokintetics studies of anaesthetized dogs after a single intravenous or perineural administration of the drugs. Such studies are important in the context of improving the pain management treatment of dogs following tooth extraction.

The analytical method for determining bleomycin in blood-derived and tumour samples was optimized, simplified and revalidated. In this frame, novel extraction materials were included and the extraction was transferred to a positive-pressure 96-well-plate extraction system. In the context of validation, the stability of the analyte in different matrices was examined and a quality control system was established. The method was further adapted for the determination of bleomycin at trace-level concentrations in *in vitro* systems.

A literature review of analytical methods for determining licit drug residues such as tobacco (nicotine) and alcohol (ethanol) as well as psychoactive substances, e.g., antidepressants, antipsychotics, benzodiazepines and their metabolites in wastewaters was performed. Selected methods were developed in our laboratory and applied to wastewater from Slovene wastewater treatment plants of different sizes and configurations.

Metrology

Metrology – the science of measurement – is crucial for the department as most research is related to measurements or the use of measurement results. The department is the institute designated to develop the national metrology system identifying the amounts of substances, particularly of trace elements in organic and inorganic materials.

Metrology in a traditional stable-isotope analysis of light elements covers participation in the interlaboratory comparisons at the highest metrology level. In 2022, we participated in the evaluation of results in two interlaboratory comparative schemes – CCQM-P212: Coherence of carbon isotope delta reference materials, and CCQM-204: Pilot study on CO2. The paper *Minimum requirements for publishing hydrogen, carbon, nitrogen, oxygen and sulfur stable-isotope delta results* was published as the IUPAC Technical Report. In the STELLAR project we performed an analysis of prepared synthetic isotope mixtures and determined the n(13C)/n(12C) isotope amount ratios for the samples with known or certified d13C values to trace the measurements to SI units.

The department is also actively involved in two metrology-related networks: ESFRI Infrastructure for the Promotion of Metrology in Food and Nutrition (METROFOOD-RI) where the JSI acts as the coordinator of the Slovenian Joint Research Unit (METROFOOD-SI).

The department also joined the newly established European Metrology Network on Food Safety and Sustainability (EMN-FOOD) and EMN for Pollution Monitoring.

Within the GMOS-Train and SI-Hg projects, we focused on measuring atmospheric Hg species. The evaluation of the existing calibration methods for gaseous oxidized mercury (Hg^{II}) species (permeation tubes) was compared to the performance of our newly developed calibration system. This calibration system is based on comparing non-thermal plasma oxidation of elemental mercury to oxidized Hg species in the presence of specific reaction gasses. We validated this calibration approach using both ^{197}Hg radiotracer and NIST SRM 3133, thus making it the first SI-traceable calibration procedure for Hg^{II} species at ambient concentration levels. The existence of individual oxidized Hg species produced using non-thermal plasma approach was confirmed with the quadrupole mass spectrometer.
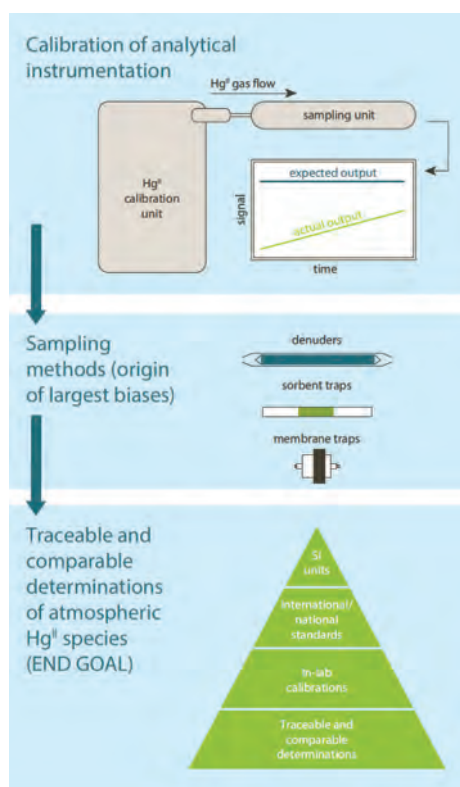
Figure 2: Improving the metrology of atmospheric HgII species

In 2022 we started with the activities within the EPM project MetroPOEM, coordinated by the National Physical Laboratory (NLP), which covers the development of analytical methods with accurately evaluated measurement uncertainties based on mass spectrometry to determine radionuclides (U, Np, Am, Sr) and isotopic ratios of Li, B, Cr, Cd, Ni, Sb, Pb and U.

As part of the work of the institute for the determination of trace elements in organic and inorganic materials, we participated in interlaboratory comparison schemes SIM.QM-S12 and APMP.QM-P41 Trace Elements in Natural Water; APMP.QM-S19 and P40 Toxic Elements in Seafood; CCQM-K158 A Elements and Inorganic Arsenic in Rice Flour, and CCQM-K160 Platinum Group Elements in Automotive Catalyst.

Nanomaterials and biosensors

As part of the GMOS-Train project, we started to develop a protein-based biosensor to detect Hg in different water samples.

In collaboration with the National Chemical Institute, Ljubljana, Slovenia, and the Hebrew University of Jerusalem, Israel, we reported on the deposition, testing and antioxidation properties of ultra-thin (1–3 nm) mono-, di- and tri-layer hybrid organic-inorganic polyhedral oligomeric silsesquioxanes (POSS) on Inconel 617. We envision that such coatings will have significant potential as primers for spectrally selective absorber coatings used for the concentrated solar power (CSP) hybrid absorber technology. Our collaboration activities also resulted in a publication in *Solar Energy Materials and Solar Cells*.

The production, synthesis, characterization, scaling-up and properties of 2D nanomaterials were also studied in different international and national projects. The findings were published in *Nanoselect*.

We collaborated with the Electronic Ceramics Department (K5) to develop nanomaterial thin and thick films using screen-printed methods on two different substrates (Al_2O_3 and LTCC) and utilize them as transducer-based biosensor platforms for the detection of different targeted analytes.

In collaboration with the National Institute of Animal Biotechnology (NIAB), India, we worked on electrochemical-based biosensors for SARS-CoV-2 and cancer research. Within this work, we prepared peptides and bioconjugates to target cancer cells and develop strategies to immobilise biomolecules on nanomaterials. The above activities resulted in publications in *Frontiers in Immunology* and *Cancers.*

Biogeochemistry and climate change

In collaboration with the national Geological Survey, we explored the molecular and isotopic composition of natural gas at the Petišovci-Dolina oil and gas field in north-eastern Slovenia. The molecular composition was relatively homogeneous at all depths between ∼1000 and ∼3000 m, namely, methane reached 85% or more, CO_2 was below 4% and hydrocarbons C2-C6 were around 11%. Based on the carbon isotope composition of methane, a thermogenic origin was confirmed. We also investigated the origin of the karst sulphur spring Žepovnik in the Alpine part of northern Slovenia. Using a multi-isotope (O, H, C, S) approach to characterise the origin of water and sulphur, we found that the water is young and of meteoric origin, while the sulphur originates mainly from the dissolution of evaporites in the bedrock.

Further, the first geochemical and isotopic studies of "anthropogenic" pedogenic carbonates and CO_2 from irrigated drylands of southwestern United States were performed. A pecan orchard and an alfalfa field, where flood irrigation from the Rio Grande river is a common practice, were compared to a nearby natural dryland site. Strontium and carbon isotope ratios show that bulk pedogenic carbonates in irrigated soils at the pecan orchard primarily formed due to flood irrigation, and that approximately 20–50% of soil CO_2 in these irrigated soils is calcite-derived abiotic CO_2 instead of being of soil-respired or atmospheric origins. Multiple variables that control the salt build-up in this region were identified and the impact of crop production on soil sustainability was determined regionally and globally.

A new research was started, covering small microplastics and nanoplastics in natural systems. In this context, we published a review article in collaboration with other international research institutions that presents the current state of the art of multidetector field-flow fractionation used for a nanoplastic analysis and critically discusses future trends and needs aiming at analysing the nanoplastics in food. Within the UPTAKE project (ARRS project L7-4422), we started studying the uptake and distribution of metal-doped nanoplastics in hydroponically grown tomato plants. Using enriched stable isotopes of cadmium, lead, zinc and chromium in the presence of nanoplastics, we also followed the uptake of the mentioned pollutants in hydroponically grown tomato plants.

In the field of nanoparticle analysis, we followed the occurrence and origin of titanium dioxide nanoparticles (TiO_2NPs) in the Sava River with the use of spICP-MS. The results of the study showed that the levels of TiO_2NPs found in the river water were highly impacted by urban, agricultural and/or industrial activities, hydrological conditions and river sediment composition.
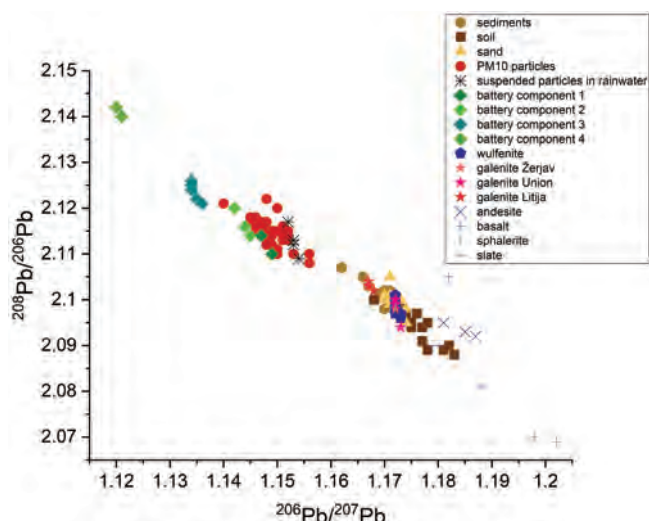
Figure 3: Pb isotope ratio in different environmental samples from the Mežica Valley and its surrounding

Within the Danube Hazard m3c project, coordinated by the Technical University of Vienna, we continued to measure selected elements in the river water, wastewaters, atmospheric deposition, soil sediments and suspended particulate matter, collected at 20 sampling sites alongside the Danube River Basin. The results showed that the most polluted river water was found in the Romanian Vit catchment including zinc and copper due to mining activities, where the measured concentrations exceeded 2000 ng/mL. Elemental contamination of the other river catchments studied was low to moderate. Different types of inorganic nanoparticles were also identified, quantified and characterized in the river water and sediment/soil samples. To this end, we optimised the procedure for extraction of inorganic nanoparticles from sediments, followed by their analysis with spICP-MS.

In collaboration with the Rudjer Bošković Institute, we studied the spatial and temporal variability and sources of dissolved trace elements in the Sava River in Slovenia and Croatia.

Within the project on non-traditional isotopes as identifiers of authigenic carbonates, which ended in 2021, we started with the development and optimization of the analytical procedure for the determination of Mo isotopes in freshwater and marine environments. In 2022 we used the developed method for determining $\delta^{97/95}$Mo and $\delta^{98/95}$Mo in the study of oxidation-reduction processes in the sediments of Lake Brljan on the Krka River in Croatia. In collaboration with the Department of Geology at the Faculty of Science and Technology of the University of Ljubljana, we studied the formation and primary sources of Pb and Mo in various minerals and rocks using $\delta^{97/95}$Mo, $\delta^{98/95}$Mo and Pb isotopic ratios.

As part of the project *New indicators of climate change in stalagmites in Slovenia*, we optimized the analytical procedure for determining the ^{87}Sr/^{86}Sr isotopic ratio and elemental composition using laser ablation coupled to MC-ICP-MS and/or QQQ-ICP-MS. With them, we will study the changes in the growth of speleothems due to climate change in the Dovčja Cave, Slovenia.

Water cycle

The complex surface water (SW)-groundwater (GW) system of the alluvial aquifer at the south-western margin of the Danube Basin (Varaždin, N Croatia) was investigated to understand the interactions of carbon and water cycling in the critical zone. Using the isotopic composition of water (O, H), dissolved inorganic and organic carbon and physico-chemical parameters of water, it was determined that the groundwater acts as both the source and sink of atmospheric CO_2, and that the current SW-GW dynamics regulates the carbon balance without having negative impacts on the water quality. Nitrate concentrations and nitrate N and O isotope compositions were determined to identify the origin of the nitrate pollution in the aquifer. In the field of urban hydrology, we investigated the chemical and isotopic composition of water in the Ljubljana public water supply network. Data showed that in spite of a very narrow range of the δ^{18}O and δ^2H values for the water in the network, each of 41 wells exhibits a unique nature considering additional parameters. Based on the isotopic composition of dissolved inorganic carbon, distinctions could be made between the river-groundwater interactions within the piping network, depending on shallower or deeper wells and their distances from the river bed.

Monthly monitoring, sampling and measurements of Hg and different water parameters on the Idrijca and Soča Rivers continued on six locations on both rivers. Pilot sampling in the Gulf of Trieste was also performed and it will be the subject of further research. The Soča River still, even 25 years after the closure of the Hg Mine in Idrija, brings considerable amounts of Hg into the Gulf; however, the species of Hg depends on the location, environmental conditions and biogeochemical processes that occur in the river and gulf. Our work is done within the project *Innovative isotopic techniques for identification of sources and biogeochemical cycling of mercury in contaminated sites – IsoCont*.

Air

As part of the project *Sources, transport and fate of persistent air pollutants in the environment of Slovenia* (STRAP, Slovenian Research Agency), we continued our investigation of the ambient-air quality in Ljubljana, using radon as the indicator of the atmosphere dynamics. Based on multi-year continuous measurements of the radon concentration in outdoor air, we classified atmospheric stability and determined the atmospheric boundary layer.

In addition, the sources of polycyclic aromatic hydrocarbons (PAHs) as persistent organic pollutants on particulate matter were investigated at selected locations in Slovenia. With a compound, specific stable-isotope analysis (CSIA) we were able to determine the δ^{13}C values for 14 PAHs: acenaphthylene (AcPhty), acenaphthene (AcPht),

fluorene (Fl), fluoranthene (FlAl), pyrene (Py), benzo(a)anthracene (B(a)A, chrysene (Cy), benzo(b)fluoranthene (B(b)F), benzo(j)fluoranthene (B(j)F), benzo(k)fluoranthene (B(k)F), benzo(a)pyrene (BaPy), indeno(1,2,3,c,d) pyrene (IPy), dibenzo(a,h)anthracene (DB(a,h)At, benzo(g,h,i)perylene (B(g,h,i,)Pe. The $\delta^{13}C$ values for the PAHs ranged from -62.4‰ to -18.3‰ indicating that the main sources of the PAHs are liquid fossil fuels, petrogenic sources and biomass combustion.

With the project *CAEmissionMonitor – Determination of primary carbonaceous aerosol emission rates and formation rate of secondary organic aerosol* (Slovenian Research Agency), we are involved in the extensive research *Sarajevo Aerosol Experiment: Composition, Sources and Health Effects of Atmospheric Aerosol*. At the Federal Hydrometeorological Institute in Sarajevo (Bosnia and Herzegovina), we continuously monitor radon concentration at two locations to explain the influence of the atmospheric mixing layer on the aerosol concentration. As part of the SRNSFG project *Radon mapping and radon risk assessment in Georgia*, we continued the radon survey in water, soil and air to upgrade the related radon maps for Georgia.

In an indoor air quality research, we selected several buildings with different airtightness levels of the building envelope, different usages (homes for the elderly, private houses, apartments in a block) and in different areas of Slovenia. The places were chosen according to the radon risk (low, moderate and high) based on our Radon Map produced in 2018. In addition to radon (Rn), carbon dioxide (CO_2) concentrations were continuously monitored. In elderly care homes, the Rn and CO_2 concentrations reflect room ventilation more than the risk area in the Radon Map or building construction/technical characteristics. In one of the private houses, in the area with a moderate risk for radon and good airtightness of the building envelope, the Rn and CO_2 concentrations often exceeded the limit values in winter. Simulations of design ventilation rates (DVRs) showed that air exchange rates of 1.4 to 1.8 per hour would ensure good air quality, hardly achieved with natural ventilation, and so installing a ventilation system was proposed. In a smaller apartment in the block, the ventilation simulation showed that sufficiently low concentrations of Rn and CO_2 could be maintained in the cold season with 0.5 air exchanges per hour. Since the apartment was not aerated overnight, the CO_2 concentration in the morning usually exceeded the limit value. During the energy crisis, we generally faced high CO_2 concentrations in apartments. For our research, we were using advanced research equipment purchased within the infrastructure project RI-SI-EPOS.

Colloid biology

Within the SURFBIO project, a twinning funding scheme and a consortium of research partners from which the JSI is transferring the knowledge, carried out several staff training activities to boost our expertise in surface and colloid biology research. Together with the partners, we started to build a research innovation hub, initially a virtual entity, which will help us gain new scientific collaborations and industrial partners.

Within the GREENER project, artificially constructed multi-cellular structures bound to specific types of carriers in order to biotransform chemically complex polymeric compounds, like lignin, into added-value compounds were used. The innovation was described in a newly submitted patent application.

Within the BIOSYSMO project, first model different metabolic remediation pathways were implemented with the partner institutions, with the aim to reconstruct them using the approach of aggregation of different bacteria to form artificial consortia able to perform the modelled biotransformation processes.

Artificial bacterial consortia were implemented in several other ongoing projects funded by the Slovenian Research Agency. Within the international project ARRS N1-0100 BE MERMAiD – Bioavailable mercury methylation in the Adriatic Sea – several experiments were conducted to demonstrate that cellular aggregates can form internal anaerobic conditions important for the methylation of mercury.

In the international project CROSSING (a collaborative research project between the JSI and Helholz-Zentrum Dresden-Rosendorf – HZDR, Germany, funded by HZDR) the interactions between bacteria and nanoparticles, as well as bacteria and metal surfaces with different physical characteristics obtained with nanoprinting and etching were characterised.

Two national research projects in the field of characterizing bacterial isolates from the oral cavity and the skin microbiome of babies were completed.
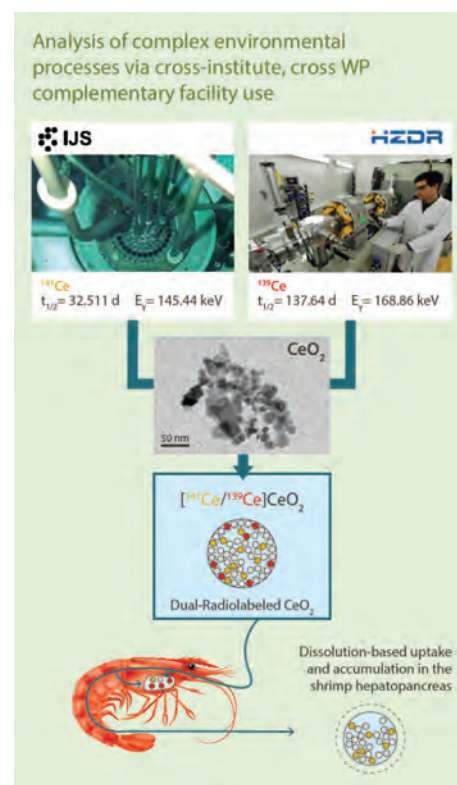
Figure 4: Analysis of complex environmental processes via cross-institute, cross WP complimentary facility use
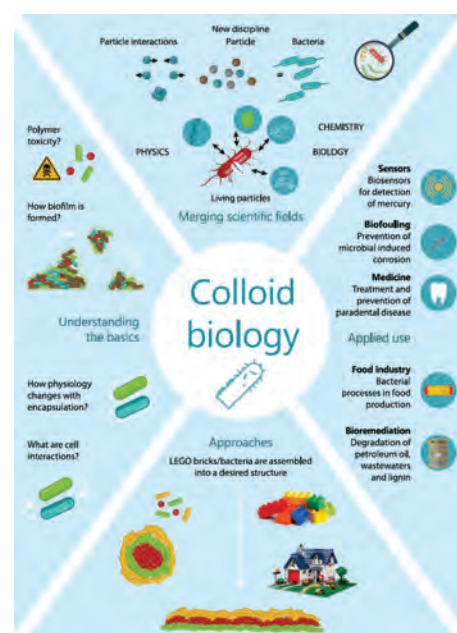
Figure 5: Colloid biology approach

In order to promote the scientific field of colloid biology, we launched a new web page – https://biocolloid.ijs.si, disseminating the results to a wider audience on social media.

Environment and health

Human biomonitoring

In collaboration with the Faculty of Health Sciences, University of Ljubljana, we studied the release of metal ions from orthodontic appliances in *in-vitro* and *in-vivo* settings. Together with the Faculty of the Electrical Engineering, University of Ljubljana, we continued the investigation of the metal-ion release from the electrodes used in electroporation and cisplatin.

In order to provide high-quality and comparable data in the context of human biomonitoring across Europe, the European Initiative for Human Biomonitoring (HBM4EU) organized interlaboratory comparative studies (ICIs) for the biomonitoring of Cr in human serum, blood and urine. The investigation was carried out within four interlaboratory comparative studies, in which our laboratory also participated. The results of the study show that regularly checking the competences of the laboratories participating in human biomonitoring studies is extremely important and helps to ensure the quality and comparability of the data obtained.

In the HBM4EU project a health risk assessment for inorganic arsenic in the general European population covering internal and external exposure data over the last twenty years was done. Due to the low concentration of arsenic in drinking water in most of Europe and low dietary arsenic intake, the exposure is low and, taking into account the latest studies on the mechanism of action of inorganic arsenic at low concentrations, the risk to the general population is very low.

In the context of the MERFISH project our investigation of gene-environment interactions using general linear statistical models continued. Using the human biomonitoring data from the PHIME study, we tried to assess the associations between maternal *ALAD*, *APOE* or *VDR* single-gene polymorphisms (SNPs) and (cord)blood Pb or Hg in healthy Italian pregnant women (n = 900) with low dietary or/and environmental exposure to nonessential, potentially toxic metals. We identified statistically significant gene-metal (Pb/Hg) associations for selected SNPs of the *ALAD* and *APOE* gene, while VDR polymorphisms showed no effects (Palir et al., 2023). We also noticed fatal sex-based associations between maternal genotypes and metal levels in (cord)blood. A similar study was performed on the data for Slovenian healthy women and their children participating in the CROME study where interactions were estimated between the *APOE* genotypes and trace elements (blood/urine) or biomarkers of the redox/oxidative stress status.

The workflow for suspect and non-targeted screening of exposure biomarkers in human urine was developed and validated. This workflow included the sample preparation, instrumental analysis and data processing procedures. It was then applied as a proof of concept to identify biomarkers of exposure in the urine of a cohort of 200 children from Slovenia, aged 6–9 yrs. The analysis revealed 76 biomarkers of exposure to several classes of pharmaceuticals, personal care products, plasticizers, pesticides, etc. The results shed light on simultaneous exposures of Slovenian children, raising questions on potential adverse effects of such mixtures on this vulnerable population.

The field work within the national HBM program (HBM2018-23), which deals with the chemical exposure assessment of children (6–9 years) and teenagers (12–15 years) continued. Due to the low number of children and teenagers recruited in the Vrhnika area in 2021, the recruitment was extended to Logatec Primary School and Prestranek Primary School in 2022 where we were able to recruit an additional 69 children/teenagers. For the first time since the start of the Covid-19 epidemic, sampling could be carried out according to the original protocol, i.e., in schools. In the autumn, recruitment and sampling continued at Trbovlje Primary School where the response rate was also low. We successfully recruited 45 children and adolescents. Samples collected in the Vrhnika area were analysed for trace elements, bisphenols, parabens and triclosan. Urine and plasma samples collected from the Mežica Valley, Jesenice and Celje areas were sent to our contract laboratory in Brno, Czech Republic (RECETOX) for analysis of polychlorinated biphenyls (PCBs), organochlorine pesticides, brominated and organophosphorus flame retardants, and per- and polyfluoroalkyl compounds (PFAS), thus obtaining urine/plasma concentrations of the listed compounds, which will allow a comprehensive assessment of the exposure of the study population.

The recruitment of pregnant women and sample collection during pregnancy, at birth and postnatally continued in the Celje region, in collaboration with the Celje Maternity Hospital. By the end of 2022 we successfully completed the recruitment with a total of 235 pregnant women.

In cooperation with the University Medical Centre in Ljubljana (UKCL), the department is responsible for the analysis of endocrine-disrupting chemicals and trace elements within the ARRS project *Impact of endocrine disruptors (bisphenols, parabens, triclosan) and potentially toxic and essential chemical elements on childbirth, infertility and ovarian cancer in Slovenia*, which involved the collection of biological samples of pregnant women, controls and patients at the University Clinical Centre in Ljubljana, Slovenia, in 2022. For one of the project tasks,

data on concentrations of endocrine disruptors (bisphenols, parabens, triclosan, phthalates and DINCH) and trace elements from the first national HBM programme were prepared for linkage with the data on the incidence of premature ovarian failure in Slovenia, at the level of statistical regions, municipalities and administrative units. Spatial data were also obtained for various environmental parameters (e.g., elemental concentrations in drinking water, moss, soil, PM2.5 and 10 concentrations as well as road density, proportion of agricultural land, etc.).

Figure 6: Schematic presentation of the study investigating the effect of genetic factors on phthalate and DINCH exposure and biotransformation in the human adult population

Based on the data from the first national HBM programme, a study was published on the influence of genetic factors on phthalate and DINCH exposure of the adult population, investigating single nucleotide polymorphisms in the genes encoding enzymes responsible for phthalate and DINCH metabolism, mainly cytochrome P450 enzymes (CYP) and UDP-glucuronosyltransferase (UGT) (Figure 7). In this study, we were the first to test and confirm in humans the previously proposed influence of genetic variation on the activity of enzymes and the subsequent biotransformation of phthalates, especially DEHP, which has important implications for the susceptibility of individuals to the harmful effects of these chemicals. The study was classified as an 'Outstanding Achievement in Science' by the ARRS.

We took part in the European HBM4EU project, focusing on the geographic variability of cadmium exposure in Europe, and investigating the variability in exposure between countries/regions related to dietary intake. By linking geospatial and HBM data, we showed that the use of organophosphorus fertilisers in agriculture contributes significantly to dietary cadmium intake from cereals in the European adult population, while cadmium from transport and industry also contributes to the exposure. As co-authors, we also contributed to many publications on exposure and risk assessment, geographical variability and sources of exposure to phthalates, DINCH, flame retardants, glyphosate and pyrethroids, which were the results of the harmonised study called *Aligned Studies* of the HBM4EU project, which also included a Slovenian study of children and teenagers in Prekmurje. At the national level, we carried out an exposure and source assessment for PFAS covering the Prekmurje study population.

In 2022 the European human biomonitoring project HBM4EU was completed, while activities continued within the PARC (Partnership for Assessment of Risk from Chemicals) project (2022–29) where the JSI is involved in the preparation of materials for the implementation of the standardisation of studies at the European level, the design of analyses of biomarkers of exposure and effects (target and non-target), data processing (existing and new datasets, and integration with environmental and health data), establishing the FAIR principle in data management (collaboration with the Department of Knowledge Technologies, E8), reviewing advanced risk assessment methodologies, and building long-term laboratory and data capacities.

We started the EU EIRENE PPP project, the purpose of which is to prepare a consolidated European research infrastructure that enables the development of advanced technologies and complementary services required for the characterization of complex environmental exposures and their impact on the European population.

Wastewater epidemiology

Wastewater-based epidemiology (WBE) can provide reliable and objective spatiotemporal data for both licit and illicit drug use. We have been involved in the SCORE network's annual monitoring of illicit drug use, aiming to advance wastewater-based epidemiology (WBE) to benefit human health and the environment through international collaboration and knowledge exchange. In SCORE 2022, we participated for the 6th time and included seven Slovenian wastewater treatment plants/municipalities. The highest mass loads of most studied biomarkers, i.e., benzoylecgonine (a biomarker of cocaine), MDMA (a biomarker of ecstasy) and methamphetamine, were observed in Ljubljana, while amphetamine was the highest in Velenje. The biomarker of THC (THC-COOH) was the highest in Koper, closely followed by Ljubljana.

In addition, we were involved in an international study, assessing new psychoactive substances (NPSs) with WBE. As part of this study, we analysed raw wastewater samples from a municipal wastewater treatment plant during Christmas-New Year. The results revealed the presence of three NPSs, namely 3-MMC, ethylone and mitragynine. The results showed that this approach is valuable for rapidly following the changing profiles of the NPS use.

Enantiomeric profiling can supplement WBE by providing additional information on drug origin (licit or illicit), improving consumption estimates, i.e., differentiating between disposal and consumption, and offering an insight into the potency of drugs available on the illicit drug market. Our study validated a chiral derivatisation GC–MS/MS method for determining amphetamines in wastewater. With this method, we showed that high MDMA (ecstasy) loads in Ljubljana are likely to result from disposal and not use and that more potent S-methamphetamine is present in the illicit drug market in Ljubljana.
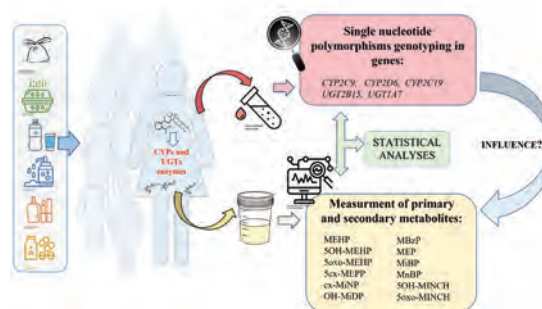
Other studies

ECOSAR ecotoxicity tests and algal growth-inhibition tests (OECD Test No. 201 Guideline, 2022) of ten selected licit and illicit drug residues were studied. No significant inhibition of algal growth (Chlamydomonas reinhardtii) was observed for the tested compounds during 72 h and 240 h of exposure, although effects on aquatic plants were predicted in silico.

The EH SECURE project started, within which we will be developing novel radionuclides for the production of radiopharmaceuticals for theranostic applications. We will be focusing on Tb-161, Au-198 and Ag-111, developing separation and purification protocols, targeting preparation and optimizing irradiation protocols.

Citizen science and other participatory approaches in the environmental health monitoring

We successfully completed the H2020 CitieS-Health project (citieshealth.eu), which was based on the principles of Citizen Science and co-creation, and brought to the forefront of research the health issues that concern the majority of the general public. Within the project, a pilot study was carried out in Ljubljana where residents were involved in research on the quality of the living environment (with a focus on noise) and lifestyle habits, and the impact on the (mental) health and well-being of individuals.

The H2020 project URBANOME (urbanome.eu) continued; it addresses health and quality of life in urban environments by systematically integrating these aspects into citizens' urban policies and activities. In collaboration with various stakeholders, we designed a study to investigate, with the help of volunteers, the exposure of individuals to urban stressors when using alternative cycling routes.

The H2020 project INQUIRE (inquire-he.eu) was launched, which will address indoor air quality – identifying different chemical and biological agents, their sources and strategies to promote healthier homes. The pilot study in Slovenia will include selected households where different air-quality parameters will be measured.

Food/nutrition including ERA Chair ISO-FOOD

The research related to the use of stable isotopes of light and heavier elements included:

– Establishing and updating a stable-isotope database of authentic samples on relevant commodities (www. foodtrack.ijs.si) including: selected fruits and vegetables (garlic, apples and kaki), honey, pork and spices (paprika, cinnamon, saffron) in cooperation with the Administration of the Republic of Slovenia for Food Safety, Veterinary and Plant Protection, Slovenian Beekeepers' Association, the PROMEDLIFE project, MSCA ITN FoodTraNet and ARRS project L7-4568.

– Upgrading the database of authentic samples with the relevant data automatically extracted from scientific literature using the Natural Language Processing (NLP) technique focusing on milk and dairy products and saffron. The NLP method was also used to obtain data on fish and seafood as selected commodities within the new Horizon Europe FishEUTrust project where we act as the coordinator. For more information see: www.fisheutrust.eu. The obtained data on the investigated food commodities are also included in the e-component of different EU projects such as METROFOOD-RI and FNS-Cloud.

– Evaluating results using standard statistical methods and artificial intelligence. The research performed on strawberries demonstrates the appropriateness and usefulness of an explorative analysis, classification and class modelling chemometric approaches in determining the geographical origin of strawberries using the stable-isotope ratio and a multielement analysis. When the origin of commercial samples with declared Slovenian origin was investigated, 39% of the samples were found to be potentially mislabelled. Further, an upgrade of the available methodologies and development of new ones by involving explainable machine learning were carried out. This approach will be used to classify a given food product and provide a justification for the assessment made.

The characterization of new alternative protein sources focusing on algae and insects was performed. Nutritional quality and safety of the *Spirulina* products were evaluated, while in the second part of the research an authenticity assessment of the *Spirulina* products from the Slovenian market, regarding their composition and geographical origin was performed. It is interesting to note that although iron contents were relatively high, the actual bioavailability of iron was much lower since it was mainly present as the ferric cation. Further, it was also shown that pure *Spirulina* supplements are a good source of essential and non-essential amino acids and w-6, but not w-3 polyunsaturated fatty acids. An investigation of the insects farmed for food and feed under the INPROFF project was also performed. The results are under evaluation.

The analysis of stable isotope and elemental composition of honey was upgraded with other methods such as investigation of volatile organic compounds (VOCs). The composition of VOCs was proved to be useful for classifying honey samples according to the type of honey and the region. Another study included the investigation of VOCs in dry-cured ham Kraški pršut. A comparison of VOC profiles indicated a possible separation of the dry-cured ham based on the raw material, heavy and light ham, and muscle type, with a high overall prediction ability of

95%, 97% and 98%, respectively. Regarding the storage, the highest differences in VOCs were seen between 1 and 7 months of storage under the same circumstances. This research was performed under ARRS project J7-4568 in collaboration with Jata Emona and Kras Sežana companies.

Volatile organic compounds were also used for an artistic project *One tree ID* performed in collaboration with the Kapelica Gallery. The result of the project is a list of volatile organic compounds in the leaves, stem and roots of *Cercidiphyllum japonicum* tree. Based on the results, a perfume was created and presented at the exhibition in Kapelica in September 2022.

In cooperation with the Beekeeping Association of Slovenia, we determined the elemental and Sr isotopic composition of samples of Slovenian honey of various types with the aim of establishing a record of parameters that are important for determining the geographical origin of honey.

As part of the project *Role of soil properties and environmental conditions in elemental and isotopic composition of the olive: basis for oil geographic traceability* led by the Institute for Adriatic Crops and Karst Reclamation (Croatia), we developed an analytical procedure for the determination of $^{87}Sr/^{86}Sr$ in olive oil with the aim of determining the geographical origin of oil.

Figure 7: MSCA ITN FoodTraNet in conjunction with ERA Chair ISO-FOOD is successfully operating in the field of safe and healthy food

Environmental technologies

Within the EU project LIFE HIDAQUA, coordinated by the Slovenian National Building and Civil Engineering Institute, we measured elements in industrial wastewaters and treated waters and contributed to the development of a device for the remediation of wastewater for its intended use in high-water-demanding industries, such as the automotive industry.

In the EU project LIFE IP RESTART, coordinated by the Ministry of Natural Resources and Space, we participated in the tasks related to the environmental impacts of recycled non-hazardous construction waste and waste from the demolition of buildings and their use in the recultivation of degraded land and the preparation of fertile land. The goals are to reduce the amount of waste and ensure the greatest possible material self-sufficiency, greater circularity in the waste-processing sector, thereby reducing the carbon footprint.

Together with the Department for Nanostructured Materials, we investigated electrochemical routes for environmentally friendly recycling of permanent magnets based on rare earths (e.g., Sm-Co).

In collaboration with the Biotechnical Faculty in Ljubljana, we investigated microbial growth in increasing concentrations of Cr(VI) and its reduction by a microbial community enriched from tannery effluent and by the bacterial strains isolated from the enriched community. By monitoring the bacterial growth (optical density) and measuring Cr(VI) using spectrophotometry and HPLC-ICP-MS, it was found that three *M. sciuri* and one *P. aeruginosa* isolates were able to reduce 50% of Cr(VI) with an initial concentration of 100 mg/L within 24 h (pH of 7.1). The enriched microbial community was better adapted to the elevated Cr(VI) concentrations, but needed a longer time (48 h) to reduce the Cr(VI) with the same efficacy. The ability of the enriched microbial community and the isolated bacterial strains to reduce the Cr(VI) highlights their potential for use in the rapid bioremediation of wastewaters contaminated with Cr(VI).

A research on cement-organics-radionuclide interactions continued for a safe disposal of low- and intermediate-level radioactive waste within the framework of work package CORI of the EURAD H2020 European Joint Programme on Radioactive Waste Management. We studied the sorption of EDTA and NTA on cement. EDTA and NTA are complexing agents, used for decontaminating surfaces in the nuclear industry. During their disposal they might

alter the mobility of radionuclides under disposal conditions. We found that the sorption of NTA is much stronger than that of EDTA, and we continue to investigate these systems.

The removal of psychoactive drug residues during wastewater treatments using different technologies, their occurrence in receiving river waters and the environmental risk were assessed. Removal efficiencies of treatments involving activated sludge or membrane bioreactors were comparable, while the moving biofilm bed reactor (MBBR) removed cotinine, cocaine and benzoylecgonine to a lesser extent. Accordingly, higher levels of nicotine and cocaine residues were detected in the river water receiving MBBR discharge. The environmental risk assessment revealed that levels of nicotine, methadone, 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine (EDDP), morphine and 3,4-methylenedioxymethamphetamine (MDMA) pose a risk to aquatic organisms.

We continued our research on the recycling of 16 bisphenols (BPs) during wastewater treatment and performed mass-flow analyses of wastewater and sludge from different treatment stages utilizing a sequencing batch reactor treatment process. BPA and BPS were the most abundant bisphenols in the influent, effluent and sludge, i.e., 80–90% of all BPs. The total concentration of BPs increases during the mechanical stage of treatment, with the highest values for the primary settler effluent. For sludge, the highest concentrations were found in the anaerobically stabilized sludge, followed by primary and secondary sludge. The study also found that significant amounts of BPs remain in the WWTP effluent (8%), the primary (10%) and secondary sludge (1%), with the majority being biodegraded (81%) in the sequencing batch reactors. Overall, the removal amounted to 92%, and the highest daily emissions recorded were 1.48 g day−1 and 4.63 g day−1 for BPA via the effluent and anaerobically stabilized sludge. Given their potential toxicity, these results could prove useful when assessing environmental risk and the reuse of wastewater and sludge in agriculture.

For many regions, water scarcity is a major issue, and the argument for using treated wastewater for irrigation is compelling, making the knowledge about the risks associated with the uptake of harmful chemicals by crops crucial. We studied the uptake of 14 chemicals of emerging concern (CECs), and 27 potentially toxic elements (PTEs) were studied in tomatoes grown in soilless (hydroponically) and soil (lysimeters) media irrigated with potable and treated wastewater using LC-MS/MS and ICP-MS. Bisphenol S, bisphenol F and naproxen were detected in fruits irrigated with spiked potable water and wastewater under both conditions, with BPS having the highest concentration. The levels of all three compounds were statistically more significant in the tomatoes grown hydroponically than in soil. Their elemental composition shows differences between the tomatoes grown hydroponically or in soil and the tomatoes irrigated with wastewater and potable water. Contaminants at determined levels showed a low dietary chronic exposure. When the health-based guidance values for the studied CECs are determined, the results from this study will be helpful for risk assessors.
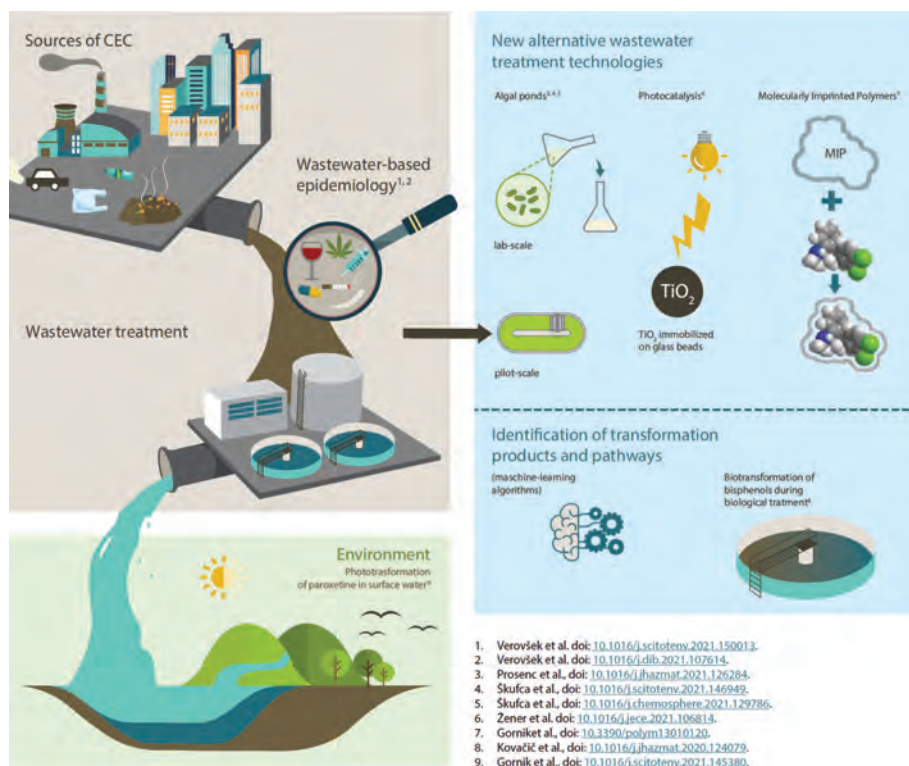
Alternatives to conventional wastewater (WW) treatment, including algal biomass and cold atmospheric pressure (CAP) plasma treatment, were also investigated. In the case of algal treatment, an alternative treatment that could contribute to the circular economy by valorising reclaimed water and algal biomass, we investigated the state of selected CECs in lab-scale bioreactors and their partitioning between the aqueous phase and algal biomass. These nature-based solutions show encouraging results regarding the CEC removal, but we need further research to understand the risks and requirements of safe wastewater and biomass reuse. Our study with plasma treatment demonstrated that CAP could remove BPA (>98%) and BPS (>70%) from water and WW where the degradation was compound-, time- and power-dependent, while the initial concentration or matrix had a negligible effect. Novel BPA and BPS transformation products were also identified. CAP plasma's relatively low energy

Figure 8: Occurrence, treatment, removal and transformation of contaminants of emerging concern (CEC)

1. Verovšek et al. doi: 10.1016/j.scitotenv.2021.150013.
2. Verovšek et al. doi: 10.1016/j.dib.2021.107614.
3. Prosenc et al., doi: 10.1016/j.jhazmat.2021.126284.
4. Škufca et al., doi: 10.1016/j.scitotenv.2021.146949.
5. Škufca et al., doi: 10.1016/j.chemosphere.2021.129786.
6. Zener et al. doi: 10.1016/j.jece.2021.106814.
7. Gorniket al., doi: 10.3390/polym13010120.
8. Kovačič et al., doi: 10.1016/j.jhazmat.2020.124079.
9. Gornik et al., doi: 10.1016/j.scitotenv.2021.145380.

requirements make it a promising treatment technology. Both CAP and nature-based solutions show encouragement, and we plan further research in both fields.

We continued our work within the framework of the national project *Cost-effective separation of tritium from water with biological systems – BIOTRISEP*. We performed preliminary experiments for tritium separation using cyanobacteria to demonstrate the preliminary proof of concept of the biological approach. In two other national projects, we collected and characterized bacterial isolates from the oral cavity and skin surface of infants and began to characterize their antimicrobial activity. We also started sequencing the genomes of selected bacterial isolates.

In cooperation with the Institute of Chemistry, we prepared a system for removing various organic pollutants used in the production of paper, which was based on a system for the immobilization of bacteria, demonstrating the so-called proof of concept for this type of cleaning system.

We also successfully acquired and started two new research projects, financed by the Research Agency of the RS (ARRS), within which we will prepare bacterial catalytic aggregates for the biotransformation of olive pomace waste and produce new types of biofertilizers.

Environmental management, environmental impact assessment and risk assessment

In 2021 we continued the activities within the TransCPEarlyWarning project, which aims to improve the level of coherence of the existing civil-protection early warning to increase the capacity to anticipate, warn and respond to threats and improve information exchange and coordination with the EU civil-protection mechanism and risk management. Specifically, this refers to increasing uniformity and homogeneity through the integration of the existing early warning approaches and thus improving the exchange of information within the European Civil Protection Mechanism. The work consisted of the finalisation of the preparatory work for the modelling phase for floods and wildfires to be used in the development of a common early-warning platform, to help harmonise and improve the detection of risks and related emergency responses. Data collection, management and analysis have been performed for the partner countries with the aim of generating a clear picture about the current state of the art regarding the civil protection and early warning systems.

We participated in the HERA project (Health and Environment Research Agenda, HERA Integrating Environment and Health Research: a Vision for the EU 2019–2022). The purpose of the HERA project was to set research priorities in the field of environment, climate and health in the EU. This research intended to guide decision-making and help achieve the ultimate goals of protecting and improving the quality of the environment and human health. The aim of the project was to identify the key orientations for future research, strategies and tools to address environmental, climate and health issues, taking into account identified societal needs, related sectoral policy objectives and knowledge gaps in the field. This was achieved by establishing effective communication between the stakeholders at the national and European levels, i.e., by involving stakeholders, developing additional guidelines for the health impact assessment and health risk assessment, increasing coordination and enrichment of ideas, and contributing to the European policy and practice.

Education

Within the EU H2020 project A-CINCH and in collaboration with the JSI Centre for Knowledge Transfer in Information Technology, we started preparing educational videos in the field of nuclear forensics, for which we were designing a hands-on training course for determining uranium isotope ratios with MC-ICP-MS for nuclear forensics applications. In addition, in collaboration with other project partners we designed a virtual laboratory with different exercises in the field of radiochemistry.

In September 2022, we prepared a Metrology training course for early-stage researchers, strengthening their knowledge in applying the basic metrological concepts.

Environmental monitoring

In collaboration with the Environmental Agency from Croatia, we continued with the monitoring of organotin compounds and total mercury in sea and surface waters. For the company Novartis, we performed numerous expert analyses of the content of microelements in active medicinal ingredients. We continued with the monitoring of the isotope composition of precipitation in Slovenia in the frame of the Slovenian Network of Isotopes in Precipitation (SLONIP) and updated the website https://slonip.ijs.si/.

The monitoring of natural radionuclides within the influential area of the former uranium mine and mill at Žirovski vrh was performed. We also participated in the off-site monitoring of the Krško Nuclear Power Plant (NPP), determining strontium and tritium in environmental samples, as well as tritium and radiocarbon in the gas effluents from the NPP. With the analyses of strontium and tritium, we also participated in the monitoring of radioactivity in drinking water in Slovenia, as well as in the monitoring of the living environment in Slovenia.

The methods used for the determination of strontium, tritium and radiocarbon for the monitoring purposes were accredited by the Slovenian Accreditation Body (SA LP-090).

The monitoring of Hg in precipitations for the Slovenian Environmental Agency was also performed at the Iskrba meteorological measurement station that is considered as a pristine area.

Infrastructural Centre for Mass Spectrometry (CMS)

Organised within the Department of Environmental Sciences, the CMS participates in the projects, research and measurements, performed with fourteen different mass spectrometers. The CMS operation is carried out in research areas including analytical chemistry, biochemistry, pharmaceutical and synthetic chemistry, medicine, health preservation, food control and environmental protection. The studies and analysis procedures within the framework of research programs and projects in the fields of pollutants in the environment, control and authenticity of food, effects of various substances and chemicals on human health deal in more detail with the speciation of chemical elements, quantitative determination of the size distribution of nanoparticles, spatial distribution of trace elements in the determination of bioavailability of essential elements, toxicity of elements in food products, geochemical cycles, identification and determination of the structure of biological molecules, medicinal agents and chemotherapeutic agents in various biological materials, organic compounds, their metabolites and degradation products, the quality and origin of foods based on isotopic measurements and tracking transport and origin of pollutants in environmental samples. We also carry out control measurements of the environment, which contribute to the protection of human health and the protection of air, surface water and drinking water.

The CMS research, made in collaboration with other infrastructural spectroscopic centres, contributes significantly to the determination of the chemical compositions, structures and properties of substances and materials, primarily for the qualitative and quantitative analysis of macro components and chemical elements, micro components of elements or traces of organic compounds in complexly composed materials in various matrices: drinking, surface or waste water, waste, food, drugs, tissues and biological fluids, air, soil, sediments, etc.

A new Orbitrap high-resolution tandem mass spectrometer was installed at the CMS last year; it enables a detailed and precise analysis of harmful substances in the environment, food and biological samples. The new Orbitrap ExplorisTM 240 mass spectrometer represents a significant advance in the chemical analysis of organic compounds. Coupled with a high-performance liquid chromatograph, it has significantly higher mass resolution and analytical sensitivity than the 15-year-old Q-TOF Premier high-resolution mass spectrometer, which means that it can accurately weigh and thus measure the molecular weight of a compound to four decimal places, dissociate molecular ions and determine the structural parts of molecules. With this instrument, we will be involved in numerous research projects at home and abroad in the fields of environment, health and food, the development of medical diagnostics, new drugs, clinical research, non-target analyses, bioremediation of degraded areas, etc.

Infrastructural Centre for Measurements of Ionising Radiation (ICMIS)

Together with the Department of Low and Medium Energy Physics, we formed the Infrastructural Centre for Measurements of Ionising Radiation, bringing together infrastructural capacities of both departments in the field of measurements of ionising radiation and merging an extensive set of research equipment, special rooms and accredited procedures for the radiological characterization of samples from the environment, industrial processing, production of building materials, materials from the chemical and pharmaceutical industry, and materials from landfills and mine tailings. Large infrastructural equipment consists of spectrometric systems for the detection of gamma, beta and alpha rays, as well as complex systems for sampling and sample preparation. With its capacities, the ICMIS functions as the key national infrastructure for the detection of ionizing radiation in the environment and as the national standard for ionizing radiation in the international metrology system, supporting numerous public research organizations, universities and state bodies in the Republic of Slovenia. The top measuring capabilities of the ICMIS were entered in the Key Comparison Data Base (KCDB) of the International Bureau of Weights and Measures (BIPM).

Figure 9: Mobile chemical laboratory of the Ecological Laboratory with a Mobile Unit (ELME) within the Civil Protection and Rescue System intervenes in the event of environmental pollution and ecological accidents with hazardous substances

Ecological Laboratory with a Mobile Unit

The mobile chemical laboratory of the Ecological Laboratory with a Mobile Unit (ELME) operates within the Department of Environmental Sciences. It intervenes within the Civil Protection and Rescue Units in the event of environmental pollution and ecological accidents involving hazardous substances. In 2022, the ELME mobile chemical laboratory intervened eighteen times in the field as surface water was polluted due to a long dry period, illegal dumping of waste and endangering the health of residents with hazardous substances, especially polluted air during fires. The most tragic accident, in which the chemical laboratory intervened last year, was

the explosion of a tank with epichlorohydrin and a fire in the Melamin chemical factory in Kočevje, in which six people died. In addition to emergency interventions, the members of the ELME mobile chemical laboratory tested their skills at regular ELME drills, received additional training for operations in the event of accidents involving dangerous substances at sea, and improved their knowledge and analytical procedures used within the mobile laboratory. Last year, we upgraded the analytical equipment of the mobile chemical laboratory with an Agilent Cary 60 spectrophotometer for the determination of hazardous chemicals in water.

Some outstanding achievements in the past year

1. Ester Heath received a Zois Award for Outstanding Achievements in the application of organic analysis in the field of environment, health and food

2. European Public Sector Awards: The EPSA Award is given by the European Institute of Public Administration (EIPA), which promotes the efforts of organizations to promote an innovative, digital and green public sector. European project APPLAUSE on the transformation of invasive alien plants into useful products and raw materials for industry won the 3rd place in the category Green Public Sector (A. Lapanje and T. Rijavec).

3. Helena Plešnik's master's thesis entitled "Determination of degradation products of bacterial lignin by liquid chromatography combined with mass spectrometry", on which she worked as part of the APPLAUSE project received the Krka Award.

4. Taja Verovšek: Best Oral Presentation by Young Researcher, 26th International Symposium on Separation Sciences (Ljubljana, June 2022)

5. Coordination of the new Horizon Europe FishEUTrust project

6. Best Poster Award to Lidija Strojnik for the poster presentation entitled "Tracing the geographical origin of fruits and vegetables" at RAFA Conference, 6–9 September 2022, Prague

7. Outstanding Achievement in Science presented by the ARRS for the paper Stajnko et al., Assessment of susceptibility to phthalate and DINCH exposure through CYP and UGT single nucleotide polymorphisms, Environment International. 2022, 59, 107046-1-107046-13, DOI: 10.1016/j.envint.2021.107046 and co-authorship of the paper by Prosenc et al., Microalgae-based removal of contaminants of emerging concern: Mechanisms in Chlorella vulgaris and mixed algal-bacterial cultures, Journal of Hazardous Materials, 41, 2021, 126284, https://doi.org/10.1016/j.jhazmat.2021.126284.

Some outstanding publications in the past year

1. Gačnik, Jan, Živković, Igor, Ribeiro Guevara, Sergio, Kotnik, Jože, Berisha, Sabina, Nair, Sreekanth Vijaya-kumaran, Jurov, Andrea, Cvelbar, Uroš, Horvat, Milena. Calibration approach for gaseous oxidized mercury based on nonthermal plasma oxidation of elemental mercury. *Analytical Chemistry*, ISSN 0003-2700. [Print ed.], 2022, vol. 94, iss. 23, pp. 8234–8240, illustr., DOI: 10.1021/acs.analchem.2c00260.

2. Stajnko, Anja, Runkel, Agneta Annika, Kosjek, Tina, Snoj Tratnik, Janja, Mazej, Darja, Falnoga, Ingrid, Horvat, Milena. Assessment of susceptibility to phthalate and DINCH exposure through CYP and UGT single nucleotide polymorphisms. *Environment International*. 2022, 59, 107046-1-107046-13. DOI: 10.1016/j.envint.2021.107046.

3. Snoj Tratnik, Janja, Kocman, David, Horvat, Milena, et al. Cadmium exposure in adults across Europe: Results from the HBM4EU Aligned Studies survey 2014–2020. *International Journal of Hygiene and Environmental Health*. 2022, vol. 246, pp. 114050-1-114050-14. ISSN 1438-4639. DOI: 10.1016/j.ijheh.2022.114050.

4. Tkalec, Žiga, Codling, Garry, Snoj Tratnik, Janja, Mazej, Darja, Klánová, Jana, Horvat, Milena, Kosjek, Tina. Suspect and non-targeted screening-based human biomonitoring identified 74 biomarkers of exposure in urine of Slovenian children. *Environmental Pollution*. 2022, vol. 313, pp. 120091-1-12009-11. DOI: 10.1016/j.envpol.2022.120091.

5. Škufca, David, Prosenc, Franja, Griessler Bulc, Tjaša, Heath, Ester. Removal and fate of 18 bisphenols in lab-scale algal bioreactors. *Science of the Total Environment*. vol. 804, 2022, 149878-1-149878-9, DOI: 10.1016/j.scitotenv.2021.149878.

6. Verovšek, Taja, Heath, David John, Heath, Ester. Enantiomeric profiling of amphetamines in wastewater using chiral derivatisation with gas chromatographic-tandem mass spectrometric detection. *Science of the Total Environment*. vol. 835, 2022, 155594. DOI: 10.1016/j.scitotenv.2022.155594.

7. Kovačič, Ana, Modic, Martina, Hojnik, Nataša, Vehar, Anja, Kosjek, Tina, Heath, David John, Walsh, James L., Cvelbar, Uroš, Heath, Ester. Degradation of bisphenol A and S in wastewater during cold atmospheric pressure plasma treatment. *Science of the Total Environment*. vol. 837, 2022, 155707. DOI: 10.1016/j.scitotenv.2022.155707.

8. Strojnik, Lidija, Potočnik, Doris, Jagodic Hudobivnik, Marta, Mazej, Darja, Japelj, Boštjan, Škrk, Nadja, Marolt, Suzana, Heath, David John, Ogrinc, Nives. Geographical identification of strawberries based on stable isotope ratio and multi-elemental analysis coupled with multivariate statistical analysis: a Slovenian case study. *Food Chemistry*. [Print ed.]. 2022, vol. 381, art. 132204, 25. DOI: 10.1016/j.foodchem.2022.132204.

9. Masten, Jasmina, Jagodic Hudobivnik, Marta, Nečemer, Marijan, Vogel-Mikuš, Katarina, Arčon, Iztok, Ogrinc, Nives. Nutritional quality and safety of the spirulina dietary supplements sold on the Slovenian market. *Foods*. 2022, vol. 11, no. 6, pp. 849-1-849-20. DOI: 10.3390/foods11060849.

Awards and Appointments

1. Prof. dr Ester Heath: Zois Award for outstanding achievements, presented by the Committee of the Republic of Slovenia for the awarding of awards and recognitions for outstanding achievements in scientific, research and development activities, Use of organic analysis in the field of environment, food and health, 2022

2. Prof. dr Ester Heath, dr David Heath, dr Ana Kovačič and dr David Škufca: Excellent in Science 2022 (Medicine), ARRS, Modern Organic Pollutants – How Can we Control them with Algae?, 2022

3. Dr Anja Stajnko, dr Agneta A. Runkel, dr Tina Kosjek, dr Janja S. Tratnik, dr Darja Mazej, dr Ingrid Falnoga and prof. dr Milena Horvat: Excellent in Science 2022 (interdisciplinary research field), ARRS, Assessment of Susceptibility to Phthalate and DINCH Exposure via Single Nucleotide Polymorphisms in Genes Encoding CYP and UGT Enzymes, 2022

4. dr Lidija Strojnik: Best Poster Award, RAFA 2022, 10th Intenational Symposium on Food Analysis, Prague, Tracing the geographical origin of fruits and vegetables: the Slovenian model, 2022

5. Taja Verovšek: Best Oral Presentation by Young Reseracher, 26th International Symposium on Separation Sciences, 2022

Organization of conferences, congresses and meetings

1. Professional meeting of the Slovenian Association for Geodesy and Geophysics: Research in the field of geodesy and geophysics 2022, 27 January 2022, Ljubljana (online)

2. 8th International k0-NAA Users' Workshop, JSI Reactor Centre, Ljubljana, 6–10 June 2022

3. 15th International Symposium on the Interaction between Sediments and Water (IASWS), Piran, 13–15 June 2023

4. National workshop within the Danube Hazard m3C Project, JSI Reactor Centre, Ljubljana, 21–22 June 2022

5. FishEUTrust kick-off meeting, JSI Reactor Centre, Ljubljana, 12–13 September 2022

6. Week of Microbial Technologies, JSI Reactor Centre, Ljubljana, 7–11 November 2022

Patent granted

1. Alenka Vesel, Nives Ogrinc, Method for functionalization of polyolefins with simultaneous combination of nitrogen and oxygen functional groups, SI26091 (A), Slovenian Intellectual Property Office, 29. 04. 2022.

INTERNATIONAL PROJECTS

1. Supporting Research Activities in Environmental Sciences/Organic Analysis
   Prof. Ester Heath
   Sherwin-williams Company

2. 8th International k0-NAA Users Workshop; Ljubljana, Slovenia, 06 - 10 June 2022
   Prof. Radojko Jaćimović
   IAEA - International Atomic Energy Agency

3. EMPIR - EDC-WFD; Metrology for Monitoring Endocrine Disrupting Compounds Under the Water Framework Directive
   Prof. Ester Heath
   Euramet E.v.

4. LIFE18 ENV/SI; LIFE HIDAQUA
   Prof. Radmila Milačič
   European Commission

5. EMPIR; STELLAR; Stable Isotope Metrology to enable Climate Action and Regulation
   Prof. Nives Ogrinc
   Euramet E.v.

6. EMPIR; Si-Hg; Metrology for Traceable Protocols for Elemental and Oxidised Mercury Concentrations
   Prof. Milena Horvat
   Euramet E.v.

7. EMPIR - Food-MetNet; Support for a European Metrology Network on Food Safety
   Prof. Nives Ogrinc
   Euramet E.v.

8. EMPIR - MetroCycleEU; Metrology for the Recycling of Technology Critical Elements to support Europe's Circular Economy Agenda
   Prof. Radojko Jaćimović
   Euramet E.v.

9. Use of Isotope Techniques for the Evaluation of Water Sources for Domestic Supply in Urban Areas; Multi-isotope characterization of water resources for domestic supply in Ljubljana, Slovenia
   Dr. Polona Vreča
   IAEA - International Atomic Energy Agency

10. Authenticity of High-Quality Slovenian Food Products Using Advanced Analytical Techniques; Implementation of Nuclear Techniques for Authentication of Foods with High-Value Labelling Claims (INTACT Food) (D52042)
    Prof. Nives Ogrinc
    IAEA - International Atomic Energy Agency

11. Isotope Variability of Rain for Assessing Climate Change Impacts; Trends in Isotopic Composition of Precipitation in Slovenia under Climate Change
    Prof. Sonja Lojen
    IAEA - International Atomic Energy Agency

12. TC Regional Project RER/7/014: Improving Environmental Monitoring and Assessment for Radiation Protection in the Region

Asst. Prof. Marko Štrok
IAEA - International Atomic Energy Agency

13. Training Fees for Hosting Ms. Kasiet Salymbekova, 02.03.2020 - 31.12.2020, ICTP/IAEA
STEP Programme
Prof. Milena Horvat
ICTP - Centro Internazionale di Fisica Teorica

14. COST CA19120 - WATSON; WATer isotopeS in the critical zONe: from groundwater
recharge to plant transpiration
Dr. Polona Vreča
Cost Association Aisbl

15. COST CA19123 - PHOENIX; Protection, Resilience, Rehabilitation of Damaged
Environment
Prof. Aleš Lapanje
Cost Association Aisbl

16. Training Fees for Hosting Ms. Nurgul Nursapino, Kazakhstan, ICTP/IAEA STEP
Programme
Asst. Prof. Marko Štrok
Ictp - Centro Internazionale Di Fisica Teorica

17. H2020 - ERA-PLANET; The European Network for Observing Our Changing Planet
Prof. Milena Horvat
European Commission

18. H2020 - HBM4EU; European Human Biomonitoring Initiative
Prof. Milena Horvat
European Commission

19. H2020 - NEUROSOME; Exploring the Neurological Exposome
Prof. Milena Horvat
European Commission

20. H2020 - CitieS-Health; Citizen Science for Urban Environment and Health
Dr. David Kocman
European Commission

21. H2020 - HERA; Integrating Environment and Health Research: A Vision for the EU
Prof. Milena Horvat
European Commission

22. H2020 - GREENER; InteGRated systems for Effective ENvironmEntal Remediation
Prof. Aleš Lapanje
European Commission

23. H2020 - EURAD; European Joint Programme on Radioactive Waste Management
Prof. Milena Horvat
European Commission

24. H2020 - FNS-Cloud; Food Nutrition Security Cloud
Prof. Nives Ogrinc
European Commission

25. H2020 - METROFOOD-PP; METROFOOD-RI Preparatory Phase Project
Prof. Nives Ogrinc
European Commission

26. H2020 - A-CINCH; Augmented Cooperation in Education and Training in Nuclear and
Radiochemistry
Asst. Prof. Marko Štrok
European Commission

27. H2020 - TUNTWIN; TWINING Towards Advanced Analytical Strategies for Capacity
Building and Innovation for the Tunisian Economy: Application to Three Industrial Key
Sectors in Tunisia
Prof. Nives Ogrinc
European Commission

28. H2020 - MERFISH; Health-Benefit Understanding of Mercury-Selenium Interactions
from Fish to Human
Prof. Milena Horvat
European Commission

29. H2020 - URBANOME; Urban Observatory for Multi-participatory Enhancement of
Health and Wellbeing
Prof. Milena Horvat
European Commission

30. H2020 - GMOS-Train; Global Mercury Observation and Training Network in Support to
the Minamata Convention
Prof. Milena Horvat
European Commission

31. H2020 - SurfBio; Innovation Hub for Surface and Colloid Biology Research
Prof. Aleš Lapanje
European Commission

32. H2020 - FoodTraNet; Advanced Research and Training Network in Food Quality, Safety
and Security
Prof. Nives Ogrinc
European Commission

33. H2020 - STROMASS; Rapid 90Sr Determination Using Laser Ablation ICP-QQQ-MS
Asst. Prof. Marko Štrok
European Commission

34. Photochemical Fate and Treatment of Pharmaceutical Contaminants in Drinking Water
Asst. Prof. Tina Kosjek

35. Non-Traditional Isotopes as Novel Tools for Elucidation of Terrestrial Sinks of CO2
Prof. Sonja Lojen

36. OrgPlant - Authentication of Organically Grown Plant Products by Novel Stable Isotope
Approaches
Prof. Nives Ogrinc

37. AlgFer - Lactic acid fermentation to increase microalgae nutritional and
bioactivecomponents
Prof. Nives Ogrinc

38. Graphitic Carbon Nitride Nano-Carrier Loaded with Curcumin for Treatment of Highly
Potent Synergistic Anticancer Treatment
Dr. Raghuraj Singh Chouhan

39. HE - PARC; Partnership for the Assessment of Risks from Chemicals
Prof. Milena Horvat
European Commission

40. HE - AgroServ; Integrated SERvices supporting a sustainable AGROecological transition
Prof. Nives Ogrinc
European Commission

41. HE - INQUIRE; Identification of Chemical and Biological Determinants, Their Sources,
and Strategies to promote Healthier Homes in Europe
Dr. David Kocman
European Commission

42. HE - SECURE; Strengthening the European Chain of sUpply for next generation medical
RadionuclidEs
Asst. Prof. Marko Štrok
European Commission

43. HE - BIOSYSMO; BIOremediation systems exploiting SYnergieS for improved removal
of Mixed pOllutants
Prof. Aleš Lapanje
European Commission

44. HE - PIANOFORTE; European Partnership for Research in Radiation Protection and
Detection of Ionising Radiation: Towards a Safer Use and Improved Protection of the
Environment and Human Health
Asst. Prof. Marko Štrok
European Commission

45. HE - EIRENE PPP; Environmental Exposure Assessment Research Infrastructure
Preparatory Phase Project
Prof. Milena Horvat
European Commission

46. HE - FishEUTrust; European Integration of New Technologies and Social-Economic
Solutions for Increasing Consumer Trust and Engagement in Seafood Products
Prof. Nives Ogrinc
European Commission

47. HE - BPEC-DW; Development of Novel Technology Based on a Hybrid of Bio-Photo-
Electrochemical Detritiation Light-Water for Tritium Separation and Simultaneously
H2 Generation
Asst. Prof. Marko Štrok
European Commission

48. LIFE+: LIFE IP RESTART; Boosting Waste Recycling into Valuable Products by Setting the
Environment for a Circular Economy in Slovenia
Prof. Radmila Milačič
European Commission

49. PRIMA; PROMEDLIFE - Novel food products for the PROmotion of MEDiterranean
LIFEstyle and healthy diet
Prof. Nives Ogrinc
Prima Foundation - Partnership For Research And

50. EMPIR; MetroPOEM - Metrology for the Harmonisation of Measurements of
Environmental Pollutants in Europe
Asst. Prof. Tea Zuliani
Euramet E.v.

51. Training Fees for Five IAEA's Fellows Ms. Ayesha Ali Bakheet Salem Alshouq
(EVT2105657-0010-ARE), Mr. Hamzeh El Jeaid (EVT2105657-0005-LEB), Mr. Salah
Alnajadat (EVT2105657-0001-JOR), Mr. Hussam Khalily
Asst. Prof. Marko Štrok
IAEA - International Atomic Energy Agency

52. Measurements and Reporting on Certified Reference Materials BCR-402 and ERM-BB185
Asst. Prof. Tea Zuliani
European Commission

53. Training Fees for Hosting of IAEA"s Fellow Mr. Serfor-Armah Yaw, Ghana, IAEA TC
Project: GHA0017, Fellowship Code: EVT1703937, from 02 December 2018 to 18
December 2018
Prof. Milena Horvat
IAEA - International Atomic Energy Agency

54. Influence of Application of Mineral Fertilizers on Accumulation Ability of Radionuclides
and Heavy Metals in Root Vegetables
Asst. Prof. Marko Štrok
Al-farabi Kazakh National University

55. Training Fees for Scientific Visits for IAEA"s Fellows Mr. Roberto Meigikos dos Anjos
from Brazil, Mr. Carlos Manuel Alonso Hernandez from Cuba and Mr. Saif Uddin from
Kuwait under SV-INT7019-1704875, from 10 December 2018 to 14 December 2018
Prof. Nives Ogrinc
IAEA - International Atomic Energy Agency

56. Stability Monitoring of CRMs BCR-667 and BCR-670
Prof. Radojko Jaćimović
European Commission

57. Measurements and Reporting on Certified Reference Material BCR-176R
Asst. Prof. Tea Zuliani
European Commission
58. Training Fees for Hosting Ms. Veronika Tursunova, Kyrgyzstan, ICTP/IAEA STEP
Programme, from 01 September 2022 to 30 November 2022
Asst. Prof. Ingrid Falnoga
ICTP - Centro Internazionale di Fisica Teorica

RESEARCH PROGRAMMES

1. Design of novel (nano) material properties & Applications
Dr. Doris Potočnik
2. Modelling and environmental impact assessment of processes and energy technologies
Prof. Borut Smodiš
3. Cycling of substances in the environment, mass balances, modelling of environmental
processes and risk assessment
Prof. Milena Horvat

R&D GRANTS AND CONTRACTS

1. Record of environmental change and human impact in Holocene sediments, Gulf in
Trieste
Prof. Sonja Lojen
2. Novel innovative solutions for diaper rash treatment using diapers with probiotic
bacteria
Prof. Aleš Lapanje
3. Methodology approaches in genome-based deversity and ecological plasticity study of
truffles from their natural distribution
Prof. Nives Ogrinc
4. Lactic acid fermentation for enrichment of microalgae biomass with new nutrients
Prof. Nives Ogrinc
5. Molybdenum geobiochemical Cycle in modern environments
Prof. Sonja Lojen
6. Impact of endocrine disruptors (bisphenols, parabens, triclosan) and potentially
toxic and essential chemical elements on childbirth, infertility and ovarian cancer in
Slovenia
Prof. Milena Horvat
7. Monitoring of the clinical and immune response to improve the outcome of combined
electrochemotherapy and IL-12 gene therapy in dogs with spontaneous peripheral
tumours
Asst. Prof. Tina Kosjek
8. Indentifying the genetic determinants of chemical toxicity in the green alga
Chlamydomonas reinhardtii
Prof. Milena Horvat
9. CRIME – CRemation or Inhumation of ancientpopulations? A Multidisciplinary question
at the European level
Dr. Doris Potočnik
10. The unrevegled information on soil biodiversity in leached waters
Prof. Nives Ogrinc
11. Subglacial carbonate deposits - a new source for studying the presence of glaciers in a
glaciokarstic environment
Prof. Sonja Lojen
12. Algal technologies for green products – ALGreen
Prof. Ester Heath
13. Oaks for future forests and forestry in Slovenia: Quercus robur versus Quercus petraea
Dr. Bor Krajnc
14. Climate changes and ectomycorrhizal fungi - how far can we go with an assisted
migration of truffles?
Dr. Lidija Strojnik
15. Nanofibers for codelivery of selected microbiota cocktails and antimicrobials for local
treatment of vaginal infections
Prof. Nives Ogrinc
16. Preclinical development of new Mitochondrial ion channel inhibitors for Cancer
therapy
Asst. Prof. Tina Kosjek
17. BE MERMAiD - Bioavailable mercury methylation in the Adriatic sea
Prof. Milena Horvat
18. STRAP - Sources, TRansport and fate of persistent Air Pollutants in the environment of
Slovenia
Prof. Nives Ogrinc
19. Novel approaches for the estimation of the use of psychoactive pharmaceuticals and
illicit drugs by wastewater analysis
Prof. Ester Heath
20. Novel proxies of the Holocene climate variability in stalagmites in Slovenia
Prof. Sonja Lojen
21. Cost-efficient separation of tritium from water with bio-based systems – BIOTRISEP
Asst. Prof. Marko Štrok
22. Innovative isotopic techniques for identification of sources and biogeochemical cycling

of mercury in contaminated sites – IsoCont
Prof. Milena Horvat
23. Quality, Safety and Authenticity of INsect PROtein-Based Food and Feed Products
Dr. David John Heath
24. New biofertilization approach based on the microbial multispecies biocatalytic
aggregates
Asst. Prof. Tomaž Rijavec
25. Valorisation of olive oil waste material by microbial multispecies biocatalytic aggregates
Prof. Aleš Lapanje
26. Photocatalytic water treatment - development of immobilized catalysts and compact
reactor systems
Prof. Ester Heath
27. CAEmissionMonitor - Determination of primary carbonaceous aerosol emission rates
and formation rate of secondary organic aerosol
Prof. Janja Vaupotič
28. Authentich high-quality product and sustainable pig production (A-SUS)
Prof. Nives Ogrinc
29. „Uptake": agricultural reuse of wastewater and sewage sludge: uptake and distribution
of contaminants of emerging concern in tomato plant as a model
Prof. Ester Heath
30. Assessment of the potential impact of incineration and co-incineration of waste on
human health effects: a model study on the case of the Salonit Anhovo cement plant
Prof. Milena Horvat
31. EPOS-SI (EPOS-European Plate Observing System)
Prof. Janja Vaupotič
32. METROFOOD
Prof. Nives Ogrinc
33. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/
nutrition
Prof. Nives Ogrinc
Ministry of Education, Science and Sport
34. Circular 4.0: Digital technologies as enabler to foster the transition to the circular
economy bythe SME in the Alpine Space area
Asst. Prof. Davor Kontić
Government Office of the Land of Salzburg
35. Danube Hazard m3: Tackling hazardous substances pollution in Danube River Basin by
Measuring, Modelling-based Mangement and Capacity building
Prof. Radmila Milačič
Ministry of Finance
36. Smart mobility measures for sustainable mobility in Slovenia – SmarMOVE
Asst. Prof. Davor Kontić
Ljubljanski urbanistični zavod
37. Cofinancing of LIFE18 ENV/SI; LIFE HIDAQUA: Sustainable Water Management in High
Water Demanding Industries
Prof. Radmila Milačič
Ministry of the Environment and Spatial Planning
38. Assessment of the potential impact of incineration and co-incineration of waste on
human health effects: a model study on the case of the Salonit Anhovo cement plant
Prof. Milena Horvat
Ministry of Health
39. Ecology laboratory with mobile unit
Dr. Dušan Žigon
Ministry of Defence
40. Measurements of mercury in air and precipitation for 2021 and 2022
Prof. Milena Horvat
Ministry of the Environment and Spatial Planning
41. Analysis of honey
Prof. Nives Ogrinc
Slovenian Beekeepers' Association
42. Environmental radioactivity monitoring of living environment in Republic Slovenia in
2022
Asst. Prof. Marko Štrok
Ministry of the Environment and Spatial Planning
43. Monitoring of radioactivity in drinking water for the year 2022
Asst. Prof. Marko Štrok
Ministry of Health
44. Implementation of the Human Biomonitoring program 2018-2022
Prof. Milena Horvat
Ministry of Health
45. Analyzes of official samples for the content of elements and stable isotopes for the year
2022
Prof. Nives Ogrinc
Ministry of Agriculture, Forestry and Food
46. Services; Determination of the Isotopic Composition of Carbon in Sugar Samples
Prof. Nives Ogrinc
47. Different Analyses
Prof. Sonja Lojen
48. Small Services in the Year 2022
Prof. Milena Horvat
49. Analyses of Metals, TBT and DBT in Sediments, Mussels and Fish
Prof. Janez Ščančar

50. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
Prof. Aleš Lapanje
Helmholtz-Zentrum Dresden-Rossendorf E.V.
51. Monitoring of the Environmental Fingerprint in Graviera Naxou PDO Product for Certification of Authenticity and Geographical Origin - Sr Isotopes and H, O, C, N Stable Isotopes
Asst. Prof. Tea Zuliani
Agricultural Cooperatives Union of
52. Dual (Oxygen and Strontioum) Stable Isotope-Based Wood Provenancing
Asst. Prof. Tea Zuliani
Stefan Cel Mare University of Suceava
53. Radon Mapping and Radon Risk Assessment in Georgia
Prof. Janja Vaupotič
Ivane Javakhishvili Tbilisi State University
54. 8th International k0-NAA Users Workshop; Ljubljana, Slovenia, 06 - 10 June 2022
Prof. Radojko Jaćimović
IAEA - International Atomic Energy Agency
55. Mercury Analysis for Latvian State Forest Institute
Prof. Milena Horvat
Latvian State Forest Research Institute
56. Measurements of TBT Concentrations in Seawater Extracts and Hg Concentrations in Water Samples; Water Analyses of the Northern, Central and Southern Adriatic Sea
Prof. Janez Ščančar
Institut „Ruđer Bošković"

NEW CONTRACTS

1. Qualitative and quantitative monitoring of groundwater in the impact area of the dam for HPP Mokrice
Dr. Tjaša Kanduč
Irgo Consulting d. o. o.
2. Elemental analysis by mass spectrometry for the characterisation of biological drugs
Prof. Janez Ščančar
Lek d. d.
3. LOT 1: Measurements of gaseous effluents - Specific analyzes of H-3 and C-14 in 2022, 2023, 2024 and 2025; LOT 2: Measurements of gaseous effluents - Gamma

spectrometry and analysis of strontium Sr-89/90 in 2022, 2023, 2024 and 2025
Asst. Prof. Marko Štrok
Nuklearna Elektrarna Krško d. o. o.
4. Environmental radioactivity monitoring in the vicinity of the Krško Nuclear Power Plant in connection with Hydro Power Plant Brežice for the years 2022 and 2023
Asst. Prof. Marko Štrok
Nuklearna Elektrarna Krško d. o. o.
5. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Komunala Kranj d. o. o.
6. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
JP CČN Domžale-Kamnik d. o. o.
7. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Komunala d. o. o.
8. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Občina Krško
9. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Komunala Novo Mesto d. o. o.
10. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Komunalno Podjetje Velenje d. o. o.
11. Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in tomato plant
Prof. Ester Heath
Ksd d. o. o.

VISITORS FROM ABROAD

1. Dr Božena Skoko, Institute for Medical Research and Occupational Health, Zagreb, Croatia, 31 January to 11 February 2022
2. Ayesha Al Shouq, FANR, Abu Dhabi, United Arab Emirates, 14 February to 1 April 2022
3. Hamzeh El Jeaid, LAEC, CNRS, Beirut, Lebanon, 14 February to 1 April 2022
4. Hanadi Al Shammari, Kuwait Institute for Scientific Research, Shuwaikh, Kuwait, 14 February to 1 April 2022
5. Nurgul Nursapina, Faculty of Chemistry and Chemical Technology, Al-Farabi Kazakh National University, Almaty, Kazakhstan, 14 February to 29 April 2022
6. Salah Alnajadat, EMRC, Aman, Jordan, 14 February to 1 April 2022
7. Cealan Henry, Ulster University, Belfast, Northern Ireland, 28 March to 1 April 2022
8. Sandra Curiel Alegra, University of Burgos, Burgos, Spain, 1 April to 30 June 2022
9. Maria Beatriz Lapuente de Ojeda, University of Burgos, Burgos, Spain, 1 April to 30 June 2022
10. Nayyer Rehman, WRG Europe, London, Great Britain, 5 April to 28 June 2022
11. Sholpan Nazarkulova, Al-Farabi Kazakh National University, Almaty, Kazakhstan, 14–23 April 2022
12. Tianui Ma, Vrije Universiteit Brussel, Brussels, Belgium, 21 April to 21 July 2022
13. Vincent Perrot, Vrije Universiteit Brussel, Brussels, Belgium, 21 April to 21 July 2022
14. So Fujiyoshi, Hiroshima University, Hiroshima, Japan, 14–21 May 2022
15. Ons Kasraoui, INRAP, Ariana Medina, Tunisia, 29 May to 12 June 2022
16. Ines Ben Amour, INRAP, Ariana Medina, Tunisia, 29 May to 12 June 2022
17. Maria Angela Menezes, CDTN/CNEN, Belo Horizonte, Brazil, 6 June to 1 July 2022
18. Matteo Nigro, University of Pisa, Italy, 21 June to 4 October 2022
19. Veronika Tursunova, Osh State University, Osh, Kirgizistan, 1 September to 14 December 2022
20. Bogdan Parakhonsky, Ghent University, Ghent, Belgium, 13–23 September 2022
21. Kasiet Salymbekova, Centre for Environmental Medicine and Human Ecology of the Scientific and Production Centre for Preventive Medicine of the Ministry of Health of the Kyrgyz Republic, Bishkek, Kirgizistan, 15 September to 14 December 2022
22. dr Davide Vione, University of Turin, Italy, 21–30 September 2022
23. Wided Ben Lazareg ep Chahdura, Institut National de Recherche et d'Analyse Physico-Chimique, Ariana, Tunisia, 25 September to 9 October 2022
24. Samira Bejaoui ep Jelassi, Institut National de Recherche et d'Analyse Physico-Chimique, Ariana, Tunisia, 25 September to 9 October 2022
25. Hayato Uwashitomi, Graduate School of Science and Engineering, Kagoshima University, Kagoshima, Japan, 3–9 October 2022
26. Hitoshi Kodamatani, Graduate School of Science and Engineering, Kagoshima University, Kagoshima, Japan, 3–9 October 2022
27. Taiju Wakimaru, Graduate School of Science and Engineering, Kagoshima University, Kagoshima, Japan, 3–9 October 2022
28. Takashi Tomiyasu, Graduate School of Science and Engineering, Kagoshima University, Kagoshima, Japan, 3–9 October 2022
29. Dominik Andelini, Institute of Agriculture and Tourism, Department of Agriculture and Nutrition, Poreč, Croatia, 14–25 November 2022
30. Danko Cvitan, Institute of Agriculture and Tourism, Department of Agriculture and Nutrition, Poreč, Croatia, 14–25 November 2022
31. Lucija Knežević, Dora Crmarić, Institut Ruđer Bošković, Martinska, Croatia, 5–9 December 2022

STAFF

Researchers
1. *Prof. Ljudmila Benedik, retired 01.10.22*
2. Dr. Raghuraj Singh Chouhan
3. Asst. Prof. Ingrid Falnoga
4. Dr. David John Heath
5. Prof. Ester Heath
6. **Prof. Milena Horvat, Head**
7. Prof. Radojko Jaćimović
8. Dr. Tjaša Kanduč
9. Dr. Norbert Kavasi
10. Dr. David Kocman
11. Asst. Prof. Davor Kontić
12. Asst. Prof. Tina Kosjek
13. Asst. Prof. Jože Kotnik
14. Prof. Aleš Lapanje
15. Prof. Sonja Lojen
16. Dr. Darja Mazej
17. Prof. Radmila Milačič

18. Prof. Nives Ogrinc
19. Asst. Prof. Tomaž Rijavec
20. Prof. Borut Smodiš
21. Prof. Janez Ščančar
22. Asst. Prof. Zdenka Šlejkovec
23. Asst. Prof. Marko Štrok
24. Prof. Janja Vaupotič
25. Dr. Janja Vidmar
26. Dr. Polona Vreča
27. Asst. Prof. Tea Zuliani
28. Dr. Dušan Žigon

Postdoctoral associates
29. Dr. Ermira Begu
30. *Dr. Jan Gačnik, on leave since 15.11.22*
31. Dr. Marta Jagodic Hudobivnik
32. *Dr. Ana Kovačič, on leave since 01.11.22*
33. Dr. Bor Krajnc
34. Dr. Katarina Marković
35. Dr. Stefan Marković
36. Dr. Doris Potočnik
37. Dr. Leja Rovan
38. Dr. Agneta Annika Runkel
39. Janja Snoj Tratnik, B. Sc.
40. *Dr. Anja Stajnko, on leave since 01.09.22*
41. Dr. Lidija Strojnik
42. Dr. Žiga Tkalec
43. Dr. Igor Živković

Postgraduates
44. Saeed Waqar Ali, M. Sc.
45. Eirini Andreasidou, M. Sc.
46. Teodor-Daniel Andron, M. Sc.
47. Katja Babič, B. Sc.
48. *Tine Bizjak, M. Sc., left 01.04.22*
49. Dominik Božič, B. Sc.
50. Tjaša Goltnik, B. Sc.
51. Pia Leban, B. Sc.
52. Jasmina Masten Rutar, B. Sc.
53. Rok Novak, B. Sc.
54. Neža Palir, B. Sc.
55. Brina Pavlovič, B. Sc.
56. Žan Rekar, B. Sc.
57. Cathrine Terro, M. Sc.
58. Anja Vehar, B. Sc.
59. Taja Verovšek, B. Sc.
60. Sreekanth Vijayakumaran Nair, M. Sc.
61. Maja Zugan, B. Sc.
62. Klara Žagar, B. Sc.

Technical officers
63. Jure Ftičar, B. Sc.
64. Polona Klemenčič, B. Sc.
65. Karolina Trentelj, B. Sc.
66. Vanja Usenik, B. Sc.
67. Tina Vrabec, B. Sc.

Technical and administrative staff
68. Barbara Svetek, B. Sc.
69. Stojan Žigon

DEPARTMENT OF AUTOMATION, BIOCYBERNETICS AND ROBOTICS   E-1

The research strategy within our department (http://abr.ijs.si/) combines the fields of robotics (including robot learning, intelligent control, humanoids, cognitive robotics and robot vision), industrial robotics and automation, factories of the future, biomechanics, biocybernetics, ergonomics and environmental physiology. The common theme of our research endeavours to date has been optimizing the behaviour of man and machine, accounting for the interactions with the environment. An additional synergy is provided by the research topic human-robot collaboration. Our research strategy supports a variety of multi- and interdisciplinary research projects. By combining engineering and life sciences, we have been able to make breakthrough contributions in robot learning based on imitation and deep neural networks, development of a planetary habitat simulation facility, reconfigurable robotic workcells, humanoid robotic systems, exoskeletons, manikins enabling the evaluation of protective garments for industry and recreation, and new strategies for physical human-robot interaction.

Head:

Prof. Aleš Ude

The department maintains the programme group Automation, robotics and biocybernetics (led by prof. dr Igor B. Mekjavic). Members of the department participate in numerous EU projects in the area of robotics and artificial intelligence, factories of the future, health and space technologies. For example, in collaboration with the European Space Agency we launched a new programme Long-Term Hypoxic Bed Rest with Resistance Vibration Exercise. In 2022 we also coordinated the Horizon 2020 project ReconCycle, developing new reconfigurable and adaptive robotic systems in the domain of recycling. We are also continually active in transferring our research results to applications through direct collaborations with industry.

Research in the area of humanoid robotics and robot learning is primarily conducted within the Humanoid and Cognitive Robotics Lab (led by prof. dr Bojan Nemec), which operates within the department. The aim of this laboratory is to create robots that can acquire new knowledge through continuous learning and collaborate with people in their natural environments. Another laboratory that operates within the department is the Laboratory for Neuromechanics and Biorobotics, led by prof. dr Jan Babič. The main focus of this lab is to integrate the results of biomechanics, neurophysiology and robotics to study human the motor control and develop new robot systems that can effectively assist people with their daily activities.

> **By maintaining a critical mass of researchers in the areas of robotics, automation and life sciences within one department, we have managed to foster exciting multidisciplinary projects.**

During the past year, our research focused on the development of reconfigurable robotic systems for factories of the future, automation of production processes in manufacturing, new robot-learning methodologies primarily based on kinesthetic teaching, reinforcement learning and deep learning, human-robot collaboration, development of new control methods for robotic assistive devices such as exoskeletons, studies of human physiology in extreme environments, evaluation of protective equipment as well as development of biomedical methods.

Robotics

In 2022 we were coordinating the Horizon 2020 project **ReconCycle** (Self-reconfiguration of a robotic workcell for the recycling of electronic waste, http://www.reconcycle.eu/). The main aim of the project is to introduce **self-reconfigurable hardware and software for the disassembly of electronic devices**, based on a reconfigurable robotic cell developed within the ReconCell project, http://www.reconcell.eu/, which was also coordinated by our group. The challenge of this project is to provide methodologies for a re-design of the recycling cell including the location of robots and other elements in the workcell and the choice of grippers and sensing systems. On the software side, approaches to the **fast re-programming**

Figure 1: Reconfigurable cell for a disassembly of heat cost allocators

and adaptation of manipulation actions for soft robots and grippers suitable for recycling tasks need to be provided. Soft components make grasping and compliant control easier, but they can be problematic with regard to assembly tasks that usually rely on high-precision position control. However, high precision is less important for disassembly operations that are typical for the domain of recycling of electronic devices where physical constraints guide compliant robot movements to successfully accomplish the desired task.

In 2022 we successfully completed the H2020 project **CoLLaboratE** (Enabling genuine human-robot collaboration for performing assembly tasks in a co-production cell, https://collaborate-project.eu). The main objective of this project was to **revolutionize the way industrial robots learn to collaborate with human workers** when performing assembly tasks within a co-production cell. Within the project we developed and experimentally verified a collaborative cell for a car starter assembly where we demonstrated our scientific and technological advancements. Throughout the project, we achieved several significant milestones. One of our key contributions was the development of a framework for **human intention recognition**, enabling the robot to understand and respond to the intentions of a human worker. We also devised a novel approach to **incremental policy learning**, which utilized bidirectional dynamic-motion primitives to facilitate a robot's learning process. Additionally, we established a framework for **incremental collaborative learning of exception strategies**, allowing the robot to adapt and respond effectively to unforeseen circumstances during the assembly process.

> **In the H2020 project ReconCycle coordinated by our department we aim at substantially increasing the degree of automation in recycling by introducing new robot-learning technologies.**

In the area of humanoid robotics we conducted several studies focusing on **humanoid-robot sensorimotor-skill learning** where we exploit the mobility of a humanoid robot while taking into account its stability. We demonstrated that programming by demonstration, which is suitable for humanoid robots due to their similarities to humans, can be supplemented by reinforcement learning to improve the newly acquired mobile skills. The advantage of our approach is that it can be used effectively in situations where no accurate models of robot and/or task dynamics are available.

Figure 2: Stewart platform for the design of reconfigurable robotic cells

In 2022 we launched a new ARRS project called Robot Textile and Fabric Inspection and Manipulation (https://abr.ijs.si/rtfm/). Within this project we aim to apply novel, advanced deep-learning and sim-to-real transfer learning methods onto a real-world problem of **textile and fabric manipulation and inspection**. We will advance the state of the art of perception/inspection and robotic manipulation of textile and fabric, in order to bridge the technological gap and enable automation of such material handling. The outcomes of this project will serve as the foundation for future implementations in manufacturing companies that deal with the production and logistics of textile and fabric items.

In the field of machine learning we investigated how to **implement curriculum learning** to speed up knowledge acquisition by proposing the sequences of tasks an agent should train on. To do so, we introduced **surprise, novelty, interestingness and typicality** that quantify various aspects of the tasks stochastically proposed by the curriculum learning algorithms for the learner to train on. We modelled the proposed tasks with Gaussian mixture models, which enable their probabilistic interpretation, and used Hellinger distances between the distributions and training rewards in the formulation of the proposed metrics. Results showed differences in the prioritization of various aspects of the task creation and statistically different mean metric values when comparing the agent's best and poorest training performances.

In the field of exoskeleton robotics, we finalized the study of using arm exoskeletons for overhead work in an industrial setting. We developed a **probabilistic estimation algorithm to analyse the effect of using an exoskeleton** at the whole-body level. Results demonstrated that an exoskeleton provides support to the human shoulders by reducing the joint effort of the targeted limbs, and that part of the internal wrenches are intuitively transferred from the upper body to the thighs and legs, which is shown with an increment in the torques at the leg joints. The promising outcomes show that the probabilistic estimation algorithm can be used as a validation metric to quantitatively assess exoskeleton performance, paving the way for the next challenging milestone, such as the optimization of the human joint torques via adaptive exoskeleton control.

> **We developed an exoskeleton that provides support to the human shoulders by reducing the joint effort of the targeted limbs.**

We also continued our research in the field of physical human-robot interaction where we address the hypothesis that the **human central nervous system** integrates an internal model with sensory feedback in order to generate accurate movements when in contact with the environment. However, how the brain understands external force through explorative movements, or how humans accurately estimate a force from their experience of the force, is yet to be fully understood. To address these questions, we tested human behaviour in different stiffness profiles even though the force at the goal was the same. The results

of our study showed that stiffness profiles of the environment had an effect on the rate of learning and that the human estimation of a position was accurate irrespectively of the environment. These results have an important impact on **the way we program robots that operate with humans in physical interactions**.

In 2022 the Cobotat group, led by prof. Tadej Petrič, continued its work on the **SWITCH** bilateral project (Learning by Switching Roles in Physical Human-Robot Collaboration, accessible at https://switch-project. github.io/), conducted in collaboration with the research institute Idiap from Switzerland. The primary focus of the project during 2022 was the development of a novel control approach to humanoid robots, incorporating human-like learning mechanisms. Extensive laboratory experiments were conducted to investigate the **physical interaction between humans and humanoid robots**, specifically in the context of a **standing-up task**.

Figure 3: Skill learning of humanoid robot Talos

Utilizing the acquired data, we developed models to describe the behaviour of both the assisting agent and the individual receiving assistance. These models were subsequently employed in the creation of control systems for humanoid robots, exhibiting predictive behaviour. Furthermore, the gathered data played a pivotal role in advancing the development of a new quasi-passive mechanism, which was successfully submitted for patent registration at the Slovenian Patent Office. Integration of this mechanism into a knee exoskeleton was accomplished, followed by an evaluation of its practical application.

In 2022 we were granted the project **BodyCoM** (Rethinking dynamic whole-body multicontact interaction: Towards next generation of collaborative robots). The primary objective of BodyCoM is to **enhance the**

We investigated physical interactions between humans and humanoid robots and used the results to develop predictive control systems for humanoid robots.

manipulation accuracy by leveraging physical interaction with the robot structure, such as utilizing environmental support for the elbows. Within this project, we already devised a new method for calibrating collaborative robots. Our innovative methods for humanoid robot control and exploitation of physical interaction will contribute to the advancements in human-robot collaboration, ushering in new possibilities for precision manipulation and seamless cooperation between humans and robots in the future.

The main objective of the **TRINITY** project (https://trinityrobotics.eu/), another Horizon 2020 project at our department, is to create a network of multidisciplinary and synergistic local digital innovation hubs (DIHs) composed of research centers, companies and university groups, covering a wide range of topics that can contribute to agile production: advanced robotics as the driving force and digital tools, data privacy and cyber security technologies to support the introduction of advanced robotic systems in the production processes. In 2022 we focused on the experimental validation of demonstrators that show the **industrial potential of programming by demonstration** for the specification of contact skills and **passive reconfiguration** using a fixturing system built from Stewart platforms. The modules from our demonstrators have already been made available to the manufacturing companies.

Automation and robotics in industrial and other applications

In the H2020 project **QU4LITY** (https://qu4lity-project.eu) we aimed to demonstrate, in a realistic, measurable and replicable way an open, certifiable and highly standardised, SME-friendly and transformative shared data-driven ZDM (zero-defect manufacturing) product and service model for Factory 4.0. In 2022 we finalized our work on the robot-aided adaptive visual quality control of automotive parts. In collaboration with Kolektor, a Slovenian company, we developed a full end-to-end quality inspection pipeline. The system is based on deep-learning methodologies that use process parameters in order to predict if there is a potential defect in a product and also the most probable location of the defect. By excluding the defects that are not likely to happen and checking products only from the critical viewpoints, we avoid creating bottlenecks in a production line while bringing the process closer to the desired ZDM policy.

Within the EIT Manufacturing project **Smart Flex Cell**, we developed, implemented and tested a reconfigurable, affordable and simple-to-use robotic cell to be used by small and medium enterprises (SMEs). One of the key components of the newly developed cell is a new version of the passive reconfigurable fixturing system based on Stewart platforms. It is equipped with position sensors in each leg to better control production parameters during operation. The ability to use robots for the small-batch production of highly personalized products with a high added
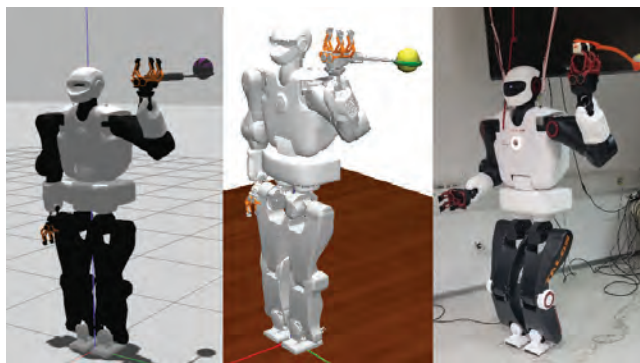
Figure 4: Humanoid robot maintaining its stability while generating an assistive behaviour

value is a big advantage. The project generated two successful reconfigurable robotic solutions: one for robotic spot welding and one for robotic machining.

In the scope of the **Stellaverde** project (https://kons-platforma.org/en/projekti/stellaverde/), we developed an autonomous spider robot designed for vertical gardening. With its agile multi-legged design, the robot can effortlessly navigate vertical surfaces, allowing it to tend to plants in urban environments where space is limited. This innovative robot has a high impact on modern urban agriculture by enabling efficient and sustainable vertical gardens and promoting a greener, more self-sufficient future.

Within the EIT Manufacturing project Smart Flex Cell we developed and evaluated a new reconfigurable, affordable and simple-to-use robotic cell.

Figure 5: Lower limb exoskeleton

In September 2022 we launched a new four-year programme "Long-term hypoxic bed rest with resistance vibration exercise" supported by the European Space Agency.

Figure 6: Robotic cell for visual quality inspection

In the past years, our department was working towards the implementation of **smart specialization strategy S4** and recently also **S5**. As part of the Strategic Research and Innovation Partnership of the Factory of the Future (SRIP FoF), we **chaired** the SRIP FoF Board of Directors, **coordinated** the SRIP FoF horizontal network "Robotics", thus providing support for the introduction of advanced robotic technologies into the factories of the future, being developed by the Slovenian industry. In 2022 SRIP FoF continued with the implementation of a new program to foster the cooperation of manufacturing companies with the research departments in academia and transfer the latest robotics research results into industrial practice.

Environmental physiology and ergonomics

Life science research in our department focuses on the physiology and pathophysiology of humans in extreme environments. We contribute to the development of new strategies and equipment to mitigate the effects of environmental factors on human health and well-being, and to enhance the safety and productivity of workers in industrial, military and space environments.

Gravitational physiology: The Jožef Stefan Institute maintains the European Space Agency ground-base research facility »Planetary Habitat Simulation« (PlanHab) in Planica (Rateče, Slovenia). The current focus of the PlanHab team is the development of an exercise countermeasure that would mitigate the effects of weightlessness on physiological systems, specifically the musculoskeletal and cardiovascular systems. Within the framework of the ESA BRAVE project we are assessing the efficacy of resistance vibration exercise combined with artificial gravity as a potential countermeasure for preventing a loss of muscle and bone mass, and cardiovascular deconditioning during missions to Mars.

The ability to conduct resistance exercise at elevated head-to-foot gravitational load on the short arm human centrifuge, as being considered for future space missions, is dependent on the appropriate perfusion of active muscles for oxygen delivery and elimination of metabolic by-products, and of the skin for the necessary dissipation of generated heat within the skeletal muscle. The regulation of vasomotor activity in peripheral vascular beds is regulated by physiological systems regulating the body temperature and arterial pressure. The manner in which these two physiological systems interact in the regulation of peripheral vasomotor tone in the presence of elevated head-to-foot gravitational load in thermoneutral and hot, hypoxic and normoxic conditions is the focus of the ESA-INTREPID project.

Protective clothing: Within the framework of the ReMOS (Regulation of the microenvironment of clothing systems) project, supported by the Slovenian Ministry of Defence, we collaborated with industrial partner Prevent-Deloza d.o.o. in developing a ventilated vest that enhances evaporative heat loss from the torso and mitigates heat strain during activities in hot environments. The ventilated vest has embedded sensors and processors to provide automatic regulation of the microenvironment within the cooling vest. The ventilated vest was evaluated under simulated hot conditions in a climatic chamber, and during simulated field operational activities of the Slovenian Armed Forces. With industrial partner Proalp d.o.o. we developed hiking boots with embedded sensors that register impending cold injury based on the temperature of the toe region.

Global warming: Summer heat waves are becoming more frequent, greater in intensity and longer in duration. One of our tasks within the Ministry of Defence ReMOS project was the development of a software application that would provide support in the preparation for missions in extreme environmental conditions. The software application takes into consideration the clothing worn, together with the user's (soldier's) anthropometry and anticipated activity, and the prevailing or anticipated environmental conditions, to provide suggestions for optimal protective clothing ensembles for the entered environmental conditions. This software application has now been modified for civilian use (Heat Health) to alert users of a potential heat strain. The application has been tested successfully in Europe (Slovenia, Greece, Denmark, the UK), Asia Pacific (Japan, New Zealand), Africa (Gamibia) and North America (Canada).

Individual variability: It is well appreciated that there is a great deal of individual variability in the responses of astronauts to microgravity. This is also evidenced in the magnitude of the loss of muscle and bone mass, and of cardiovascular deconditioning during space analogues such as bed rest and dry immersions. Under contract with the European Space Agency, we continue to explore the possibility of determining individual variability in the responses of physiological systems to inactivity.

Figure 7: Autonomous spider robot designed for vertical gardening

Some outstanding publications in the past year

1. L. Žlajpah, T. Petrič (2022), Kinematic calibration for collaborative robots on a mobile platform using motion capture system. Robotics and Computer-Integrated Manufacturing, vol. 79, pp. 102446-1–102446-15.
2. L. Mišković, M. Dežman, T. Petrič (2022), Pneumatic quasi-passive variable stiffness mechanism for energy storage applications. IEEE Robotics and Automation Letters, vol. 7, no. 2, pp. 1705–1712.
3. M. Dežman, T. Asfour, A. Ude, A. Gams (2022), Mechanical design and friction modelling of a cable-driven upper-limb exoskeleton. Mechanism and Machine Theory, vol. 171, pp. 104746-1–104746-16.
4. D. Gorjan, N. Šarabon, J. Babič (2022), Inter-individual variability in postural control during external center of mass stabilization. Frontiers in Physiology, vol. 12, pp. 722732-1–722732-7.
5. J. T. Fisher, U. Ciuha, L. G. Ioannou, L. Simpson, C. Possnig, J. Lawley, I. B. Mekjavić (2022), Cardiovascular responses to orthostasis during a simulated 3-day heatwave. Scientific Reports, vol. 12, pp. 19998-1–19998-12.
6. J. T. Royal, J. T. Fisher, T. Mlinar, I. B. Mekjavić, A. Mcdonnell (2022), Validity and reliability of capillary vs. venous blood for the assessment of haemoglobin mass and intravascular volumes. Frontiers in Physiology, vol. 13, pp. 1021588-1–1021588-13.

Organization of conferences, congresses and meetings
1. H2020 ReconCycle meeting, 24–25 May 2022 (virtual)

Awards and Appointments
1. Peter Nimac: Prešeren Award for students, Ljubljana, Faculty of Electrical Engineering, University of Ljubljana, Design and implementation of a smart traffic light radar

INTERNATIONAL PROJECTS

1. FlexHex Patent „Cardon Joint"
   Asst. Prof. Igor Kovač
   Flex Hex Aps
2. COST CA16116 - 20786; Wearable Robots for Augmentation, Assistance or Substitution of Human Motor Functions
   Prof. Jan Babič
   Cost Office
3. ESA - Individual Variation in Human Response to prolonged Bed Rest in Slovenia Bed Rest Programme
   Prof. Igor Mekjavić
   Esa/estec.
4. H2020 - CoLLaboratE: Co-production CeLL performing Human-RobotCollaborative AssEmbly
   Prof. Bojan Nemec
   European Commission
5. H2020 - TRINITY; Digital Technologies, Advanced Robotics and increased Cyber-Security for Agile Production in Future European Manufacturing
   Prof. Aleš Ude
   European Commission
6. H2020 - QU4LITY; Digital Reality in Zero Defect Manufacturing
   Prof. Aleš Ude
   European Commission
7. H2020 - ReconCycle; Self-reconfiguration of a Robotic Workcell for the Recycling of Electronic Waste
   Prof. Aleš Ude
   European Commission
8. The Interaction of Regional Thermal and Baroreflex Regulation of the Peripheral Circulation

Prof. Igor Mekjavić
Slovenian Research Agency

9. Generation and Learning of Adaptive Cyclic Movements in Assist-As-Needed Applications for Human-Robot Interaction
Prof. Tadej Petrič
Slovenian Research Agency

10. Effects of robotically induced local gravity rendering on human motor control in various environmental gravities
Prof. Jan Babič
Slovenian Research Agency

11. Expanding Model Predictive Control of Humanoid Robots with Pre-Learned Dynamics
Prof. Andrej Gams
Slovenian Research Agency

12. Ergonomic Human-Robot Interaction Through Machine Learning Optimization
Prof. Jan Babič
Slovenian Research Agency

13. HE - EUROfusion; WP17: RM_HE-FU
Prof. Aleš Ude
European Commission

14. HE - euROBIN; European ROBotics and AI Network
Prof. Aleš Ude
European Commission

15. EIT M - Smart Flex Cell; Smart Reconfigurable Manufacturing Cell
Asst. Prof. Igor Kovač
Eit Manufacturing

16. Optimising Athletic Performance in the Environmental Heat Stress Conditions of the Paris 2024 Olympic Games
Dr. Urša Ciuha
Sveriges Olympiska Kommitté

17. ESA - INTREPID; -Interaction of Human Temperature and Blood Pressure Regulation in the Responses of Regional Peripheral Perfusion During Exposure to Artificial Gravity on the Short Arm Human Centrifuge
Prof. Igor Mekjavić
Esa/estec

18. ESA - BRAVE; Bed Rest, Artificial Gravity, Vibration, Exercise
Prof. Igor Mekjavić
Esa/estec.

RESEARCH PROGRAMME

1. Avtomation, robotics and biocybernetics
Prof. Igor Mekjavić
Slovenian Research Agency

R&D GRANTS AND CONTRACTS

1. Mechanisms of hypoxia (in)tolerance in prematurely born individuals
Prof. Tadej Debevec

2. Intermittent exogenous ketosis: a novel strategy to improve hypoxic tolerance and adaptation
Prof. Tadej Debevec

3. Adaptation and sensorimotor processing during increased gravity gradients
Dr. Adam Mcdonnell

4. The effect of hypercapnic exercise on intracranial pressure and the eye
Prof. Igor Mekjavić

5. Learning by Switching Roles in Physical Human-Robot Collaboration (SWITCH)
Prof. Tadej Petrič

6. The use of Resistive Vibration Exercise (RVE) to mitigate hypoxic inactivity induced cartilage degeneration: implications for Covid-19 patients
Dr. Adam Mcdonnell

7. Rethinking Dynamic Whole-body Multicontact Interaction: Towards Next Generation of Collaborative Robots
Prof. Tadej Petrič

8. Robot Textile and Fabric Inspection and Manipulation (RTFM)
Prof. Andrej Gams

9. Body asymmetries as a risk factor in musculoskeletal injury development: studying etiological mechanisms and designing corrective interventions for primary and tertiary prevenitve care
Prof. Jan Babič

10. Ecology laboratory with mobile unit
Dr. Tilen Brecelj
Ministry of Defence

11. Microclimate regulation in the clothing systems
Prof. Igor Mekjavić
Ministry of Defence

12. Keep on moving
Prof. Jan Babič
Univerza na Primorskem

13. Stimulators for Foreign Customers
Prof. Aleš Ude

14. Customer Service – Abroad
Prof. Aleš Ude

15. Mitten Testing
Prof. Igor Mekjavić
Ministry Of Defence

NEW CONTRACT

1. Green-blue wall
Prof. Jan Babič
Arelt, Gregor Krpič s.p.

VISITORS FROM ABROAD

1. Wout Lauriks, Leuven University, Belgium, 15 February to 15 May 2022
2. Gregoire Millet, University of Lausanne, Switzerland, 22–27 February 2022
3. Giorgio Manferdelli, University of Lausanne, Switzerland, 22–27 February 2022
4. Atae Jafari Tabrizi, Polymer Competence Center Leoben GmbH, Germany, 2 May to 30 June 2022
5. Sebastian Ruiz, University of Göttingen, Germany, 1–14 August 2022
6. Rafael José Escarabajal Sánchez, Technical University of Valencia, Spain, 1 September to 30 November 2022
7. Elena Paris Quijada, University of Twente, Netherlands, 14 October to 24 December 2022
8. Elmar Rückert, University of Leoben, Austria, 22 December 2022

STAFF

Researchers
1. Prof. Jan Babič
2. Dr. Urša Ciuha
3. Prof. Tadej Debevec*
4. Prof. Andrej Gams
5. Prof. Polonca Jaki Mekjavić*
6. Asst. Prof. Igor Kovač
7. *Prof. Jadran Lenarčič, retired 04.01.22*
8. Dr. Adam Mc Donnell
9. Prof. Igor Mekjavić
10. Prof. Bojan Nemec
11. Asst. Prof. Tadej Petrič
12. Dr. Anton Ružić
13. Prof. Blaž Stres*
14. **Prof. Aleš Ude, Head**
15. Asst. Prof. Leon Žlajpah

Postdoctoral associates
16. *Dr. Edwin Johnatan Avila Mireles, left 01.06.22*
17. Dr. Tilen Brecelj
18. Dr. Jernej Čamernik
19. Dr. Miha Deniša
20. *Dr. Miha Dežman, on leave since 01.05.21*
21. Dr. Leonidas Ioannou
22. Dr. Rok Pahič*
23. Dr. Lydia Tsoutsoumpi

Postgraduates
24. Victorien Olivier Faivre-Rampant, M. Sc.
25. Benjamin Fele, B. Sc.
26. Jason Thomas Fisher, M. Sc.
27. Dr. Marko Jamšek
28. Tjaša Kunavar, B. Sc.
29. Boris Kuster, B. Sc.

30. Zvezdan Lončarević, B. Sc.
31. Matija Mavsar, B. Sc.
32. Luka Mišković, M. Sc.
33. Tinkara Mlinar, M. Sc.
34. Benjamin Jonathan Narang, M. Sc.
35. Peter Nimac, B. Sc.
36. Joshua Toby Royal, B. Sc.
37. Kristina Savevska, B. Sc.
38. Mihael Simonič, M. Sc.
39. Riccardo Sorrentino, M. Sc.
40. **Technical officers**
41. Martin Bem, B. Sc.
42. Jack Patrick Fortune, B. Sc.

43. Niko Kroflič, B. Sc.
44. *Rebeka Kropivšek Leskovar, B. Sc., left 16.08.22*
45. Matevž Majcen Hrovat, B. Sc.
46. *Primož Radanovič, B. Sc., left 16.04.22*
47. Simon Reberšek, B. Sc.
48. Bogomir Vrhovec, B. Sc.
49. Andrej Zadnik, B. Sc.
Technical and administrative staff
50. Tanja Dragojević, B. Sc.
51. Petra Movh, B. Sc.

Note:

* part-time JSI member

DEPARTMENT OF SYSTEMS AND CONTROL

E-2

The Department of Systems and Control is engaged in the analysis, control and optimization of systems and processes. The activities are focused on the research of new methods and algorithms for automatic control, the development of procedures and tools for supporting the design of control systems, the development of specific measurement and control modules, and the development and construction of complete systems for the control and supervision of machines, devices and industrial processes.

Head:
Asst. Prof. Gregor Dolanc

Research and projects in 2022 were devoted to the following sub-areas: modelling of complex dynamic systems, advanced control methods, prognostics and diagnostics and tools and building blocks for control system implementation. With these methodologies, we addressed open problems in the fields of industrial production, energy, ecology, medicine, and social and economic sciences.

In the field of **modelling of complex dynamic systems**, our research focused on the simulation of approximated autoregressive models and modelling of air pollution above complex terrains using methods of decision trees and Gaussian-process models.

For the project *Sources, transport and fate of persistent air pollutants in the environment of Slovenia*, a model was developed based on computational-intelligence modelling methods for the identification of surrogate models for air pollutants, in particular sulphur dioxide dispersion modelling. We evaluated three different identification methods that were used for developing surrogate models.

For the Slovenian Research Agency project *Modelling the dynamics of short-term exposure to radiation*, a model was developed using ensembles of decision trees for the identification of surrogate models useful for forecasting short-term exposure to radiation. In modelling, we placed particular emphasis on the computational burden of the modelling method and the prediction of the exposure to radiation in the region around the Krško Nuclear Power Plant.

In the frame of **advanced control methods**, we were researching the feasibility and limitations of using nuclear energy as a dispatchable electrical power source for covering the daily fluctuations in the energy produced from photovoltaic panels. In particular, we were investigating the prospect of electrical energy production in Slovenia until 2050, focussing on the projected rapid increase in the solar energy production and the implied large-scale annual and daily fluctuations. We presented a simulation study based on a nonlinear pressurised water reactor (PWR) model with 2-point neutron kinetics controlled by two groups of control rods using a new simplified control approach.

In the thematic area of **prognostics and health management**, the research focused on robust diagnostic techniques capable to cope with uncertain system dynamics, system disturbances and variable operating conditions. A novel framework applicable to fuel cells and electrolyser systems was devised by combining (i) the passive feature extraction from conventional signals and lumped models of a stack and system and (ii) an active approach that utilizes additional perturbation to obtain the complete fingerprint of the stack dynamics (electrochemical impedance spectra, EIS). EIS spectra are further deconvoluted using equivalent circuit models (ECMs). To compensate for the influence of variable operating conditions on EIS spectra, a Gaussian process model is adopted to evaluate the ECM parameters as the functions of the operating current and temperature.

In the field of **specific measurement and control modules**, we developed an electronic system for a non-invasive analysis of electrochemical systems, which is based on the electrochemical impedance spectroscopy technique developed by our group. The system is used in several laboratories (TU Graz, CEA, in the near future also in EPFL and VTT) for an automated analysis of fuel cells, electrolysers and
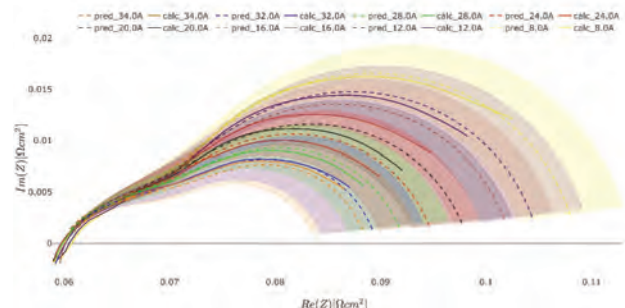
Figure 1: Condition monitoring and prediction for electrochemical systems: True (solid lines) and predicted (dashed lines) Nyquist curves for different current levels with uncertainty regions

Figure 2: International project INEVITABLE, optimization and diagnostic of the cold-rolling mill process
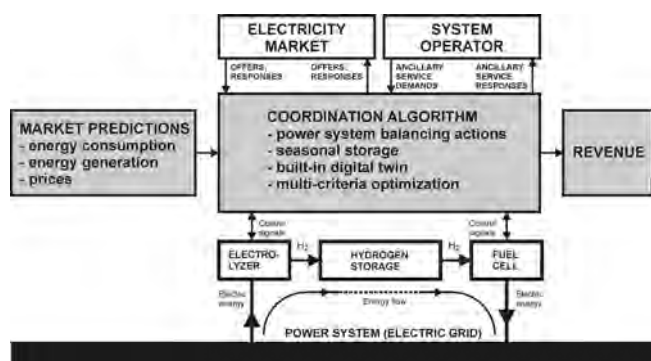
Figure 3: Concept of integration of hydrogen technologies with the electric-power system and market
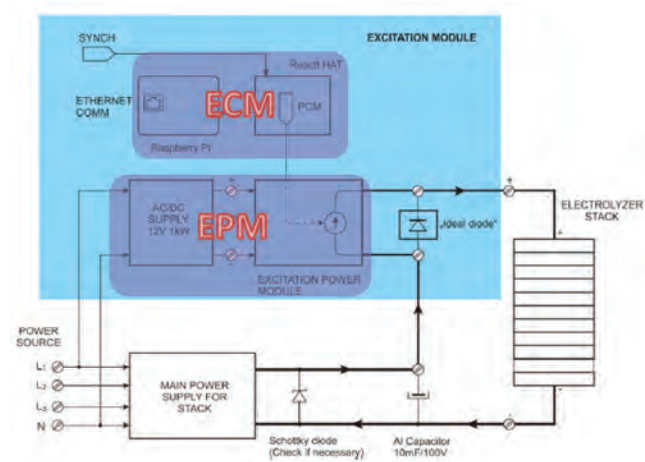
Figure 4: Project REACTT, block scheme of the stack external excitation module. The excitation module consists of a power module (EPM) and control module (ECM).
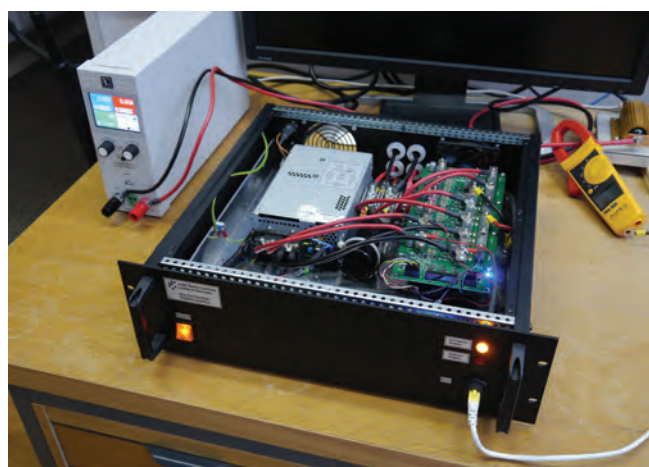
Figure 5: Electronic module for non-invasive diagnostics of electrochemical systems

batteries within the projects, in which our department participates and also beyond. We also developed an electronic excitation-measuring system for the characterization of piezoelectric materials using impedance spectroscopy. The system is used at the technical universities TU Darmstadt and TU Graz. Special features of the system are a high measuring range of impedances and high ratio between the excitation signal and DC voltage (1:10000). We applied for an international patent for the system, and some European companies are already interested in buying the rights.

Within the track **clean environment**, our focus was on the advanced control of wastewater systems. We developed a computationally efficient sub-optimal algorithm for a distributed nonlinear predictive control based on Gaussian process models and tested it on a simplified sewer-system model. In addition, based on the measurements of the contaminants of emerging concern (bisphenols) in different stages at a wastewater treatment plant, we estimated the biodegradation and adsorption of the contaminants to the sludge using mass balances.

We started to participate in the project *UPTAKE – Agricultural reuse of wastewater and sewage sludge: Uptake and distribution of contaminants of emerging concern in the tomato plant as a model*, led by the Department of Environmental Sciences. We will work on the development of plant-uptake models for the contaminants of emerging concern. The aim is to predict the plant uptake, translocation and accumulation of pollutants in different plant parts based on the physicochemical properties of the contaminants, plant physiology and environmental factors.

In the field of **smart factories**, research was aimed at the development of a self-learning system for monitoring of production equipment, based on an analysis of signals, generated by the production systems. In the reported year, individual building blocks of such a system were developed; they allow the segmentation and comparison of repeatable segments based on the measured time series of a process operation. Further activities for the identification of discrete-event systems (DES) in the operation of production equipment have also begun.

We started to coordinate a new research project entitled *Minimum-invasive and self-organising diagnostic systems: an ultimate component of the Factories of the Future*. The aim of the project is to develop methods and algorithms for the detection of industrial production states and processes based on signals from general-purpose or simply embedded sensors. To achieve this goal, it will be necessary to develop methods for the pre-processing, segmentation and classification of time series signals, as well as approaches to building discrete-event models to represent the event's digital twin. The aim is to achieve automated monitoring of the production and detection of deviations from an established procedure.

Following the initiative of the Republic of Slovenia for the establishment and operation of strategic innovative partnerships within the framework of the Slovenian Smart Specialization Strategy S4, the Strategic Innovative Partnership of the Factory of the Future – **SRIP ToP** – is also operating. Our department plays a very active role in the SRIP ToP, in the management of the area called Control Technologies and in the implementation of its Multi-Annual Action Plan. The members of the department are representatives of the SRIP ToP network in the European associations **Processes4Planet** and **Made in Europe**.

In the field of **energetic sector and hydrogen technologies**, in the frame of the research project entitled *Optimisation-based control of a P2G converter connected to a hydropower plant*, we designed and developed a decision-support tool for the future design of and investment in hydrogen technologies in a hydropower plant, taking into account both technical and economic aspects of their implementation. Such a tool enables a more efficient selection of the size of hydrogen system components and gives an estimate of the economic benefits of a hydrogen production.

At the same time, in this area, we started coordinating a new research project in the field of using hydrogen technologies in the energy sector. In the project, with the help of modelling and simulation, we will analyse in what ways the systems from the field of hydrogen technologies (electrolysers, fuel cells, hydrogen storage systems) can be integrated into electrical-energy systems, what functions they can perform (energy storage, system services, participation in electricity markets) and what is the economic aspect of using these systems. The participating partners in the project are the Faculty of Electrical Engineering, Computer Science and Informatics of Maribor and the Drava Hydro Plant Group, which co-finances the project.

In the field of **battery systems**, we are starting the project *Precise physics-based state of health assessment of lithium-ion batteries based on low-frequency impedance measurements with stochastic excitation*. The project has four main objectives focused on developing novel physics-based impedance models for graphite-anode and full Li-ion batteries, validating the EIS-SOH correlation for an individual commercial battery, implementing a CWT-based EIS measurement module (DRBS-EIS module), and integrating and testing the DRBS-EIS module(s) with a demonstrational battery module.

Figure 6: System for non-invasive characterization of piezoelectric materials, developed in collaboration with TU Darmstadt in TU Graz.

We continue with the research in the field of **medicine**. We started a new project entitled *Synchronised cardiorespiratory coronary rehabilitation*, which aims to evaluate the effectiveness of the synchronised cardiorespiratory rehabilitation (SCR) approach, including a coordinated use of slower movements with synchronized breathing patterns, reducing stress and increasing rehabilitation effectiveness. The SCR method will be evaluated with a measurement and data analysis of the standard parameters such as blood pressure, heart-rate variability and cardiorespiratory system capacity, as well as special measurements, which will include high-resolution electrocardiography, respiratory motility, microvascular blood circulation, pulse plethysmography, skin temperature, near-infrared spectroscopy (NIRS) and electroencephalography (EEG).

In the field of **social and economic sciences**, we continue the collaboration with the Faculty of Economics within the new research project *Investments as the key to building a sustainable business: building a theoretical model and multi-methodological empirical analysis* aimed at building a theoretical framework for sustainable companies, determining the types of investments required, and evaluating the existing and required investments in Slovenian firms to achieve sustainable companies.

We also started to participate in the new project *The impact of artificial intelligence on the labour market: economic analysis, reducing the competence gap and ensuring labour law protection*. The project focuses on artificial intelligence (AI) in the labour market, and aims to raise awareness about the use of AI solutions and identify and manage risks in employment processes.

After an ERC project application, we obtained a national research project, entitled *Air in karst underground as a sink of greenhouse gases*. Methane is a major greenhouse gas that was found to swiftly decompose in underground air. Using measurements, modelling and theory, we will quantify the flow rate of air through the karst underground, which is a major source of uncertainty in quantifying the role of the underground as a methane sink.

We participated in and coordinated international research projects. One of them is the project *H2020 Inevitable,* coordinated by our group, focusing on optimization in the metal industry by using digitalization techniques. The project is focused on the steel industry; the Slovenian part of the project deals with a multifaceted optimization of the process in an electric-arc furnace and cold-rolling process. We developed tools for decision support and condition monitoring of the cold-rolling mill process. The main focus of the work was on the implementation of the previously developed models in the industrial environment. The prepared solutions support the determination of the parameter settings for the process and the control over the operation of the cold-rolling mill equipment.

Figure 7: Fully automatic end-of-line quality inspection system, type ML16, for the Domel company (development and fabrication at the JSI)

The *RUBY* project pursues the development of advanced techniques and dedicated hardware for the monitoring, diagnosis, prognosis and optimizing control (MDPC) of PEM and SOFC fuel cells with the aim to maximize efficiency and durability. Our team contributed a set of diagnostic algorithms for active and passive diagnosis of solid oxide fuel cell systems. A particular contribution of our team concerns the probabilistic approach to the diagnostic fusion,

Figure 8: Semi-automatic end-of-line quality inspection system, type 714, for the Domel company

which combines all the available symptoms in order to produce a ranked list of suspected faults with the associated probability mass.

The main idea of *REACTT* is to provide an embedded technological platform that will help leverage the existing SOE and rSOC systems to their optimal performance, durability and economic exploitation whilst ensuring portability, scalability and easy operability. The most distinguished contribution of our team is a special module for the external perturbation of stacks for the purpose of online electrochemical impedance spectroscopy. Designed as a current generator that operates in series with a default (voltage) power source, it is capable of injecting an almost deliberately chosen waveform on the frequency range up to 18 kHz, while providing 200 A maximum direct current to the stack.

The *H2020 Hecat* project aims to improve the experience and outcomes of unemployment for EU citizens by offering real-time evidence-based insights into their personal positions in the labour market. It builds on the existing algorithmic techniques used by some European Public Employment Services to broaden the focus on job quality and sustainable employment, incorporating measures of labour demand, and using big data processing to treat each individual as a unique subject. The platform uses artificial intelligence and visualization techniques to support decision-making.

We also carried out **contractual projects for Slovenian industry**. In 2022 the development of a new diagnostic system (type 714) for end-of-line quality assessment for the Domel company was completed. It is a semi-automatic diagnostic system for a new production line of brushless electric DC motors. The system poses a new challenge in terms of digitization, data transfer and operation monitoring as it will be installed in the factory in China. In 2022 we also received an order from the Domel company for the development and implementation of a new fully automatic and comprehensive system for the end-of-line quality inspection of various types of electric motors for the ML-16 production line. Compared to the devices we have implemented so far, the new device is characterized by an extremely high degree of flexibility, which enables the diagnosis of different types of electric motors with different geometries. Adaptations for different motor types are carried out programmatically using a series of smart mechatronic actuators. This has brought our devices even closer to the concepts of Industry 4.0 and Smart Factories.

Educational and training activities

Some members of the department give lectures and practical courses at different faculties and universities: the Faculty of Electrical Engineering, University of Ljubljana; the Faculty of Logistics, University of Maribor; the Faculty of Industrial Engineering Novo mesto; the University of Nova Gorica; and Jožef Stefan International Postgraduate School.

Some outstanding publications in the past year

1. Jovan, David Jure, Dolanc, Gregor, Pregelj, Boštjan. Utilization of excess water accumulation for green hydrogen production in a run-of-river hydropower plant. Renewable Energy, ISSN 0960-1481. [Print ed.], 2022, vol. 195, pp. 780–794, doi: 10.1016/j.renene.2022.06.079. [COBISS.SI-ID 112296195]

2. Kos, Tomaž, Slabki, Mihail, Petrovčič, Janko, Vrančić, Damir, Dolanc, Gregor, Koruza, Jurij. Measurement system for piezoelectric resonance impedance spectroscopy under combined AC and high-voltage DC loading. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, ISSN 1525-8955, 2022, vol. 69, iss. 11, pp. 3137–3144, doi: 10.1109/TUFFC.2022.3185534. [COBISS.SI-ID 115062787]

3. Andonovikj, Viktor, Boškoski, Pavle, Evkoski, Bojan, Redek, Tjaša, Boshkoska, Biljana Mileva. Community analysis in Slovenian labour network 2010-2020. Journal of Decision Systems, ISSN 1246-0125, 2022, vol. 31, suppl. 1, pp. 308–318, doi: 10.1080/12460125.2022.2070944. [COBISS.SI-ID 107861251]

4. Ješić, Dimitrij, Erklavec Zajec, Vivian, Bajec, David, Dolanc, Gregor, Berčič, Gorazd, Likozar, Blaž. Computational investigation of auto-thermal reforming process of diesel for production of hydrogen for PEM fuel cell applications. International Journal of Energy Research, ISSN 1099-114X, 2022, vol. 46, iss. 12, pp. 17068–17083, doi: 10.1002/er.8370. [COBISS.SI-ID 117494531]

5. Königshofer, Benjamin, Höber, Michael, Nusev, Gjorgji, Boškoski, Pavle, Hochenauer, Christoph, Subotić, Vanja. Accelerated degradation for solid oxide electrolysers: analysis and prediction of performance for varying operating environments. Journal of Power Sources, ISSN 0378-7753, 2022, vol. 523, pp. 230982-1-230982-14, doi: 10.1016/j.jpowsour.2022.230982. [COBISS.SI-ID 94771715]

Some outstanding achievements in the past year

1. The innovation *The electronic module for perturbing SOEC stacks during their operation to get the dynamic response needed for the condition assessment* was selected for publication on the EU Innovation Radar's public website https://www.innoradar.eu/innovation/48360

2. Results on the collaboration with industry including the design and implementation of two new advanced end-of-line quality inspection systems for the Domel company.

Awards and Appointments

1. Jernej Mlinarič: awarded with the PCT technology network award (Process Control Technology) for his master's thesis entitled "Diagnostics and prognostics of electromechanical systems based on mechanical, electrical, vibrational and acoustic signals"

INTERNATIONAL PROJECTS

1. H2020 - RUBY; Robust and Reliable General Management Tool for Performance and Durability Improvement of Fuel Cell Stationary Units
Prof. Đani Juričić
European Commission
2. H2020 - HECAT; Disruptive Technologies Supporting Labour Market Decision Making
Asst. Prof. Pavle Boškoski
European Commission
3. H2020 - INEVITABLE; Optimization and Performance Improving in Metal Industry by Digital Technologies
Dr. Dejan Gradišar
European Commission
4. H2020 - REACTT; REliable Advanced diagnostics and Control Tools for increased lifetime of solid oxide cell Technology
Prof. Đani Juričić
European Commission
5. TRACE - Phylogenetic Reconstruction Using Gaussian Processes
Prof. Juš Kocijan
Slovenian Research Agency

RESEARCH PROGRAMME

1. Program systems and control
Prof. Đani Juričić
Slovenian Research Agency

R&D GRANTS AND CONTRACTS

1. Synchronised cardiorespiratory coronary rehabilitation
Asst. Prof. Pavle Boškoski
2. Corporate investment as the key to building a sustainable company: building a theoretical model and multimethod empirical analysis
Asst. Prof. Pavle Boškoski
3. STRAP - Sources, TRansport and fate of persistent Air Pollutants in the environment of Slovenia
Prof. Juš Kocijan
4. Accurate physics-based State-of-Health estimation of Lithium ion batteries based on ultra-low frequency impedance measurements with stochastic excitation
Asst. Prof. Pavle Boškoski
Kemijski Inštitut Ljubljana
5. Optimization based control of P2G converter connected to hydro power plant
Asst. Prof. Gregor Dolanc
6. Stability of nuclear reactors in load follow mode of operation
Dr. Boštjan Pregelj
7. Modelling the Dynamics of Short-Term Exposure to Radiation
Prof. Juš Kocijan
8. Supervisory control system for plant-wide optimization of wastewater treatment plant operation
Dr. Darko Vrečko

9. Minimum-Invasive Self-Evolving Diagnostic Systems: An ultimate component of the Factories of the Future
Prof. Đani Juričić
10. Multifunctional hydrogen technologies supporting power system balancing, energy storage and market
Dr. Janko Petrovčič
11. „Uptake": agricultural reuse of wastewater and sewage sludge: uptake and distribution of contaminants of emerging concern in tomato plant as a model
Dr. Nadja Hvala
12. The impact of artificial intelligence on the labour market: economic analysis, reducing the competence gap and providing labour law protection
Asst. Prof. Pavle Boškoski
13. Circular 4.0: Digital technologies as enabler to foster the transition to the circular economy bythe SME in the Alpine Space area
Dr. Miha Glavan
Government Office of the Land Of Salzburg
14. The impact of artificial intelligence on the labour market: economic analysis, reducing the competence gap and providing labour law protection
Asst. Prof. Pavle Boškoski
Služba Vlade Republike Slovenije

NEW CONTRACTS

1. Optimization based control of P2G converter connected to hydro power plant
Asst. Prof. Gregor Dolanc
Hidroelektrarne na Spodnji Savi, d. o. o.
2. Modelling the Dynamics of Short-Term Exposure to Radiation
Prof. Juš Kocijan
Nuklearna Elektrarna Krško d. o. o.
3. Supervisory control system for plant-wide optimization of wastewater treatment plant operation
Dr. Darko Vrečko
JP CČN Domžale-Kamnik d. o. o.
4. Supervisory control system for plant-wide optimization of wastewater treatment plant operation
Dr. Darko Vrečko
Kolektor Sisteh d. o. o.
5. Supervisory control system for plant-wide optimization of wastewater treatment plant operation
Dr. Darko Vrečko
Komunala Novo mesto d. o. o.
6. Supervisory control system for plant-wide optimization of wastewater treatment plant operation
Dr. Darko Vrečko
Komunala Kranj d. o. o.
7. Multifunctional hydrogen technologies supporting power system balancing, energy storage and market
Dr. Janko Petrovčič
Dem d. o. o.
8. Minimum-Invasive Self-Evolving Diagnostic Systems: An ultimate component of the Factories of the Future
Prof. Đani Juričić
Domel, d. o. o.

VISITORS FROM ABROAD

1. Prof. Dr Ivana Palunko, University of Dubrovnik, Croatia, 2–5 May 2022
2. Dr Domagoj Tolić, Rochester Institute of Technology Croatia, Dubrovnik, Croatia, 2–5 May 2022
3. Dr Rade Garić, University of Dubrovnik, Croatia, 2–5 May 2022
4. Dr Rade Garić, University of Dubrovnik, Croatia, 29 November to 7 December 2022

STAFF

Researchers
1. Asst. Prof. Pavle Boškoski
2. **Asst. Prof. Gregor Dolanc, Head**
3. Dr. Samo Gerkšič
4. Dr. Miha Glavan
5. Dr. Giovanni Godena
6. Dr. Dejan Gradišar
7. Dr. Nadja Hvala
8. *Dr. Vladimir Jovan, retired 16.07.22*
9. Prof. Đani Juričić
10. Prof. Juš Kocijan
11. *Dr. Marko Nerat, left 01.07.22*
12. Asst. Prof. Matija Perne
13. Dr. Janko Petrovčič
14. Dr. Boštjan Pregelj
15. Asst. Prof. Damir Vrančić
16. Dr. Darko Vrečko

Postgraduates
17. Martin Brešar, B. Sc.
18. Žiga Gradišar, B. Sc.
19. Tadej Krivec, B. Sc.
20. Jernej Mlinarič, B. Sc.
21. *Gjorgji Nusev, B. Sc., left 01.06.22*
22. Aljaž Pavšek, B. Sc.
23. Matic Rutnik, B. Sc.
24. Žiga Stržinar, B. Sc.
25. Luka Žnidarič, B. Sc.

Technical officers
26. Stanislav Černe, B. Sc.
27. Primož Fajdiga, B. Sc.
28. David Jure Jovan, B. Sc.

Technical and administrative staff
29. Maja Janežič, B. Sc.
30. Miroslav Štrubelj

DEPARTMENT FOR ARTIFICIAL INTELLIGENCE

E-3

The Department for Artificial Intelligence (http://ailab.ijs.si/) is concerned mainly with the research and development of information technologies with an emphasis on artificial intelligence. Our main areas of research are: data analysis with an emphasis on text, web and cross-modal data; scalable real-time data analysis; machine learning; analysis and modelling of large networks; visualization of complex data; semantic technologies; language technologies; reasoning methods and knowledge management. The Department for Artificial Intelligence has employees and students with an international background and expertise in different areas of artificial intelligence. In addition to publishing their research results in international publications and presenting their work at international events, our researchers have also developed numerous software tools for multimodal data analysis. These tools include: Text-Garden (https://ailab.ijs.si/tools/text-garden/), a suite of text mining tools; OntoGen (https://ailab.ijs.si/tools/ontogen-2/), a tool for ontology learning; Document-Atlas (https://ailab.ijs.si/publications/past-projects/documentatlas/), a tool for complex visualization; Atlas of Slovenian Science (http://scienceatlas.ijs.si/), a web portal for analyzing the scientific community; Enrycher (http://enrycher.ijs.si/), a system for semantic enrichment of textual data; SearchPoint (http://searchpoint.ijs.si/), a portal for visual and contextualized Web browsing; OntoPlus (https://ailab.ijs.si/tools/ontoplus/), a methodology for semi-automatic ontology extension; Contextify, a tool for contextualized e-mail and contact management; Qminer (http://qminer.ijs.si/), a data analytics platform for processing large-scale real-time streams containing structured and unstructured data; NewsFeed (https://ailab.ijs.si/tools/newsfeed/), a clean, continuous, real-time aggregated stream of semantically enriched news articles from RSS-enabled sites across the world; Event Registry (http://eventregistry.org/), a system for identifying world events in news media including a DarkNET component of Event Registry; Wikifier (http://wikifier.org), a system for document annotation with links to relevant Wikipedia concepts; StreamStory, an exploratory data stream analysis tool offering an alternative type of visualization by representing the multivariate data stream using a Markovian model; Videolectures Explorer, a tool enabling users to search through video lectures and find similarities between them; EDSA dashboard, a tool aggregating demand data (job postings around Europe) and supply data (training materials) in data science; nextPin, a system for the analysis of time-varying data of geographic locations; Connection tool, a tool based on Event Registry news data, which allows a user to follow business and personal named

Head:

Prof. Dunja Mladenić

The H2020 project SILKNOW was the winner of the EuropaNostra Grand Prix Award.

entities in time and establish broad relations between named entities (based on shared Wikipedia concepts from news articles) as well as to view the changes in these relations; Graph Based Analytics, a service for business relation identification from text which enables identification of business relations, such as mergers & acquisitions, bankruptcy, earnings, dividends, etc., based on the sentence level; streamfusion, a universal system for the preprocessing of heterogeneous stream data; ELEXIS ER (http://er.elex.is/), a lexicography-adapted version of Event Registry; a public procurement anomaly detection tool (http://tbfy.ijs.si/); a service for processing, analyzing and searching through environmental legal documents; Infominer, a tool for interactive data analysis; Water Observatory (http://naiades.ijs.si/); MultiCOMET, a system for automatic generation of commonsense descriptions (https://multicomet.ijs.si/); Smell Tracker (https://odeuropa.ijs.si/); EUJapan Observatory (https://eujapan.ijs.si/), monitoring the use of AI in manufacturing; the Slovenian Terminology Hub (https://fedterm.ijs.si/), part of the European network of terminology portals and a tool for converting time series into system states (http://atena.ijs.si:8080/). The Department's strategy is to combine scientific excellence with strong industrial collaboration, enabling the transfer of research results into real-world business environments.

In 2022 we were very actively involved in submitting new project proposals, particularly within the EU Horizon Europe Programme. Two new EU projects began in 2022: enRichMyData and CONDUCTOR, while seven new Horizon Europe projects will begin in 2023. We continue with our successful efforts to include the Slovenian industry

into the European research area where, over the last 20 years, we helped numerous companies to participate in the EU projects.

Members of the Department for Artificial Intelligence successfully continued participating in the EU, national and regional projects. In the last 20 years, we participated in 80 EU projects, of which 3 were concluded in 2022 and 10 were still ongoing. We also participated in 7 national projects.

In 2022, in the area of **Statistical Data**, **Modelling and Machine Learning**, we began work on a new project called **CONDUCTOR** and continued work within **CogLo**, **Naiades**, **FACTLOG** and **STAR**. The EU H2020 project **Cog-Lo** (*Cognitive Logistics*) was concluded in 2022, after a six month extension due to the Covid-19 pandemic.

The H2020 project FACTLOG was chosen as one of the key innovation projects on the topic of "Enhanced Cognitive Digital Twins" by the EC Innovation Radar Committee.

The aim of the project was to design and develop an intelligent logistics platform with cognitive services for postal operators/infrastructure. The project focused on observing the postal infrastructure as an object in time, with a dynamic parcel (packet) flow being driven through basic infrastructural tools. In the scope of the project, the AILAB successfully designed a methodology for building a digital representation of a physical infrastructure, methodology for optimization of resources on the graph distribution, and methodology for large graph processing with clustering. The Cognitive Adviser tool was developed as the main agent monitoring events in the infrastructure in real time and creating interventions for the process optimization.

Together with E7, we began work on the EU Horizon Europe project **CONDUCTOR** (*Fleet and Traffic Management System for Conducting Future Cooperative Mobility*), whose aim is to design, integrate and demonstrate advanced, high–level traffic and fleet management that will allow efficient and globally optimal transport of passengers and goods, while ensuring seamless multimodality and interoperability through dynamic balancing and priority–based management of vehicles (automated and conventional). To do so, CONDUCTOR will build upon the state-of-the-art fleet and traffic management solutions from the CCAM (Connected, Cooperative and Autonomous Mobility) ecosystem and develop the next generation of simulation models and tools at different levels, enabled by AI and data fusion, enhancing the capabilities of transport authorities and operators, who will become true conductors of future mobility networks. Analytical functionalities will be integrated and implemented in four industrial pilot settings for testing and verification, namely: Athens, Madrid, Almeo and SLO-IT region. Use cases deployed will include integrated traffic management with intermodality, demand-response transport and urban logistics.

Figure 1: Water consumption prediction. Screen caption from the NAIADES platform (https://naiades.simavi.ro/, built by Konnektable Technologies), showing the graphical user interface for the Braila use case with AILAB-generated predictions for water consumption (graph on the lower left-hand side) and the hydrological model (lower right, developed by IHE Delft Institute for Water Education) built on top of predictions.

Within the EU H2020 project **Naiades** (*a holistic water ecosystem for digitisation of urban water sector*), we completed work on four tasks: (1) creation of a system for converting time series into a system of states; (2) building an anomaly detector that runs in real time; (3) making real-time predictions of water consumption; and (4) construction of a water observatory. We built the system for converting time series into states in 2021, and in 2022 we added a new function – alerting to changes to specific states in time series in real time – to the Naiades platform. A user can determine which states are of interest to him or her, and these also include anomaly detection. For anomalies, we developed additional systems (i.e., (i) detection of anomalies in time series, (ii) detection of the approximate location of a leak in the water supply network and (iii) detection of the exact location of the leak in the water supply network) and integrated their solutions into the Naiades environment. The real-time forecasting system was integrated into the Naiades platform and the forecasts were validated by all three pilots. We additionally developed a monitoring system to send alerts in case of issues in the workflow (at the levels of data download, data fusion, prediction formation and data upload). We upgraded the water observatory (http://naiades.ijs.si) with a tab for medium-term forecasts of weather and water resources. The project was concluded in November 2022.

The goal of the EU Horizon 2020 project **FACTLOG** (*Energy-Aware Factory Analytics for Process Industries*) is to support the process industry through the development of digital twins. As a digital representation of a factory supported by analytics systems, a digital twin supports functions such as: raising an alarm when encountering an anomaly, planning the optimal order of production and appropriately setting the parameters of production machinery. Together with other FACTLOG partners, we designed a framework in which machine-learning models work together with domain-expert models and optimization algorithms to solve industry problems. Our main contributions are software libraries for forecasting industry system states from data streams and detection of anomalies in data streams. The methods were successfully tested on industry pilots, the main two being: JEMS, a Slovenian

company processing waste into fuel and Tüpraş, a Turkish oil refinery. The models and analytical components were successfully integrated into a common digital platform where they were validated with domain KPI indicators.

The goal of the **STAR** project (*Safe and Trusted Human-Centered Artificial Intelligence in Future Production Lines*) is to develop human-friendly artificial-intelligence solutions in the field of manufacturing. The project investigates different approaches and the use of artificial intelligence in production, which enables (a) a safer production environment or collaboration with robots, (b) security against cyber-attacks, (c) interpretability of artificial intelligence models to better understand or gain insight into the way these models reason/learn/predict, and (d) research and use of active learning approaches that, through collaboration between humans and machine-learning models, aim to improve the learning of machine-learning models. Our main contributions in the past year were: (a) the development of a machine-learning solution for automatic detection of production defects, (b) the use of explainable artificial-intelligence methods and their evaluation, helping to identify production defects faster and better, (c) the use of machine learning to detect images that had been modified with the intention of corrupting the predictions of machine-learning models, (d) developing new approaches to measuring the quality of calibration models, and (e) using active learning approaches to reduce data labeling needs and learn about machine models better. We developed machine-learning models for two key project partners: Philips and IBER.

In the field of **Complex Systems Analysis**, within the nationally funded project **Slovenian Artificial Intelligence Observatory** we developed the first version of this Observatory, which is publicly available at http://slovenian-observatory.ijs.si. The basic functionality of the system includes data analytics, a system front-end with a user interface with a visualization of results, and a subsystem for generating reports. For the purpose of building the system, we collected data from open sources and

Figure 2: Image annotation interface developed within the H2020 project STAR. This and other similar interfaces are used to perform different image labelling experiments.

identified additional data sources to be acquired over the next year. We semantically tagged the acquired data and produced a series of analyses and visualizations of the results. In a nationally funded pilot project for the Slovenian Ministry of Defense, a system called **Si-Twin** is being developed, representing a digital twin of Slovenia. The system will be responsible for a comprehensive understanding of events in Slovenia, as well as in a broader context, enabling users to understand information in real time and also predict and recognize potential complex crises. The architecture is based on microservices and allows for a flexible development and greater scalability of the entire system. The analytical part of the infrastructure already supports real-time storage and processing of data streams, which are also appropriately aggregated and stored in the system's database. An interface was implemented to display stored data using interactive visualizations. The NCKU system was also integrated, allowing for a separate display of events in Slovenia from the perspective of domestic and foreign media. The integration of an interactive map is also underway, displaying the transmission network of electricity in Europe and the corresponding state of this infrastructure. The development of artificial-intelligence models has also begun and it will enable forecasting for various available data sources. Data is sent to the system from various data sources, including weather, consumption and production of electricity in Slovenia, and the state of groundwater in the country.

In the area of **Data Streams Analysis**, we continued the development of the *Platform for Anti-Money Laundering* and *Countering the Financing of Terrorism* as one of the 15 fintech pilots of flagship project **INFINITECH** (*Tailored IoT & BigData Sandboxes and Testbeds for Smart, Autonomous and Personalized Services in the European Finance and Insurance Services Ecosystem*). Among 15 different pilots from the Fintech domain, one includes the development of an analytical platform for Anti-Money Laundering and Countering the Financing of Terrorism (PAMLS) for the needs of the supervision of financial institutions where our partner is the Bank of Slovenia. Only two partners are involved in the development of the pilot – the Bank of Slovenia as the content partner and the end user and the AILAB from the JSI as the technology partner. We have integrated the developed AI methods into the PAMLS platform and validated the functionalities on actual current-enriched transactional data. The entire PAMLS platform is placed on the BS testbed and includes the third version of the Risk Assessment Tool and the second version of the Screening Tool, which are also mutually integrated in the platform. Functionality validation was performed on real live data and the results proved to be extremely useful, not only for the AML supervision processes themselves, but they also opened up other possibilities of using the PAMLS tools. Another important result of the project is the pseudo-anonymizer – a service for data pseudo-anonymization, which was installed and used for pseudo-anonymization of the data exchanged between different stakeholders.

We began work on the new Horizon Europe project **enRichMyData** (*The Enabling Data Enrichment Pipelines for AI-driven Business Products and Services*), which aims to create a new approach to creating high-quality, valuable datasets that can be used for big-data analytics and AI applications. This approach will be accessible to
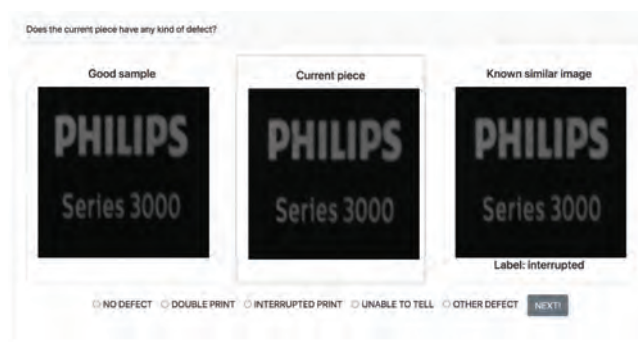
both large and small organizations that have difficulties obtaining suitable data for their analytics solutions, and can be applied to a wide range of industries, such as digital marketing, public procurement, innovation ecosystems, Industry 4.0, medical device predictive maintenance, and mineral processing. The Department for Artificial Intelligence is a key developer of data enrichment tools in this project.

The **CyberSANE** project (*Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures*) started in 2019 and ended in 2022. The aim of the project was to increase the security and resilience of the European Critical Information Infrastructure (CII). As part of the project, we developed a CyberSANE platform to help professionals in organizations deal with cyber incidents. The platform consists of several components, and within the project, the AILAB was responsible for the development of the DarkNET component, used for crawling data from the dark web and from media articles in structured and unstructured forms. The DarkNET component then semantically analyzes the captured data and extracts relevant information about cyber incidents. This gives security analysts an insight into the global state of cybercrime, as well as detecting cyber threat reports on the dark web and the news. In 2022, the development of the platform was completed and successfully tested in three pilot tests. As part of the project, the book "Crash course on cybersecurity: a manual for surviving in a networked world" by Matej Kovačič was published under a Creative Commons license. The book attempts to

Figure 3: H2020 Odeuropa project Smell Tracker, dlib dashboard, filter concept: "parfum"

explain the complex field of cyber security in a comprehensible manner, highlighting the key information on how to protect yourself and/or your business from cyber-attacks and providing technology-neutral advice on implementing the cyber-attack protection.

In the areas of **Text and Network Analysis and Language Technologies**, we concluded the Horizon 2020 European project **ELEXIS** (**European Lexicographic Infrastructure**), which started in February 2018. The aim of the project was to integrate, expand and coordinate national and regional activities in the field of lexicography, with the aim of creating a sustainable infrastructure that will (1) enable efficient access to high-quality lexical data in the digital age, and (2) bridge the gap between the more advanced and less well-equipped scholarly communities in the production of lexicographic resources. In 2022, in addition to project management activities, we continued to maintain the project website and publish the final versions of Elexifinder, Elexifier, Lexonomy, ELEXIS one-click dictionary, ELEXIS Lexicographic News Feed and Dictionary Matrix. We also successfully organized and delivered the final ELEXIS Showcase Event, which took place in Florence, Italy, in June 2022.

As a part of the H2020 EU Marie Skłodowska-Curie ITN project **CLEOPATRA (Cross-Lingual Event-Centric Open Analytics Research Academy)**, we published six research papers. Our CLEOPATRA PhD students participated in a thesis writing course at the CLEOPATRA workshop and presented their research findings at ESWC 2022. They completed their secondments hosted by the BL (British Library) and FCT-FCCN (Fundação para a Ciência e a Tecnologia). Regarding national and regional projects, we continued our work on the **Slovenian Language Development in the Digital Environment** (RSDO) project. This project is co-financed by the Republic of Slovenia and the European Union from the European Regional Development Fund and is implemented under the Operational Programme for the Implementation of the European Cohesion Policy 2014–2020. The results include new language resources, Slovenian processing tools and applications (upgrading text corpora, speech recognition, semantic technologies, machine translation, terminology portal, and the maintenance of the Language Technology Centre – CLARIN.SI). In the third year of the project, we completed the development of the MultiCOMET tool. This is a model that generates contextual statements according to the sentence that is typed in. It includes the conditions and consequences of what is typed, from which it generates a graphical representation of the statements. A deep neural network parses the input and makes a conclusion based on the context and influences.

In 2022 we completed the implementation of the **CurliCat** project (**Curated Multilingual Language Resources for CEF AT Action**), which aimed to collect curated databases for seven consortium languages (Bulgarian, Croatian, Hungarian, Polish, Romanian, Slovak, Slovenian) to improve the European Commission's machine translator. In the framework of this project, in November 2022, we completed the development of a text anonymisation system for all 7 languages. **The Federated eTranslation TermBank Network** (**FedTerm**) project also ended in 2022. Its aim was to develop federated terminology databases (hubs) where users can manage and share their terminology with other users and search for terms in private and publicly available terminology databases. The project developed a network that will allow EU organizations and institutions to locally deploy individual eTranslation TermBank federation nodes, which will be linked to the central federation node (eTranslation TermBank) and will regularly synchronize terminology changes. The project covers all official EU languages plus Norwegian and Icelandic, focusing on the partner languages (Latvian, Danish, Icelandic, Estonian, Lithuanian, German, Estonian, Swedish

and Slovenian). In the final year of the project, the Slovenian Terminology Hub was launched at https://fedterm. ijs.si/ as part of the European network of terminology portals.

The **European Language Resource Coordination** (**ELRC**) project also ended in 2022. ELRC aims to manage, maintain and coordinate relevant language resources in all official languages of the EU and the CEF (Connecting Europe Facility) associated countries. These activities will help to improve the quality, coverage and efficiency of automated translation solutions in the context of the current and future digital services of the CEF programme. In 2022 we organized the (third) international ELRC workshop, held in the large lecture theatre at the JSI and via the Zoom platform. During the event, we presented the current state of play, projects and plans for the development of language resources and tools for Slovenian. Developers, integrators and users of language technologies, from both the private and public sector, shared experiences, requirements and ways of replacing digital communication in our multilingual Europe with language technologies. Finally, they discussed how linguistic data, i.e., text and speech, can stimulate developments in the field of artificial intelligence.

In 2022 we also participated in the **ELG** (**European Language Grid**) and **ELE** (**European Language Equality**) initiatives. ELG has contributed to the creation of a truly connected, multilingual and monolingual digital single market with powerful multilingual, cross-lingual and monolingual technologies. The ELG initiative came to an end in 2022. The main outcome of the project is linking the ELG and CLARIN.SI repositories in such a way that they communicate with each other and the content of both is automatically coordinated (harvested). ELE continues to develop a strategic research, innovation and implementation programme and a roadmap for achieving full digital language parity in Europe by 2030. In 2022 we finalized a report on the state of the art of the language technologies for Slovenian available at https://european-language-equality.eu/wp-content/uploads/2022/03/ELE___Deliverable_D1_31__Language_Report_Slovenian_.pdf. Together with the Department of Knowledge Technologies (E8), we continued to manage **the Slovenian research infrastructure CLARIN.SI**, which enables easy publication and sustainable access to digital language data for researchers in the humanities and social sciences. In addition to providing support for the CLARIN.SI repository, we uploaded a wide range of data (lexical resources, corpora, lists) and technologies for processing the Slovenian language.

The project **Monitoring Corpus and Accompanying Language Resources** (**SLED**) was completed in 2022. It primarily addressed one of the fundamental needs of the Slovenian language, i.e., the creation of a monitoring corpus, which is an indispensable basic infrastructure for monitoring, observing and also inventorying various diachronic linguistic phenomena in the face of the extremely rapid changes in the language (e.g., the changes in the time of the Covid-19 pandemic). In 2022, the following project outputs were published: a monitoring corpus of trends; a user survey; frequency lists containing the words or sets of words whose usage has increased most markedly in the selected period compared to the previous period; and a tool for topical tagging of texts. In 2022 we launched the **SLOKIT** project (**Corpus Information Tool and Text Analyser**), whose main aim is to upgrade the CLARIN.SI research infrastructure portal with services that will bring the site's content, especially the corpora, closer to a wider range of users. An important outcome of the project will be a tool that identifies difficult parts of texts and offers solutions for their simplification, which will help both end-users and designers of study materials (tutorials). The focus of both tools will be adapted for people with disabilities.

In the area of **semantic technologies**, we continued work on the H2020 **ODEUROPA** project (*Negotiating Olfactory and Sensory Experiences in Cultural Heritage Practice and Research*), which intends to apply state-of-the-art AI techniques to cultural heritage text and image datasets spanning four centuries of European history, to find out and trace how 'smell' was expressed in different languages, with what places it was associated, what kinds of events and practices it characterized, and to what emotions it was linked. In 2022 the Odeuropa partners proceeded with building the project infrastructure, organizing and participating in smell-related events (workshops, conferences, dissemination to public) and discovering smell textual and visual resources. In particular, we contributed to the extraction of smell-related knowledge from the Slovenian Odeuropa corpora. In accordance with the project tasks, we organized the annotation of emotions for the Odeuropa benchmark and trained initial models for emotion extraction. In November 2022, the AILAB was a core organizer of the Odeuropa hackathon and workshop "Improve your olfactory knowledge", along with the National and University Library of Slovenia. The two-day event attracted researchers in the area of smell, historians, IT professionals from different European institutions and provided the foundation for an evaluation and validation of Odeuropa tools and technologies.

We concluded national project **Causalify**, within which we developed a theoretical model for multi-resolution causality modeling and tested its applicability on several scenarios. The model was then adjusted for several approaches to modeling in different domains. The focus was on modeling different aspects of global social dynamics, information spreading barriers and reporting bias. We developed an approach to predicting the future development of scientific research based on scientific publications from the past two centuries. On the problem of text analysis, we developed a model for understanding text using agent-based models that was validated on a short story. In the financial domain, we developed an approach to characterizing financial markets from the event-driven perspective.

To analyze the cause and effects of personal activities, we developed a system for automatic generation of commonsense descriptions *MultiCOMET* and in the last year of the project we extended the system and conducted an evaluation focusing on Slovenian. During the last year, we developed a novel methodology for training an event argument extraction system in a semi-supervised setting and tested it on real-world scenarios analyzing events of earthquakes and terrorist attacks in a cross-lingual setting. With regard to the analysis of information spreading barriers, we studied information cascading and propagation barriers within global news, applying the proposed methodology to three distinctive kinds of events: global warming, earthquakes and FIFA World Cup. In collaboration with the British Library, we studied stylistic features of news reporting on the use case of BREXIT. With regard to information reporting bias, we investigated the impact of geographical bias on news sentiments in articles about the Olympic legacy in London and Rio written over two years.

In the area of **knowledge management**, the group's main focus is on research and development using methods and tools from a broader artificial-intelligence area in real business settings. The EU Horizon 2020 project **HumanE-AI-Net** (*Making artificial intelligence human-centric*) is a continuation of **HumaneAI** (*Toward AI Systems that Augment and Empower Humans by Understanding us, our Society and the World around us*), which brings together the leading European research centres, universities and industrial enterprises into a network of Centres of Excellence. The leading global artificial intelligence (AI) laboratories collaborate with the key players in areas such as human-computer interaction, cognitive, social and complexity sciences. The project aim is to drive researchers out of their narrowly focused field and connect with people exploring AI on a much wider scale. The challenge is to develop robust, trustworthy AI systems that can 'understand' humans, adapt to complex real-world environments and interact appropriately in complex social settings. HumanE-AI-Net will lay the foundations for designing the principles for a new science that will base AI on European values and bring it closer to Europeans.

> **We successfully concluded three EU H2020 projects: CogLo (Future COGnitive Logistics Operations through Social Internet of Things), Cybersane (Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures) and ELEXIS (European Lexicographic Infrastructure).**

The aim of the **EU-Japan.AI** H2020 project (*Advancing Collaboration and Exchange of Knowledge between the EU and Japan for AI-Driven Innovation in Manufacturing*) was to establish and stimulate a long-term cooperation between the EU and Japan in areas relevant for AI-driven innovation in manufacturing and digital industry by implementing a platform-based approach, connecting all the relevant stakeholders, and by promoting the use modern, online-driven awareness approaches. As part of the project, we developed an online platform with all relevant information on the use of artificial intelligence in the production in the EU and Japan. The platform is also used for connecting partners from both regions and fostering cooperation between them. As part of the project, we collected data on events, projects, organizations and opportunities for financing projects in the field of artificial intelligence in manufacturing in the EU and Japan. The AILAB developed the AI Observatory, a web platform that shows various analyses and visualizations of scientific publications in the field of artificial intelligence, media reports on events related to artificial intelligence, analyses of the job market and demand for skills in the field of artificial intelligence, analyses of EU research projects and open source projects related to artificial intelligence. We also prepared a report, in which we presented an analysis of the investments in artificial intelligence technologies and a visualization and analysis of public policies on artificial intelligence. For publication on the online platform, we also prepared several articles on the advantages and dangers of artificial intelligence in practice. The nationally funded project **For the Quality of Slovenian Textbooks** (**KaUč**) was dedicated to the review and research of the use of textbooks in Slovenia. Based on the findings, the main objective of the project was to develop textbook quality indicators for practical use in the textbook validation and evaluation process. The project ended in 2022. The main deliverable was an automatic textbook evaluation tool based on text and image features.

> **We successfully concluded six nationally and regionally funded projects: Causalify, CurliCat, FedTerm, ELRC, Kauč and SLED.**

The promotion of science is continually present in the efforts of our department. In 2022 members of the Artificial Intelligence Department were very active in promoting artificial intelligence and science in general.

- Marko Grobelnik gave numerous talks on the topic of artificial intelligence, including the keynote address at the AI Con conference (https://ai-con.ai)
- Dunja Mladenic took part of the OECD panel at the International Conference on AI in Work, Innovation, Productivity and Skills
- Alenka Guček gave an interview for the Delo newspaper on Visualization relating to the International Day for the Elimination of Violence against Women
- Alenka Guček, Joao Pita Costa and Matej Kovačič contirbuted to 3 webinars within the NAIADES project
- Simon Krek gave various talks on language technologies and lexicography including **Opening up dictionaries for natural language understanding** at the Language Technology Conference in Copenhagen

– Iztok Kosem gave various talks on dictionaries, including **Dictionary makers and dictionary users in the era of technological progress** at the International Symposium on Lexicographical Innovation in the Era of Disruptive Technology in China

Together with the Centre for Knowledge Transfer in Information Technologies (CT3), we continued to use the Videolectures.NET portal to promote artificial intelligence, the Jožef Stefan Institute and Slovenian research in general. We are also among the main organizers and supporters of the annual national ACM Computer Science Competition for secondary-school students; in 2022, 188 students from 28 schools participated in the competition.

We have also been active in promoting women in science, providing a virtual exhibition about female PhD holders in the area of computer science and electrical engineering in Slovenia. We are also constantly updating our publicly available resources related to women-in-science issues and related international news (http://ScienceWithArt.ijs.si/).

Gender equality required to unlock research potential is the topic of the H2020-CSA project **Athena**, in which we are collaborating; the project aims at removing barriers to the recruitment, retention and career progression of female researchers, lowering gender imbalances in decision-making processes and generating a cultural change needed to avoid gender bias and discriminatory practices through the implementation of gender equality plans (GEPs). To ensure a systemic institutional change, we conducted an assessment of the procedures and practices already in place, together with an analysis of the national legislation and policy frameworks. In parallel, we put in place a participatory process aimed to understand the needs and preferences of the stakeholders and train them on selected topics related to gender. We developed the Gender Equality Plan for the JSI and started implementing it at the institutional level.

> **Members of the Department hold important positions in professional associations:**
> - **Simon Krek: ELRA Board – treasurer, member of the board**
> - **Iztok Kosem: EURALEX Board**
> - **Dunja Mladenic: SLAIS – member of the Executive Board**
> - **Dunja Mladenic: ACM Slovenija – member of the Executive Board**
> - **Iztok Kosem: Advisory Board of EURAC**
> - **Marko Grobelnik: ACM Slovenija – member of the Advisory Board**

In 2022 **the International Research Center on Artificial Intelligence under the auspices of UNESCO (IR-CAI)**, a laboratory within the Department of Artificial Intelligence, expanded the NAIXUS network to strengthen AI research centers of excellence around the world and facilitate their collaboration and networking to increase the research capacity in AI and sustainable development. As part of this initiative, we contributed to the development of ethical and trustworthy artificial intelligence, as expected in the UNESCO recommendation. Within the NAIXUS network, IRCAI successfully launched a new scientific journal on artificial intelligence and sustainable development.

Within the IRCAI activities, we organized a virtual event to present the IRCAI Award for 2021 to researcher Adriana-Euforsina Bora for outstanding achievements of her AIMS project in the field of artificial-intelligence solutions in tackling forms of modern slavery through understanding the annual reports of multinationals.

IRCAI published an international list of artificial-intelligence innovations for sustainable development for the benefit of humanity, comprising stakeholders working to achieve 17 Sustainable Development Goals, covering multiple sectors and every geographic region of the United Nations. After the implementation of the international program, IRCAI published a report with an analysis of the 100 submitted solutions. The projects called 'exceptional solutions' were presented on Friday, 18 February, at an event co-organized by IRCAI and the Permanent Mission of Slovenia to the UN. The agenda included the speeches by Ambassador Boštjan Malovrh, Permanent Representative of Slovenia to the UN, Tawfik Jelassi, Assistant Director General for Communication and Information of UNESCO, Maria-Francesca Spatolisano, Acting Representative of the Office of the Secretary General for Technology, Ambassador Collen Vixen Kelapila, Permanent Representative of Botswana at the UN, President of ECOSOC, and John Shawe-Taylor, Director of IRCAI.

Some outstanding publications in the past year

1. Alba, Ester, Gaitán, Mar, León, Arabella, Mladenić, Dunja, Brank, Janez. Weaving words for textile museums: the development of the linked SILKNOW thesaurus. *Heritage Science*. 2022, vol. 10, pp. 59-1-59-14. ISSN 2050-7445. DOI: 10.1186/s40494-022-00681-x. [COBISS.SI-ID 108280323], [JCR, SNIP, WoS, Scopus]

2. Althoff, Tim, Nilforoshan, Hamed, Hua, Jenna, Leskovec, Jurij. Large-scale diet tracking data reveal disparate associations between food environment and diet. *Nature Communications*. 18 Jan. 2022, vol. 13, pp. 1–12, illustr. ISSN 2041-1723. https://www.nature.com/articles/s41467-021-27522-y.pdf, DOI: 10.1038/s41467-021-27522-y. [COBISS.SI-ID 133884419]

3. Beltramo, Gabriele, Škraba, Primož. Persistent homology in l∞metric. *Computational Geometry*. [Print ed.]. Feb. 2022, vol. 10, pp. 1–28. ISSN 0925-7721. DOI: 10.1016/j.comgeo.2021.101821. [COBISS.SI-ID 119533315], [JCR, SNIP, WoS, Scopus]

4. Beltramo, Gabriele, Škraba, Primož, Andreeva, Rayna, Sarkar, Rik, Giarratano, Ylenia, Bernabeu, Miguel O. Euler characteristic surfaces. *Foundations of Data Science*. Dec. 2022, vol. 4, iss. 4, str. 505-536. ISSN 2639-8001. DOI: 10.3934/fods.2021027. [COBISS.SI-ID 119732483], [WoS, Scopus]

5. Besher, Massri M., Novalija, Inna, Mladenić, Dunja, Brank, Janez, Graça Da Silva, Sara, Marrouch, Natasza, Murteira, Carla, Hürriyetoglu, Ali, Šircelj, Beno. Harvesting context and mining emotions related to olfactory cultural heritage. *Multimodal Technologies and Interaction*. 2022, vol. 6, iss. 7, 22 pp., illustr. ISSN 2414-4088. DOI: 10.3390/mti6070057. [COBISS.SI-ID 116087299].

6. Besher, Massri M., Pita Costa, João, Grobelnik, Marko, Brank, Janez, Stopar, Luka, Bauer, Andrej. A global COVID-19 observatory, monitoring the pandemics through text mining and visualization. *Informatica: an International Journal of Computing and Informatics*. [Print ed.]. March 2022, vol. 46, no. 1, pp. 49–55. ISSN 0350-5596. https://www.informatica.si/index.php/informatica/article/download/3375/1741, DOI: 10.31449/inf.v46i1.3375. [COBISS.SI-ID 107602179], [SNIP, WoS]

7. Brbić, Maria, Cao, Kaidi, Hickey, John W., Leskovec, Jurij, et al. Annotation of spatially resolved single-cell data with STELLAR. *Nature Methods*. [Online ed.]. Nov. 2022, vol. 19, iss. 11, pp. 1411–1418, illustr. ISSN 1548-7105. https://www.nature.com/articles/s41592-022-01651-8, https://cs.stanford.edu/~jure/pubs/stellar-natmet22.pdf, DOI: 10.1038/s41592-022-01651-8. [COBISS.SI-ID 133196547]

8. Kenda, Klemen, Mellios, Nikolaos, Senožetnik, Matej, Pergar, Petra. Computer architectures for incremental learning in water management. *Sustainability*. 2022, vol. 14, no. 5, pp. 2886-1-2886-18. ISSN 2071-1050. DOI: 10.3390/su14052886. [COBISS.SI-ID 105346563], [JCR, SNIP, WoS, Scopus]

9. Rožanec, Jože Martin, Trajkova, Elena, Novalija, Inna, Zajec, Patrik, Kenda, Klemen, Fortuna, Blaž, Mladenić, Dunja. Enriching artificial intelligence explanations with knowledge fragments. *Future Internet*. May 2022, vol. 14, iss. 5, [article no.] 134, pp. 1–13, illustr. ISSN 1999-5903. DOI: 10.3390/fi14050134. [COBISS.SI-ID 140408579]

10. Rožanec, Jože Martin, Lu, Jinzhi, Rupnik, Jan, Škrjanc, Maja, Mladenić, Dunja, Fortuna, Blaž, Zheng, Xiaochao, Kiritsis, Dimitris. Actionable cognitive twins for decision making in manufacturing. *International Journal of Production Research*. 2022, vol. 60, no. 2, pp. 452–478, illustr. ISSN 0020-7543. DOI: 10.1080/00207543.2021.2002967. [COBISS.SI-ID 87580163]

11. Rožanec, Jože Martin, Fortuna, Blaž, Mladenić, Dunja. Reframing demand forecasting: a two-fold approach for lumpy and intermittent demand. *Sustainability*. 2022, vol. 14, no. 15, pp. 9295-1-9295-18. ISSN 2071-1050. DOI: 10.3390/su14159295. [COBISS.SI-ID 117263619]

12. Sittar, Abdul, Mladenić, Dunja, Grobelnik, Marko. Analysis of information cascading and propagation barriers across distinctive news events. *Journal of Intelligent Information Systems*. 2022, vol. 58, no. 1, pp. 119–152, illustr. ISSN 0925-9902. DOI: 10.1007/s10844-021-00654-9. [COBISS.SI-ID 87232003], [JCR, SNIP, WoS, Scopus]

13. Sittar, Abdul, Major, Daniela, Mello, Caio, Mladenić, Dunja, Grobelnik, Marko. Political and economic patterns in COVID-19 news: from lockdown to vaccination. *IEEE Access*. 2022, vol. 10, pp. 40036–40050, illustr. ISSN 2169-3536. DOI: 10.1109/ACCESS.2022.3164692. [COBISS.SI-ID 105869315].

14. Novak, Erik, Bizjak, Luka, Mladenić, Dunja, Grobelnik, Marko. Why is a document relevant? Understanding the relevance scores in cross-lingual document retrieval. *Knowledge-Based Systems*. [Print ed.]. 2022, vol. 244, art. 108545, 41 pp. ISSN 0950-7051. DOI: 10.1016/j.knosys.2022.108545. [COBISS.SI-ID 100777731]

Awards and Appointments

1. Pasquale Lisena, Daniel Schwabe, Marieke van Erp, Raphaël Troncy, William Tullett, Inger Leemans, Lizzie Marx, Best Resources Paper, Heraklion, Greece, ESWC conference
2. 2022 European Heritage Awards / Europa Nostra Awards, H2020 Silknow project Europa Nostra Grand Prix Award, H2020 Silknow project, Prague, Czechia

Organization of Conferences, Congresses and Meetings

1. Science Dialogues, 5 January 2022 (virtual)
2. Connect AI webinar, 5 January 2022 (virtual)
3. IRCAI Top 10, 14 January 2022 (virtual)

4. Science Dialogues II: AI in Climate, 18 January 2022 (virtual)
5. Science and Innovation Dialogues: Machine Learning in Healthcare: Towards a New Human-Machine Partnership, 11 February 2022 (virtual)
6. AI Award and Round Table on Artificial Intelligence for Monitoring Sustainable Development, 17 March 2022 (virtual)
7. STI Forum side event: Launching a Global Network of AI Excellence Centres in Sustainable Development, 4 May 2022 (virtual)
8. ELRC workshop, Ljubljana, 27 May 2023
9. NAIXUS project kick-off, 17 June 2022 (virtual)
10. IRCAI – Amazon Sustainability Data Initiative (ASDI) Global Hackathon, 27–28 June 2022 (virtual)
11. Science and Innovation Dialogues: Stronger Together through the Power of Artificial Intelligence for the Common Good, 7 October 2022 (virtual)
12. SiKDD, Slovenian KDD Conference, Ljubljana, 10 October 2022 (hybrid)
13. OdEuropa project meeting, Ljubljana, 9–10 November 2023
14. EU D4D: Roundtable A: Shaping an EU-LAC approach to human-centred and inclusive digitalisation: the role of emerging technologies, 12 December 2022 (virtual)

INTERNATIONAL PROJECTS

1. European Language Grid (GA 825627)
   Asst. Prof. Simon Krek
   Dfki Gmbh - Deutsches Forschungszentrum Fuer
2. Action on CEF Automated Translation Core Service Platform (CSP); CEF SMART 2019/1083; LC-01325001
   Asst. Prof. Simon Krek
   Dfki Gmbh - Deutsches Forschungszentrum Fuer
3. INEA/CEF: CURLICAT; Curated Multilingual Language Resources for CEF AT
   Asst. Prof. Simon Krek
   Innovation And Networks Executive Agency (inea)
4. INEA/CEF: FedTerm; Federated eTranslaton Termbank Network
   Asst. Prof. Simon Krek
   Innovation And Networks Executive Agency (inea)
5. PPPA - ELE; European Language Equality
   Asst. Prof. Simon Krek
   European Commission
6. ERASMUS+: BRIDGES - Bridging Educational Emergency to Digital Pedagogies
   Kim Sevšek
   Agenzia Nazionale Erasmus Plus Indire
7. COST CA18209; European Network for Web-Centred Linguistic Data Science
   Asst. Prof. Simon Krek
   Cost Association Aisbl
8. COST CA18231; Multi3Generation: Multi-Task, Multilingual, Multi-Modal Language Generation
   Marko Grobelnik
   Cost Association Aisbl
9. H2020 - Cleopatra; Cross-Lingual Event-Centric Open Analytics Research Academy
   Marko Grobelnik
   European Commission
10. H2020 - NAIADES; A Holistic Water Ecosystem for Digitisation of Urban Water Sector
    Marko Grobelnik
    European Commission
11. H2020 - CyberSANE; Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures
    Marko Grobelnik
    European Commission,the Directorate-general
12. H2020 - INFINITECH; Tailored IoT&BigData Sandboxes and Testbeds for Smart, Autonomous and Personalized Services in the European Finance and Insurance Services Ecosystem
    Marko Grobelnik
    European Commission
13. H2020 - FACTLOG; Energy-aware Factory Analytics for Precess Industries
    Prof. Dunja Mladenić
    European Commission
14. H2020 - HumanE-AI-Net; HumanE AI Network
    Marko Grobelnik
    European Commission
15. H2020 - STAR; Safe and Trusted Human Centric Artifical Intelligence in Future Manufacturing Lines
    Marko Grobelnik
    European Commission
16. H2020 - ODEUROPA: Negotiating Olfactory and Sensory Experiences in Cultural Heritage Practice and Research

Prof. Dunja Mladenić
European Commission
17. H2020 - EU-Japan.Ai: Advancing Collaboration and Exchange of Knowledge Between the EU and Japan for AI-Driven Innovation in Manufacturing
    Marko Grobelnik
    European Commission
18. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
    Prof. Dunja Mladenić
    European Commission
19. H2020 - ELEXIS; European Lexicographic Infrastructure
    Asst. Prof. Simon Krek
    European Commission
20. HE - CONDUCTOR; Fleet and Traffic Management Systems for Conducting Future Cooperative Mobility
    Marko Grobelnik
    European Commission
21. Slovenian Innovation Ecosystem Watch
    Marko Grobelnik
    Google Ireland Limited
22. AIRISE - International Policy Observatory Framework
    Prof. John Stewart Shawe-Taylor
    Iceed - International Council On Environmental
23. COST CA21167; Universality, Diversity and Idiosyncrasy in Language Technology (UniDive)
    Asst. Prof. Simon Krek
    Cost Association Aisbl

RESEARCH PROGRAMME

1. Knowledge Technologies
   Prof. Dunja Mladenić
   Slovenian Research Agency

R&D GRANTS AND CONTRACTS

1. Correlating desired phenotypic traits using behavioural, physiological and anatomical features with genetic markers in Lipizzan horse
   Dr. Aljaž Košmerlj
2. Causalify - Causality in global social dynamics
   Prof. Dunja Mladenić
3. Defining a framework to ensure public trust in systems and applications of Artificial Intelligence
   Marko Grobelnik
4. A framework for measuring the potential of artificial intelegence implementation in Slovenia with an in-depth analysis of the situation in Slovenia and the EU and a multi-method approach to analysis of status and trends in Slovenia
   Prof. Dunja Mladenić
5. Proteverb - Legal, ethical and technological aspects of processing textual and speech

data for scientific, research and development purposes
Asst. Prof. Simon Krek
6. Slovenian Artificial Intelligence Observatory
Prof. Dunja Mladenić
7. Clarin
Asst. Prof. Simon Krek
Institut Jožef Stefan
8. For the Quality of Slovene Textbooks
Asst. Prof. Simon Krek
Ministry of Education, Science and Sport
9. Development of Slovene in the digital environment
Dr. Aljaž Košmerlj
Ministry of Culture
10. A framework for measuring the potential of artificial intelegence implementation in Slovenia with an in-depth analysis of the situation in Slovenia and the EU and a multi-method approach to analysis of status and trends in Slovenia
Prof. Dunja Mladenić
Služba Vlade Republike Slovenije
11. Proteverb - Legal, ethical and technological aspects of processing textual and speech data for scientific, research and development purposes
Asst. Prof. Simon Krek
Služba Vlade Republike Slovenije
12. Defining a framework to ensure public trust in systems and applications of Artificial Intelligence
Marko Grobelnik
Služba Vlade Republike Slovenije
13. Accompanying corpus and accompanying data sources, JR-infrastructure-SJ-2021-2022
Dr. Iztok Kosem
Ministry of Culture
14. Financing of projects visits at the Slovenian higher education institutions
Dr. Alenka Guček
Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia

15. IRCAI - International Research Center for Artificial Intelligence – UNESCO
Mitja Jermol, M. Sc.
Ministry of Education, Science and Sport
16. SLOKIT: Upgrade of CLARIN.SI: Corpus informer and text analyzer
Dr. Iztok Kosem
Ministry of Culture
17. Digitization of analytical support in the national crisis management center
Marko Grobelnik
Ministry of Defence
18. Slovenian Artificial Intelligence Observatory
Prof. Dunja Mladenić
Ministry of Public Administration
19. Slovenian Artificial Intelligence Observatory
Prof. Dunja Mladenić
Ministry of Foreign Affairs
20. Slovenian Artificial Intelligence Observatory
Prof. Dunja Mladenić
Urad Vlade Republike Slovenije Za
21. Slovenian Artificial Intelligence Observatory
Prof. Dunja Mladenić
Ministry of Education, Science and Sport
22. Preparation and Analysis of Data for Workshops
Dr. Iztok Kosem
Universidade de Coimbra
23. A Series of Events Organized with the Slovenian Embassies
Mihajela Črnko
24. Management of the European Statistics Award for Web Intelligence - LOT 1
Marko Grobelnik
European Commission
25. Management of the European Statistics Award for Nowcasting - LOT 2
Marko Grobelnik
European Commission

VISITORS FROM ABROAD

1. Magdim Pašić, University of Zagreb, Croatia, 21 March 2022
2. Nadira Ahmadi, Afghanistan, 15 April 2022
3. Wassim Haroun, Conser, Dubai, United Arab Emirates, 6 May 2022
4. Natasa Milic-Frayling, Intact Digital, United Kingdom, 14 June 2022
5. Natasa Milic-Frayling, Intact Digital, United Kingdom, 21 July 2022
6. Prof. dr Maria Fasli, University of Sussex, United Kingdom, 1 August 2022
7. Michael Witbrock, University of Auckland, New Zealand, 3 August 2022
8. Rok Sosič, Stanford University, USA, 3 August 2022
9. Tel Amiel, University of Brasilia, Brazil, 17 August 2022 – an ongoing visit
10. Anastassia Fedyk, University of California, Berkeley, USA, 6 September 2022
11. James Hodson, AI for Good, USA, 6 September 2022
12. Laurence Devillers, Sorbonne University, Paris, France, 29 September 2022

STAFF

Researchers
1. Asst. Prof. Branko Kavšek*
2. Dr. Iztok Kosem
3. Asst. Prof. Simon Krek*
4. *Asst. Prof. Simon Krek, left 01.11.22*
5. Dr. Jurij Leskovec
6. **Prof. Dunja Mladenić, Head**
7. Prof. John Stewart Shawe-Taylor
8. Asst. Prof. Primož Škraba
Postdoctoral associates
9. Dr. Luka Bradeško*
10. *Dr. Luka Bradeško, left 01.07.22*
11. Dr. Jaka Čibej*
12. Dr. Kaja Dobrovoljc*
13. Dr. Blaž Fortuna*
14. Dr. Alenka Guček
15. *Dr. Aljaž Košmerlj, left 24.01.22*
16. *Dr. Adam Rambousek, left 01.08.22*
17. *Dr. Luka Stopar, left 01.12.22*
Postgraduates
18. Swati , M. Sc.
19. Rayid Ghani, M. Sc.
20. Jakob Jelenčič, B. Sc.
21. Mitja Jermol, M. Sc.
22. Klemen Kenda, B. Sc.
23. Mark D Minevich, M. Sc.
24. Erik Novak, B. Sc.
25. Jose Martin Rožanec, M. Sc.
26. Abdul Sittar, M. Sc.
27. Jan Šturm, B. Sc.

Technical officers
28. *Luka Bizjak, B. Sc., left 01.10.22*
29. Dr. Janez Brank
30. Dr. Miha Cimperman
31. Teja Goli, B. Sc.
32. Dr. Matej Kovačič
33. Dr. Gregor Leban*
34. Jose Luis Machado Rei, M. Sc.
35. Dr. Inna Novalija
36. Dr. Ervin Pfeifer*
37. *Matej Posinković, B. Sc., left 18.04.22*
38. Dr. Jan Rupnik*
39. Dr. Polona Škraba Stanič
40. Maja Škrjanc, B. Sc.
Technical and administrative staff
41. Aleš Buh
42. Mihajela Črnko
43. Jasna Franko, B. Sc.
44. Marko Grobelnik
45. Mojca Kregar, B. Sc.
46. Monika Kropej, B. Sc.
47. Blaž Novak, B. Sc.
48. Kim Sevšek, B. Sc.
49. Špela Sitar, B. Sc.
50. Mateja Škraba, B. Sc.

Note:
* part-time JSI member

LABORATORY FOR OPEN SYSTEMS AND NETWORKS

E-5

The main activities of the laboratory are R&D in the area of next-generation networks, telecommunications technologies, components and integrated systems, information-society services, mechanisms and applications, especially those that enable better privacy protection of citizens and an increased trustworthiness of information and communication technologies and services.

The research in 2022 was performed within the research programme *Future Internet Technologies: concepts, architectures, services and socio-economic issues*, funded by the Slovenian Research Agency. In addition, research was carried out within the EU Horizon 2020 projects CONCORDIA, DE4A, BD4OPEM and iFlex, the EU DG Justice EIO-LAPD project, and national projects *Artificial intelligence for cybersecurity* and *Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation*. The focus was on the development of the technologies and services of advanced next-generation networks, security and privacy in information systems, and technology-enhanced learning.

Members of the laboratory teach at the undergraduate and postgraduate levels at the Jožef Stefan International Postgraduate School, the DOBA Faculty, and the Faculty of Commercial and Business Sciences. The laboratory is a member of the European Cyber Security Organisation (ECSO).

Head:
Asst. Prof. Tomaž Klobučar

Concepts and architectures of the secure internet, internet technologies and information systems

Research in the first area was related to security infrastructure and trusted services in the areas of public administration, healthcare and industrial systems.

The **DE4A** (Digital Europe for All) project aims at facilitating migration towards secure European digital public services, co-delivered across borders, across sectors to different participants, and at implementing the latest EU directives and regulations (e.g., eIDAS, Single Digital Gateway). The project simplifies the cross-border user interaction with the selected procedures, systems and platforms, and demonstrates, in practice, the benefits of realizing cross-borders principles of Once-Only and Digital-by-Default for different stakeholders. Our main role in the project is to coordinate the Studying Abroad pilot, one of three project pilots, and carry out an analysis of the current eGovernment landscape. The pilot implements and validates the cross-border higher-education procedures of the Single Digital Gateway Regulation, in particular applications to higher education institutions, applications for study grants, and recognition of diplomas. In 2022 we improved the grant-application service that allows students from Portugal and Spain to use their national eIDs to access the services and explicitly request the use of the DE4A technical system to have their thesis evidence required through an electronic transfer from a trusted source in their home country. This way, students no longer have to search for evidence and fill in the necessary application forms by themselves. We further assessed infrastructure building blocks and the readiness of the EU member states to introduce secure cross-border services. Other Slovenian partners in the project launched in 2020 are the Ministry of Education, Science and Sport, the Ministry of Public Administration, and the University of Maribor.

An adequate security architecture is also important in the field of healthcare. The interconnectedness of medical devices through the Internet of Things (IoT) has increased the quality of patient care and facilitated the work of healthcare professionals, but also introduced new cybersecurity challenges. Device or system vulnerability can directly affect patients' safety and lives as well. We established a clinical IoT architecture that enables cybersecurity by design by addressing trust, identity, privacy, protection, safety and security (TIPPSS) as architecture principles. It detects requirements that, although critical in healthcare, are partially or completely

> We have created building blocks for security infrastructures and secure internet services, supporting the process of digitalization in various public sectors.
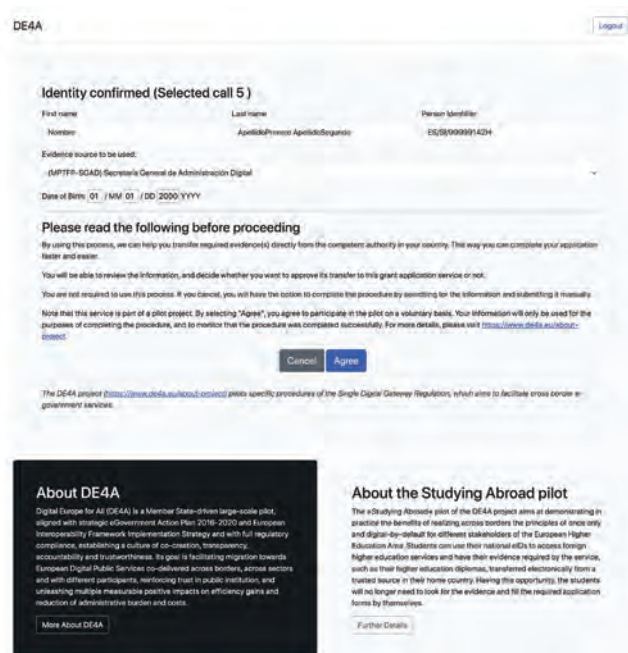
Figure 1: Cross-border DE4A service

unaddressed by the current reference architectures. The work elicited a holistic architecture framework for the clinical IoT that is specific enough to be formalized and sufficiently generic for application to any clinical IoT domain. Based on this architecture, a taxonomy of TIPPSS architecture principles was devised with a goal-based evaluation methodology for cybersecurity architectures.

The problem of performing cybersecurity tests of the existing critical infrastructure is wellknown. Once it is deployed, a critical system cannot be made unavailable for simulating cyber-attacks. On the other hand, a high-security posture is required for the critical infrastructure from the beginning. Since the creation of a physical model is often costly or impossible, we proposed the introduction of a specific architectural view in the system's architecture blueprint, called the Cybersecurity Digital Twin. It is an Enterprise Architecture model of the system specifically targeted at providing a sound base for simulations to devise proper countermeasures without any outage of the physical infrastructure. To provide a proof of concept and demonstrate the practical viability of the proposed solution, we applied the methodology to a Cooperative Intelligent Transport System use case, evaluating the system security of the obtained solution. After its successful application, the methodology was fine-tuned and adjusted for additional use cases, both in transportation and in other critical and non-critical sectors (smart grids and energy, health, business, and education).

The inherent scalability and flexibility of structured overlay networks make them an excellent choice for the support of modern-day applications with complex, volatile, mobile and heterogeneous infrastructures. However, the heterogeneity and volatility of the infrastructure increase the need for more reliable maintenance mechanisms to guarantee the availability and performance of structured overlay networks in the presence of autonomous participants. To address this issue, we have proposed the use of a state-based predictive maintenance mechanism based on the intelligent prediction of the dynamics of the neighbouring node (k closest successors as defined in a DHT finger table) to schedule proactive maintenance of the nodes having periodic availabilities. The evaluation of the proposed model of the chord-based overlay network, using the proposed predictive maintenance approach, shows a 54% improvement in the lookup success ratio and a 59% improvement in the maintenance overhead as compared to the state-of-the-art periodic maintenance with a frequent stabilization interval.

Internet technologies facilitate the integration of end-users into the electricity market and help power distributors in the market operation.

As part of the **infrastructure program in research organizations** we continue to provide support services that enable better communication among members of various research programs, as well as students and their mentors from geographically dispersed institutions. These services proved crucial to the smooth operation of the Institute during the COVID-19 pandemic. In addition, the infrastructure program provided 20 GoToMeeting licences and, together with the Centre for Network Infrastructure, additional 150 Zoom licences. The services and licences were provided to 31 departments, laboratories, centres and other organizational units of the Institute. We also supported the organization and implementation of the Slovenian and European Science Festival 2022.

Digital services and internet technologies in the energy sector

A large share of the projects is related to the planning, implementation and use of digital services and internet technologies in the energy sector. The **BD4OPEM** (Big Data for Open Innovation Energy Marketplace) project uses a data-centric approach to innovate between the needs of energy stakeholders and the solutions being developed. A data flow through the marketplace enables the development of analytic services to boost business processes. To date, the laboratory has focused on predictive maintenance, a non-technical loss analysis, flexibility prediction in the distribution network, and privacy and security of the marketplace and services. A module for service provision and automated service management has been developed. An article on behaviour segmentation of electricity consumption patterns was published in the Elsevier journal Knowledge Based Systems. Electro Celje smart metering data were analysed for typical groups and features were defined for an efficient classification of the consumers. Two JSI departments, our laboratory and the Department of Communication Systems participate in the project, while a key Slovenian partner from the energy sector is Elektro Celje.
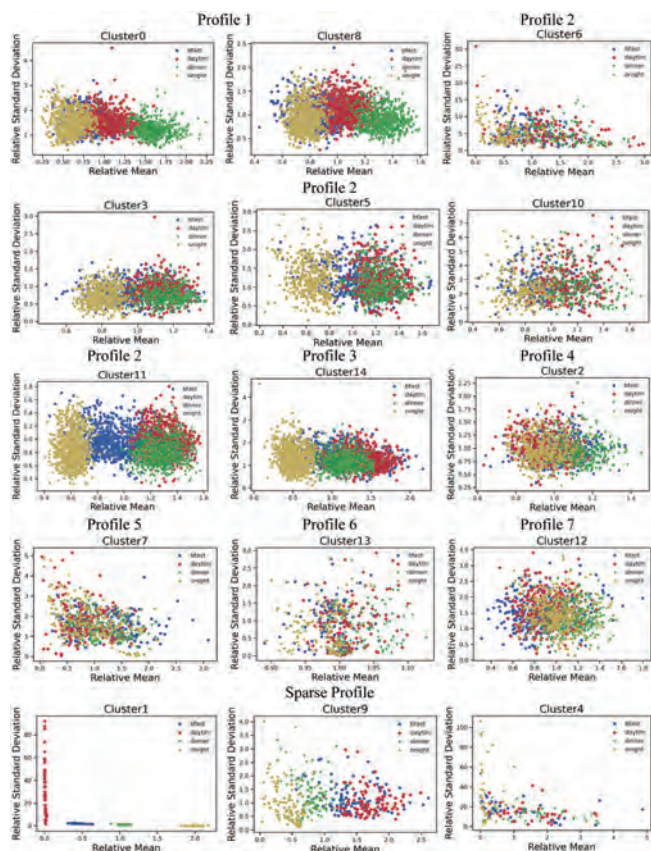
Figure 2: Behaviour variability of energy users

The **iFlex** (Intelligent Assistants for Flexibility Management) project focuses on the design, development and evaluation of supporting tools for consumers' successful participation in various flexibility services of the smart grid of the future and for their easier pursuit of sustainability goals in their premises. A strong Slovenian consortium is participating in the project: Elektro Celje, Elektro Celje Energija, Smart Com, Slovene Consumers Associations, and the JSI Laboratory for Open Systems and Networks. The tasks of the laboratory include security and privacy of the project solutions, data analytics, consumer profiling, development of the digital twin of consumer premises and optimal, multicriteria control of consumer home power consumption. In 2022 we developed and setup a basic data management service for pilot consumers and a digital twin of a household with a heat pump and storage boiler.

In 2022 we secured a major new project from the Horizon Europe programme. Within the **Resonance** (Replicable and Efficient Solutions for Optimal Management of Cross-Sector Energy) project, we will develop a catalogue of hardware and software solutions for the efficient management of energy consumption and production for a wide range of end users. The end users supported will be households, apartment buildings, office buildings, shopping centres and industry. The elements of the catalogue will be developed at three levels: resource manager, customer energy manager, and aggregation. The catalogue solutions will be evaluated within pilots in six countries: France, Germany, Sweden, Finland, Greece and Slovenia. A strong Slovenian consortium is involved in the project: ECE, Elektro Celje, SmartCom, Amibit, and the JSI. The Slovenian pilot will initially focus on households with heat pumps and renewables, price-based demand response, and aggregation for imbalance management and renewables balancing. In the second piloting cycle, the solutions developed in other pilots will be evaluated: apartment building heating, the network batteries and EV charging and optimization of solutions for energy efficiency. In the project, we are leading the work package on the resource manager catalogue and tasks related to secure and privacy-preserving data management.

Mechanisms for security and privacy provision in information systems

Ensuring the security and privacy of information systems is the key to the functioning of the modern information society and the development of an efficient digital market. In 2022 a research topic was mathematical models for constructing significant Boolean functions used in symmetric cryptographic algorithms. We studied sufficient conditions for a function of the form to have a five-valued Walsh spectrum. The presented method specifically identifies several classes of five-valued Walsh spectrum functions by adding an arbitrary product of linear functions to a known quadratic bent function. The significance of this result is that it allows the control of the degree of function by adding an arbitrary product of linear functions. As a result, functions with a degree of 2 or 3 or even with an optimal algebraic degree can be obtained, depending on the number of variables. This is in contrast to the recently proposed results, which do not offer this level of control over the degree of a function. The results were published in the Journal of Discrete Mathematical Sciences & Cryptography.

Advanced technologies that promise a more effective cybersecurity provision include artificial intelligence (AI), which is especially useful in analysing and processing a large number of security-relevant events and in detecting and responding to unknown threats and forms of cyber-attacks. In addition to appropriate competences and collaboration, information on research gaps in this field, and R&D capabilities and comparative advantages of Slovenia are also important for a more efficient research and development and the breakthrough of Slovenian security solution providers in the EU and global markets. The **Artificial intelligence for cybersecurity** project was aimed at the research of AI methods and use cases for cybersecurity, analysing the current situation in this field in Slovenia, EU and the rest of the world, identifying potential areas where Slovenia has comparative advantages and development potentials, and preparing the guideline proposals for this development. We prepared a taxonomy of AI methods for cyber security and described cases of the use of AI for cyber security. Based on a literature analysis, we created a list of research and development gaps, which were classified into four groups: i) new areas of AI use in cyber security, (ii) data sources and presentation, (iii) advanced UI methods for cyber security, and (iv) research and development of a new infrastructure. Research and development gaps combined with an analysis of the capacities and needs of Slovenian researchers, providers and users of solutions in the fields of cyber security and AI, EU priorities and stakeholder requirements were also the basis for the preparation of a proposal for short-term, medium-term and long-term goals and measures for further development.

Research on the acquisition of cross-border digital evidence in crime investigation, enabled by the implementation of Directive 2014/41/EU and Slovenian legislation, was part of the **EIO-LAPD** (European Investigation Order – legal analysis and practical dilemmas of international cooperation) project funded by the EU DG Justice. The project, where we closely collaborated with institutions from Austria, Croatia, Italy, Germany, Slovenia and Portugal, was successfully finished in 2022.

The Laboratory for Open Systems and Networks is a member of **CONCORDIA** (Cyber security competence for research and innovation), one of the four European centres of excellence in cyber security from the H2020 programme with leading competences in research, technology, industry and the public domain. The centre provides

research and development solutions for a safe, resilient and trustworthy European ecosystem. Within CONCORDIA, the laboratory contributes its research on user-centric security, mainly through models for fighting disinformation, facilitating online trust management, and establishing electronic identities. In addition, the laboratory is actively involved in the area of cybersecurity education focused on the development of new educational methods and approaches. The laboratory contributed to the new methodology for cyber security education that was published as one of the project deliverables. The methodology is currently applied in teaching high cybersecurity school students in Slovenia. As a result of this work, an article was published in a journal with a high impact factor.

> **Our research and development activities and results enable a more secure and trustworthy information society.**

In 2022, together with several other research departments and centres at the JSI (F1, F5, E6, CMI), we secured another important project. **SiQUID** (Slovenian Quantum Communication Infrastructure Demonstration) aims to establish quantum key distribution (QKD) links among multiple government nodes in Slovenia, while also creating a test-bed quantum network for advanced quantum-communication protocols among research institutions in Ljubljana. The project will involve collaboration with public and industrial stakeholders, and training of key personnel, young researchers, and engineers in quantum technology. It will test advanced quantum communication protocols like measurement-device-independent QKD and the long-distance distribution of entanglement to further increase the security of QKD implementations, and to prepare the ground for a future full-fledged quantum-communication network. In addition, the project will be in close contact with the QCI initiatives from the neighbouring countries to facilitate the harmonisation of national efforts, future cross-border links and the implementation of the space segment of EuroQCI.

Information-society services, applications and socio-economic issues

Successful teaching of basic digital skills requires an approach based on the needs and abilities of older adults. Within the scope of the DIGIBLEND (Improving adult digital literacy through innovative gamified blended learning) project, we have continued developing a new and innovative approach to teaching basic digital skills to a target group of older adults. To achieve this, we used familiar game-based elements combined with an interactive blended learning approach to develop a physical knowledge-assessment board game.

The Laboratory for Open Systems and Network is involved with several other research departments and Director's office at the Jozef Stefan Institute in the **Athena** project, aiming at removing barriers to the recruitment, retention and career progression of female researchers, lowering gender imbalances in decision-making processes and generating a cultural change needed to avoid gender bias and discriminatory practices through implementation of Gender Equality Plans (GEPs). To ensure a systemic institutional change, the project plans to assess procedures and practices already in place in partner organizations, together with an analysis of the national legislation and policy frameworks. In parallel, it will put in place a participatory process aimed, on the one hand, to understand the needs and preferences of the stakeholders and, on the other hand, to train them in selected topics related to gender. As a final result, each partner organization is preparing its own GEP and monitoring the implementation with specific indicators. In 2022 the Laboratory for Open Systems and Networks contributed to the GEP document a chapter addressing the diagnosis of the current situation at the IJS and organized the first workshop for the state holders of the project from all over Slovenia in September 2022

Figure 3: A board game to determine the digital knowledge of senior citizens

In 2022, in collaboration with the Centre for Technology Transfer and Innovation from the Jožef Stefan Institute, the laboratory successfully completed the national project on the evaluation of intellectual property as the basis for proposing a long-term sustainable state-aid model to promote science-business cooperation. The project, funded by the Ministry of Education, Science and Sport and the Slovenian Research Agency, provided quantitative and qualitative analyses of the critical points of intellectual property rights (IPR) and pathways for the transfer of IPR, accompanied by guidelines for the IPR management in collaborative R&D projects. A proposal for the regulation of the state-aid system with the properties that ensure its sustainability was submitted. The required changes for the achievement of a more effective cooperation in the innovation helix were prepared.

The laboratory is also an active member of the IEEE P2933 Working Group on Clinical IoT Standardisation. It co-chairs the Trust and Identity Subgroup (T&I SG) and is an active member of the Intelligent System Design SG. As part of the standard, the laboratory has outlined the standard development methodology from an identity and

trust point of view and developed the taxonomy of the clinical IoT system design. These served as an alignment between different subgroups in the integration of their parts into the standard's architecture. At the same time, the laboratory is acting as a link between the EU and US (technological and regulatory) perspectives on trust and identity in Clinical IoT, bringing into the standard the experience and lessons learned from the e-SENS and CONCORDIA architectures for the e-health pilots. In 2022 we were involved in the finalization of the first draft of the standard, covering the parts on and actively contributing to the computational trust model for the Clinical IoT architecture, inter-dependencies between trust and identity, and evaluation of the Clinical IoT reference architecture from the cybersecurity aspect.

Some outstanding publications in the past three years

1. Kaur, R., Gabrijelčič, D. Behavior segmentation of electricity consumption patterns: a cluster analytical approach. Knowledge-based systems, ISSN 0950-7051. [Print ed.], 2022, vol. 251, art. 109236, 39 pages.
2. Jerman Blažič, B., Jerman Blažič, A. Cybersecurity skills among European high-school students: a new approach in the design of sustainable educational development in cybersecurity. Sustainability, ISSN 2071-1050, 2022, vol. 14, iss. 8, 23 pages.
3. Joksimoski, B., Zdravevski, E., Lameski, E., Miguel Pires, I., José Melero, F., Puebla Martinez, T., Garcia, N., Mihajlov, M., Chorbev, I., Trajkovik, V. Technological solutions for sign language recognition: a scoping review of research trends, challenges, and opportunities. IEEE Access, ISSN 2169-3536, 2022, vol. 10, March, pp. 40979-40998.

Organization of conferences, congresses and meetings

1. 27th Slovenian Festival of Science with international participants, 9. – 15. November, 2022 (virtual).

INTERNATIONAL PROJECTS

1. EIO-LAPD-JUST-AG-2018/JUST-JCOO-AG-2018; European Investigation Order - Legal Analysis and Practical Dilemmas of International Cooperation
   Prof. Borka Džonova Jerman Blažič
   European Commission, Directorate General Justice
2. ERASMUS+; DigiBlend - Improving Adult Digital Literacy Through Innovative Gamified Blended Learning
   Dr. Martin Mihajlov
   European Commission
3. H2020 - CONCORDIA; Cyber Security Competence Research and Innovation for Research and Innovation
   Dr. Tanja Pavleska
   European Commission
4. H2020 - DE4A; Digital Europe for All
   Asst. Prof. Tomaž Klobučar
   European Commission
5. H2020 - BD4OPEM; Big Data for Open Innovation Energy Marketplace
   Dr. Dušan Gabrijelčič
   European Commission
6. H2020 - iFLEX; Intelligent Assistants for Flexibility Management
   Dr. Dušan Gabrijelčič
   European Commission
7. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Borka Džonova Jerman Blažič
   European Commission
8. COST CA21107; Work Inequalities in Later Life Redefined by Digitalization
   Dr. Martin Mihajlov
   Cost Association Aisbl

RESEARCH PROGRAMME

1. Future Internet Technologies: concepts, architectures, services and socio-economic issues
   Prof. Borka Džonova Jerman Blažič
   Slovenian Research Agency

R&D GRANTS AND CONTRACTS

1. Artificial intelligence for cybersecurity
   Asst. Prof. Tomaž Klobučar
2. Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation
   Prof. Borka Džonova Jerman Blažič
3. Artificial intelligence for cybersecurity
   Asst. Prof. Tomaž Klobučar
   Urad Vlade Republike Slovenije Za
4. Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation
   Prof. Borka Džonova Jerman Blažič
   Ministry of Education, Science and Sport

STAFF

Researchers
1. Asst. Prof. Rok Bojanc*
2. Prof. Borka Džonova Jerman Blažič
3. Dr. Dušan Gabrijelčič
4. **Asst. Prof. Tomaž Klobučar, Head**
5. Dr. Martin Mihajlov
6. *Dr. Živa Stepančič, left 01.05.22*
Postdoctoral associates
7. Dr. Ramanpreet Kaur
8. Dr. Samed Bajrić
9. Dr. Primož Cigoj

10. Dr. Andrej Jerman Blažič
11. Dr. Tanja Pavleska
Technical officers
12. *Klemen Stanič, B. Sc., left 13.10.22*
13. Davud Topalović, B. Sc.
Technical and administrative staff
14. Tatjana Martun, B. Sc.

Note:
* part-time JSI member

DEPARTMENT OF COMMUNICATION SYSTEMS E-6

The core activities of the Department of Communication Systems comprise the research, development and design of heterogeneous communication, computer and sensor networks, wireless technologies and next-generation communication services; the design of new procedures for parallel and distributed computing of computationally intense problems in various high-performance computing architectures and time-sensitive problems in edge devices; and the integration of sensor, communication, computing and data technologies to support digitalization and smart infrastructures. Within these activities our research work includes the development and investigation of new methods and architectures, software tools and libraries, pilot deployments and experimental testbeds.

Head:
Prof. Mihael Mohorčič

The research and development activities at the department are carried out in three laboratories: the *Communication Technology Laboratory (CTL),* the *Parallel and Distributed Systems Laboratory (PDSL)* and the *Networked Embedded Systems Laboratory (NESL).* The research work of the three laboratories is complementary, which is reflected in the joint applied projects.

The research and development activities of the **Communication Technology Laboratory** have been primarily, but not exclusively, related to the access segment of wireless communication networks in terrestrial and satellite communications, and to radio and network resource management in mobile cellular systems. The research is part of the Communications Networks and Services research program (P2-0016) and three research projects: J2-2507 "Towards the environment-aware intelligent wireless communications", J2-3048 "Advanced modelling of radio channels using ray-optical and numerical meshless methods", and J2-4461 "Terahertz radio waves for sensing and localization in future 6G communication systems". In addition, we continued the research and collaboration with the industry in the area of power grids that we started in recent years, maintained and enhanced the LOG -a- TEC testbed with new functionalities.

> We are developing approaches of intelligent integrated environment sensing and communications for future wireless communication systems.

Radio-channel modelling is an important part of the research activities of the Communication Technology Laboratory. We have been involved in deterministic channel modelling for terrestrial communication systems, especially for indoor environments, and statistical channel modelling for satellite communication systems. Among deterministic channel models, ray tracing is the most widely used, but it models only a subset of the known radiowave-propagation mechanisms, and in its current form, does not provide adequate radio-channel models for next-generation communications. A reduction in the effective geographic area of radio cells and increase in computational power opened up the possibility of solving the fundamental Maxwell equations numerically. We investigated the techniques for modelling telecommunication channels in complex environments as part of project J2-3048 "Advanced modelling of radio channels using ray-optical and numerical meshless methods". In this context, we studied ray tracing in rectangular tunnels, which proved to be mathematically equivalent to purely analytical modal methods. The equivalence holds for modelling reflections using image theory, while other variants of the ray tracing algorithm still have approximation errors. The use of ray-tracing by ray-launching can be questionable, at least if characteristic sequences are used to avoid double-counting errors. In addition to the known path inaccuracies, we identified the previously untreated inconsistent rays as the most problematic ones, resulting in a significantly overestimated signal at distances exceeding 100 m. We quantified the errors and proposed an improvement in double-count filters to detect inconsistent rays.

Figure 1: Identification of indoor environment properties using the channel impulse response (CIR) and machine learning approach

The intelligence of future wireless-communication systems relies on radio-environment awareness, which is estimated from the received signal properties, current and past allocated network resources. In this context, we studied wireless-communication systems that enable prediction of radio-channel characteristics by taking advantage of the environmental information, measured partial channel state information (CSI), and information about radio nodes. This research is the topic of project J2-2507, "Towards the environment-aware intelligent wireless communications". In this respect, we critically

reviewed existing wireless communication technologies with respect to environment awareness and their capabilities for estimating CSI. In the first generations of communication systems CSI is available only as channel attenuation, while in almost all currently used broadband radio technologies CSI is estimated as the channel impulse response (CIR), but this information is generally not available outside the communication systems. Also, CSI is estimated only for a channel with active communication. The new radio (NR) wireless technology offers the possibility of estimating the CIR for non-active channels, and thus the possibility to initiate environmentally aware wireless communications. We also proposed a network architecture that enables environment-aware wireless communications.

In addition, we further explored the idea of integrated sensing and communication by estimating the 3D environmental geometry and electrical properties of the building elements by exploiting the channel impulse response (CIR). The idea assumes that a received radio signal is distorted by the interaction with the surrounding objects, thus containing the signature of the radio environment. We used machine learning (ML) to process reflected radio waves and gain the knowledge about the materials of the surfaces bounding the indoor environment. We formalized the problem as a multi-target classification task. The results obtained show that for some combinations of the materials used in the room, it is difficult to predict the material of a single surface without considering the materials of all the other surfaces.

During the outbreak of the COVID-19 epidemic we actively participated in the research that could help in modelling the intensity of interpersonal contacts. We proposed innovative proximity estimation methods based on the person-radio environment trace recorded by a smartphone, defining the proximity parameter. For this purpose, we developed a smartphone application and backend services. The results show that we can estimate the proximity between two devices in terms of near, medium and far distances with reasonable accuracy in real case studies. In addition, we investigated the limitations of the machine learning-based approach that detects the proximity between two devices based on WiFi and BLE fingerprints.

Figure 2: Sharp interface meshless simulation of dendritic crystal grain growth during solidification

Future wireless services will frequently necessitate environment sensing inputs as part of the application functionality. Therefore, a coexistence of communication, sensing and localization is envisioned in 6G systems. In this context, we launched, in 2022, the project J2-4461 "Terahertz radio waves for sensing and localization in future 6G communication systems", whose main objective is to study, identify and develop novel THz channel models suitable for the design and evaluation of joint communication, environment sensing and precise localization in indoor environments using 6G communications in THz frequency bands.

Our laboratory is also part of a COST Action CA 20210 INTERACT "Intelligence-enabling radio communications for seamless inclusive interactions". It aims to achieve scientific breakthroughs by introducing novel design and analysis methods to make future radio communication networks intelligent, i.e., aware, adaptive and parsimonious, and to contribute to the creation of intelligent environments. We participate in several working groups.

We also continued our research on the Internet of Things (IoT), focusing on localization and positioning. We developed two new methods of phase-based ranging for wireless technologies based on the 6TiSCH (IPv6 over TSCH mode of IEEE 802.15.4e) standard. The proposal improves known algorithms by reducing the number of phase samples required without reducing the accuracy and sensitivity of the algorithm, while increasing energy efficiency. We also designed a unified circular antenna array with 12 monopole antennas and RF switches to select the active antenna for estimating the direction of arrival (DoA) of the signal for Bluetooth Low-Energy systems. The system was tested in a semi-controlled environment and achieved an error in the direction of arrival estimation of less than 1 degree. We have extended the LOG-a-TEC experimental test environment with features that support experiments with the BLE technology.

In the area of signal processing, we continued to perform extensive statistical analyses of the signal obtained during three years of beacon measurements from the Alphasat satellite at 19.7 GHz and 39.4 GHz. We analysed the tropospheric scintillation fading and compared it with the ITU-R P.618-13 model.

Research topics related to the electric power system infrastructure are becoming extremely important with the dramatic shift towards sustainable and renewable energy sources. We have addressed the need to efficiently identify the topology of the low-voltage grid to make it resilient to the increasing load and the growing number of
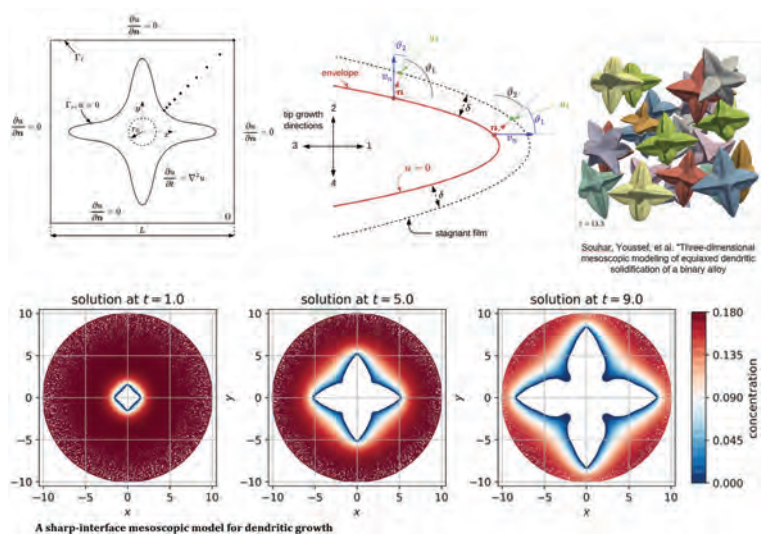
distributed energy sources. In addition to reconstructing the unknown topology using smart-meter measurements, we developed a method for approximating unknown impedances and detecting illicit energy losses.

We were developing cryptographically secure random number generators in collaboration with colleagues from the Department of Theoretical Physics (F1) and the Department of Condensed Matter Physics (F5). These activities are part of the Target research program, funded partly by the Slovenian Research Agency and partly by the relevant government agency. In 2022 we organized a public workshop on cryptographically secure random-number generators, their standardization and testing, but most of the research conducted is confidential.

Part of the laboratory work was dedicated to the efficient management of radio resources in the future communication system using the Cloud Radio Access Network (C-RAN) architecture. The main goal is to provide services that meet the QoS requirements of individual users while ensuring an efficient use of network resources. We demonstrate a dynamic resource allocation algorithm in a heterogeneous C-RAN network that enables an optimal resource utilization in mobile communication networks.

In the **Parallel and Distributed Systems Laboratory**, we continued developing local mesh-free methods for numerical solving of the systems of partial differential equations (PDEs). In 2022 we developed an hp-adaptive solution procedure based on a well-established iterative solve–estimate–mark–refine paradigm. We demonstrated that the developed hp-adaptive method significantly outperforms the state-of-the-art methods in two- and three-dimensional contact problems. In conjunction with hp-adaptivity, we introduced a novel implicit-explicit (IMEX) error indicator, which assumes that the error relates to the difference between the implicitly obtained solution and a local explicit re-evaluation of the PDE at hand, using a higher-order approximation. We showed that the proposed IMEX error indicator adequately captures the global behaviour of the error in all considered cases. In the context of domain discretization, we continued our research on developing dedicated meshless node generation algorithms by introducing a hierarchical algorithm for a fast generation of quasi-uniform and variable density spatial nodes on domains whose boundaries are represented as computer-aided design (CAD) models, more specifically, non-uniform rational B-splines (NURBS). In the context of partial differential operator approximation, we observed that the solution

We developed an *hp*-adaptive meshless method including the original IMEX error indicator.

error dependence on the stencil size has several local minima and related this behaviour to the spatial dependency of the approximation error. We also experimented with approximation using hybrid scattered/uniform nodes to reduce the computational cost of meshless methods. Finally, we developed a sharp interface meshless solution procedure for a simulation of dendritic crystal grain growth during solidification.

We continued our collaboration with the Geological Survey of Slovenia and the University of Ljubljana, Faculty of Arts, Department of Geography on the ARRS project "J1-2479 – Past climate change and glaciation at the Alps-Dinarides junction". We assembled digital elevation maps for the areas of Snežnik and Trnovski gozd. We built climatological models for both areas and tuned them through optimisation procedures. Using our climatological models and PISM simulation environment, we simulated the extent of glaciers, achieving a relatively good agreement with field observations.

We continued the research within the ARRS project "J7-2599 – Decay of an invasive ctenophore bloom as a perturbation to the costal marine microbial community". In 2022 we kept working on a novel population-based model for microbial growth based on Monod and Luedeking-Piret models. The model was expanded by generalizing it to an arbitrary number of age groups, eventually leading to a continuous model, which resembles the von Foerster equation. Using this enhanced population model we showed the ability to predict biomass decay through bacterial degradation for several experimental datasets, yielding consistent results throughout.

In cooperation with the Faculty of Electrical Engineering (FE) and the Communication Technology Laboratory, we continued the research within the project "J2-3048 – Advanced modelling of radio channels using ray-optical and numerical meshless methods". We generalised the finite difference time domain (FDTD) method to a meshless setting. This was done using the Radial Basis Function-generated Finite Differences (RBF-FD) method that has the potential to accurately model electromagnetic fields on complex domains. We have verified that our method can reproduce FDTD on the grid and explored some of its further properties, focusing on stability and dispersion.

In cooperation with the Faculty of Sport and the Laboratory for Machine Intelligence at the Faculty of Electrical Engineering, we continued with the project "J3-3115 AiCoachU – Artificial intelligence is coaching you". Based on the requirements agreed with the partners, we developed a sensor platform based on the STM32L476JG MCU sensor with communication with the sensor performed via I2C and SPI buses where we added an SD card for local storage. Wireless connectivity was provided via BLE. We developed a software code for the sensor device (firmware) and a mobile android application to control the measurements, where we introduced a specific communication protocol for device management and data transfer. We also developed and implemented an algorithm to synchronise multiple sensors.

In the context of project "N2-0171 – Graph Theory and Combinatorial Scientific Computing" carried out with the Faculty of Computer and Information Science (SI), InnoRenew (SI) and the Alfréd Rényi Institute of Mathematics (HU), we designed a computer environment for implementing algorithms to solve graph theory problems. We used this environment to participate in a competition for solving hard combinatorial problems where we managed to solve all the tasks (only two out of five teams did so). We further used the environment to develop a new fast algorithm for finding k-cliques in k-partite graphs.

In collaboration with the F1 department and the Communication Technology Laboratory, we continued our work on project "N2-0171 – Cryptographically secure random number generator". We investigated the state and trend of the operating system development and selected target operating systems for the development of a library for generating random numbers from the sensors typically present on mobile devices. For further development we selected the most promising sensors whose output contains a high degree of randomness, i.e., the camera, microphone and accelerometer. We also developed a demonstration application that generates random numbers from the selected sensors on Android and iOS operating systems.

Figure 3: Time-series signal to graph transformation and classification

In the scope of applied research, we continued the development of DiTeR – a modular dynamic thermal rating (DTR) software designed to predict the thermal state of power lines, which is in operational use at ELES, ltd. and it is marketed world-wide by the company Operato. In 2022 we continued with the maintenance of the system and performed a pilot deployment for the Lithuanian transmission system operator LitGrid.

In 2022 we continued with the project "TrafoFlex – advanced concept of efficient use of transformers leveraging the DTR technology". We developed a new multibody thermal model that, besides the transformer core and oil, takes into account also the transformer station. We also extended the model to consider the more meteorological inputs, namely the wind speed, solar irradiation and precipitation. We trained the model using the measurements for 19 transformers and demonstrated that the developed model adequately captures the top oil temperature.

For the Diagnostics and Analytics Centre (DAC) at ELES, ltd., we successfully completed the project "Forecasting maintenance interventions of the on-load tap changer with advanced analytics" where we developed the tap-changer load prediction model and implemented it in the DAC operational environment. The developed decision-support software is used to make maintenance predictions for up to one year in the future and it is in operational use in the DAC since April 2022.

Under the OPUS call within the Weave programme 2021/43/I/ST3/00228 we started, in collaboration with the University of Wrocław (UWr), the project "N2 – 0275 Inertial effects on fluid flow in complex porous media". The project focuses on systematic numerical studies of the flow through complex porous media to account for hydraulic tortuosity and investigate the usability of the Carman-Kozeny law. In particular, we will study flows through Sierpinski carpets, random models and real samples of packed grains. The goal of our group is to develop an adaptive meshless solution procedure for simulating the flow through highly complex geometries.

The research of the **Networked Embedded Systems Laboratory** is focused on the digitalization of smart infrastructures with the aim to improve their accessibility, utility and efficiency of resource utilisation. To this end we are furthering the state of the art with respect to signal processing and time-series modelling in view of decision making using various intelligent techniques such as representation learning, clustering and classification.

We performed a first-time analysis of the image-based representation techniques for wireless anomaly detection using recurrence plots and Gramian angular fields for binary and multiclass classification and proposed a new deep neural network architecture to distinguish between the wireless link layer anomalies.

In the frame of the research programme P2-0016 (Communication networks and services) we continued with the investigation and adaptation of machine- and deep-learning methods for advanced data-driven radio-resource management, with special attention to transfer learning, self-supervised learning, explainable AI and alternative techniques for the representation of time series data such as sub-windowing and graphs. In addition to commonly used techniques for dimensionality reduction to the most representative features for motif recognition and classification, we continued the investigation of methods for dimensionality extension with the aim to improve the anomaly and motif recognition in time series. In particular, we investigated Gramian angular fields and recurrence plots for the image-based representation of the time series data for wireless link-layer anomaly detection.

The increasing complexity of the machine-learning and deep-learning models used for the AI-based optimization of wireless communication networks is manifested in the increased energy consumption of communication networks and corresponding environmental impacts. This motivated our investigation in the sustainability and energy-efficiency aspects of machine-learning models, resulting in the development of a new deep learning architecture for indoor wireless fingerprinting localization.

We also continued the development and investigation of the procedures for the life-cycle automation of smart infrastructures with the support of artificial intelligence. We systematically analysed the deployment and operation phases in the lifecycle of smart infrastructures, showing the benefits of zero-touch provisioning methods, automation through AI-powered voice assistants and DevOps solutions using data/knowledge-driven AI models, and fault and anomaly detection. For smaller, non-enterprise smart-infrastructure environments we identified a number of challenges for an on-premise deployment of compute clusters. We developed Kubitect, a solution based exclusively on open-source technologies that enables on-premise cluster deployment, scaling and upgrade on a single or multiple physical hosts, and supports specifying the configuration using a user-friendly declarative language.

In 2022 we also successfully concluded two H2020 projects, RESILOC and Fed4FIRE+, continued with the research work within the H2020 project BD4OPEM, and started a new HE MSCA project, TimeSmart.

Our focus in the final year of the RESILOC (Resilient Europe and Societies by Innovating Local Communities) project was on the use of a non-intrusive privacy-preserving detection of people's presence and movement patterns. It is based on Bluetooth and WiFi technologies and exploits the network management messages transmitted by personal devices. The proposed approach was calibrated with a labelled, publicly available dataset, extensively tested and validated with measurements in a controlled rural and semi-controlled indoor environment, and finally demonstrated in an uncontrolled crowded urban trial in the city of Catania.

In the BD4OPEM project (Big Data for OPen innovation Energy Marketplace) we finalized the development and initial testing of data-driven services for grid-disturbance simulations, flexibility aggregation, energy management at the household/community level and demand estimation. We already started with their full integration in the project-developed energy marketplace. The objective of these data-driven services is an efficient and automatic management of distributed renewable-energy sources and loads for the shifting or reduction of peak energy demand and the fluctuations in transport and distribution as well as optimization of energy consumption with respect to fluctuating power tariffs.

In October 2022 we started a HE MSCA project, TimeSmart, within which dr Jernej Hribar, a postdoctoral fellow, will investigate the applicability of the novel Age of Information (AoI) metric in smart grid networks. While the metric has already become a valuable tool for measuring a system's performance, its practical value and impact in a real-time system remain unanswered. The project thus seeks to remedy this by applying the metric to a system, in which the timing of collected data, currently measured through jitter or latency, profoundly impacts its management and control. The AoI metric provides a new perspective on how the system should collect and process information, as such decisions are also based on the context of processed information, i.e., its semantic nature. In turn, the new approach can offer an innovative way of improving the efficiency of renewable electrical energy supply and electrical loads by taking advantage of the available edge infrastructure.

Some outstanding publications in the past year

1. R. Novak. Inconsistent rays in propagation prediction by ray launching in rectangular tunnels. IEEE Access. 2022, vol. 10, pp. 122548–122559, illustr. ISSN 2169-3536. https://ieeexplore.ieee.org/document/9956815, doi: 10.1109/ACCESS.2022.3223868. [COBISS.SI-ID 131904771]

2. A. Švigelj, A. Hrovat, T. Javornik. User-centric proximity estimation using smartphone radio fingerprinting. Sensors. 2022, vol. 22, no. 15, pp. 5609-1-5609-17. ISSN 1424-8220, doi: 10.3390/s22155609. [COBISS.SI-ID 117648387]

3. D. He, K. Guan, B. Ai, Z. Zhong, J. Kim, H. Chung, A. Hrovat. Channel measurement and ray-tracing simulation for 77 GHz automotive radar. IEEE Transactions on Intelligent Transportation Systems. [in press] 2022, 11 pp. ISSN 1558-0016, doi: 10.1109/TITS.2022.3208008. [COBISS.SI-ID 123191299]

4. M. Depolli, J. Slak, G. Kosec. Parallel domain discretization algorithm for RBF-FD and other meshless numerical methods for solving PDEs, Computers & Structures, 2022 [doi: 10.1016/j.compstruc.2022.106773] [COBISS: 98533123]

5. E. Merdjanovska, A. Rashkovska. Comprehensive survey of computational ECG analysis: databases, methods and applications. Expert Systems with Applications, 2022 [doi: 10.1016/j.eswa.2022.117206] [COBISS: 106991107]

6. A. Rashkovska, M. Jančič, M. Depolli, J. Kosmač, G. Kosec. Uncertainty assessment of dynamic thermal line rating for operational use at transmission system operators. IEEE Transactions on Power Systems. 2022, vol. 37, [doi: 10.1109/TPWRS.2022.3144740] [COBISS: 95914243]

Awards and Appointments

1. Blaž Bertalanič, Gregor Cerar, Carolina Fortuna, Halil Yetgin: Student Best Paper Award, Bologna, Italy, WiMob'2021, "A Deep Learning Model for Anomalous Wireless Link Detection".
2. Aleksandra Rashkovska Koceva, Roman Trobec: Excellent in Science 2021, ARRS, "Personalized management of hidden temperature variables in real-time therapeutic cooling of the knee".

INTERNATIONAL PROJECTS

1. COST CA18203; ODIN - Optimising Design for Inspection
   Dr. Gregor Kosec
   Cost Association Aisbl
2. COST CA20120 - INTERACT; Intelligence-Enabling Radio Communication for Seamless Inclusive Interactions
   Prof. Tomaž Javornik
   Cost Association Aisbl
3. H2020 - Fed4FIREplus; Federation for FIRE Plus
   Prof. Mihael Mohorčič
   European Commission
4. H2020 - RESILOC; Resilient Europe and Societies by Innovating Local Communities
   Prof. Mihael Mohorčič
   European Commission
5. H2020 - BD4OPEM; Big Data for Open Innovation Energy Marketplace
   Prof. Mihael Mohorčič
   European Commission
6. Joint Scheduling and Routing Algorithm for Delay Sensitive Industrial Applications in Wireless Networks
   Asst. Prof. Andrej Hrovat
   Slovenian Research Agency
7. Machine Learning Supported Indoor Localization
   Dr. Klemen Bregar
   Slovenian Research Agency
8. HE - TimeSmart; Timeliness of Information in Smart Grids Networks
   Prof. Mihael Mohorčič
   European Commission

RESEARCH PROGRAMMES

1. Communication networks and services
   Prof. Mihael Mohorčič
2. Parallel and Distributed Systems
   Dr. Gregor Kosec

R&D GRANTS AND CONTRACTS

1. Past climate and glaciation at the Alps-Dinarides junction
   Dr. Gregor Kosec

2. Decay of an invasive ctenophore blooms as a perturbation to the coastal marine microbialcommunity - from molecules to ecosystem - an integrated interdisciplinary approach
   Dr. Gregor Kosec
3. Graph Theory and Combinatorial Scientific Computing
   Dr. Matjaž Depolli
4. AiCoachU – Artificial intelligence is coaching you
   Dr. Gregor Kosec
5. Towards the environment-aware intelligent wireless communications
   Prof. Aleš Švigelj
6. Advanced modelling of radio channels using ray-optical and numerical meshless methods
   Prof. Tomaž Javornik
7. Terahertz radio waves for sensing and localization in future 6G communication systems
   Asst. Prof. Andrej Hrovat
8. Cryptographically secure random number generator
   Dr. Matjaž Depolli
9. Agreement on cooperation in the development and marketing of a dynamic thermal model for the assessment of transmission capacity of transmission lines
   Dr. Gregor Kosec
   Elektroinštitut Milan Vidmar
10. Cryptographically secure random number generator
    Dr. Matjaž Depolli
    Government Office for the Protection of Classified Information
11. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
    Dr. Matjaž Depolli
    Helmholtz-Zentrum Dresden-Rossendorf E.v.

NEW CONTRACTS

1. DTR software: DiTeR
   Dr. Gregor Kosec
   Eles, d. o. o.
2. Forecasting maintenance interventions of the on-load tap changer with advanced analytics
   Dr. Gregor Kosec
   Eles, d. o. o.
3. Advanced concept of efficient use of transformers leveraging the DTR technology
   Dr. Gregor Kosec
   Operato d. o. o.

VISITORS FROM ABROAD

1. Dawid Strzelczyk, Univeristy of Wrocław, Poland, 28. 11. – 9. 12. 2022
2. Milan Mladen, University of Banja Luka, Bosnia and Herzegovina, 7. – 10. 12. 2022
3. Želimir Maletić, University of Banja Luka, Bosnia and Herzegovina, 7. – 10. 12. 2022
4. Maciej Matyka, Univeristy of Wrocław, Poland, 1-3. 12. 2022

STAFF

Researchers
1. Dr. Andrej Čampa*
2. Dr. Matjaž Depolli
3. Dr. Carolina Fortuna
4. Dr. Ke Guan
5. Dr. Jernej Hribar
6. Asst. Prof. Andrej Hrovat
7. Prof. Tomaž Javornik
8. Dr. Arsim Kelmendi*
9. Dr. Gregor Kosec
10. Prof. Andrej Lipej*
11. **Prof. Mihael Mohorčič, Head**
12. Asst. Prof. Roman Novak
13. Asst. Prof. Aleksandra Rashkovska Koceva
14. Prof. Aleš Švigelj
Postdoctoral associates
15. Dr. Klemen Bregar
16. Dr. Gregor Cerar
17. Dr. Sebastijan Mrak
18. Dr. Filip Strniša
Postgraduates
19. Blaž Bertalanič, B. Sc.
20. Marko Hudomalj, B. Sc.
21. Mitja Jančič, B. Sc.
22. Andrej Kolar - Požun, B. Sc.
23. Ljupcho Milosheski, M. Sc.

24. Grega Morano, B. Sc.
25. Miha Rot, B. Sc.
26. Aleš Simončič, B. Sc.
27. Denis Sodin, B. Sc.
Technical officers
28. Viktor Cvrtila, B. Sc.
29. Nika Mlinarič Hribar, B. Sc.
30. Miha Mohorčič, B. Sc.
31. Din Mušić, B. Sc.
32. Blaž Rojc, B. Sc.

33. Miha Smolnikar, B. Sc.
Technical and administrative staff
34. Polona Anžur, B. Sc.
35. *Tomaž Krištofelc, 01.10.22, transferred to Department U1*
36. *Tamara Matevc, B. Sc., 01.09.22, transferred to Department K8*
37. Marko Mihelin*, B. Sc.

Note:
* part-time JSI member

COMPUTER SYSTEMS DEPARTMENT
E-7

The Computer Systems Department is primarily concerned with the development of efficient optimization algorithms, intelligent massive-data processing, effective data management and visualization, and adaptive computing structures for faster and more reliable algorithm execution. Within this broad area, we focus on self-adaptive systems, modeling and optimization of complex, dynamic and non-deterministic systems. Our research results are used within applications for manufacturing, transportation, bioinformatics, nutrition, health and medicine. As an integral part of our research activities, members of the department maintain close contacts and collaborations with scientists around the world through academic affiliations and industry contacts, thus enabling us to remain at the forefront of rapidly evolving fields.

Head:
Prof. Gregor Papa

In 2022 we continued the work on our **research program** (Computer Structures and Systems – P2-0098) funded by the Slovenian Research Agency. The program focuses on relevant research and development in the areas related to reconfigurable systems: reliability, architectures for data-intensive systems, hardware/software co-design, resource planning and scheduling, adaptive and learning control methods, dynamic adaptation to changing contexts, decision and control in uncertain and changing environments. The interdisciplinary, cutting-edge research challenges combine areas of computer science, engineering and mathematics. Our research work in 2022 was complemented by the design, development and implementation of various solutions within 13 European projects in the *Horizon 2020, Horizon Europe, ECSEL JU, PRIMA, EFSA* and *Interreg* programs, as well as within 8 national projects. Our work is also actively connected with the activities of the Slovenian *Strategic Research and Innovation Partnerships* (SRIP) in the areas of *Smart Cities and Communities* (SC&C) and *Factories of the Future* (FoF).

Optimization algorithm design

Many real-world applications involve the optimization of multiple, often time-consuming and conflicting objectives. They may require the use of computational intelligence or artificial intelligence, for example, to maximize the quality while minimizing the cost, using sophisticated numerical simulations.

Automated configuration and selection of algorithms has become very important in the field of evolutionary computation in recent years. Two crucial, sometimes implicit, components of these AutoML methods are 1) feature-based representations of problem instances and 2) performance prediction methods that use these features as the input for estimating how well a given algorithm instance will perform in a given problem instance. Along these lines, in an ARRS ERC StG Complementary Scheme, launched in February, *RESPONSE – Representation Learning of Landscape Spaces for Explainable Performance of Stochastic Optimization Algorithms* (https://cs.ijs.si/projects/190), we are investigating

Publication of a book on the performance of stochastic optimization algorithms

meta-features that can be used to describe the properties of single-objective optimization problems further involved in the AutoML studies, such as reproducible benchmarking results, automatic algorithm selection and automatic algorithm configuration. We investigated the state-of-the-art landscape features extracted from a problem decision space by artificially sampled candidate solutions from the problem decision space in different learning scenarios and identified the minimum number of features required for a reliable prediction of an algorithm's performance across different algorithms (presented at *IEEE Congress of Evolutionary Computation – CEC 2022*). We provided explanations of the importance of landscape features for predicting an algorithm performance (presented at the *International Conference on the Applications of Evolutionary Computation – Evo* 2022*), which were also used as a meta-representation to find the configuration of the algorithm (presented at the *Genetics and Evolutionary Computation Conference – GECCO 2022*) and analyze its behavior (presented at the *Bioinspired Optimization Methods and their Applications – BIOMA 2022*).

Our colleagues, assist. prof. Tome Eftimov and prof. Peter Korošec, have published a book called *Deep Statistical Comparison for Meta-Heuristic Stochastic Optimization Algorithms*. It presents a comprehensive comparison of the **performance of stochastic optimization algorithms**, including an introduction to benchmarking and statistical analysis, and providing insights into a web-based tool for a statistical comparison of optimization algorithms. We also organized three tutorials on the statistical analysis of single-objective and multi-objective metaheuristics at *IEEE CEC 2022, GECCO 2022* and *PPSN 2022*.

In the ARRS young-researcher project, the research focuses on feature-free approaches to computing trajectory-based meta-features that encode algorithm behavior and can also be used for problem identification and automated algorithm design. In another ARRS young-researcher project, we conducted a comprehensive analysis of the invariance of the **exploratory landscape features** of function transformations (presented at *IEEE CEC 2022*). We also investigated the generalization of a model for the automatic algorithm selection across different benchmark datasets and showed that a model trained on one benchmark suite exhibits poor generalization when used for another benchmark suite whose feature distribution is completely different from the distribution of the data used for training (published in *Mathematics* journal).

Constructing useful features that can help select the best algorithms is an important research topic. In the field of time series, we investigated the relationships between **time-series algorithms** and their properties, and explored the use of the existing features and their contribution to predicting the performance of particular algorithms. We showed that there are features that contribute a lot towards getting accurate performance estimates based only on time-series properties, and that these properties can be used to select better forecasting algorithms. Specific features will be further explored to determine why certain algorithms behave differently than others. The work was published in the journal *Expert Systems with Applications*. We also studied new topologically inspired features that have desirable properties, such as being invariant to different transformations, which is a problem for some of the existing feature sets. Using a newly developed approach, each optimization problem is transformed into a set of features that attempt to capture the existence of higher-dimensional holes. With topologically inspired feature extraction, it is possible to create more informative benchmarks and eventually use them to aid algorithm selection and configuration. The work was presented at the *IEEE Symposium Series on Computational Intelligence*.

In October we started the ARRS research project *AutoOPT – Automated selection and configuration of single-objective continuous optimization algorithms* (https://cs.ijs.si/projects/199). In collaboration with the E8 department, we are researching how users can obtain good solutions to a given optimization problem without having a deep prior knowledge of optimization algorithms or the problem instance. To achieve this, a number of different characteristics of the problem instance must be considered to determine the suitability of a given optimization algorithm for a given problem instance. This is a complex multidimensional problem with dependencies between individual characteristics. Using **explainable machine-learning techniques**, we can find the relationships between the characteristics of the problem instance and the performance of the optimization algorithm. If sufficiently general relationships can be found, they can be used to predict the performance of optimization algorithms on unknown problem instances. In the first few months, we focused primarily on collecting problem instances. Initial work on exploring the features of analytic problems and extending the OPTION ontology has already begun.

In November we started the Horizon Europe project *CONDUCTOR – Fleet and traffic management systems for conducting future cooperative mobility* (https://conductor-project.eu/), in which we are technically coordinating the development, integration and demonstration of an advanced, high-level traffic- and fleet-management system that will allow for an **efficient and globally optimal transport** of passengers and goods while ensuring seamless multimodality and interoperability. Together with 15 partners from 7 countries, we will employ innovative dynamic balancing and priority-based management of automated and conventional vehicles. To achieve this, the consortium will build on the state-of-the-art solutions for the fleet and traffic management within a Cooperative Connected and Autonomous Mobility (CCAM) ecosystem and develop next-generation simulation models and tools, enabled by machine learning and data fusion, to enhance the capabilities of transport authorities and operators and enable them to become conductors of future mobility networks. Our department, in collaboration with the E3 department, will focus on integrating optimization and prediction approaches in the selected use cases.

Our research on **min-max optimization** problems with parallel hierarchical differential evolution and SciPy was presented at the *International Conference on Bioinspired Optimization Methods and their Applications – BIOMA 2022*. The paper focused on evaluating the performance of the algorithm in addressing complex optimization problems. Through experiments with benchmark functions, we analyzed the convergence speed in relation to the number of cores and the dimensionality of the test problems. The paper provides valuable insights for the researchers and practitioners looking for effective approaches to address challenging min-max optimization problems.

In collaboration with the E9 department, we worked on the industrial project *Simulation-based optimization of cogging torque in the design of electric motors* for MAHLE Electric Drives Slovenija. The work is about finding the best electric motor design that satisfies a set of constraints, including, most importantly, a low cogging torque. The search for suitable motor designs involves performing computationally intensive computer simulations. The
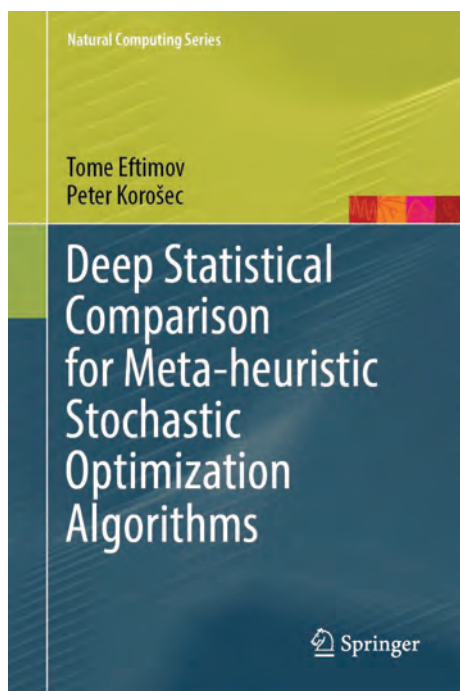

Figure 1: Book cover of Deep Statistical Comparison for Meta-Heuristic Stochastic Optimization Algorithms

task of the project is to develop a method for efficient search in the solution space by applying a **multilevel optimization approach** combined with surrogate optimization. In the first two phases of the project we successfully formulated the optimization problem, set up and implemented a prototype optimization environment, and conducted an in-depth investigation of the symmetric electric motor model with initial results on the asymmetric model. The results showed a high potential for improving the desired characteristics of the motor using asymmetric models, which led the company to extend the project to the third phase, in which the focus will be on researching asymmetric models.

At PPSN 2022, we offered a tutorial on a more systematic use of **dynamic selection of control parameters** for evolutionary computation. We gave an overview of the existing techniques for automatic selection of control-parameter values on the fly. In addition, we discussed both theoretical and experimental results showing the unexploited potential of dynamic parameter selection. We also organized a BENCHMARKING workshop at *GECCO 2022* and Autodesign4EC: Automated Algorithm Design for Evolutionary Computation at *IEEE CEC 2022*.

Our paper on *Electric Bus Routes in Hilly Urban Areas: Overview and Challenges,* published in *Renewable and Sustainable Energy Reviews,* was awarded the **Excellent in Science 2022** (*ARRS Odlični v znanosti 2022*). The article proposes a new, challenging, hilly benchmark route that provides a technical assessment of urban transit electrification in a geographically specific area with particularly challenging driving conditions.

In cooperation with the E9 department of the JSI and the Faculty of Electrical Engineering and Computer Science, University of Maribor, we organized, for the nineteenth consecutive year, the *Nature-inspired algorithms* workshop, which focuses on stochastic optimization techniques. In addition, we co-organized the *International Conference on Bioinspired Optimization Methods and their Applications BIOMA 2022* in Maribor, Slovenia, in November. Its papers were published in the Lecture Notes in Computer Science (LNCS) Proceedings by Springer.

In the area of optimization, we actively collaborate with the Sorbonne University (France), Leiden University (the Netherlands) and University of Malaga (Spain), among others.

We have served as editors and guest editors to regular and special issues of various journals, i.e., *Natural Computing*, *Sensors* and *Automatika*.

Technical coordination of a project dedicated to efficient and globally optimal transportation

Data processing

Electronic Components and Systems (ECS) are essential to the EU economy and citizens. They support areas ranging from transport and mobility to medicine and energy. A key area is **improving the reliability** of increasingly complex chips and systems designed to process vast amounts of data while providing for a greater processing speed and accuracy and decreasing energy consumption. We continued our work on the ECSEL JU / Horizon 2020 project *iRel40 – Intelligent Reliability 4.0* (https://www.irel40.eu) in collaboration with 75 partners from 13 countries to reduce ECS failure rates across the value chain. The ultimate goal of the project is to improve the reliability of electronic components and systems through the use of advanced intelligent technologies such as artificial intelligence and simulations. Our work focused on the reliability of in-wheel electric motors developed by the Slovenian company Elaphe. Establishing a reliable automotive electric drive system requires an intelligent condition-monitoring device capable of reliably assessing the condition and health of an electric motor. To enable a massive integration of such monitoring devices, they must be inexpensive and small. These requirements limit their accuracy. However, we have shown that these limitations can be significantly reduced with appropriate processing of sensor data. We have used machine learning models to transform very noisy measurements of the insulation resistance of motor windings measured by a low-cost device into much more reliable values that can compete with the measurements made by a state-of-the-art high-priced measurement system. The proposed method is an important building block for a future intelligent condition-monitoring system, providing a low-cost and accurate assessment of the condition of electric motors in conjunction with the condition of their winding insulation. Part of this work was also presented at the *IEEE Industrial Electronics Society conference – IECON 2022*. In addition, we played a leading role in reviewing and categorizing various artificial-intelligence methods used in more than 20 use cases and drew conclusions on the characteristics of reliability problems and solutions to address them. In November 2022, we organized a General Assembly in Ljubljana with almost 100 participants, including the leading European experts from various fields related to reliability.

We continued our activities within the ECSEL JU / Horizon 2020 project *InSecTT – Intelligent Secure Trustable Things* (https://www.insectt.eu/), which involves 52 partners and brings together artificial intelligence (AI) and internet-of-things (IoT) techniques. It is devoted to fostering cooperation between large industrial companies from various domains, a number of highly innovative SMEs spread across Europe and cutting-edge research institutions and universities. Our department is involved in two use cases. The first use case relates to smart and adaptive connected solutions for the entire healthcare continuum within a smart hospital where we are working on the development of the methods for **detecting anomalies in biomedical patient signals**, using deep neural networks (DNN). In 2022

we extended the training and testing datasets from various public ECG databases to nearly 80,000 annotated 12-lead ECG signals with 10-second segments and a sampling rate of 500 Hz. After exploring and testing various supervised and unsupervised training methods, we focused on the denoising auto-encoder architecture, which proved to be a very suitable system due to the fact that ECG input signals are often noisy. We explored more in detail the latent space, the space into which the signals are first encoded, before being decoded back into the time domain. In this way, the dimensionality of the input data is significantly reduced (from 60,000 to 40), but the accuracy of anomaly detection over the reduced data remains about the same. We prepared a live demonstration of anomaly detection in ECGs via the FastAPI protocol, which returns the probability that a patient's ECG is anomalous and an image with anomalous locations marked. This service has already been integrated into the use-case architecture along with solutions from other use-case partners. The second use case is related to emergency healthcare logistic services, for which we are developing a solution for **indoor localization and navigation,** using smartphones without a network and satellite navigation. An Android app is being developed to support rescue teams in emergency situations such as mass casualty incidents. The app is able to navigate the user to a selected destination on a floor by obtaining all the necessary information, such as the floor plan, possible destinations and navigation graphs from the QR code at the entrance to the floor. The Dijkstra navigation algorithm was applied and the Pedestrian Dead Reckoning algorithm was used to track a user's movement between the QR codes that serve as position beacons. In the event of a mass casualty incident, the app can send the user's current location, along with the triage decision made by first responders, to the cloud, where it is available to others, such as rescue team members picking up the injured. In the event that the data communication network is unavailable, the triage messages are stored in a local JSON-based database and sent later when the connectivity is available again. In both use cases, we focus on developing and using explainable and trustworthy AI methods that help users understand the reasons behind the results of specific procedures.

We developed an approach based on unsupervised machine learning and graph theory techniques that allows us to select diverse and unbiased benchmark problems that lead to a **reproducible performance evaluation** (presented at *GECCO 2022*). We also investigated the landscape features computed from the candidate solutions observed by the algorithm during its run and used for automatic prediction of the algorithm performance (presented at *IEEE CEC 2022* and *Parallel problem solving from nature – PPSN 2022*).

In October we launched the PRIMA project *WEFE4MED – Towards a Mediterranean WEFE Nexus Community of Practice*. The project aims to ensure a resilient, circular and green economy and achieve sustainable-development goals for water, energy, food and ecosystems. Together with the E8 department and the Center for Smart Cities, we will contribute our knowledge of data analytics and decision support, where our data analytics, optimization and machine learning solutions will help to achieve the overall goals and put the solutions into practice. In another PRIMA project, *PROMEDLIFE – Novel food products for the PROmotion of MEDiterranean LIFEstyle and healthy diet*, we will support partners in the analysis of the environmental data on innovative functional foods from the Mediterranean region. We also intend to extend our existing web-based tool FoodTrack with the data collected in this project and add analysis and visualization methods to its functionality.

Figure 2: Indoor navigation app developed as part of the InSecTT project

Our paper *Energy and nutritional composition of school lunches in Slovenia: the results of a chemical analysis in the framework of the national school meals survey* published in the journal *Nutrients*, was awarded the **Excellent in Science 2022** (*ARRS Odlični v znanosti 2022*). The paper presents the results of a survey aimed at comparing the composition of school meals in Slovenian elementary school with the national dietary guidelines.

Our PhD student Eva Valenčič received the award for the *best PhD student scientific paper* in 2022 from the University of Newcastle, Australia, where she conducted her dual doctorate research on digital nudging in food and nutrition.

Data management and visualization

As part of the national project *OPKP – Open Platform for Clinical Nutrition* (http://www.opkp.si), supported by the Ministry of Health, we upgraded the Slovenian Food Composition Database (FCDB) using a newly developed data- and knowledge-base management system implemented as a **web-based tool** *FoodMapper*. It is intended for use by experts and allows searching, reviewing, compiling FCDB and knowledge base (KB) and linking relevant evidence-based information into a 'data chain'. The developed tool and underlying bases provide a reliable baseline for other systems (e.g., mobile apps, web-based tools, online grocery stores, etc.) that may be useful to further in-
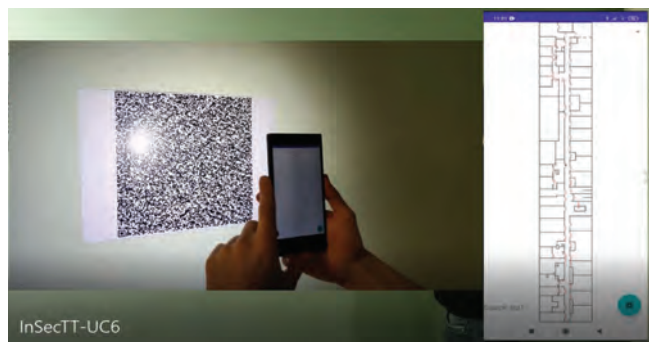
form and educate consumers and assess their dietary intake. The work was presented in two papers at the *Central European Congress on Food and Nutrition* and at the *Health of children and adolescents* conference.

In June, we started the Horizon Europe project *FishEUTrust – European integration of new technologies and social-economic solutions for increasing consumer trust and engagement in seafood products* (https://www.fisheutrust.org/), where we continue our research on **semantic interoperability** of food data. We will also contribute our advanced methods for the analysis of fish microbiome data using machine learning and natural language processing.

As part of the ESFRI project *MetroFood – Infrastructure for Promoting Metrology in Food and Nutrition* (https://www.metrofood.eu), which ended in 2022, we developed the project website to promote the **datasets and services** developed as part of the project. We also consulted the Slovenian partners in MetroFood-PP on the guiding principles of Open Science and Open Research Data and FAIR at the *Open Science Summer School*. At the final conference of MetroFood-PP we gave an invited talk, presenting the results of our recent research in food and nutrition.

We completed the national project *Šolski lonec* (The School Pot) (http://solskilonec.si) in collaboration with the National Institute of Public Health (NIJZ), which was supported by the Ministry of Health. We developed a web-based dietary-meal planning tool for schools and kindergartens. The tool was tested in collaboration with 25 primary schools. The work was presented at the *Health of children and adolescents* conference.

Development of a pipeline for explainable predictive models and a pipeline for imputation of missing values

The mission of the Horizon 2020 project *COMFOCUS – Community on Food Consumer Science* (https://comfocus.eu) is to advance the food consumer science beyond its current fragmentation that prevents it from becoming a data-rich scientific field that contributes to solving society's problem of (un)healthy food choices. We conducted a multimodal analysis of users' recipe interactions in Porter to explore their consumer behavior (presented at *Healthinf at BIOSTEC 2022*). As part of the project, we developed a pipeline for explainable predictive models and a **pipeline for imputing missing values** in food-composition databases. We evaluated the pipeline for explainable predictive models to provide explanations for predicting each country's Covid-19 mortality rate using a fusion of the WHO comorbidity data, FAO food consumption data for each country, and socioeconomic factors of each country (published in *Expert Systems with Applications* journal). In addition, we tested the pipeline to gain deep insights into Alzheimer's disease (published in *Scientific Reports* journal). We developed and tested the pipeline for imputing missing values in food-composition databases using autoencoders, a deep-learning algorithm that is able to approximate values by learning a higher-level representation of its input (published in the *Journal of Food Composition and Analysis*).

As part of the European Food Safety Authority (EFSA)-funded project *CAFETERIA – ExtraCting and Annotating Food NamEd EnTitiEs fRom ScIentific LiterAture*, we developed **information-extraction workflows** for food entity recognition from text data and created annotated corpora of text documents with food annotations required for the development of supervised ML information extraction workflows. The first annotated corpus consists of recipe-description data with food entities linked to various semantic resources (published in the *Foods* journal) and the second one consists of scientific abstracts annotated with food entities (published in the *Database-Oxford* journal). Both resources support biomedical research in natural language processing and have already been used to develop Named Entity Recognition and Named Entity Linking models using the state-of-the-art representation learning approaches.

In the Horizon 2020 project *FNS-Cloud – Food Nutrition Security Cloud* (http://www.fns-cloud.eu), we contributed to the development of the FNS Cloud. This is a new cloud platform for food and nutrition that will be integrated into the European Open Science Cloud (EOSC). Our main contribution is the development of food **matching services and pipelines** using machine learning and natural language processing, which are used to harmonize heterogeneous food and nutrition data and analyze them. We also created a protocol for FAIRness self-assessment of datasets and software. As part of this project, we published several peer-reviewed and international-conference papers on data interoperability and standardization methodology, e.g., in *Trends in Food Science & Technology* and *Journal of Food Composition and Analysis*.

To promote our research and support the knowledge exchange with other scientists and industry, we organized the *AI & Food and Nutrition Track* at the *Applied Machine Learning Days* in Lausanne, Switzerland. We also organized the third *Big Food, Nutrition, and Environment Data Management and Analysis (BFNDMA 2022)* at the *IEEE Big Data 2022* conference in Osaka, Japan. Last but not least, we held the ELIXIR All Hands workshop linking food, nutrition, biomedical and environmental data for trustworthy AI predictive healthcare in Amsterdam. We also gave invited talks at the *Slovenian Artificial Intelligence Society (SLIAS)* and the *MCCHE Convergent Innovation Webinar Series Event*, McGill University, Canada.

In September 2022 Gjorgjina Cenikj completed her master's thesis on *Information extraction workflows for knowledge graph construction from food and biomedical scientific literature*. The thesis aims to develop

information-extraction workflows for identifying relationships between foods, chemicals and diseases from abstracts of scientific articles that can automate the process of knowledge graph creation.

In December 2022 Gordana Ispirova defended her doctoral dissertation entitled *Exploiting domain knowledge in predictive learning from food and nutrition data*. The work was focused on incorporating domain knowledge at each step of a novel ML pipeline for the task of predicting nutritional values, creating two corpora with predefined domain-specific embeddings, and generalizing predictive models and different ways of selecting a representative training dataset.

In the area of **efficient interaction systems**, we focused on the web tools and mobile apps for nutrition and food informatics. We deeply investigated and designed visual representations for various projects, applications and web pages. In collaboration with partners and end-users, we analyzed user needs and defined appropriate user experiences and designed corresponding interfaces for several tools related to nutrition.

In 2022 we successfully completed the project *Innovative solutions for informed decisions: ensuring the functionality of the VešKajJeš mobile application* and expanded it with additional information and *VešKajPiješ? – Support for residents to reduce risky alcohol consumption with a mobile application*, both funded by the Ministry of Health. In the projects, we took care of the technical development of iOS and Android **mobile applications and back-end processes**. The application puts the data about the nutritional composition of food in the context of a nutrition traffic light, providing information and warnings about products containing alcohol that are not otherwise on the packaging, and serving as a tool to collect crowd-sourced data about the products on the Slovenian market. Annually, over half a million queries are made with the application. With a survey before and after the upgrade with the information about alcohol, we showed the effectiveness of the tool in raising awareness and educating about the dangers of alcohol consumption. A description of the data collection system can be found in the journal *Frontiers in Nutrition*.

As part of our collaboration with the E8 department and the *Jožef Stefan International Postgraduate School*, we are participating in the Horizon 2020 project *IPM Decisions – Decision Support for Integrated Pest Management in Europe*, to help farmers' transition to more environmentally friendly methods of pest management. To do this, we are using decision support systems that will be uniformly available as part of the platform. We have also developed an online tool (https://ipmadviser.ijs.si/) that provides an overview of the existing decision-support systems and a comparison between them.

The project from the Interreg program *SI4Care – Social Innovation for integrated health CARE of aging population in ADRION Regions* (https://si4care.adrioninterreg.eu) deals with the social innovation in the field of long-term care and aims to create a joint transnational strategy and action plans for each of the countries from the Adriatic-Ionian region involved in the project. In 2022 the project entered the final phase, in which we completed the pilot projects in the field of active lifestyle (sports, nutrition) and prepared 21 actions based on the results, which form the action plan for Slovenia. We presented the campaign proposals to various stakeholders at several events. The activities were also presented in the journal *Geriatrics* and at the *Information Society 2022* conference.

We started our collaboration within the ARRS research project in historical sciences *SHT – Historical Thopography of Posavinje and Posotelje Regions* (https://piir.zrc-sazu.si/sl/programi-in-projekti/historicna-topografija-posavinja-in-posotelja) with the *Slovenian Academy of Sciences and Arts*. The research is the third phase of a long-term plan and relates to the historical topography of the Posavinje and Posotelje regions. It focuses on the research of the historical topography of the two regions. In the first months, an entire book, published decades ago, was scanned, and the entries on Posavinje and Posotelje were isolated and processed using optical character recognition (OCR) software. Due to a large amount of text and many errors that occur with OCR, we support the **automatic processing** of the texts into a data structure that forms the basis for further research and connection with the existing Slovenian database of historical topography.

Adaptive computing platforms

To support and accelerate our algorithms, several approaches have been explored and developed at the hardware and computational structure levels, including the use and online reconfiguration of FPGAs, customized embedded systems and sensors. We are building a high-performance **FPGA acceleration infrastructure** based on Xilinx ALVEO acceleration boards. We have studied the hardware implementations of artificial neural networks on FPGA devices. The use of the high-performance accelerator card ALVEO FPGA has been investigated for fixed-point array multiplication, which can be used in an ANN. The research is also focused on the adaptive quality of delivered computations, i.e., the **approximate-computing** approach.

In collaboration with *Indian Institute of Technology Indore*, we developed an efficient hardware implementation of the Softmax (SF) unit. It is based on a CORDIC-based pipeline architecture with adjustable exponential unit (ExU) and division unit (DiU). The solution was tested on an FPGA device. The tradeoffs between bit precision,

pipeline depth, speed and SF accuracy were investigated. An article describing the evaluation of the developed unit was submitted to the *IEEE Access* journal.

We continued the ECSEL JU / Horizon 2020 project *DAIS – Distributed Artificial Intelligent Systems* (https://dais-project.eu/) in collaboration with 47 partners from 11 countries. Together we research and deploy distributed and secure artificial intelligent systems. We tend to solve the problems encountered when running the existing algorithms on these widely distributed edge devices. Our department, in collaboration with *Cosylab* and *TPV*, is developing an autonomous automated guided vehicle (AGV) that will be used to transport materials and products between a factory and its warehouse. Our tasks in the consortium are system design and the development and deployment of an artificial intelligence solution. This is supported by our research of the hardware architectures for highly **quantized neural networks**. In 2022 we succeeded in deploying a quantized neural network on an FPGA circuit capable of detecting objects of interest in a factory environment. The result will help us develop an autonomous solution capable of detecting and avoiding such obstacles.

We continued research within the ARRS project *CODA – Context-aware on-device approximate computing* (https://www.fri.uni-lj.si/en/projects/1719) in collaboration with the *Faculty of Computer and Information Sciences*, *University of Ljubljana*. The project aims to drastically reduce resource requirements in mobile computing by **adapting computational complexity to the requirements** dictated by the context of use. Our task in the project is to investigate use cases, in which the algorithms developed in the project come into play. To this end, we looked at the issue of safety in the mountains in winter when avalanche danger is at its highest.

Figure 3: Object recognition system integrated into the FPGA of the AGV

We conducted a series of surveys and conversations with stakeholders, from which we derived requirements for an application that would be used to raise awareness and educate mountain visitors about the dangers they face. The work was presented at the *Human-Computer Interaction Slovenia 2022* conference.

Compressive sensing (CS) is a mathematical approach that takes advantage of an inherent structure observed in numerous real-world data sources to reduce the sampling rate of a signal, allowing a reliable reconstruction of the signal even when the sampling rate is far below the Nyquist rate. In our work, we explore the use of CS in combination with deep learning (DL) models constructed to further process the sampled signal, typically for the purpose of higher-level inference. In *Artificial Intelligence Review*, we provide a thorough overview of the CS field with a particular focus on the use of CS for DL-enabled edge intelligence. We identify the key properties that future CS-DL frameworks must have to support efficient execution on mobile devices, such as: 1) the ability to adapt the sample size to a changing context, in which the data is collected, and 2) a dynamically adapting neural network architecture able to process a varying set of samples collected via CS. At the *ACM International Conference on Computing Frontiers*, we presented the pipeline we developed, CS-DL, which uses a data-driven sampling matrix to dynamically adjust the sampling level of a mobile device. The sampling layer is then followed by a DL model that provides inference on an input vector of different sizes via a tailored input adaptation layer. In this work, we also develop a SoftMax algorithm for sampling-rate adaptation and show that our approach can save up to 46 % energy in the domain of human activity recognition from sensor data without sacrificing inference accuracy. In addition to an open-source implementation of our framework in Python, we also demonstrate the concept on an actual Android mobile device.

Figure 4: Human activity recognition on Android with compressive sensing-inspired deep learning, https://www.youtube.com/watch?v=StFrB1AtGmc&feature=youtu.be

As part of the *D-Rabbit* project, which aims to transfer technology from academia to industry, we participated in the **gamification of sensorimotor training** with a balance board. The basic building blocks for the game are the movements we can detect on the board itself. This is achieved using a 9DOF sensor and deep learning on an AMI sensor device. The work was presented at the *Design and Architecture for Signal and Image Processing 2022* conference.

A Gender Equality Plan (GEP), meeting a set of mandatory requirements, is an eligibility criterion for all public institutions, higher education institutions and research organizations from Member States and Associated Countries wishing to participate in Horizon Europe, in calls with deadlines starting in 2022. A GEP was prepared under the *Athena* project (https://www.athenaequality.eu/), which was then approved by the *JSI Scientific Council* in October 2022. We have also developed a GEP monitoring and evaluation system that will help to understand the

progress made thanks to the implementation of the new GEP. In addition, it will help, if needed, to identify the remaining challenges and obstacles and provide tailored solutions for properly addressing them and modifying the GEP accordingly.

Some outstanding publications in the past year

1. Tome Eftimov, Gašper Petelin, Gjorgjina Cenikj, Ana Kostovska, Gordana Ispirova, Peter Korošec, Jasmin Bogatinovski, Less is more: selecting the right benchmarking set of data for time series classification, Expert Systems with Applications, 2022, vol. 198, pp. 116871-1-116871-10, doi: 10.1016/j.eswa.2022.116871.
2. Milena Trajanoska, Risto Trajanov, Tome Eftimov, Dietary, comorbidity, and geo-economic data fusion for explainable COVID-19 mortality prediction, Expert Systems with Applications, 2022, vol. 209, pp. 118377-1-118377-15, doi: 10.1016/j.eswa.2022.118377.
3. Francesco Vitali, Paola Zinno, Emily Schifano, Agnese Gori, Ana Costa, Carlota De Filippo, Barbara Koroušić-Seljak, Panče Panov, Chiara Devirgiliis, Duccio Cavalieri, Semantics of dairy fermented foods: a microbiologist's perspective, Foods, 2022, vol. 11, no. 13, pp. 1939-1-1939-18, doi: 10.3390/foods11131939.
4. Gordana Ispirova, Gjorgjina Cenikj, Matevž Ogrinc, Eva Valenčič, Riste Stojanov, Peter Korošec, Ermanno Cavalli, Barbara Koroušić-Seljak, Tome Eftimov, CafeteriaFCD corpus: food consumption data annotated with regard to different food semantic resources, Foods, 2022, vol. 11, no. 17, pp. 2684-1-2684-13, doi: 10.3390/foods11172684.
5. Rok Hribar, Timotej Hrga, Gregor Papa, Gašper Petelin, Janez Povh, Nataša Pržulj, Vida Vukašinović, Four algorithms to solve symmetric multi-type non-negative matrix tri-factorization problem, Journal of Global Optimization, 2022, vol. 82, pp. 283-312, https://link.springer.com/article/10.1007%2Fs10898-021-01074-3, doi: 10.1007/s10898-021-01074-3.
6. Gregor Papa, Marina Santo-Zarnik, Vida Vukašinović, Electric-bus routes in hilly urban areas: overview and challenges, Renewable & Sustainable Energy Reviews, 2022, vol. 165, pp. 112555-1-112555-19, doi: 10.1016/j.rser.2022.112555.
7. Yasmine Emara, Barbara Koroušić-Seljak, Eillen R. Gibney, Gorjan Popovski, Igor Pravst, Peter Fantke, Workflow for building interoperable food and nutrition security (FNS) data platforms, Trends in Food Science & Technology, 2022, vol. 123, pp. 310–321, doi: 10.1016/j.tifs.2022.03.022.

Awards and Appointments

1. Eva Valenčič, University of Newcastle, PhD Student Best Paper Award: Digital Nudging in Online Grocery Stores: A Scoping Review on Current Practices and Gaps, Newcastle, Australia, December 2022
2. Sen. lec. Rok Poličnik, dr Katja Rostohar, prof. dr Barbara Koroušić Seljak, dr Barbara Blaznik, assist. prof. dr Jerneja Farkaš Lainščak received the ARRS Excellent in Science 2022 in the field of public health for research work: Energy and nutritional composition of school lunches in Slovenia: the results of a chemical analysis in the framework of the national school meals survey
3. Prof. dr Gregor Papa, dr Marina Santo Zarnik, dr Vida Vukašinović received the ARRS Excellence in Science 2022 in the field of engineering for the scientific article: Electric-bus routes in hilly urban areas: overview and challenges, Renewable & Sustainable Energy Reviews

Organization of conferences, congresses and meetings

1. AI & Food and Nutrition, Applied Machine Learning Days (AMLD) 2022, Laussane, Switzerland, 26–30 March 2022
2. 40th Slovenian online workshop Algorithms by Nature Models (AVN), Žavcarjev vrh, Slovenia, 15 June 2022
3. BENCHMARK workshop at GECCO 2022, Boston, USA, 9–13 July 2022
4. AUTODESIGN4EC 2022 : Automated Algorithm Design for Evolutionary Computation at IEEE CEC 2022, Padua, Italy
5. Workshop for external stakeholders of the Athena project GENDER EQUALITY with awareness of diversity in an inclusive organizational culture, Ljubljana, Slovenia, 15 September 2022 (co-organization)
6. Education within the framework of the European Athena project "How to establish a balance between professional and private life", Ljubljana, Slovenia, 25 October 2022 (co-organization)
7. Consortium meeting M37, FNS-Cloud, Ljubljana, Slovenia, 25–27 October 2022
8. Project meeting Intelligent Reliability 4.0 (iRel40), Ljubljana, Slovenia, 7–10 November 2022
9. 10th International Conference on Bioinspired Optimization Methods and their Applications, BIOMA 2022, Maribor, Slovenia, 17–18 November 2022
10. Big Food, Nutrition, and Environment Data Analysis and Management (BFNDMA) at IEEE BigData, Osaka, Japan, 12–17 December 2022

INTERNATIONAL PROJECTS

1. EFSA - CAFETERIA; Support of Automating Some Specific Steps of Systematic Review Process Using Artifical Intelligence
   Prof. Barbara Koroušić Seljak
   European Food Safety Authority - Efsa
2. H2020 - FNS-Cloud; Food Nutrition Security Cloud
   Prof. Barbara Koroušić Seljak
   European Commission
3. H2020 - METROFOOD-PP; METROFOOD-RI Preparatory Phase Project
   Prof. Barbara Koroušić Seljak
   European Commission
4. H2020 - iRel40; Intelligent Reliability 4.0
   Prof. Gregor Papa
   European Commission
5. H2020 - InSecTT; Intelligent Secure Trustable Things
   Dr. Drago Torkar
   European Commission
6. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Dr. Vida Vukašinović
   European Commission
7. H2020 - COMFOCUS; Communities on Food Consumer Science
   Prof. Barbara Koroušić Seljak
   European Commission
8. H2020 - DAIS; Distributed Artificial Intelligent Systems
   Prof. Gregor Papa
   European Commission
9. H2020 - FoodTraNet; Advanced Research and Training Network in Food Quality, Safety and Security
   Prof. Barbara Koroušić Seljak
   European Commission
10. HE - AgroServ; Integrated SERvices supporting a sustainable AGROecological transition
    Prof. Barbara Koroušić Seljak
    European Commission
11. HE - CONDUCTOR; Fleet and Traffic Management Systems for Conducting Future Cooperative Mobility
    Prof. Gregor Papa
    European Commission
12. HE - FishEUTrust; European Integration of New Technologies and Social-Economic Solutions for Increasing Consumer Trust and Engagement in Seafood Products
    Prof. Barbara Koroušić Seljak
    European Commission
13. PRIMA; PROMEDLIFE - Novel food products for the PROmotion of MEDiterranean LIFEstyle and healthy diet
    Prof. Barbara Koroušić Seljak
    Prima Foundation - Partnership For Research And
14. PRIMA; WEFE4MED - Towards a Mediterranean WEFE Nexus Community of Practice
    Prof. Gregor Papa
    Prima Foundation - Partnership For Research And
15. WBL GRANT; Work-Based Learning Grant
    Asst. Prof. Tome Eftimov
    The University Of Wales Trinity Saint David

RESEARCH PROGRAMME

1. Computer Structures and Systems
   Prof. Gregor Papa

R&D GRANTS AND CONTRACTS

1. Context - aware on-device approximate computing
   Dr. Bojan Blažica
2. Quality, Safety and Authenticity of INsect PROtein-Based Food and Feed Products
   Prof. Barbara Koroušić Seljak
3. Personalized Fingerprints for Black-Box Optimization
   Asst. Prof. Tome Eftimov
4. Auto-OPT: Automated selection and configuration of single-objective continuous optimization algorithms
   Prof. Peter Korošec
5. Political and social systems, structures and processes
   Prof. Peter Korošec
6. METROFOOD
   Prof. Barbara Koroušić Seljak
7. Social Innovation for Integrated health CARE of ageing population in ADRION Regions-SI4CARE
   Dr. Bojan Blažica
   The Emillia-romagna Region
8. Support for Strategic Research and Innovation Partnerships (SRIP) in priority areas of Smart Specialization
   Prof. Gregor Papa
   Ministry of Economic Development and Technology
9. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
   Dr. Marina Santo Zarnik
   Ministry of Economic Development and Technology
10. School pot: Continuous upgrade of the web portal „Šolski lonec" to support the implementation of the national dietary guidelines in educational institutions and the transfer of skills in using e-tools for planning quality school menus into practice
    Prof. Barbara Koroušić Seljak
    Ministry of Health
11. Innovative solutions for informed choices: A tool to encourage healthier choices by supporting consumers to monitor and evaluate food composition data
    Dr. Bojan Blažica
    Ministry of Health
12. Supporting residents to reduce the risk of alcohol use through a mobile app
    Dr. Bojan Blažica
    Ministry of Health
13. OPKP: Upgrade of the Open platform for clinical Nutrition (OPKP) with respect to the national dietary guidelines and state-of-the-art ICT
    Prof. Barbara Koroušić Seljak
    Ministry of Health
14. Digital solutions and increasing the competence of using Information Technologies to promote healthy choices and health promotion (DoIT
    Prof. Barbara Koroušić Seljak
    Zveza Potrošnikov Slovenije
15. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
    Prof. Gregor Papa
    Helmholtz-Zentrum Dresden-Rossendorf E.V.

NEW CONTRACT

1. Simulation-based optimization of cogging torque in electric motor design
   Prof. Peter Korošec
   Mahle Electric Drives Slovenija d. o. o.

VISITORS FROM ABROAD

1. Laura Bardon, University College Dublin, Ireland, 9–20 May 2022
2. Maja Omieljaniuk, Quadram Institute, Norwich, Great Britain, 15 May to 15 June 2022
3. Prof. Tamara Bucher, University of Newcastle, Australia, 6 July to 26 August 2022

STAFF

Researchers
1. Asst. Prof. Anton Biasizzo
2. Dr. Bojan Blažica
3. Asst. Prof. Tome Eftimov
4. Prof. Peter Korošec
5. Prof. Barbara Koroušić Seljak
6. **Prof. Gregor Papa, Head**
7. Asst. Prof. Veljko Pejović*
8. *Dr. Marina Santo Zarnik, retired 01.04.22*
9. Dr. Drago Torkar
10. Dr. Vida Vukašinović
Postdoctoral associate
11. Dr. Marko Pavlin*
Postgraduates

12. Margarita Antoniou, M. Sc.
13. Gjorgjina Cenikj, B. Sc.
14. Rok Hribar, B. Sc.
15. Dr. Gordana Ispirova
16. Gašper Petelin, B. Sc.
17. Urban Škvorc, B. Sc.
18. Eva Valenčič, B. Sc.
19. Jure Vreča, B. Sc.
Technical officers
20. Robert Modic, B. Sc.

21. *Peter Novak, B. Sc., left 01.03.22*
22. Matevž Ogrinc, B. Sc.
Technical and administrative staff
23. Jolanda Jakofčič
24. Tina Kondić
25. Andraž Simčič
26. Andreja Vlašič, B. Sc.

Note:
* part-time JSI member

DEPARTMENT OF KNOWLEDGE TECHNOLOGIES

<div style="text-align:right">**E-8**</div>

At the Department of Knowledge Technologies we develop artificial intelligence methods and other advanced information technologies that support the acquisition, management, modeling and use of knowledge and data, thus enabling a knowledge-based society. Our research covers many areas of artificial intelligence, such as machine learning and natural language processing as well as related fields, such as decision support. Our research has five pillars: machine learning, decision support and artificial intelligence, artificial intelligence and science, natural language processing and digital humanities, and knowledge technologies for society. We use the developed knowledge technologies in various fields, from sustainable agriculture to personalized medicine and health, through media, education and the arts, to various industrial sectors such as energy, transport and space research.

Head:
Prof. Sašo Džeroski

In 2022 we were involved in two national research programs (on knowledge technologies and quantum technologies), eighteen national projects and ten EU projects. Among these, we were coordinators of two EU projects, EMBEDDIA and IMSyPP, and were also involved in one CEF project. We also participated in two infrastructure projects, two applied projects and one COST action. Finally, we had four young researcher projects, within which we hosted junior researchers working towards their PhDs.

Machine Learning. In this area, we focused on the development and evaluation of the methods for *multi-target prediction,* addressing machine learning tasks such as multi-label classification and multi-target regression. We designed a novel method for learning survival trees, based on semi-supervised learning of predictive clustering trees for multi-target regression and evaluated it on a number of medical datasets. We also conducted an extensive empirical comparative study of the methods for multi-label classification, comprising a large number of methods, datasets and performance metrics. Finally, we developed several methods for learning ensembles of relational decision trees for classification, including bagging, random forests and gradient-boosted ensembles.

In machine learning, we also addressed the topic of *representation learning* where we developed data mining methods for the analysis of heterogeneous data. In particular, we developed an approach to deep node ranking for neuro-symbolic structural node embedding and classification, and provided a comprehensive evaluation of approaches to ontology completion with graph-based machine learning. We also developed the ReliefE approach to feature ranking in high-dimensional spaces via manifold embeddings.

Decision Support and Artificial Intelligence. In the field of decision support, we develop decision-modeling methods and decision-support software. An extensive chapter on the DEX (Decision EXpert) method was published in the Springer book *Multiple Criteria Decision Making: Techniques, Analysis and Applications*. The method, which was developed at our department, was in this way put alongside the most important methods in the field of multi-criteria decision modeling. We supplemented the analytical part of DEX with the BAG-DSM algorithm, which solves a hard combinatorial problem using a Bayesian optimization approach, answering the questions of the target analysis: what do we need to change in a given decision alternative so that it is evaluated better or, alternatively, worse? We have expanded the collection of our DEX supporting tools with software used in R and Python.

Figure 1: Nada Lavrač received the national ZOIS award for outstanding research achievements in the area of machine learning.

We also applied decision-support approaches to a variety of practically relevant problems. This applied research mainly focused on the completion of the H2020 NARSIS project, in which we developed a system called Severa, aimed at decision support during severe accidents in nuclear power plants. The DEX method was also used to support stakeholders in the remediation of nuclear facilities and assess the quality of Slovenian textbooks. Finally, DEX was used for the integration of the DSS with the human resources management, and identity and access management systems in an enterprise, for the development of a DSS tool for sustainable labor market integration and for a community analysis in the Slovenian labour network 2010–2020.

In the area of *explainable artificial intelligence,* we developed and evaluated methods for variable importance estimation and feature ranking in several contexts. This includes novel methods for the feature ranking of multi-class and multi-label classification, based on low-dimensional manifold embeddings of the input and output spaces and the Relief method. Similarly, this includes new approaches for feature ranking in the context of relational learning, based on methods for learning ensembles of relational decision trees.

In this area we also work on the EU project TAILOR (Foundations of Trustworthy AI Integrating Learning, Optimisation and Reasoning). Within the project, we focus on AutoAI approaches for automated configuration of different AI methods to achieve better performance on a given task, as well as understand and explain the conditions (task properties), under which certain methods perform well. We have applied meta-learning (on top of the results of machine learning) to explain the performance of multilabel classification methods with data set properties. Similarly, we have used machine learning to analyze the performance of different configurations of modular optimization algorithms and relate their performance on different optimization tasks to the properties of the task.

Artificial Intelligence for Science. In this area we continued working on *semantic technologies* to support the process of data analysis in the spirit of *open science*. After developing formalisms for ontological descriptions of machine learning algorithms, datasets and experiments, we worked on populating the respective ontologies. For example, we prepared a catalogue of semantic annotations, including multilabel datasets FAIR (i.e., findable, accessible, interoperable and reusable). Similarly, we developed an optimization algorithm benchmarking ontology (OPTION) to support the benchmarking of algorithms in the domain of optimization, allowing the description of optimization algorithms, optimization problems and performance information resulting from benchmarking studies. We then collected benchmarking data, annotated appropriately, and used it for meta-learning, e.g., to analyze the performance of different configurations of modular optimization algorithms and relate their performance on different optimization tasks to the properties of the task.

In the field of *computational scientific discovery*, a key area of using artificial intelligence for science, our research concentrated within the SESAME project – Automating the Synthesis and Analysis of Scientific Models. Here we proposed the use of probabilistic grammars to represent domain knowledge in equation discovery. After the initial work on discovering algebraic equations, we extended our approaches to learn ordinary differential equations from the data and domain knowledge specified through probabilistic grammars. Our work in the related domain of *computational creativity* includes the use of computational creativity inspired metrics for the evaluation of curriculum learning algorithms.

> Department members co-organized the ninth edition of the VarDial workshop on NLP for similar languages, varieties and dialects, co-located with the COLING international conference on computational linguistics, held in Gyeongju, Republic of Korea. Besides hosting 13 regular and 2 invited talks, the workshop's evaluation campaign focused on discriminating between dialects of Italy, cross-domain French dialect identification, as well as dialectal extractive question answering in English, Arabic and Kiswahili.

Figure 2: Evolution of Slovenian Twitter communities and hate speech in 2018–2020. Nodes are the largest detected communities for weeks t = 0, 22, 68, 91, 132. The node size indicates the community size, darker areas correspond to unacceptable tweets and lighter areas to acceptable tweets. An edge denotes the external influence of a community on another one. Linked communities form super-communities: left-leaning (left, top), sports (middle) and right-leaning (right and SDS, bottom).

We also extensively used *machine learning for science*, considering scientific data from different domains, resulting in publications in both computer science and application domain literature. In the area of life sciences, medicine and pharmacology, we used multi-target prediction methods to perform virtual compound screening. We looked for drugs that would help reverse lung fibrosis within the INTERREG V-A Slovenia-Italy project TRAIN: Big Data and Disease Models: A Cross-border Platform for Validated Biotech Industry Kits, and found a candidate, which was confirmed to be active through wetlab experiments. Within the project "Restoration of moldy canvas paintings: improvement or deterioration?", we study the damage to paintings caused by fungi, in particular for the Celje Ceiling, a biodeteriorated tempera painting on canvas, where we analyzed the relation between the properties of paintings and biodeterioration.

We also used multi-target prediction methods to model the relation between small mammal populations and the composition of communities of owls.

In the area of environmental sciences, we used machine learning methods to identify contaminants of emerging concern from mass spectra of their silylated derivatives. We also applied methods for multi-target prediction to study the occurrence, diversity and anti-fungal resistance of fungi in the sand of an urban beach in Slovenia, using the data collected via environmental monitoring, and explore the possible health risk implications. Finally, we also used multi-target prediction in robotics to determine the exception context in assembly operations from multimodal data.

Language Technologies and Digital Humanities. In these areas we address the issues of natural language processing and understanding, text and network analytics, open access language resources and digital humanities.
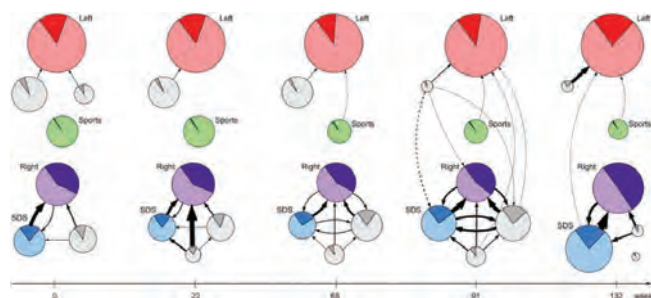
In the field of *natural language processing and understanding* we successfully completed the European project EMBEDDIA (Cross-Lingual Embeddings for Less-Represented Languages in European News Media) that we coordinated. The work resulted in many new technologies for cross- and multilingual news analysis and generation, which were also presented in the scope of invited talks at events and foreign universities. News analysis was also at the core of the ongoing national project CANDAS (Computer-assisted multilingual news discourse analysis with contextual embeddings). We evaluated various keyword extraction methods for Slovenian and cross-lingual settings. We also conducted a comparative study on unsupervised keyword extraction systems in terms of trade-offs between the retrieval speed and quality and proposed our own fast and robust unsupervised method. Next, we developed a novel text representation approach based on knowledge graphs and demonstrated its potential with the task of fake-news classification. We also proposed an approach to extracting and analyzing metaphors in media discourse on migrations. Online workflows for interactive experimentation with word embeddings in the ClowdFlows platform was showcased at a digital humanities workshop. On the applied side of news analysis, we further developed and evaluated the methods for sentiment analysis, keyword and named entity extraction, document clustering and retrieval in the scope of the industrial project for the media monitoring company Kliping d.o.o. We also released novel datasets for keyword extraction and developed methods for headline generation in low resource settings.

Figure 3: Fake news detection approach using standard and novel knowledge-graph-based representations

In the scope of the EU project MaCoCu (Massive Collection and Curation of Monolingual and Bilingual Data: Focus on Under-Resourced Languages), we published the first data release of monolingual crawls of Slovenian, Croatian, Macedonian, Bulgarian, Turkish, Maltese and Icelandic. Most of the published text collections represent the largest text collections of the corresponding languages and are of great use for training large language models. We also released a series of large language models, most of which represent the state-of-the-art of some natural language understanding tasks (https://huggingface.co/MaCoCu). Along with the monolingual collections, parallel data collections were published as well, in the following language pairs: Slovenian-English, Croatian-English, Macedonian-English, Bulgarian-English, Turkish-English, Maltese-English and Icelandic-English. Along with the work on enriching these text collections, we developed a new schema and a training dataset for web-based genre identification, performed cross-lingual experiments with automating genre identification and performed a feature analysis of the task. An additional direction for data enrichment is discrimination between language varieties.

We developed an approach to natural language processing by combining neuro-symbolic representations and constrained clustering, included in the NeSyChair system, applicable to the problem of semi-automated conference scheduling. Next, we introduced Linguoplotter, a workspace-based architecture for generating short natural language descriptions of data and proposed a clause-level compositional example generation method for text-to-SQL parsing. We also participated in several shared tasks in the field of natural language processing. We won the first place at the TextGraphs-16 natural language premise selection task in the domain of natural language processing for mathematical logic, took the fifth place in a news similarity shared task, contributed to the multi-label classification of biomedical literature on the topic of Covid-19 and proposed approaches to the alignment of representations of dictionary definitions and entries.

Finally, we contributed to a novel corpus of textbooks and core vocabulary for learning Slovenian as the second language and developed language models and evaluation sets for Buddhist Sanskrit, showing that context does improve inter-annotator agreement significantly, especially in most radical examples of hate speech. We further investigated the interplay of retweet networks, topics and hate speech over three years of Slovenian Twitter, showing that most hate speech stems from ideological discussions, where right-wing communities are the primary generators of a hateful content. Finally, we focused on the recent Russian invasion of Ukraine through the lens of ex-Yugoslavian Twitter. Our community evolution analysis depicts a unifying reaction of the western part of ex-Yugoslavian republics, very different to that of Serbia, where almost no change in the community structure can be observed.

We worked on the topic of hate and offensive speech detection in the scope of the projects RobaCOFI (Robust and adaptable comment filtering), which was selected for funding in the scope of the AI4Media Open Call and the national project SOVRAG (SOVRAG – Hate speech in contemporary conceptualizations of nationalism, racism, gender and migration). We released a multilingual hate and offensive speech classifier and a new annotated CoRAL dataset of hate speech and offensive language in news comments in Croatian, specifically covering the phenomena of implicitness and reliance on the local and global context. We show experimentally that the current models for detecting abusive language degrade when comments are not explicit and further degrade when the language skill
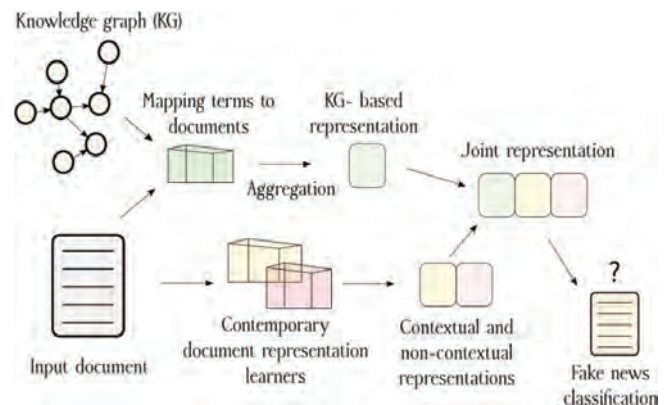
and context knowledge are required to interpret a comment. In addition to the focus on hate speech, user-generated content was also the topic of the analysis of tweets during the French presidential campaign and in an approach to understand and incorporate misspelling semantics in the example of Thai for improving the performance of user-generated content classification tasks.

We also use the network analysis to explore the social graph of the Internet Engineering Task Force (IETF), based on public email discussions and co-author relationships, and the influence of key contributors. We show that a small core of participants dominates, but that influence has become relatively more decentralized with time. We analyze correlations between influence, affiliation and success in getting new proposals adopted.

Figure 4: A workshop for embedding-based corpus analysis developed in the Cloudflows platform and used by participants of the Digital Humanities Workshop was organized in January 2022.

We continued our work in the Formica project within the national project Formica 2 (Quantitative and qualitative analysis of the unregulated corporate financial reporting), where we developed a financial sentiment classification system leveraging background knowledge from financial ontologies, a system for sustainability detection from short financial texts. We also conducted a diachronic study of the language used for environmental, social and governance (ESG) issues in the UK company annual reports. The paper won the best paper prize at the First Computing Social Responsibility Workshop at LREC 2022.

In the field of *open access language resources,* we lead CLARIN. SI, the Slovenian national node of the European CLARIN ERIC research infrastructure, which provides easy publication and sustainable access to digital language data for scholars in the humanities and social sciences and other disciplines that use or produce language resources. CLARIN.SI maintains the CTS-certified CLARIN.SI repository, concordancers and other Web services, and supports the creation of language resources and promotion of digital linguistics.

CLARIN.SI was a partner in the CLARIN ERIC funded project ParlaMint "Towards Comparable Parliamentary Corpora" that we successfully concluded in 2021 and, in 2022, started with the continuation of the project. In ParlaMint II we led three out of five work packages, i.e., WP1 "Documentation, Interoperability, Metadata" where we wrote the encoding guidelines and improved the encoding schema for the corpora, WP2 "Corpus Expansion" where we coordinated the addition of new corpora and expansion of the previous ones with new transcriptions, and WP3 "Corpus Enrichment" where we will machine translate the corpora to English, as well as adding speech data to selected corpora.

In the scope of the project "Development of Slovenian in a Digital Environment", financed by the Slovenian Ministry of Culture, and with partners from 12 institutions, the JSI has been developing methods for terminology extraction and semantic change detection. For the latter, we also released a novel evaluation dataset for Slovenian. In terms of the methods for automated terminology management, we formulated terminology extraction as a sequence labeling task. We evaluated the role of different language models in a monolingual setting, investigated the power of ensembling their outputs, and evaluated the methods in a cross-lingual setting. We also tested a combination of contextual and global sequential labeling approaches and proposed a methodology for cross-lingual term-alignment. Another line of research in terminology included modelling the karstology domain in terms of definitions and frames.

In the project Development of Slovenian in a Digital Environment, CLARIN.SI is tasked with making all the resources produced within the project to be archived and made openly available in the CLARIN.SI repository. CLARIN.SI also gives guidelines for the use of standards and best practices in encoding and annotation of the project's language resources and mounts the submitted corpora on its Web-based concordancers. As a case in point, we helped with the annotation of the Corpus of Slovenian academic writing KAS 2.0 and the Slovenian parliamentary corpus siParl 3.0.

We encoded and linguistically annotated several corpora, compiled at the Research Centre of the Slovenian Academy of Sciences and Arts (ZRC SAZU): the Corpus of 1968 Slovenian literature Maj68 2.0; Annotated sample of the Slovenian Biographical Lexicon SBL-51abbr 1.0 where we also oversaw the annotation campaign and subsequently published a paper on how to expand abbreviations using machine learning techniques applied to this dataset; and Collection of Slovenian paremiological units Pregovori 1.0 where we linguistically annotated the collection and converted it from its source format to XML. We also published a paper on the development of the Corpus of Slovenian school texts, which was published in the repository in 2021.

Every year, CLARIN.SI publishes a call for projects that further the goals of CLARIN. In 2022 six project were accepted for funding and all were successfully completed. Three datasets based on the KAS corpus of Slovenian academic writing and the result of the CLARIN.SI project "Extractions from the KAS corpus" from 2021, were also published, i.e., the Machine translation datasets from the KAS corpus KAS-MT 1.0, the Abstracts from the KAS corpus

KAS-Abs 2.0 and the Summarization datasets from the KAS corpus KAS-Sum 1.0. Furthermore, the monitor corpus of written Slovenian Trendi 2022-05 was also prepared for publication and deposited in the repository.

As part of the work of the CLARIN.SI, CLADA-BG and IHJJ Knowledge Centre for South Slavic languages (CLASSLA), we continued improving the CLASSLA-Stanza NLP pipeline and published new models. We also collaborated in the construction of the monitor corpus of Slovenian where we primarily ensured a high-quality topic classification of the data harvested. We also continued our community building and defining best practices for using language resources and technologies in language research. CLASSLA has also collaborated within the ParlaMint projects on the tasks of generating sentiment identification datasets and models for parliamentary proceedings, as well as parliament-based speech datasets for automatic speech recognition and speaker profiling.

CLARIN.SI was a co-organizer of the biennial Conference on Language Technologies and Digital Humanities. The conference in 2022 was the most successful so far, with two invited speakers, 30 regular papers, 9 extended abstracts and 12 student papers, having each contribution reviewed by three reviewers. The total number of authors of the accepted papers was 120, a third of whom were from abroad. We edited the proceedings of the conference and published an overview paper on CLARIN.SI.

At the CLARIN ERIC level, we participated by contributing to the work of the CLARIN Standards Committee, as well as serving as the programme committee chair and proceedings editor of the CLARIN Annual Conference, which took place on 10–12 October 2022 in Prague. We also co-organized ParlaCLARIN III, a workshop on creating, enriching and using parliamentary corpora at the 2022 LREC conference, and edited its proceedings. We were the co-editors of the anniversary book "CLARIN: the infrastructure for language resources" published by De Gruyter and wrote the chapter on the CLARIN resource and tool families.

We continued work on two Slovenian basic research projects, both lead by ZRC SAZU, the Scientific Research Center of the Slovenian Academy of Sciences and Arts, namely "Traditional Paremiological Units in Dialogue with Contemporary Use" and "Formant Combinatorics in Slovenian". We also contributed to the work of the Slovenian Institute for Standardization as the Slovenian representatives at ISO TC37/SC4 (Language and Terminology / Language Resources Management) by reviewing, translating and approving Slovenian standards from this field.

Knowledge Technologies and Society. This part of our work covered the use of knowledge technologies for solving practically relevant problems from many different areas, ranging from agriculture and industry, through medicine and healthcare, to media and education. In the area of *agriculture, environment and sustainability,* we were involved in several projects where we used data mining and decision modeling methods to develop predictive and decision models to support the development of sustainable agricultural and food systems.

Based on the results of the already finished Horizon 2020 TRUE project (Transition paths to sustainable legume-based systems in Europe), we have published the Multi-SWOT method, developed for a comprehensive analysis of the sustainability of agri-food chains for legumes in Slovenia. The method belongs to the broader framework of multi-criteria decision modeling. Using the Multi-SWOT method, we identified the actors that promote (combined factors of strengths and opportunities) and constrain (combined factors of weaknesses and threats) sustainability. Based on the criteria of the two groups mentioned above, we defined themes and focus areas of sustainability aspects at the level of the chain. Using a new method, we discovered key factors, topics and focus areas that could improve the sustainability of Slovenian agri-food chains for pulses.

Figure 5: Results of the Multi-SWOT methodology applied to the sustainability assessment of the legume-based agri-food chain in Slovenia

As part of the Horizon 2020 IPM Decisions project (Stepping-up IPM decision support for crop protection), we continued to develop the IPM Adviser application. The application allows users to search across and compare 80 decision support systems for integrated plant protection. We have linked the application to the IPM Decisions platform (https://www.platform.ipmdecisions.net/). This provides platform users with an extensive collection of metadata on each DSS included in the IPM Decisions platform. Through an extensive survey of DSS users, we have identified their preferences regarding the desired user-friendly features of DSS. The results will be integrated in the final design of the web interface of the IPM Decisions platform (https://www.platform.ipmdecisions.net/) and the IPM Adviser application.

As part of the Horizon 2020 project COCOREADO (Connecting consumers and producers to rebalance farmers' position), we have continued to actively engage stakeholders (farms and creative supply chains) in the development and verification of the effectiveness of the decision support system in public procurement of sustainable production and food supply facilities. We have also started developing a comprehensive decision support system for public
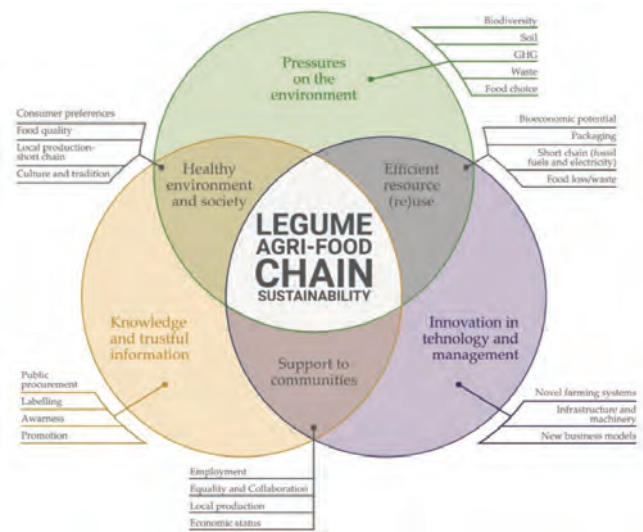
procurement of sustainably and locally produced food. The system will create synergies in the investment of public funds in the development of sustainable food production and consumption at the municipal and regional levels.

In the Horizon 2020 project RADIANT (Realising dynamic value chains for underutilized crops) we have continued to develop a new methodological approach of the analysis of dynamic supply chains for neglected crops. The decision support system is designed to enable producers to access the market, while helping consumers to meet their needs. The entire system is based on sustainability criteria and follows the theory of change approach. We have adapted its hierarchical multi-criteria decision-making structure to the DEX method. The DSS consists of two basic modules – Lean Canvas and Business Plan, which contain qualitative decision models.

As part of the COST project EUdaphobase (European Soil-Biology Data Warehouse for Soil Protection) we have developed the free and open-source software tool BEFANA for the analysis and visualization of ecological networks. It is adapted to the needs of soil ecologists and allows them to study the topology and dynamics of ecological networks of soil organisms and apply selected machine learning algorithms. BEFANA is implemented in Python and structured as an ordered collection of interactive notebooks.

Department members developed BEFANA, a tool for biodiversity-ecosystem functioning assessment by network analysis. The tool was published and released publicly (https://github.com/MartinMarzi/BEFANA).

Figure 6: Architecture of the BEFANA tool for biodiversity-ecosystem functioning assessment

In the area of *health and well-being*, we continued work on the HECAT project, performing community analysis within the Slovenian labor network in the period 2010–2020. We also performed some work on applying natural language processing in the context of well-being and mental health, which included development of approaches for automated detection of depression. We also edited a special issue of an International journal on environmental research and public health, covering the topic of "E-health for active ageing".

In the area of *knowledge technologies for education*, we continued our collaboration with the University of Nova Gorica and the JSI Center for Knowledge Transfer in IT, while our focus moved primarily to the activities supporting open education through target open education applications that cover also management processes, such as identifying knowledge gaps, quality assessment and shaping strategic policies. We enhanced the cooperative creation of open educational resources (OERs) for the implementation of sustainable development goals (SDGs). The projects developed in the SDG7 related hubs of the Open Education for a Better World (OE4BW) international mentoring program, devoted to energy, biodiversity and sustainable living, were studied with a focus on interconnections with other SDGs and processes contributing to closing knowledge gaps. The resulting guidelines were generalized to provide further increase in OERs's contribution to the achievement of SDGs. We also proposed a novel approach to the development of supportive policies for OERs, following, encouraging and enhancing active learning with data analytics. During an observed learning process, students interacted within a social network called Mastodon, from where data on student posting and interactions were extracted, analyzed and periodically presented to the students. This was used to help understand how interactions were taking place and track the overall student engagement over time, opening up avenues for dialogue between students and professors. Outlier behaviors were detected and taken into account for the improvements of the learning process, proving that analytics can be an interesting tool for finding novel forms of engagement and dialogue.

Finally, we also applied knowledge technologies to problems from *industry*, with a focus on the *space sector*, especially the use of machine learning for Earth observation and space operations. Following the project GalaxAI – Machine Learning for Predicting Spacecraft Subsystem Power Consumption, financed by the European Space Agency, we published, as open data, the telemetry data for the Mars Express spacecraft related to the thermal power consumption. We also published a paper about using machine learning to help operate the INTEGRAL spacecraft through dynamic radiation environments.
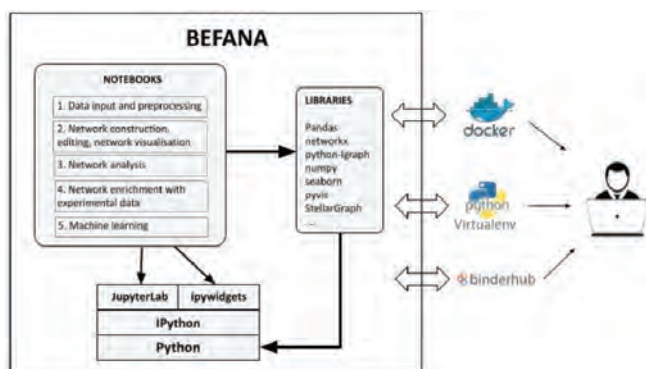
Some outstanding publications in the past year

1. Škrlj, Blaž, Kralj, Jan, Konc, Janez, Robnik Šikonja, Marko, Lavrač, Nada. Deep node ranking for neurosymbolic structural node embedding and classification. International Journal of Intelligent Systems, 2022, vol. 37, iss. 1, pp. 914–943. ISSN 0884-8173, doi: 10.1002/int.22651.
2. Škrlj, Blaž, Džeroski, Sašo, Lavrač, Nada, Petković, Matej. ReliefE: feature ranking in high dimensional spaces via manifold embeddings. Machine Learning, 2022, vol. 111, no. 11, pp. 273–317. ISSN 0885-6125, doi: 10.1007/s10994-021-05998-5.

3. Evkoski, Bojan, Pelicon, Andraž, Mozetič, Igor, Ljubešić, Nikola, Kralj Novak, Petra. Retweet communities reveal the main sources of hate speech, PLoS ONE, 2022, 17(3): e0265602. doi: 10.1371/journal.pone.0265602.

4. Mojca Drevenšek, Tanja Urbančič. The role of teamwork in the creation of open educational resources for closing SDG-related knowledge gaps. Open praxis, vol. 14, no. 161, pp. 148-161. ISSN 2304-070X, doi: 10.55982/openpraxis.14.2.266.

5. Petković, Matej, Ceci, Michelangelo, Pio, Gianvito, Škrlj, Blaž, Kersting, Kristian, Džeroski, Sašo. Relational tree ensembles and feature rankings. Knowledge-based systems, vol. 251, pp. 109254-1-109254-19. ISSN 0950-7051, doi: 10.1016/j.knosys.2022.109254.

6. Koloski, Boshko, Stepišnik Perdih, Timen, Robnik Šikonja, Marko, Pollak, Senja, Škrlj, Blaž. Knowledge graph informed fake news classification via heterogeneous representation ensembles. Neurocomputing, 2022, vol. 496, pp. 208-226. ISSN 0925-2312, doi: 10.1016/j.neucom.2022.01.096.,

7. Dergan, Tanja, Ivanovska, Aneta, Kocjančič, Tina, Iannetta, Pietro, Debeljak, Marko. Multi-SWOT multi-stakeholder-based sustainability assessment methodology: applied to improve Slovenian legume-based agri-food chains. Sustainability, 2022, vol. 14, no. 22, pp. 15374-1-15374-26. ISSN 2071-1050, doi: 10.3390/su142215374.

8. Marzidovšek, Martin, Podpečan, Vid, Conti, Erminia, Debeljak, Marko, Mulder, Christian. BEFANA: a tool for biodiversity-ecosystem functioning assessment by network analysis. Ecological modelling, 2022, vol. 471, pp. 110065-1-110065-6. ISSN 0304-3800, doi: 10.1016/j.ecolmodel.2022.110065.

9. Bogatinovski, Jasmin, Todorovski, Ljupčo, Džeroski, Sašo, Kocev, Dragi. Comprehensive comparative study of multi-label classification methods. Expert systems with applications, vol. 203, pp. 117215-1-117215-18. ISSN 0957-4174, doi: 10.1016/j.eswa.2022.117215.

10. Roy, Bijit, Stepišnik, Tomaž, Vens, Celine, Džeroski, Sašo. Survival analysis with semi-supervised predictive clustering trees. Computers in Biology and Medicine, vol. 141, pp. 105001-1-105001-19. ISSN 0010-4825, doi: 10.1016/j.compbiomed.2021.105001.

Awards and Appointments

1. Nada Lavrač received the national ZOIS award for outstanding research achievements in the area of machine learning.

2. The doctoral student Hanh Thi Hong Tran with her colleagues and mentor dr. Senja Pollak won first place in the TextGraphs-16 Natural Language Premise Selection Task competition, situated in the field of natural language understanding for the area of mathematical logic. The goal of the task was the automatic extraction of relevant premises for proving the given mathematical propositions. The approach with contextual text representations and transformer architecture models was proven to be more effective than statistical approaches. Link to the article: https://aclanthology.org/2022.textgraphs-1.12/

3. In the contribution "Tracking Changes in ESG Representation: Initial Investigations in UK Annual Reports", professor Matthew Purver and assistant professor Senja Pollak, together with colleagues of the project "Quantitative and qualitative analysis of unregulated parts of financial reporting of companies", analyzed the texts of English annual reports from the point of view of environmental, social and management factors. They received recognition for the best contribution at the workshop "The First Computing Social Responsibility Workshop-NLP Approaches to Corporate Social Responsibilities" which was part of the LREC 2022 conference. Source: https://aclanthology.org/2022.csrnlp-1.2

4. Bosho Koloski and Ilija Tavchioski won first place in the DragonHack 2022 competition in the general category and the category Best Google Cloud Hack. They won by presenting a creative solution to the problem of removing bulky waste. Source: https://sta.si/3040708/razglaseni-zmagovalci-tekmovanja-v-uporabi-programske-in-strojne-opreme-dragonhack

5. Boshko Koloski and the international team of the European project EMBEDDIA ranked 5th out of 33 at the competition SemEval-2022 for the task of the perception of multilingual news article similarity and achieved an excellent 2nd place for the task concerning English news article similarity. Source: https://aclanthology.org/2022.semeval-1.156.pdf

6. Biljana Mileva Boshkoska received the 2022 IFIP Service award for outstanding contributions to the IFIP and the informatics community

7. Marjan Stoimchev received the award for the best contribution to the ICT program at the event "The 14th Jožef Stefan International Postgraduate School Students Conference" (IPSSC) in Kamnik, Slovenia.

Patents granted

1. Jihed Khiari, Luis Moreira-Matias, Sašo Džeroski, Bernard Ženko, Method and system for model integration in ensemble learning, US11423336 (B2), US Patent Office, 23. 08. 2022.

INTERNATIONAL PROJECTS

1. INEA/CEF - MaCoCu; Massive Collection and Curation of Monolingual and Bilingual Data: Focus on Under-Resourced Languages
   Dr. Nikola Ljubešić
   Innovation and Networks Executive Agency (INEA)
2. ParlaMint II - Towards Comparable Parliamentary Corpora
   Prof. Tomaž Erjavec
   Jan Metal, d. o. o.
3. COST CA18237; European Soil-Biology Data Warehouse for Soil Protection
   Prof. Marko Debeljak
   COST Association Aisbl
4. H2020 - NARSIS; New Approach to Reactor Safety Improvements
   Prof. Marko Bohanec
   European Commission
5. H2020 - RESILOC; Resilient Europe and Societies by Innovating Local Communities
   Dr. Aljaž Osojnik
   European Commission
6. H2020 - FNS-Cloud; Food Nutrition Security Cloud
   Prof. Nada Lavrač
   European Commission
7. H2020 - HECAT; Disruptive Technologies Supporting Labour Market Decision Making
   Prof. Biljana Mileva Boshkoska
   European Commission
8. H2020 - TAILOR; Foundations of Trustworthy AI - Integrating Reasoning, Learning and Optimization
   Prof. Sašo Džeroski
   European Commission
9. H2020 - COCOREADO; Connecting COnsumers and producers to REbalance farmers
   Prof. Marko Debeljak
   European Commission
10. H2020 - RADIANT; ReAlising DynamIc vAlue chaiNs for underuTilised crops
    Prof. Marko Debeljak
    European Commission
11. RobaCOFI; H2020 - AI4Media; Robust and Adaptable Comment Filtering
    Matthew Richard John Purver
    European Commission
12. H2020 - ELEXIS; European Lexicographic Infrastructure
    Prof. Tomaž Erjavec
    European Commission
13. H2020 - EMBEDDIA: Cross-Lingual Embeddings for Less-Represented Languages in European News Media
    Asst. Prof. Senja Pollak
    European Commission
14. H2020 - IMSyPP; Innovative Monitoring Systems and Prevention Policies of Online Hate Speech
    Asst. Prof. Petra Kralj Novak
    European Commission
15. HE - PARC; Partnership for the Assessment of Risks from Chemicals
    Prof. Sašo Džeroski
    European Commission
16. HE - INQUIRE; Identification of Chemical and Biological Determinants, Their Sources, and Strategies to promote Healthier Homes in Europe
    Prof. Sašo Džeroski
    European Commission
17. HE - ASSAS; Artificial Intelligence for the Simulation of Severe AccidentS
    Prof. Sašo Džeroski
    European Commission
18. PRIMA; WEFE4MED - Towards a Mediterranean WEFE Nexus Community of Practice
    Prof. Marko Debeljak
    Prima Foundation - Partnership For Research And
19. CLARIN Resource Families (Secondment Agreement for Prof. Dr. Darja Fišer for the Year 2022)
    Prof. Darja Fišer
    Clarin Eric
20. CLARIN Resource Families (Secondment Agreement for Dr. Jakob Lenardič for the Year 2022)
    Dr. Jakob Lenardič
    Clarin Eric
21. Working Memory Based Assessment of Large Language Models
    Asst. Prof. Senja Pollak
    Slovenian Research Agency

RESEARCH PROGRAMMES

1. Knowledge Technologies
   Prof. Sašo Džeroski
2. Physics of quantum technologies
   Jure Brence

R&D GRANTS AND CONTRACTS

1. The linguistic landscape of hate speech on social media
   Prof. Tomaž Erjavec
2. Restoration of moldy canvas paintings: improvement or deterioration?
   Prof. Sašo Džeroski
3. Quantitative and qualitative analysis of the unregulated corporate financial reporting
   Asst. Prof. Senja Pollak
4. Tradition and Innovation: Traditional Paremiological Units inDialogue with Contemporary Use
   Prof. Tomaž Erjavec
5. CRISPR/CAS9-mediated targeted mutagenesis for resistance of grapevine and potatoagainst phytoplasmas
   Prof. Nada Lavrač
6. Determining the origin of lever metastases from liquid biopsy
   Prof. Sašo Džeroski
7. Application of single cell sequencing and machine learning in mammary gland biology
   Prof. Sašo Džeroski
8. Hate speech in contemporary conceptualizations of nationalism, racism, gender and migration
   Asst. Prof. Senja Pollak
9. Formant Combinatorics in Slovenian
   Asst. Prof. Senja Pollak
10. Corporate investment as the key to building a sustainable company: building a theoretical model and multimethod empirical analysis
    Prof. Biljana Mileva Boshkoska
11. Fundamental understanding of the hydrogen formation reaction for a new generation of nickel-based electrocatalysts in alkaline and chloralkali electrolysis
    Prof. Sašo Džeroski
12. Basic Research for the Development of Spoken Language Resources and Speech Technologies for the Slovenian Language
    Dr. Nikola Ljubešić
13. Automating the Synthesis and Analysis of Scientific Models
    Prof. Sašo Džeroski
14. Predictive clustering on data streams
    Prof. Sašo Džeroski
15. Computer-assisted multilingual news discourse analysis with contextual embeddings
    Asst. Prof. Senja Pollak
16. Innovative isotopic techniques for identification of sources and biogeochemical cycling of mercury in contaminated sites – IsoCont
    Prof. Sašo Džeroski
17. Intelligent inference system for biological discoveries and its application to cancer research
    Prof. Sašo Džeroski
18. Auto-OPT: Automated selection and configuration of single-objective continuous optimization algorithms
    Prof. Sašo Džeroski
19. Exploring the biofilm phenotype and surfactome of Listeria monocytogenes to predict its persistence and pathogenicity potential using machine learning
    Dr. Blaž Škrlj
20. 4D STEM of energy related materials down to quantum level
    Prof. Sašo Džeroski
21. Clinical course and outcome of Covid-19
    Prof. Sašo Džeroski
22. Clarin
    Prof. Tomaž Erjavec
23. Development of Slovene in the digital environment
    Prof. Tomaž Erjavec
    Ministry of Culture
24. Smart mobility measures for sustainable mobility in Slovenia – SmarMOVE
    Prof. Marko Bohanec
    Ljubljanski urbanistični zavod, d. d.
25. Clinical course and outcome of Covid-19

Prof. Sašo Džeroski
Ministry of Health
26. SLOKIT: Upgrade of CLARIN.SI: Corpus informer and text analyzer
Dr. Nikola Ljubešić
Ministry of Culture

27. The First European Summer School on Artificial Intelligence (ESSAI) and the 20th
Advanced Course on Artificial Intelligence (ACAI), 2023, Ljubljana, Slovenia, 24 - 28
July 2023
Prof. Sašo Džeroski
Lancaster University

STAFF

Researchers
1. Prof. Marko Bohanec
2. Dr. Michelangelo Ceci
3. Prof. Bojan Cestnik*
4. Prof. Marko Debeljak
5. **Prof. Sašo Džeroski, Head**
6. Prof. Tomaž Erjavec
7. Prof. Darja Fišer*
8. *Asst. Prof. Aneta Ivanovska, left 01.11.22*
9. Dr. Dragi Kocev
10. Asst. Prof. Petra Kralj Novak
11. Prof. Nada Lavrač
12. Prof. Zoran Levnajić*
13. Dr. Nikola Ljubešić
14. Prof. Biljana Mileva Boshkoska
15. Prof. Igor Mozetič
16. Asst. Prof. Pance Panov
17. Dr. Vid Podpečan
18. Asst. Prof. Senja Pollak
19. Dr. Matthew Richard John Purver
20. Prof. Ljupčo Todorovski*
21. Prof. Tanja Urbančič*
22. Asst. Prof. Ana Zwitter Vitez*
23. Asst. Prof. Bernard Ženko
24. Asst. Prof. Martin Žnidaršič

Postdoctoral associates
25. Dr. Martin Breskvar
26. *Dr. Janez Kranjc, left 01.04.22*
27. *Dr. Vladimir Kuzmanovski, left 01.12.22*
28. Dr. Jakob Lenardič*
29. Dr. Jurica Levatić
30. Dr. Matej Martinc

31. Dr. Aljaž Osojnik
32. Dr. Matej Petković*
33. Dr. Nikola Simidjievski
34. Dr. Blaž Škrlj*
35. Dr. Jovan Tanevski
36. Dr. Anita Valmarska*

Postgraduates
37. Jure Brence, B. Sc.
38. Tanja Dergan, B. Sc.
39. Boštjan Gec, B. Sc.
40. Ana Kostovska, B. Sc.
41. Taja Kuzman, B. Sc.
42. Jurij Marinko, B. Sc.
43. *Martin Marzidovšek, M. Sc., on leave since 14.05.22*
44. Katja Meden, B. Sc.
45. Sebastian Mežnar, B. Sc.
46. Nina Omejc, M. Sc.
47. Andraž Pelicon, B. Sc.
48. Marko Pranjić, M. Sc.
49. Andraž Repar*, B. Sc.
50. Sintija Stevanoska, M. Sc.
51. *Tadej Škvorc, B. Sc., left 01.06.22*

Technical officers
52. Živa Antauer, B. Sc.
53. *Tina Anžič, B. Sc., left 16.09.22*
54. Peter Rupnik, B. Sc.

Technical and administrative staff
55. Milica Bauer, B. Sc.
56. Lenka Trdina, B. Sc.

Note:
* part-time JSI member

DEPARTMENT OF INTELLIGENT SYSTEMS

E-9

The Department of Intelligent Systems focuses on developing advanced methods and techniques to create intelligent computer systems with real-world applications. The research areas include artificial intelligence, ambient intelligence, agent and multi-agent systems, computational intelligence, language and speech technologies, electronic and mobile health, and smart cities. In collaboration with the Faculty of Computer and Information Science at the University of Ljubljana, the department is part of a joint research program called Artificial Intelligence and Intelligent Systems. This program is dedicated to exploring the latest advancements in the field of AI and intelligent systems.

Head:
Prof. Matjaž Gams

Moreover, the department works closely with industry partners to incorporate intelligent systems into various products and services. These systems are designed to simulate human behaviour and intelligence by utilizing complex mechanisms and digital platforms, allowing users to interact with them seamlessly. Finally, it is worth noting that the field of intelligent systems is continually expanding and enabling the growth of the information society. As such, this field is broader than artificial intelligence and is rapidly growing worldwide.

Ambient intelligence is a research field aiming to introduce technology into our everyday environment in a friendly way that is undemanding for the user. The main area where the department applies methods of ambient intelligence is health. We concluded the Flemish-Slovenian project **STRAW** on work-related stress. We found interesting relations between stress, work engagement and work-life interference in the collected data. We continued analysing the data while aiming to develop stress-detection machine-learning models. We also finished the AAL project **CoachMyLife**, which aims to help seniors with memory impairment perform everyday tasks. Using computer vision and a sensing wristband, we developed and successfully evaluated methods for assisting with kitchen activities. In the H2020 project **WideHealth**, we engaged in training and networking

Through basic research within the Weave project carried out in collaboration with the Technical University of Ostrava, we contribute to the theoretical foundations of constrained multiobjective optimization and develop a new generation of metaheuristics for this type of problem.

activities on pervasive health and related topics. The project's two thematic schools are of particular interest, one on general pervasive health and one on human factors in this area. In the H2020 project **COVIRNA**, we are developing a diagnostic test that can predict the outcome of COVID-19 patients from the expression of long non-coding RNAs in their blood. In an applied project for the Planica Institute of Sports of the Republic of Slovenia, we developed a mobile application called **Zmorem** (I Can Do It) that monitors and encourages physical activity through gamification. We pursue **doctoral research** on contact-free sensing of physiological signals and states, particularly the multi-wavelength analysis of photoplethysmogram (optical reading of blood volume in the skin). In another doctoral study, we are developing methods to select questions for nutrition questionnaires in a way that obtains the most information with the fewest questions. In the latest doctoral study, we investigate whether detecting empathy from physiological readings during virtual reality sessions is possible.

The two key research areas in the field of **agent and multi-agent systems** are the development of intelligent autonomous systems for managing smart cities and intelligent healthcare-support systems. These fields require the creation of new algorithms, methods and approaches that incorporate artificial intelligence into computer systems. In the Interreg Italy-Slovenia project **Insieme**, we created a platform for electronic and mobile health (EMH), which offers online services to Slovenian and Italian users, including online consultations with EMH specialists. We have also designed innovative devices and solutions to support elderly and chronic patients at home, including a smartwatch for the elderly that we are now adapting to mobile phones. Additionally, we have introduced a system for predicting falls that uses a bracelet determining the stability of walking and can alert individuals to the risk of falling. In the H2020 **Urbanite**
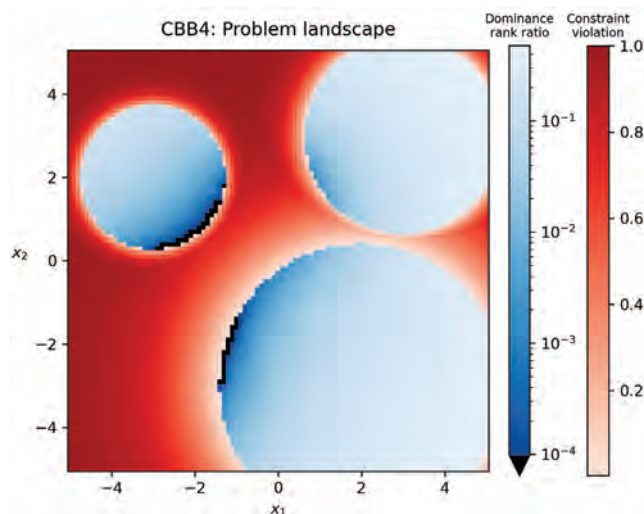

Figure 1: We are conducting research on how constraints influence the problem landscape of multi-objective optimization problems.
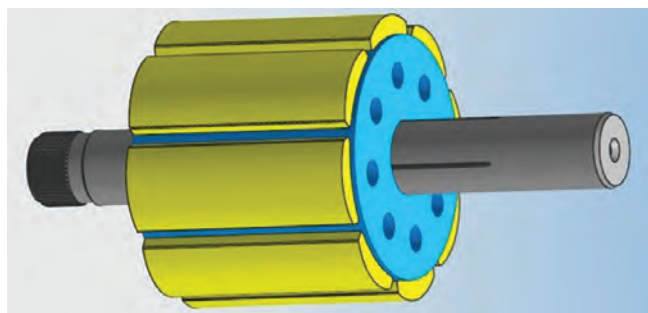
Figure 2: In cooperation with the Computer Systems Department, we are engaged in the optimization of electric motors for Mahle Electric Drives Slovenia.

We implemented an efficient software solution for scheduling workers to field tasks for the Comland company.
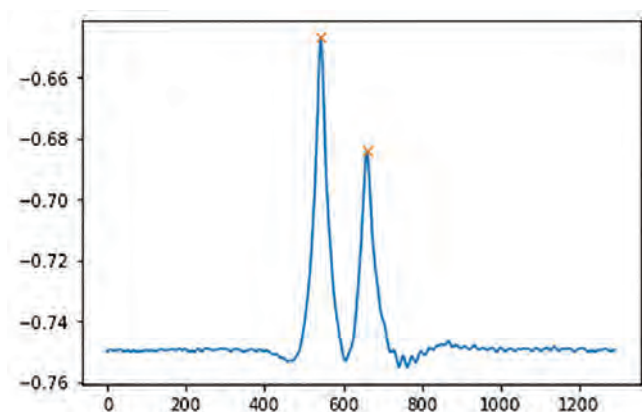

Figure 3: Our collaboration with the Cestel company has furnished us with data regarding signals from an array of bridges. By analysing a signal, we can ascertain the quantity of peaks in the curve, the wheelbase and the vehicle's weight. The number of peaks is indicative of the vehicle's axle count. In the figure, the orange cross denotes the peak, with a total of 2 peaks identified.

In the Urbanite project, our focus is on developing a smart city platform and toolset for four major European cities. Our main contribution involves the development of traffic simulations using a common approach across these cities. In addition, we created a user-friendly interface to enable an easy creation of new simulations. Based on the simulation results, we developed both a decision support system and a recommender system aimed at improving the quality of life for citizens.

project, which involves Amsterdam, Helsinki, Bilbao and Messina, we are developing a system that simulates traffic to identify the best mobility policies and measures. In the European ERA PerMed **BATMAN** project focused on the Acne Inversa disease research, we deployed a data collection, visualization and analysis system used by physicians and their patients to create a database for processing using AI methods. We also completed the **PlatformUptake.eu** project, which resulted in the publication of a method for classifying open platforms in the field of active and healthy aging in the MDPI Healthcare journal. We have recently started the **Cestel** project, which aims to predict the number of axles, wheelbase and weight of a vehicle based on the signals from bridges. Lastly, in the **Valence** project, we are working with international partners to modernize the computer science education in the Balkan region, specifically developing the high school curriculum for teaching modern artificial intelligence, including general, generative and superintelligence concepts.

Computational intelligence is a study of stochastic search, optimization and learning methods inspired by biological and physical systems. Research in this area at the Department of Intelligent Systems focuses on evolutionary computation and optimization. We study evolutionary algorithms for multiobjective optimization, their acceleration through parallel computing and surrogate models, constraint handling in multiobjective optimization, visualization of optimization results, methodology of algorithm benchmarking and their applicability in science and engineering. In 2022 we started the research project **Constrained Multiobjective Optimization Based on Problem Landscape Analysis**, which is carried out in collaboration with the Technical University of Ostrava, Czechia, and cofunded by the Slovenian Research Agency and the Czech Science Foundation under the Weave research scheme. The aim of this research is to contribute to the theoretical foundations of constrained multiobjective optimization and provide a new generation of evolutionary metaheuristics for this type of problems. This will be achieved through novel methods of problem landscape sampling and modelling, techniques for landscape visualization and constraint handling mechanisms. In the first year, the project focused on search space sampling and extracting problem features from samples. We also acquired and implemented the Jožef Stefan Innovation Fund project called **A Tool for Analysis of Industrial Optimization Problems and Their Solutions**. In this project, the research achievements of the Computational Intelligence Group in the form of experimentally verified concepts and individual methods were upgraded to a software tool that, using problem characterization and visualization, enables a better understanding and more efficient solving of demanding optimization problems. The tool represents the basis for a faster transfer of advanced optimization methods into practice. In collaboration with the Computer Systems Department, we perform **Simulation-Based Optimization of Cogging Torque in Electric Motor Design** for Mahle Electric Drives Slovenia. The goal of this project is to determine the geometric and material characteristics of a selected electric motor for the automotive industry in such a way that numerous technical requirements for its operation are met, and the manufacturing costs are minimal. Because of the high computational complexity of the simulation-based optimization, the emphasis is on the

development of a procedure that finds the most favourable solution with as few solution evaluations as possible. In the project **Intelligent and Environmentally Friendly Scheduling of Field Work (MF-Scheduler)** for the Comland company, we tackle the demanding problem of scheduling workers to field tasks. The problem is solved by a three-level optimization algorithm, which combines evolutionary computation with heuristics and mixed-integer linear programming in order to find good solutions to large problems in a reasonable time. In collaboration with the Department of Knowledge Technologies, we designed an approach for **Optimized Delivery of Gas Cylinders** for the Senso4S company. The resulting optimization algorithm uses the data from scales for remote measurement

and monitoring of gas levels in gas cylinders to propose the delivery of new gas cylinders so that it takes place at times when gas is needed while avoiding the delivery of redundant gas cylinders.

In the field of **speech and language technologies**, we work on speech synthesis, semantic analysis of text and question answering. Together with companies Alpineon and Amebis, we developed a new, high-quality speech synthesizer **eBralec** (http://ebralec.si/). The software package has more than a thousand subscribers and is an indispensable tool for blind and visually-impaired users (it is the "official" speech synthesizer of the Slovenian Association for the Blind and Visually Impaired) and people with reading impairments (the Bravo association). For these users, eBralec is free of charge and can be ordered at the Library for the Blind and Visually Impaired (http://www.kss-ess.si/ebralec-sintetizator-govora-slovenskega-jezika/). eBralec is also an integral part of the DarsTraffic+ application, which provides traffic information while its server version has been used by the National and University Library since 2017. In addition, it has been reading news on the renewed Delo (national daily newspaper) website. Furthermore, we successfully completed the **AudiBook** project: Education accessibility through a digital audio library for the blind and visually impaired.

The **25th International Multiconference Information Society – IS 2022 (is.ijs.si) was held at the Jožef Stefan Institute from 10 to 14 October 2022, comprising 11 separate conferences**, at which participants presented more than 100 papers. The Michie-Turing Award for an outstanding lifetime contribution to the development and promotion of the Information Society was awarded to Prof. Jadran Lenarčič, PhD. The Achievement of the Year Award went to NIJZ for the zVEM electronic health portal. The Information Lemon for the least appropriate information-related measure was given to the censorship on social networks and the web. The Information Strawberry for the best information achievement was given the new biometric ID card.

Figure 4: This visualization exemplifies a simulated traffic scenario, forecasting the consequences of closing Bilbao's central square to traffic. This tool is one among numerous resources offered by the platform established during the URBANITE project.

We have recently concluded the STRAW project, which involved collecting a large dataset of sensor and smartphone data linked to occupational stress questionnaires. Through this project, we have gained valuable insights into the relationships between stress, work engagement and work-life interference. We anticipate discovering further exciting results from this wealth of data in the coming months.
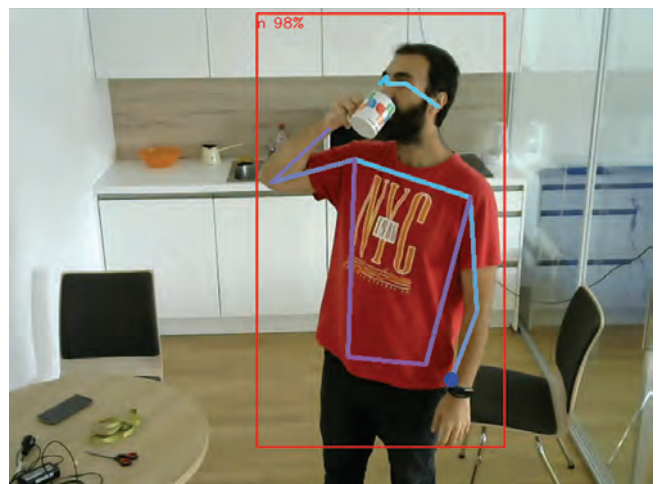
Figure 5: The AAL project CoachMyLife with the aim of assisting seniors experiencing memory decline in executing everyday tasks was completed. We developed and effectively evaluated methods for aiding kitchen activities utilizing computer vision and a sensor wristband.

Some outstanding publications in the past year

1. Brockhoff, D., Auger, A., Hansen, N., Tušar, T. Using well-understood single-objective functions in multiobjective black-box optimization test suites. Evolutionary Computation, 2022, 30 (2), 165–193

2. Gams, M., Kolar, Ž., Vuk, Z., Samuelsson, C., Jäger, B., Dovgan, E. Similarities and differences between EU platforms in the AHA and AAL domains from a software viewpoint. Healthcare, 2022, 10 (2), 401-1-401-21

3. Hansen, N., Auger, A., Brockhoff, D., Tušar, T. Anytime performance assessment in blackbox optimization benchmarking. IEEE Transactions on Evolutionary Computation, 2022, 26 (6), 1293–1305

4. Reščič, N., Mayora, O., Eccher, C., Luštrek, M. Food frequency questionnaire personalisation using multi-target regression. Nutrients, 2022, 14 (19), 1–11

5. Susič, D., Poglajen, G., Gradišek, A. Identification of decompensation episodes in chronic heart failure patients based solely on heart sounds. Frontiers in Cardiovascular Medicine, 2022, 9, 1–10

6. Vodopija, A., Stork, J., Bartz-Beielstein, T., Filipič, B. Elevator group control as a constrained multiobjective optimization problem. Applied Soft Computing, 2022, 115, 108277-1-108277-14

7. Vodopija, A., Tušar, T., Filipič, B. Characterization of constrained continuous multiobjective optimization problems: A feature space perspective. Information Sciences, 2022, 607, 244–262

Awards and appointments

1. Martin Gjoreski, Mitja Luštrek: 2020 Best Paper Runner-Up Award for IEEE Pervasive Computing, virtual, IEEE Computer Society, paper: Veljko Pejović, Martin Gjoreski, Christoph Anderson, Klaus David, Mitja

Luštrek. Toward Cognitive Load Inference for Attention Management in Ubiquitous Systems. IEEE Pervasive Computing 19

2. Anton Gradišek, Anja Pogačnik Krajnc, Luka Pirker, Maja Remškar: Prometheus of Science, Ljubljana, Slovenian Science Foundation, for "extensive professional communication to the public about the results of the testing of protective masks from various manufacturers"

3. Anton Gradišek, member of the editorial board of the online magazine Alternator: Prometheus of Science, Ljubljana, Slovenian Science Foundation, for "human-friendly presentation of research achievements in the online magazine for science and about science published by ZRC SAZU"

4. Gašper Slapničar: Best Paper Award, Slovenian Conference on AI, Ljubljana, paper: Gašper Slapničar, Peter Us, Erna Alukić, Nejc Mekiš, Miha Mlakar, Janez Žibert. IMF Quality Assurance of Mammograms Using Deep Convolutional Neural Networks and Transfer Learning

Organization of conferences, congresses and meetings

1. WideHealth Winter School on e-Health & Pervasive Technologies, Skopje, Republic of North Macedonia, 14–17 February 2022

2. 40th Slovenian Workshop on Nature-Inspired Algorithms, AVN, Žavcarjev vrh, Slovenia, 15 June 2022

3. 18th International Conference on Intelligent Environments, Biarritz, France, 20–23 June 2022

4. BBOB (Blackbox Optimization Benchmarking) Workshop at the Genetic and Evolutionary Computation Conference, GECCO 2022, Boston, USA, 9 July 2022

5. Session Evolutionary Computation in Practice (ECiP) at the Genetic and Evolutionary Computation Conference, GECCO 2022, Boston, USA, 11 July 2022 (virtual)

6. GECCO Job Market at the Genetic and Evolutionary Computation Conference, GECCO 2022, Boston, USA, 11 July 2022

7. 25th International Multiconference Information Society (IS 2022), Ljubljana, 10–14 October 2022, independent conferences:
   - Slovenian conference on artificial intelligence
   - Sikdd data mining and data warehouses
   - Demographic and family analyses
   - Cognitive science
   - Cognitonics
   - Legends of computing
   - Pervasive health and smart sensing
   - International technology transfer conference
   - Education in information society
   - Student computer science research conference 2022
   - Matcos 2022

INTERNATIONAL PROJECTS

1. ERASMUS+; Audio Library for Visually Impaired; Education Accessibility through a Digital Audio Library for the Blind and Visually-Impaired
   Dr. Tomaž Šef
   European Commission

2. ERASMUS+; VALENCE - Advancing Machine Learning in Vocational Education
   Prof. Matjaž Gams
   European Commission

3. COST CA17129: CardioRNA - Catalysing Transcriptomics Research in Cardiovascular Disease
   Dr. Mitja Luštrek
   Cost Association Aisbl

4. H2020 - PlatformUptake.eu; Assessing the State of Art and Supporting an Evidence-Based Uptake and Evolution of Open Service Platforms in the Active and Healthy Ageing Domain
   Prof. Matjaž Gams
   European Commission

5. H2020 - URBANITE; Supporting the decision-making in URBAN transformation with the use of dIsruptive Technologies
   Prof. Matjaž Gams
   European Commission

6. H2020 - COVIRNA; A Diagnostic Test to improve Surveillance and Care of COVID-19 Patients
   Dr. Mitja Luštrek
   European Commission

7. H2020 - WideHealth; Widening Research on Pervasive and eHealth – WideHealth
   Dr. Mitja Luštrek
   European Commission

8. EIT Health - SafeStep; Next-Generation of the Fall-Prevention Solution for Elderly
   Prof. Matjaž Gams
   Eit Health E.v.

9. ERASMUS+; TSAAI - Transversal Skills in Applied Artificial Intelligence
   Asst. Prof. Anton Gradišek
   European Commission

RESEARCH PROGRAMME

1. Artificial Intelligence and Intelligent Systems
   Dr. Mitja Luštrek

R&D GRANTS AND CONTRACTS

1. Precision Medicine Approach to Cell Therapy in Heart Failure
   Asst. Prof. Anton Gradišek

2. Disentangling the sources and context of daily work stress: a comprehensive real-time modelling study using wearables and technological detections
   Dr. Mitja Luštrek

3. Constrained multiobjective optimization based on problem landscape analysis
Prof. Bogdan Filipič
4. Italian-Slovenian Ecosystem for Electronic and Mobile Health
Prof. Matjaž Gams
Regione Autonoma Friuli Venezia Giulia, Direzione
5. Social Innovation for Integrated health CARE of ageing population in ADRION Regions-SI4CARE
Dr. Mitja Luštrek
The Emillia-Romagna Region
6. CoachMyLife
Dr. Mitja Luštrek
Ministry of Public Administration
7. BATMAN: Biomolecular Analyses for Tailored Medicine in Acne iNversa
Prof. Matjaž Gams
Ministry of Education, Science and Sport
8. 25th International Multiconference Information Society 2022, IS 2022, Ljubljana, Slovenia, 10 October 2022 - 14 October 2022
Prof. Matjaž Gams
9. XPRIZE: JSI vs COVID
Dr. Mitja Luštrek
Xprize

NEW CONTRACTS

1. Intelligent and environmentally friendly scheduling of field work - MF-Scheduler
Prof. Bogdan Filipič
Comland d. o. o.
2. DIH4AI-Senso4S
Asst. Prof. Tea Tušar
Senso4s d. o. o.
3. Simulation-based optimization of cogging torque in electric motor design
Prof. Bogdan Filipič
Mahle Electric Drives Slovenija d. o. o.
4. Measurements of physical activity
Dr. Mitja Luštrek
ZŠ RS Planica
5. Software designed based on AI for predicting number and load on axes
Prof. Matjaž Gams
Cestel d. o. o.

VISITOR FROM ABROAD

1. Luc Le Fessant, Adrien Vigreux, Université Paris-Saclay, Paris, France, 25 April to 22 July 2022

2. Stefan Krsteski, Matea Tashkovska, Faculty of Electrical Engineering and Information Technologies (FEEIT), Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia, 4 July to 2 September 2022

STAFF

Researchers
1. *Dr. Erik Dovgan, left 01.09.22*
2. Prof. Bogdan Filipič
3. **Prof. Matjaž Gams, Head**
4. Asst. Prof. Anton Gradišek
5. Dr. Mitja Luštrek
6. *Dr. Miha Mlakar, left 01.05.22*
7. Dr. Tomaž Šef
8. Asst. Prof. Tea Tušar

Postdoctoral associates
9. Dr. Carlo Maria De Masi*
10. Dr. Vito Janko*
11. Dr. Aleš Tavčar*

Postgraduates
12. Andrejaana Andova, B. Sc.
13. Emilija Kizhevska, M. Sc.
14. *Tine Kolenik, B. Sc., left 01.11.22*
15. Dr. Jana Krivec*
16. Gašper Slapničar, B. Sc.
17. David Susič, B. Sc.
18. Aljoša Vodopija*, B. Sc.

Technical officers
19. Ana Arnež, B. Sc.
20. *Gregor Bajt, B. Sc., left 21.09.22*
21. Marko Jordan, B. Sc.
22. Primož Kocuvan, B. Sc.
23. Žiga Kolar, B. Sc.
24. *Anže Marinko, B. Sc., left 01.05.22*
25. Maj Smerkol, B. Sc.
26. Jakob Valič, B. Sc.
27. Zdenko Vuk, B. Sc.

Technical and administrative staff
28. Jani Bizjak*, B. Sc.
29. Vesna Koricki, B. Sc.
30. Mitja Lasič
31. Liljana Lasič
32. Junoš Lukan, M. Sc.
33. Blaž Mahnič, B. Sc.
34. Nina Reščič, B. Sc.
35. Lana Zemljak

Note:
* part-time JSI member

DEPARTMENT OF REACTOR ENGINEERING R-4

The Department of Reactor Engineering is involved in basic and applied research in the fields of nuclear engineering and safety. Topics include theoretical and experimental research of basic thermal-hydrodynamic phenomena, thermal-hydraulic safety analyses of fission and fusion reactors, and structural safety analyses. Most research activities are part of international cooperation programs. Research results are incorporated into projects for the industry and for the regulatory authority, as well as into undergraduate and doctoral study programmes. The department also continued with the modelling of the COVID-19 epidemic's development in Slovenia by applying methods from nuclear energy.

Head:
Prof. Leon Cizelj

Modelling of basic thermal-hydrodynamic phenomena

In the field of two-phase gas-liquid flow, we continued simulations of Taylor bubbles (bullet-shaped bubbles that extend over almost the entire tube cross-section) in the counter-current flow regime using the OpenFoam open-source Computational Fluid Dynamics (CFD) code. Large eddy simulation (LES) was used with a volume of fluid (VOF) and an improved geometric piecewise linear interface-capturing (PLIC) method, allowing a high-fidelity reproduction of the flow. The results were validated using measurements obtained in our own THELMA laboratory. Simulations of Taylor bubbles significantly improved the predictions of the bubbles' decay rate for laminar flow conditions, but they still overestimate the decay rate for turbulent flow. To resolve this problem, additional models are being developed for bubble break-up and coalescence in the wake of Taylor bubbles.

Within the framework of the CROSSING bilateral project, together with researchers from the related department of the Helmholtz-Zentrum Dresden-Rossendorf (Germany), we continued the development of advanced simulation tools for multiphase flows with the OpenFoam library. Using a hybrid-morphology-adaptive two-fluid model, we simulated a partial reversal of liquid flow due to the counter-current flow of gas in a turbulent stratified regime in the channel of the WENKA experiment (Water Entrainment Channel Karlsruhe, Germany). Understanding the counter-current-flow limitation phenomenon is important for safety analyses of loss-of-coolant accidents in light-water nuclear reactors. Furthermore, we participated in the development of advanced models for momentum transfer across the gas-liquid interface, which can adapt the accuracy of the flow description according to the local flow regime.

We participate in the DEBORA benchmark, which is an international test within the French NEPTUNE project supported by the following organisations from France: CEA (Commissariat à l'énergie atomique et aux énergies alternatives), EDF (Electricité de France), Framatome and IRSN (Institut de radioprotection et de sûreté nucléaire). The purpose is to establish unified methods and criteria for testing and validating CFD models for subcooled boiling based on publicly available experimental data. The participating groups focus on simulations of subcooled boiling flow at high pressure in the heated pipe of the DEBORA experiment performed at CEA, Grenoble (France). In the first phase, the participants used their CFD models to predict and compare the results with publicly available experimental data, while in the second phase, the so-called "blind" simulations were carried out with experimental data to be revealed later.

Basic phenomena of vapour explosion and debris bed coolability, which might occur during a severe accident if hot reactor-core melt comes into contact with the coolant, were further investigated. Among the studies of explosions in stratified melt-coolant configurations, reactor conditions were simulated, using the developed model of the premixed layer formation, implemented in our patch of the MC3D code (IRSN). Based on previous analyses of vapour explosions in stratified configurations that indicated a potential contribution to melt-coolant mixing also from the fragmentation of the melt jet, we began to study fuel-coolant interaction in a combined stratified and melt-jet configuration. Next, to improve the understanding
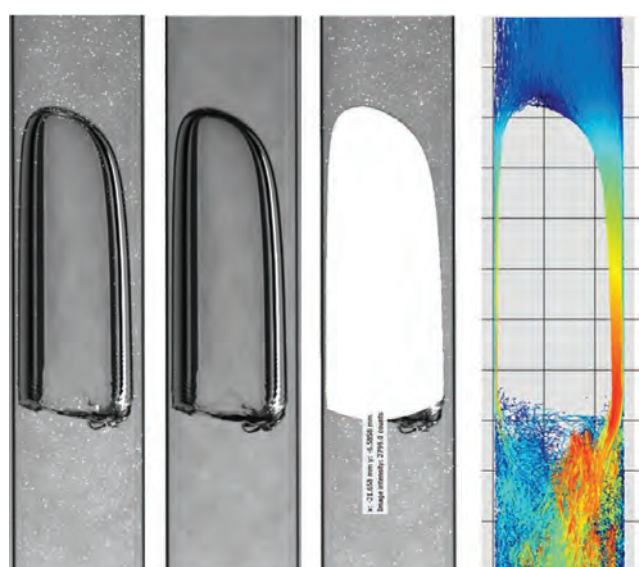

Figure 1: Taylor bubble in a turbulent flow regime. Left to right: PIV image; image without laser illumination; bubble removed with an interface reconstruction algorithm; velocity field calculated with a particle tracking algorithm

of heat transfer during the explosion phase, CFD simulations of the film boiling TREPAM experiments (CEA) were performed. We are currently developing and testing dynamic-vaporization modelling. Finally, we investigated the debris-bed coolability in top flooding conditions. Preliminary 2D and 3D simulations of the recent debris-bed experiments performed in the FLOAT facility (IKE, University of Stuttgart, Germany) were performed with the MC3D code.

In the field of hydrogen distribution in nuclear power plant (NPP) containment, we concluded simulations of the atmosphere stratification erosion using a vertical jet, performed in the PANDA (Paul Scherrer Institute, Switzerland) and SPARC (Korea Atomic Energy Research Institute) experimental facilities. The proposed modelling with dynamic Prandtl and Schmidt numbers represents an extension of the existing modelling to the conditions that may be expected during a severe accident following a reactor core oxidation and hydrogen release into the containment.

In pool scrubbing, which may be used for gas decontamination during a severe accident, gas distributed as bubbles flows through a liquid pool, and fission products in the form of solid particles (aerosols and larger) move from the bubbles into the liquid. Using a multi-fluid model (air, liquid water, particles in bubbles, and particles in water) and the OpenFoam code, an experiment that was performed in the PECA facility (CIEMAT, Spain) was simulated and the decontamination factor was predicted.

Experimental investigations in the THELMA laboratory

In the Thermal-Hydraulics Experimental Laboratory for Multiphase Applications (THELMA), we continued flow boiling experiments in a test section that represents part of a single rod in a light-water nuclear-reactor fuel assembly. New experiments were performed with a vertical orientation of the section. Flow boiling was investigated using a high-speed camera at constant flow rates and varying heating power at the wall. The obtained images were post-processed with a machine learning technique and artificial neural networks, which provided information on the bubble size distribution.

The study of Taylor bubbles in laminar or turbulent flows was carried on in cooperation with CEA. The behaviour of the gas-liquid interface was studied in a counter-current turbulent flow regime. An accurate interface recognition algorithm was developed and used for the analysis of Taylor bubble images obtained with a high-speed camera. It

The dynamics of tiny disturbance waves traveling along the interface of bullet-shaped Taylor bubbles in vertical tubes were investigated.

was observed that in turbulent flow, Taylor bubbles prefer an asymmetric shape, whereas in laminar flow, the shape is always symmetric. Moreover, the dynamics of tiny disturbance waves traveling along the interface with a Taylor bubble were tracked and cross-correlations of time-dependent interface fluctuations at different spatial positions were used to measure the propagation velocities of the waves. For sufficiently long intervals of about a minute, the time-averaged propagation velocities equal the convective velocity of the interface with remarkable accuracy. In addition, the velocity field of the liquid phase was measured using the particle image velocimetry (PIV) technique with laser-induced fluorescence (LIF). Furthermore, the bubble-decay rate and pressure-drop measurements along Taylor bubbles were performed at various temperatures and pressures. These measurements are used to validate the Taylor-bubble simulations in the counter-current turbulent flow regime, mentioned earlier.

Thermal-hydraulic safety analyses of fission and fusion reactors

The SEAKNOT European project considers severe accidents in light-water reactors, with the following purposes: identification of phenomena during severe accidents, for which further research is essential; establishment of a directory of experimental data bases; development of a network of experimental infrastructures; dissemination of the existing and novel knowledge. In 2022, activities within the project were started, with JSI being in charge of the tasks related to the NPP containment phenomena.

The purpose of the ASSAS European project is the use of artificial-intelligence methods to simulate severe accidents. As, due to the complexity of some phenomena, simulations based on physical principles are too long for an adequate severe accident simulator to be developed, the basic idea is to replace some of these models with so-called "surrogate" models that are not based on physical principles but are able to calculate sufficiently similar results in a significantly shorter time. In 2022, in cooperation with the JSI Department of Knowledge Technologies, we set up suitable methodologies for the initial development of surrogate models.

A scaling-down methodology for pressurized-water reactor-accident conditions that was used to perform an experiment supporting the Passive Isolation Condenser concept was proposed.

In the frame of the CAMP research program, the RELAP5 thermal-hydraulic system code was used to simulate various accident scenarios of a total loss of feedwater in a pressurized water reactor. The purpose of the study was to determine the time available before the core degradation starts and the necessary safety measures to prevent core heating. Four types of scenarios were studied: with normal operation systems available; without these systems; with these systems available except for the reactor coolant pumps; with these systems available and an alternative auxiliary feedwater pump. The analysis showed that considering solely safety systems gives less

conservative results than considering systems for normal operation. In addition, the analysis showed that only a timely injection using an alternative pump for the auxiliary feedwater can prevent the heating of the core.

The PIACE European project considered the concept of a passive isolation condenser that is suitable for limiting the reactor-core cooling rate during an accident. For water-cooled reactors, the concept is adequate for the prevention of thermal shocks in vessel and tube walls. In 2022, an experiment at pressurized-water-reactor accident conditions was performed in the SIRIO facility (SIET, Italy), based on a scaling-down analysis proposed by JSI. We also simulated the test before and after it was performed using the RELAP5 system code.

The AMHYCO European project deals with the prevention of hydrogen and carbon monoxide combustion in an NPP containment during a severe accident. With the ASTEC (IRSN) system code, we started simulations of the distribution of these combustible gases in a generic containment model. The final purpose of the project is an improvement of severe accident management guidelines.

In the frame of the WPDES European nuclear fusion project, the natural convection cooling of the upper port transfer cask with a hot breeding blanket segment inside was investigated. For an assessment of the thermal loading due to the decay heat generated inside the activated component, a transient CFD model was developed. The simulations were supported with the prediction of a lumped-parameter model, which was further used in parametric studies to investigate how foreseen cooling trends change if the cask's external cooling efficiency is varied.

Figure 2: Left: DEMO cryostat and bioshield structure; rigth: calculated helium temperature during an ingress accident

Thermal-hydraulic analyses of the plasma-facing units in the Divertor Tokamak Test facility (DTT) to be built in Frascati (Italy) were carried out. The ANSYS CFX code was used to predict the temperature distribution in solid structures and coolant. The calculated pressure and temperature fields were used as input loads for further thermo-mechanical analyses. The work was performed in close cooperation with ENEA (Italy).

A water-cooled divertor element for the stellarator W7-X in Greifswald (Germany) is being developed within the DIV-W7X European fusion project. CFD simulations of the boiling flow in the cooling channels of the W7-X divertor target element were performed. The boiling flow model was first validated against the available experimental data, at lower velocities and heat fluxes, where it proved to work correctly. However, it was found that under the W7-X operating conditions (high heat fluxes and flow velocities), the boiling model predicts a much higher wall temperature than the single-phase model, which is considered unphysical. It was shown that the main causes for this are incorrect physical assumptions of the wall heat flux partitioning model.

For the DEMO fusion reactor, the loss of cryostat vacuum due to a large ingress of helium was analysed with the MELCOR for Fusion code. A parametric study was performed to determine the diameter of the pressure relief rupture disk in order to maintain the pressure below the cryostat design pressure limit. The work was performed in the frame of the WPSAE European nuclear fusion project.

Structural safety analyses

The research was focused on the process of intergranular stress-corrosion cracking, in particular on the micromechanical aspects of its initiation stage. The idea is to decouple the effect of the local stress state from that of the environment by assigning grain boundaries to different types, based on their associated strengths, and then studying the distribution of intergranular normal stresses of each type. These distributions can then be used for the probabilistic modelling of the grain-boundary-damage initiation.

A simple analytical model for predicting grain-boundary stresses in an arbitrary linear-elastic polycrystalline material, on any grain-boundary type and for any uniform external loading, was constructed in a perturbative manner. A bicrystal model serving as an initial approximation was expanded to a 3D structure consisting of five 1D chains with an arbitrary number of grains, and embedded in a homogenous and isotropic elastic medium with 1D Reuss and Voigt limits applied at different length scales. The obtained stress distributions were verified by finite element simulations of different Voronoi microstructures. An additional insight was provided by means of an analytical solution to the generalized bicrystal model, especially by explicitly proving the relevance of the effective grain boundary stiffness parameter and by analysing the effect of the twist angle.

A new crystal plasticity finite-element model was proposed and implemented into a subroutine of the Abaqus code to simulate the mechanical behaviour of austenitic stainless steel subjected to hydrogen concentration and neutron irradiation.
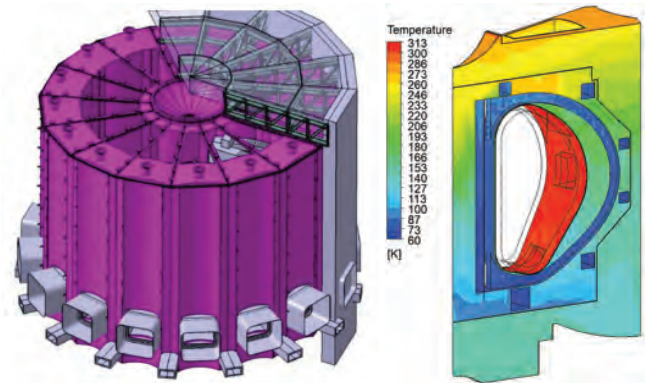
> **A simple semi-analytical model was developed for predicting local grain-boundary stresses and the corresponding statistical distributions in linear-elastic polycrystalline materials.**

An in-house solver based on the Fast Fourier Transform was developed in the framework of small strain crystal plasticity. The solver was upgraded with the Anderson acceleration technique and successfully tested on non-linear elastic materials.

Regarding the topic of thermal fatigue due to fluid flow mixing, we finalized our contribution to the ATLAS+ European project. The results of the thermomechanical and fracture mechanics analyses of a T-junction piping containing cracks provided fatigue lifetimes. Also, within the initiated cooperation with the North China Electric Power University, a thermally stratified flow past a pipe elbow was studied using CFD by the Chinese partner, whereas the fluid temperatures near the pipes were used by JSI in the subsequent analyses.

Figure 3: Perturbation-theory-based strategy for calculating the grain-boundary normal stress

The APAL European project aims at developing advanced methods for pressurized thermal shock assessment, and evaluating safety margins for long-term operations of NPPs. The definition of deterministic and probabilistic fracture mechanics benchmarks was completed, and thermomechanical and fracture mechanics calculations are being performed with thermal-hydraulic inputs from the RELAP5 system code.

Fusion-related activities included thermo-mechanical analyses using thermal loads from CFD simulations to further evaluate the deformations and stresses of the calorimeter for the neutral beam injector of the Divertor Tokamak Test facility. For the divertor component of this future tokamak, thermomechanical analyses of the plasma facing units were completed for the single-null configuration. The structural analyses of the upper port pipe forest for the DEMO reactor consisted of an assessment of natural frequencies and stresses, and proposal of a preliminary set of pipe supports.

Modelling of the COVID-19 epidemic development in Slovenia

As the equations for the spreading of infections are similar to the equations of the chain reaction in a nuclear reactor, the department was involved in the prediction of the COVID-19 epidemic progression. The SEIR (susceptible, exposed, infectious, recovered) model was fitted with publicly available data and the impact of the population's response to the measures could also be taken into account.

We considered, in an integral way, most of the available data, such as: number of confirmed cases, number of people hospitalized and in intensive care units, number of deceased people, and age structures. Immunisation and vaccination were taken into account as well. We treated four different courses of the disease and calculated nine specific reproductive numbers of the spread of the infection, on the basis of which the epidemic trend was determined. We compared the initial part of the prognosis with what was already in the "waiting room", i.e., the known number of confirmed cases in the latest period by age categories that would, with a certain time lag and probability, appear in hospitals, intensive care units and finally die. We also took into account the qualitative data.

For the Government of Slovenia expert advisory group, we prepared daily analyses of the epidemic situation and prognoses of the numbers of hospitalized and deceased people. These results were regularly made public.

Technical cooperation, consulting services and education

In 2022, the Reactor Engineering Division cooperated in projects for the industry as well. As an institution authorized for radiation and nuclear safety, we prepared an independent evaluation on the outage and refueling activities in the Krško NPP. Within the Krško NPP Third Periodic Safety Review, we finalized the review of safety factors in the area of safety analyses.

Researchers of the department represent the core staff of the Chair for Nuclear Engineering at the Faculty of Mathematics and Physics at the University of Ljubljana, and are involved in nuclear engineering undergraduate, master and doctoral studies. The programmes are associated with the European Nuclear Education Network (ENEN). In the fall of 2022, the third generation of students of the international MSc program in nuclear engineering SARENA, in which the department is actively involved, was admitted to the faculty.

Some outstanding publications in the past year

1. B. Zajec, L. Cizelj, B. Končar, Experimental analysis of flow boiling in horizontal annulus: the effect of heat flux on bubble size distributions, *Energies,* 2022, 15, 6, 2187-1-2187-12.
2. B. Končar, J. Sotošek, I. Bajsič, Experimental verification and numerical simulation of a vortex flowmeter at low Reynolds numbers, *Flow Measurement and Instrumentation*, 2022, 88, 102278.

3. B. Mikuž, F. Roelofs, Flow and heat transfer simulation in a complete pressurized water reactor fuel assembly using wall-modeled RANS, *Journal of Nuclear Engineering and Radiation Science,* 2022, 8, 4, 041402-1-041402-21.
4. M. Kunšek, L. Cizelj, I. Kljenak, New multi-fluid model of pool scrubbing in bubble rise region, *Nuclear Engineering and Design,* 2022, 395, 111873-1-111873-13.
5. T. Holler, E. M. J. Komen, I. Kljenak, The role of CFD combustion modelling in hydrogen safety management – VIII : Use of eddy break-up combustion models for simulation of large-scale hydrogen deflagration experiments, *Nuclear Engineering and Design,* 2022, 388, 111627-1-111627-16.

Awards and Appointments

1. Leon Cizelj, Matjaž Leskovar: Commemorative coin for dedication in the fight against COVID-19, Government of the Republic of Slovenia
2. Benjamin Krull, Ronald Lehnigk, Richard Meller, Fabian Schlegel, Matej Tekavčič: Best Paper Award, 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics - NURETH 19, *OpenFOAM hybrid – a morphology adaptive multifield two-fluid model*

INTERNATIONAL PROJECTS

1. H2020 - NARSIS; New Approach to Reactor Safety Improvements
   Dr. Andrej Prošek
   European Commission
2. H2020 - PIACE; Passive Isolation Condenser
   Asst. Prof. Ivo Kljenak
   European Commission
3. H2020 - sCO2-4-NPP; Innovative sCO2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants
   Dr. Andrej Prošek
   Electricite de France S.a.
4. H2020 - EURAD; European Joint Programme on Radioactive Waste Management
   Prof. Leon Cizelj
   European Commission
5. H2020 - ECC-SMART; Joint European Canadian Chinese Development of Small Modular Reactor Technology
   Prof. Leon Cizelj
   European Commission
6. H2020 - AMHYCO; Towards an Enhanced Accident Management of the Hydrogen/CO Combustion Risk
   Asst. Prof. Ivo Kljenak
   European Commission
7. H2020 - APAL; Advanced PTS Analysis for LTO
   Dr. Oriol Costa Garrido
   European Commission
8. Experimental and numerical studies of vertical slug flows
   Prof. Iztok Tiselj
   Slovenian Research Agency
9. HE - EUROfusion; WP12: DIV_HE-FU
   Asst. Prof. Boštjan Končar
   European Commission
10. HE - EUROfusion; WP08: DES-1_HE-FU
    Dr. Martin Draksler
    European Commission
11. HE - EUROfusion; WP19: SAE-1_HE-FU
    Dr. Mitja Uršič
    European Commission
12. HE - EUROfusion; WP25: PMU_HE-FU, RU-Mgmt-1_HE-FU
    Asst. Prof. Boštjan Končar
    European Commission
13. HE - EUROfusion; WP24: TRED_HE-FU, EDU_HE-FU
    Asst. Prof. Boštjan Končar
    European Commission
14. HE - HARMONISE; Towards Harmonisation in Licensing of Future Nuclear Power Technologies in Europe
    Prof. Leon Cizelj
    European Commission
15. HE - SEAKNOT; Severe Accident Research and Knowledge Management for LWRS
    Asst. Prof. Ivo Kljenak
    European Commission
16. HE - ENEN2plus; Building European Nuclear Competence Through Continuous Advanced and Structured Education and Training Actions
    Prof. Leon Cizelj
    European Commission
17. HE - OFFERR; eurOpean platForm For accEssing nucleaR R&d facilities
    Prof. Leon Cizelj
    European Commission
18. HE - ASSAS; Artificial Intelligence for the Simulation of Severe Accidents
    Asst. Prof. Ivo Kljenak
    European Commission

RESEARCH PROGRAMMES

1. Reactor engineering
   Prof. Leon Cizelj
2. Fusion technologies
   Asst. Prof. Boštjan Končar

R&D GRANTS AND CONTRACTS

1. Simulation of selected design extension conditions without core melt
   Asst. Prof. Boštjan Končar
2. Understanding stratified steam explosions in reactor conditions
   Dr. Matjaž Leskovar
3. Uncertainties in advanced safety analyses of nuclear facilities
   Dr. Andrej Prošek
4. Fuel-coolant interactions in combined stratified and melt jet configurations
   Dr. Janez Kokalj
5. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
   Dr. Matej Tekavčič
   Helmholtz-Zentrum Dresden-Rossendorf E.v.

NEW CONTRACTS

1. Cooperation in international CAMP and CSARP program
   Dr. Andrej Prošek
   Krško Nuclear Power Plant
2. L21827 Co-financing: Simulation of selected design extension conditions without core melt
   Asst. Prof. Boštjan Končar
   Krško Nuclear Power Plant
3. L2-1828 Co-financing: Understanding stratified steam explosions in reactor conditions
   Dr. Matjaž Leskovar
   Krško Nuclear Power Plant
4. NEK PSR3 Project Task „Safety Analyses"
   Dr. Mitja Uršič
   Krško Nuclear Power Plant
5. Joint Expert Assessment of the Outage Activities, Interventions and Tests during shutdown and refueling outage 2022
   Dr. Mitja Uršič
   Elektroinštitut Milan Vidmar
6. L2-4432 Co-financing: Uncertainties in advanced safety analyses of nuclear facilities

Dr. Andrej Prošek
Krško Nuclear Power Plant
7.   Z2-4437 Co-financing: Fuel-coolant interactions in combined stratified and melt jet configurations

Dr. Janez Kokalj
Krško Nuclear Power Plant

VISITORS FROM ABROAD

1.   Mr Clayton Scott, Business Development NuScale Power, Portland, Oregon, USA, 24 March 2022
2.   Mr Wadié Joseph Habboush, Habboush Group, New York, USA, 24 March 2022
3.   Dr Mario J. Müller, Emerald Horizon AG, Graz, Austria, 6 May 2022
4.   Mr Derek Schlickeisen, Advocacy Center, USA, 23 September 2022

STAFF

Researchers
1.   **Prof. Leon Cizelj, Head**
2.   Dr. Oriol Costa Garrido
3.   Dr. Martin Draksler
4.   Dr. Samir El Shawish
5.   Asst. Prof. Ivo Kljenak
6.   Asst. Prof. Boštjan Končar
7.   Dr. Matjaž Leskovar
8.   Dr. Blaž Mikuž
9.   Dr. Andrej Prošek
10. *Dr. Mohit Pramod Sharma, left 07.05.22*
11. Prof. Iztok Tiselj
12. Dr. Mitja Uršič
Postdoctoral associates
13. Dr. Janez Kokalj
14. Dr. Timon Mede

15. *Dr. Jure Oder, on leave since 01.02.21*
16. Dr. Matej Tekavčič
Postgraduates
17. Aljoša Gajšek, B. Sc.
18. Jan Kren, B. Sc.
19. Dr. Rok Krpan
20. *Matic Kunšek, B. Sc., left 18.09.22*
21. Amirhossein Lame Jouybari, M. Sc.
22. Boštjan Zajec, B. Sc.
Technical officers
23. *Anil Kumar Basavaraj, B. Sc., left 21.07.22*
24. Andrej Sušnik, B. Sc.
Technical and administrative staff
25. Tanja Klopčič
26. Zoran Petrič, B. Sc.
27. Nina Rehar, B. Sc.

REACTOR INFRASTRUCTURE CENTRE

RIC

The Reactor Infrastructure Centre (RIC) incorporates a TRIGA Mark II research reactor and a Hot-Cells Facility. The reactor, operating since 1966, is used for neutron research, education and training, and radioactive isotope production. A detailed technical description of the reactor is available at ric.ijs.si/en/. The Hot-Cells Facility is used for the treatment and handling of radioactive materials and radioactive waste in research, developmental and applicative programs, and projects. In addition, it is used for performing regular radiological control measurements of the reactor. The Reactor Infrastructure Centre staff operate and maintain the reactor and the Hot-Cells Facility. They also participate in other activities, requiring specialists skilled in working with sources of radiation and in reactor technology, such as servicing of industrial radioactive sources, surveillance of fuel management in NPP Krško, and characterization, processing and preparation of radioactive waste.

Head:
Prof. Borut Smodiš

In 2022, the reactor operated for 153 days (661 hours) and produced 89.7 MWh of heat. Altogether, 188 pulses were carried out and 465 samples were irradiated in the irradiation channels.

The reactor's operators supported users by performing operations and services for which the researchers were not qualified and authorized, such as operating the reactor, performing irradiations and experiments, and handling irradiated samples.

In 2022 the TRIGA Mark II reactor was mainly used as a neutron source for research in different areas, such as radiation-hardness studies, neutron- activation analysis, education and training. For educational purposes, it was mostly used by the Reactor Physics Department (F8), while the Nuclear Training Centre (ICJT) used it for training purposes, and the Department of Environmental Sciences (O2) and the Department of Experimental Particles Physics (F9) used it for sample irradiation. Lastly, the reactor was also used for experiments in reactor physics performed by the Reactor Physics Department (F8). The shutdown reactor, being a powerful source of gamma radiation, was used for testing radiation hardness of electronic components and other materials. At the Hot-Cells Facility, the activities were mostly performed by the Department of Environmental Sciences (O2), the Radiation Protection Unit (SVPIS) and the Slovenian Agency for Radioactive Waste Management (ARAO) – processing and preparation of radioactive waste for storage.

The reactor was used for the following research activities:
- Reactor physics and neutronics.
- Activation analysis.
- Research on radiation damage of semiconductors.
- Neutron dosimetry and spectrometry.
- Activation of materials, research on nuclear waste, and decommissioning.
- Radiation-hardness studies.
- Irradiation of materials for fusion reactors.
- Irradiation of electronic components.
- Irradiation of medical components.
- Development and testing of new detectors.
- Development of new methods for measuring power profiles, neutron spectra, etc.
- Verification and validation of methods for calculating the transport of neutrons, photons, and electrons.
- Development of educational tools in reactor physics.

Figure 1: A fire drill at the Reactor Centre, 6th December 2022, photo by Jure Jazbec

In January different organic compounds were irradiated for the National Institute of Chemistry as a part of a larger study on whether specific organic compounds, when exposed to radiation, could be used in the production of hydrogen. The study was followed by 2 weeks of intense research campaign, carried out in collaboration with CEA *(Commissariat à l'énergie atomique et aux énergies alternatives)*. Almost 150 pulses were performed with the purpose of developing a computer model that would characterise the TRIGA reactor during pulse operations.

In February the first ENEEP *(European Nuclear Experimental Education Platform)* course was hosted at our facility. ENEEP is an association of five European institutions that provide experimental education and training at their laboratories, mainly including research reactors. Two additional ENEEP courses were carried out in autumn.

In February, April and November FT-TIMS *(Fission Track – Thermal Ionization Mass Spectrometry)* samples were irradiated for CEA. Each sample had to be irradiated for 20 hours at full power. The samples were irradiated in a modified thermal column, with a ratio of 500:1 for the thermal neutron flux versus the total.

In March three research campaigns were carried out in collaboration with CEA and the Reactor Physics Department (F8). The first campaign revolved around calorimetry. The researchers observed how different materials heat up during neutron exposure. In the second campaign, precise measurements with different neutron detectors were performed – micro-fission cells, self-powered detectors and larger fission cells. The third campaign comprised measurements of dose fields with thermoluminescent dosimeters (TLD).

In March neutron TLDs were irradiated for the Department of Low and Medium Energy Physics (F2) in the dry chamber due to calibration with the Radiation Protection Unit's neutron dosimeter.

Figure 2: On 7th March 2023, the operators of the TRIGA Reactor (from left to right: Marko Rosman, Andraž Verdir, Sebastjan Rupnik, Anže Jazbec) were ceremonially awarded their renewed licences to operate the Reactor (relating to 2020, 2021 and 2022 since there were no renewals in the interim due to Covid-19) by Mr Igor Sirc, Director of the Slovenian Nuclear Safety Administration (far right). They were also congratulated by prof. Boštjan Zalar, Director of the Jožef Stefan Institute (far left) and presented with gold badges in the shape of the reactor building. Photo by Marjan Verč.

At the beginning of April, reactor's core was modified several times for the Reactor Physics Department (F8) to determine the specific reactor fuel element burnup. This also presented an opportunity for an inspection of the fuel elements extracted from the core. After all the measurements were completed, the core was restored to its primary configuration.

At the end of April, the reactor did not operate to ensure low levels of core's activity since the cleaning of beam port No. 1 was planned for the beginning of May. Beam port no. 1 was opened and rid of all the foreign material supposedly left behind after an experiment performed over thirty years ago. The material was removed and stored among radioactive waste.

A collaborative research campaign performed with CEA and the F8 department took place during two weeks in May. TLDs were inserted between fuel elements to determine the axial neutron flux profile.

In early June, SiC neutron detector tests were performed under the *e-SiCure project II*, funded by NATO. In the first days of the summer break, a course was hosted at our facility for the Aix Marseille University students.

During the summer break, the reactor tank and two spent fuel pools were inspected in collaboration with Q-Techna Ltd. The pools were in perfect condition and suitable for further use.

In the last week of September, we hosted students from Uppsala University. In October, an *EERRI (East European Research Reactor Initiative)* course took place at our facility. During autumn, preparations for the Krško NPP start-up tests began. A group of researchers from the F8 department that are in charge of the start-up tests used our reactor for the prepping stage, testing all the equipment and going through all the procedures.

During one week in October, our reactor was transformed into the Vinča Nuclear Institute to film certain scenes of a Slovenian-Serbian co-production, *Chain Reaction*, directed by Dragan Bjelogrlić.

In November we hosted students from Politecnico di Milano, who execute "pulsed operation" at our reactor once a year.

In December the reactor staff participated in an event celebrating the 80th anniversary of the first chain reaction, organised by ENEN *(European Nuclear Education Network)*, which took place online. A few days later, the reactor was occupied by the CEA researchers and the Instrumentation Technologies Ltd. staff. They performed the final tests on the *Monaco system* before its launch to the global market.

On the 6th of December a fire drill took place at the Reactor Centre. The participant list comprised a professional firefighting unit of the Ljubljana Fire Brigade, the Ecological Laboratory with the Mobile Unit (ELME), operating under the Jožef Stefan Institute, along with two volunteer fire brigades – Podgorica Šentjakob and Vižmarje Brod. An accident was simulated in the Hot-Cells Facility that included radioactive matter. The purpose of the drill was to revisit our emergency procedures and verify the reaction times of the Institute response teams. External intervenors (firefighters and ELME) were familiarised with our facilities, potential hazards and internal organisation of our units (Radiation Protection Unit – SVPIS, Reactor Infrastructure Centre – RIC, Safety and Health at Work Unit – SVZD, Technical Services – TS, Public Relations department and the Security Service).

Throughout the year we hosted students from the Faculty of Mathematics and Physics at weekly practical classes on different subjects. We participated at the Open Day at the JSI and the European Researchers' Night where the TRIGA reactor was open to the public while operating.

The reactor facilities were visited by many groups, such as primary and secondary schoolers, and university students from all over Slovenia and the neighbouring countries, course participants, researchers from abroad, etc. Altogether, in 2022, the Reactor Infrastructure Centre hosted approximately 1300 visitors.

INTERNATIONAL PROJECTS

1. Irradiation Services for the Rolls-Royce Civil Nuclear SAS Company
   Prof. Borut Smodiš
   Rolls-Royce Civil Nuclear Sas
2. H2020 - ENEEP; European Nuclear Experimental Educational Platform
   Prof. Borut Smodiš
   European Commission
3. HE - EURO-LABS; EUROpean Laboratories for Accelerator Based Science
   Prof. Borut Smodiš
   European Commission
4. Training Costs for IAEA"s Fellows Messrs. Abdul Mutalib Ridzuan & Ab Rahim Ahmad (EVT2002569-MAL9018), 14 November 2022 - 18 November 2022
   Prof. Borut Smodiš
   IAEA - International Atomic Energy Agency

R&D GRANTS AND CONTRACTS

1. Hot Cell Facility Usage
   Prof. Borut Smodiš
   ARAO, Ljubljana
2. Irradiations on the TRIGA Reactor
   Prof. Borut Smodiš
3. Irradiations of FT-TIMS Capsule on the TRIGA Reactor for Years 2020-2023
   Prof. Borut Smodiš
   CEA-Commissariat a l' Energie Atomique et Aux
4. Refubrished Lazy Susan
   Prof. Borut Smodiš
   University of Pavia
5. SiC Campaign within the Frame of the Contract between CEA/AMU and FRAMATOME
   Prof. Borut Smodiš
   CEA Saclay
6. Experimental Testing of the MONACO Acquisition System at the JSI TRIGA Reactor
   Prof. Borut Smodiš
   CEA Saclay

STAFF

Researchers
1. **Prof. Borut Smodiš, Head**
2. **Postdoctoral associate**
3. Dr. Anže Jazbec
Technical and administrative staff
4. Andrej Gyergyek, B. Sc.

5. *Jasna Kopač, B. Sc., left 01.09.22*
6. Marko Rosman
7. Sebastjan Rupnik, B. Sc.
8. Nina Udir, B. Sc.
9. Andraž Verdir, B. Sc.

NETWORKING INFRASTRUCTURE CENTRE NIC

The Networking Infrastructure Centre (NIC) manages the core network, information and communication services and computing infrastructure of the Jožef Stefan Institute. It also supports the development of the computing, communication, data and security infrastructure of our research departments, centres and organizational units at the institute and participates in numerous national and international initiatives.

The NIC's main mission is the administration of computing networks, services and equipment to support the users at the Jožef Stefan Institute, their collaborators, projects and research groups, but the centre also works in wider national and international contexts where it participates in infrastructure-development projects and initiatives. The centre provides for connectivity and integration with local and international communication networks and infrastructures, but also delivers ICT support for research activities at the Jožef Stefan Institute, including the development, management and administration of ICT infrastructures, computing facilities and services. NIC works in four main areas: networking infrastructure, central services, cyber security and distributed data and network supercomputing infrastructures.

Head:
Dr. Jan Jona Javoršek

Networking Infrastructure. The NIC maintains and develops the Institute's network backbone as well as departmental networks, wireless networks and dedicated networks for special services, such as dedicated links to other institutions, secure links to the Reactor Infrastructure Centre Podgorica and management units at Tržaška134, connections to dedicated networks and supports the realization of the activities of departments and projects at the Institute.

Physical Network: In 2022 the main challenge was to expand the physical network to the new location of management units and central services at Tržaška 134, the upgrading of equipment of management departments as well as the beginning of a complete reconfiguration of the network in the C building at Jamova 39. This dictated the updates and upgrades of the active equipment, including wireless-access-point installations and core backbone network routers. The management departments were included in the optimization of the backbone network and introduction of internal networks for departments. Remote VPN access and device support for access from outside contractors was expanded while the centre continued to support connectivity for experiments such as EuroHPC, EOSC,WLCG, Belle 2 as well as EGI and PRACE using projects over general GÉANT networks as well as dedicated scientific VRFs such as LHCONE and PRACE.

Monitoring: Continued expansion of the Institute's network was used to adapt the traffic, event and status-monitoring infrastructures as well as integrate new monitoring facilities and sensors to capture, monitor, report and react to usage fluctuations and events in our services, security policies, firewalls, authentication and authorization systems, network time systems, e-mail delivery, etc. The system had to integrate physical room and machine sensory data, environmental data, power line data etc. from the new areas to enable a consistent overview of the infrastructure.

Wireless network: Thanks to modern, highly efficient components and central control modules, the NIC was able to further improve the wireless coverage and density of the Institute's wireless networks where usage is most condensed. The wireless network was expanded to the Tržaška 134 location, a part of the Jamova campus was upgraded and a number of older access points were replaced with modern units to improve throughput and device support.

A network with a multi-10 Gbit/s backbone, modern protocol stacks, a flexible ICT infrastructure supporting numerous fixed and wireless clients has been expanded to include new locations at Tržaška cesta 134.

Figure 1: New network cabinets at our new locations

Network Security. The NIC manages security measures and policies at the external network borderline, in the internal network and regarding the services and software deployments for the users. External network security is implemented with active security devices, firewall systems, secure-first configurations and passive measures

(configuration, filtering and supervision). Constant dynamic supervision, traffic monitoring and event analysis is needed to ensure suitable security in the complex constraints and requirements of an open academic network that collide with current security considerations and demands for high throughput. Ensuring secure and open environment requires disproportionate increases in equipment capabilities and efforts in the dynamic security policy configuration, event monitoring and analytics.

E-mail security, network firewalling, secure remote connections, virtual networks, advanced monitoring and new cyber-security initiatives are crucial for an open academic network in the age of an ever more hostile Internet.

Figure 2: International cyber-security exercise KIVA 2022, Ljubljana, May 5th 2022

Since the NIC is responsible for the security of the ICT infrastructure of the Institute, we are active members of relevant institutions and groups, notably the national security response centre SI-CERT, FIRST (Forum of Incident Response and Security Teams) and EGI CSIRT (European Grid Initiative distributed computing security incident response team). The centre also takes part in the response team of the national distributed computing network consortium SLING as well as the HPC Vega system's security team. The national science certificate agency SiGNET CA (Slovenian Grid Network Certification Authority), managed by the NIC, is a full member of EU Grid PMA (EU Grid Policy Management Authority) and IGTF (Interoperable Global Trust Federation). NIC members participate in the work of the Slovenian network technology and security association SINOG (Slovenian Network Operators Group).

E-Mail: In the area of e-mail security and protection against undesired or malignant messages we have continued to develop e-mail content filters and protective measures to continuously improve solutions and provide advanced features in e-mail message and protocol stack handling and filtering.

Cryptography and certification: The use of DNSSEC-signed internet domain names using automated mechanisms for the verification of the signatures and with gradual introduction of the DANE system (integration of TLS certificates with the DNS system) in e-mail transfers and publishing SSHFP records via DNS servers ensures the basic modern measures for authenticated e-mail services.

The number of digital certificates used on the institute's servers has continued to rise, mostly using free DigiCert server certificates, courtesy of Arnes and GÉANT. The use of TLS encryption has been further expanded by favouring the use of TLS for all services. The number or users of the institute's VPN infrastructure has continued to increasing. By expanding and updating the VPN infrastructure we ensured the availability of remote connectivity to support remote working during the Covid-19 pandemic.

ICT services. The NIC provisions, develops and maintains a number of core and additional ICT services. The most important among these are e-mail (e-mail routing and delivery, inbox management, directory management, webmail services, etc.) and world wide web support (the main institute web server, web hosting for users, departments and projects, web directories). Secondary ICT services are provided in support of certain core or specific activities at the institute, such as web presentations, a conference system, supervision and monitoring, etc. In some of these services the NIC is directly invested in the software or infrastructure development, such as the network time services and e-mail filtering and security, while others are simply administered and maintained. The third NIC service category is comprised of services supporting our users (calendaring, event management, directories, file sharing, collaborative editing) and software/system developers (code repositories, integration and verification, licence management, mobile platform software development, integration and shipping for Apple Appstore and Google Play). NIC also provides physical server hosting and management, aimed primarily at larger projects and

Figure 3: On the 21st of September 2022 Sebastiano Buscaglione, Senior Network Architect and member of the GÉANT Network Evolution team, observed a significant increase in traffic on one of GÉANT's backbone trunk links between Geneva and Milan. The sharp increase in traffic from 20 Gbps in May 2021 to over 150 Gbps was flowing from ARNES network using LHCONE VRF (virtual routing and forwarding). The explanation appeared at the LHCONE meeting in October 2022 at CERN: David Cameron presented the graph showing the increase of computing tasks from ATLAS experiment after they had been able to use the new Slovenian Vega HPC and its storage. (GÉANT CONNECT Magazine, No. 42.)

systems, the administration of directories for personal computing and user management (such as departmental single sign-on or directory services) and the administration of mission-critical workstations and components.

In 2021 the hosting facility in the computing centre at Teslova, established in 2015, was expanded to use the physical capacity to the limit of available electrical power at the location. The center is hosting the new Arnes HPC system, the most powerful HPC cluster in Slovenia at the time of installation in 2020, and has been used extensively for intensive computations, but has come to its power limits in 2022.

The NIC computing centre at Jamova 39, where NIC is providing highly reliable cooling, network connectivity and uninterrupted power supply for critical services, has accepted a number of new systems in 2021. The web-hosting activity has expanded considerably (over 170 distinct sites) and started using newer hardware. Additional upgrades to power lines were installed to limit problems due to campus-wide power interventions.

The AAI Single-Sign-On (SSO) service integrated with Arnes AAI federation and European eduGAIN federation has seen increases in use. We hope that this facility will simplify user and authentication management at the institute and for software developers who work on internal projects and services in the future.

Network super-computing. In the field of network supercomputing Slovenia has been more visible since the HPC Vega system became the first new EuroHCP machine to be available for the users since April 2021. The Jožef Stefan Institute has participated with the task force build from the technical expertise at NIC and the Experimental Particle Physics Department F9 that participated in the design, architecture, procurement, installation and operations of the new system that has been established at the IZUM data centre in Maribor. Within the Slovenian National Supercomputing Network (SLING) consortium this taskforce provided operational oversight, system administration and user support, high-level support and guidance for the new system as Vega quickly became the most used system in EuroHPC. Some of its technical innovations, such as large bandwidth and on-site storage, have been very successful and well accepted. The centre also supported the EUROCC project's training and support efforts for the second year in the row, providing expertise in high-throughput computing, high-performance computing, network and grid middleware, vectorisation, software containers, software shared module installation virtualisation and ICT as a service (cloud).

> Repositories for software development, file sharing and data storage as well as support for event organization, collaborative work and development as well as project management have become essential for modern scientific collaborations. Large data storage and access to the best systems, including the new EuroHPC Vega and other new European HPC systems, have become a basic necessity for many researchers.

The NIC worked at distributed computing and supercomputing support within SLING, European Grid Initiative EGI, PRACE (Partnership for Advanced Computing in Europe), EuroHPC initiative, notably the EuroHPC Leonardo hosting entity consortium (grand opening in November 2022, operations expected in 2023), the NorduGrid ARC collaboration and a number of international projects (ATLAS – dedicated link, Belle2 – computing support, CLARIN – support for different services of Slovenian national node, ELIXIR – collaboration with the national node and the European collaboration). SLING has, with participation of NIC members, supported a number or research projects and applications, among others in high-energy physics, medical sensor and image analysis, language models, theoretical physics, astrophysics, biochemistry, protein folding simulations, crystal analysis, knowledge technologies, artificial intelligence, statistical analysis and fluid dynamics, computational linguistics etc. In a number of cases the NIC personnel participated as part of the SLING support group in the parallelization and preparation of computing tasks and administration of required run-time environments. Members of NIC have also contributed as advisers in EuroHPC and European Open Science Cloud, with Barbara Krašovec becoming a member of the Research and Innovation Advisory Group at EuroHPC Joint Undertaking as well as participated directly in the operations of HPC Vega as well as the HPC Leonardo consortium.

Awards and Appointments

1. Dr. Alja Prah: National Institute of Chemistry's Pregel award for exceptional doctoral thesis entitled "Exploring the role of electrostatic interactions in monoamine oxidase enzyme catalysis using a multiscale computational model" under supervision of Prof. Jernej Stare and Prof. Marija Sollner Dolenc.

INTERNATIONAL PROJECTS

1. EACEA: B-AIR; Art Infinity Radio - Creating Sound Art for Babies, Toddlers and Vulnerable Groups
   Dr. Jan Jona Javoršek
   Eacea - Education Audiovisual &

2. H2020 - EUROCC; National Competence Centres in the Framework of EuroHPC
   Dr. Jan Jona Javoršek
   European Commission

3. H2020 - EGI-ACE; EGI Advanced Computing for EOSC
   Dr. Jan Jona Javoršek
   European Commission

R & D GRANTS AND CONTRACTS

1. Co-financing of the Project B-AIR: Art Infinity Radio - Creating Sound Art for Babies, Toddlers and Vulnerable Groups

   Dr. Jan Jona Javoršek
   Ministry of Culture

STAFF

Postdoctoral associate
1. Dr. Alja Prah

Technical officers
2. Jan Ivanjko, B. Sc.
3. **Dr. Jan Jona Javoršek, Head**
4. Barbara Krašovec, M. Sc.
5. Mark Martinec, B. Sc.

Technical and administrative staff
6. Ivan Ivanjko
7. Janez Jezeršek
8. Matjaž Levstek
9. Janez Srakar
10. Matej Wedam

SCIENCE INFORMATION CENTRE

SIC

The Jožef Stefan Institute Science Information Centre is one of the largest special libraries in Slovenia. We provide publication access, manage the Institute bibliography, and help our researchers to fulfil open-access mandate requirements.

The peer-reviewed publication of results in scientific journals is an important, basic part of the research process. Therefore, literature access is central to research quality and relevance. The information revolution and open-science movement have brought great changes to the publishing process, but access to most research is still restricted to subscribers. The article and journal inflation of recent years has focused our subscription policy on package deals with major publishers. We are a founding member of the ScienceDirect, SpringerLink, Wiley online library, IEEExplore, RSC and ACS Slovenian consortia, and negotiate with publishers to lower the reading and publishing costs for all Slovenian researchers. We provide access to over 4000 electronic journals. Our electronic collections are supplemented by over 100,000 print journal issues and books covering the fields of physics, chemistry, biochemistry, electronics, information science, artificial intelligence, nuclear technology, energy management and environmental science. We subscribe to the Reaxys database and the SciVal research-evaluation and management tool.

The Slovenian Current Research Information System, SICRIS, is the basis of all evaluation processes of the Slovenian Research Agency (ARRS). SICRIS data are stored in the COBISS database, which has records of the Institute's research since its founding in 1949. We manage the bibliographic data for approximately 700 researchers in the COBISS database, and provide evaluation reports used in the election process at the Institute. Last year's bibliographic data are included as part of this report.

Open-access mandates have become a common part of the research environment. Slovenia adopted an open-access strategy, ARRS is a Plan S member, and requires compliance with its mandates. Preprint publication in a repository is a part of these requirements. We help researchers to comply by depositing their work in the DIRROS repository, which is OpenAire compatible.

Head:
Dr. Luka Šušteršič

R&D GRANTS AND CONTRACTS

1. E-journals subscription consortium agreement for 2022
   Dr. Luka Šušteršič
   Central Technical Library at the University of Ljubljana

STAFF

Technical officers
1. **Dr. Luka Šušteršič, Head**
2. Marjan Verč, M. Sc.

Technical and administrative staff
3. Anja Blažun, B. Sc.
4. *Tamara Debeljak, B. Sc., left 01.09.22*
5. Suzi Korošec, B. Sc.
6. Jasna Malalan
7. *Katarina Modic, B. Sc., left 01.04.22*
8. *Alenka Ana Stante, B. Sc., retired 09.05.22*
9. Jože Škulj
10. Branka Štrancar
11. Saša Žnidar, B. Sc.

ENERGY EFFICIENCY CENTRE

EEC

The basic activities of the Energy Efficiency Centre (EEC) are related to efficient energy use, long-term planning in the energy sector and the reduction of greenhouse-gas (GHG) emissions and other air pollutants. The centre is a focal point for the collection and transfer of energy-efficiency technologies to energy users, the state, energy-service and equipment providers, and other interested agencies. At the same time it covers the environmental effects of energy use and conversion. The most significant part of the EEC activities is thus cooperation with state institutions in the preparation of strategic documents and legislation in the fields of efficient energy use, energy planning, distributed electricity production, GHG emissions and air pollutants. Nevertheless, it still remains strongly connected, by its consulting and training role in energy, with industrial companies and other institutions as well as also being deeply involved in European research projects.

Head:
Stane Merše, M. Sc.

Energy and the Environment

In 2022 the EEC, with its professional work, ensured high-quality support to ministries in the preparation of strategic development documents and the transfer of EU legislation. Energy efficiency is a priority field to achieve global climate and energy goals. In accordance with the Directive on Energy Efficiency (2012/27/EU), Directive (2018/2001) on the Promotion of the Use of Energy from Renewable Sources, and the Regulation on the Governance of the Energy Union (2018/1999), the EEC prepared a report on the achievement of the national targets and implementation of the measures in 2020. The EEC continued with the preparation of the analytical basis for the development of the measures for energy-poverty mitigation, started updating the National Energy and Climate Plan (NECP) and provided expert support for the new support scheme for electricity and heat production from renewable energy sources (RES).

Within the expert support to the Ministry of Environment and Spatial Planning, the EEC activities focused on the preparation of the Fifth Climate Action Mirror, which also reports on the implementation of the Operative Programme of Measures for GHG Emission Reduction until 2020 and the Local Climate Activity Scoreboard of Municipalities. The EEC continued with activities of the LIFE IP CARE4CLIMATE – Boosting greenhouse gas emission reduction by 2020 with a view to 2030, where the EEC leads several actions on training, local energy planning and development of advanced instruments for sustainable buildings' retrofit. The EEC was also involved in the preparation of an analytical basis for international reporting in the framework of the MMR and continued with the preparation of analytical bases for fulfilling national, European and international reporting obligations.

The EEC cooperates with the Statistical Office of the Republic of Slovenia, where it annually prepares a model calculation for fuels and energy use in households for the national energy statistics, and continued with the study of energy use in the service sector and an analysis of the utilization of excess heat. Also in 2022, the EEC continued

> Research and development work of the Energy Efficiency Centre is an important contribution to the preparation of key documents in Slovenia in the fields of energy development, energy efficiency, renewables' exploitation and the transition of Slovenia to a carbon-neutral society. With its training activities and support to industry, it contributes to an increase in competitiveness and a successful green-technology transition.
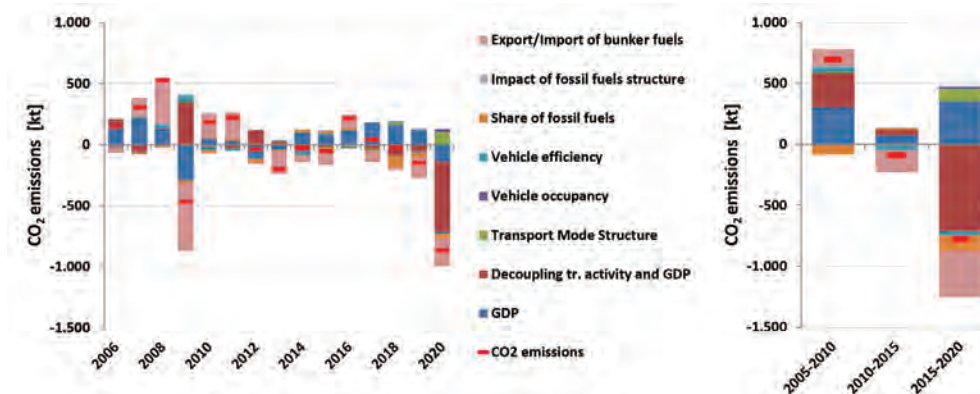

Figure 1: Decomposition analysis of CO_2 emissions in passenger transport compared to the previous year (left) or a five-year period (right)

with activities of the state referential centre for energy, preparing an expanded set of indicators for energy and the environment. For the Energy Agency, the EEC set new reference electricity-generation costs for 2022, for the support scheme for RES and cogeneration electricity generation.

Promotion of Efficient Energy Use and Energy Consulting

In 2022 the EEC continued with its training activities where, as part of the LIFE IP CARE4CLIMATE project, it continued the comprehensive training program in the field of energy management in industry and the public sector, as well as energy contracting. The EEC continued with the fourteenth cycle of energy managers' training within the European programme EUREM. Due to a very positive reaction of the participants and their interest (in Slovenia there is already more than 250 energy managers with the EUREM licence), it is clear that there is a great need for such training. High-quality knowledge in this field is of key importance for the execution of efficient solutions in practice.

In 2022 the EEC continued its intensive development work in the field of local energy planning with further development of the GIS tool for the spatial analysis of heat consumption in buildings ("heatmaps"). The GIS tool was used for the preparation of the Comprehensive assessment of the potential for efficient heating and cooling in Slovenia, a National heating and cooling strategy and upgrading the methodology for the preparation of local energy concepts. The methodology for calculating primary energy factors and CO_2 emissions for district heating systems has been developed for the Energy Agency.

The EEC continued its environmental assessments of the projects financed by green bonds in 2019 for the SID bank and calculated the carbon footprint for the NLB Group. The EEC began with the preparation of an environmental study and an energy climate plan for the company Luka Koper d.d. until 2030, with a view to 2050 and the implementation of energy audits in the companies Koto d.o.o. and Ljubljanske mlekarne, d.o.o. The EEC continued its cooperation with the company SIJ Metal Ravne in the field of waste heat utilisation.

The EEC prepared the programme for the 24th conference "Energy Managers Days", the annual meeting of energy managers with more than 200 participants, confirming the quality and public profile of the EEC professional work.

International Cooperation

In 2022 the EEC carried out as many as 10 international projects, financed from the European Union's resources in the framework of LIFE, HORIZON 2020, ERASMUS+ and EUKI program. The projects cover activities in the fields of:

- Boosting greenhouse-gas emissions reduction by 2020 with a view to 2030 (LIFE IP CARE4CLIMATE),
- Heat-pipe technology for the waste-heat recovery in industry (ETEKINA),
- Monitoring of indicators for energy use and energy efficiency in the EU (ODYSSEE MURE),
- Making heating and cooling for European consumers efficient, economically resilient, clean and climate-friendly (REPLACE),
- Creating community energy systems (CREATORS),
- Towards innovative methods for energy performance assessment and certification of buildings (TIMEPAC),
- Streamlining energy savings calculations (streamSAVE),
- Mainstreaming of refinancing schemes as enhancer for the implementation of energy efficiency projects (REFINE),

Figure 2: Training program in the field of energy contracting and energy site visits (LIFE IP CARE4CLIMATE)

Figure 3: Methodological approach to promoting the development of energy communities within the Creators project

- EU climate dialog (EUKI, Climate Recon 2050),
- Energy efficiency experts (EEE, ERASMUS+),
- Carrying out the EU directive on energy efficiency (CA – EED2).

The above projects include cooperation with research and development organisations from Europe, with a strong emphasis on concrete applications and the promotion of energy efficiency. In the framework of each project, the EEC staff took part in numerous international professional meetings and visits.

Some outstanding achievements in the past three years

Figure 4: Implemented waste-heat utilisation pilot unit onto the Allino furnace in company SIJ Metal Ravne, d.o.o (ETEKINA project)

1. **Preparation of several key support documents for the government of the Republic of Slovenia** in the field of energy and climate policy: National Energy and Climate Plan – NECP, Long-term climate strategy for Slovenia until 2050, Long-term renovation strategy to support the renovation of national building stock into a highly energy efficient and decarbonised building stock by 2050, establishment of a comprehensive monitoring system and implementation of the climate and energy policy (Climate Mirror, ARSO environmental indicators, etc.).

2. **Establishment of energy-managers training** in the framework of the European project EUREM and a new comprehensive training program for the transition to a low-carbon society within the LIFE IP CARE4CLIMATE project.

3. **Professional support to industry and other institutions** for a successful green-technology transition: Preparation of the strategy for energy and resource efficiency and renewable energy sources for a sustainable development of the company DARS d. d. until 2030; Carrying out energy audits and consulting (Luka Koper, Ljubljanske mlekarne, BTC, AMZS, etc.); Preparation of the **European Code of Conduct for Energy Contracting** and design of new financial instruments using the ECO Fund.
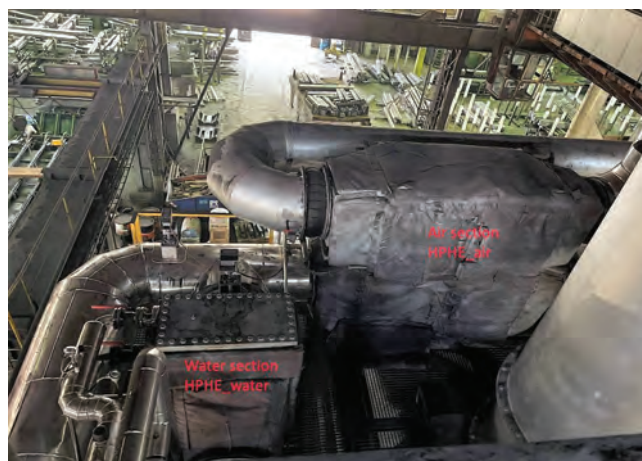
Awards and Appointments

1. Ana Marija Udovič: Würdigungspreis 2022 – award for best diploma and master's degrees, Vienna, Austria, awarded by The Federal Ministry of Education, Science and Research, for the academic performance and master's degree The Role of Bicycling for the Resilience and Sustainability of Transport in Urban Areas in the Post-COVID-19 World

Organization of conferences, congresses and meetings

1. Energy poverty requires a comprehensive approach, the first meeting of stakeholders in the field of energy poverty as part of the project "Study and expert basis for the development of measures for reducing energy poverty", 11 January 2022 (virtual)
2. Methodological challenges of reducing energy poverty, a discussion seminar as part of the project "Study and expert basis for the development of measures for reducing energy poverty", 4 May 2022 (virtual)
3. 24th Energy Managers Conference, Meeting of energy managers of Slovenia, Portorož, 11–12 April 2022
4. Preparatory workshop for the Climate Action Mirror 2022 as part of the project "Expert basis for fulfilling national, European and international reporting obligations and preparing a position in the field of mitigating climate change", Ljubljana, 17 May 2022
5. Designing measures for reducing energy poverty, a workshop as part of the project "Study and expert basis for the development of measures for reducing energy poverty", Ljubljana, 13 October 2022

INTERNATIONAL PROJECTS

1. The 1st National Round Table in Slovenia, Ljubljana, May 2022; A Sustainable Energy Investment Forums Event
   Damir Staničić, M. Sc.
   Pracsis S.r.l.
2. Life IP Care4Climate - Boosting greenhouse gas emissions reduction by 2020 with a view to 2030
   Stane Merše, M. Sc.
   European Commission
3. European Climate Initative (EUKI) - EU Climate Action Dialogues
   Katarina Trstenjak
   Europäische Klimaschutzinitiative (euki)
4. ERASMUS+; EEE - Energy Efficiency Expert
   Dr. Boris Sučić
   Inapp - Istituto Nazionale Per L'analisi
5. H2020 - ETEKINA; Heat Pipe Technology for Thermal Energy Recovery in Industrial Applications

Dr. Fouad Al-Mansour
European Commission
6. H2020 - REPLACE; Making Heating and Cooling for European Consumers Efficient, Economically Resilient, Clean and Climate-Friendly
Dr. Gašper Stegnar
European Commission
7. H2020 - REFINE; Mainstreaming of Refinancing Schemes as Enhancer for the Implementation of Energy Efficiency Service Projects
Damir Staničić, M. Sc.
European Commission
8. H2020 - streamSAVE; Streamlining Energy Savings Calculation
Dr. Matevž Pušnik
European Commission
9. H2020 - CREATORS; Creating Community Energy Systems
Dr. Boris Sučić
European Commission
10. H2020 - TIMEPAC; Towards Innovative Methods for Energy Performance Assessment and Certification of Buildings
Dr. Boris Sučić
European Commission
11. LIFE21-CET-POLICY-OdysseeMure fit-4-55; Odysee-MURE - Monitoring the Energy Efficiency Pillar for Climate Neutrality
Dr. Fouad Al-Mansour
Cinea - European Climate, Infrastructure
12. LIFE21-CET-POLICY-ENSMOV Plus; Evaluation, Quantification and Strengthening of the Implementation of the Policies and EM&V under Article 7 of the EED
Dr. Matevž Pušnik
Cinea - European Climate, Infrastructure
13. Concerted actions in the field of the directive on renewable energy (CA RES)
Stane Merše, M. Sc.
Ministry of Infrastructure

RESEARCH PROGRAMME

1. Modelling and environmental impact assessment of processes and energy technologies
Dr. Fouad Al-Mansour

R&D GRANTS AND CONTRACTS

1. Eco innovation and circular economy - a path toward a more sustainable and inclusive future: the role of demographic changes and digitalization
Dr. Boris Sučić
2. Preparation of expert documents, design of a database and development of a vehicle simulation model for calculation of the energy and environmental footprint with an aim to optimize implementation of the public transport service
Dr. Marko Kovač
3. GeoCOOL FOOD- Cold food storage using shallow geothermal energy
Dr. Gašper Stegnar
4. The establishment and development of model infrastructure fort the economic evaluation of the effects of climate and energy measures on the economy and society
Dr. Matevž Pušnik
5. Concerted Action 2 – Energy Efficiency Directive: National experts participation

Stane Merše, M. Sc.
Ministry of Infrastructure
6. Cofinancing of the Project LIFE17 IPC7SI/000007 - LIFE IP CARE4CLIMATE
Stane Merše, M. Sc.
Ministry of the Environment and Spatial Planning
7. Refreshment of the environment-energy indicators 2021-2023
Matjaž Česen, B. Sc.
Ministry of the Environment and Spatial Planning
8. Energy statistics: support to the Energy Union and further disaggregation of final energy consumption
Matjaž Česen, B. Sc.
Statistical Office of the Republic of Slovenia
9. Technical basis for fulfilling national, European and international reporting obligations and preparing positions in the field of climate change mitigation
Matjaž Česen, B. Sc.
Ministry of the Environment and Spatial Planning

NEW CONTRACTS

1. Environmental impact assessment
Stane Merše, M. Sc.
SID Banka, d. d., Ljubljana
2. Outline of portfolio environmental analysis
Tomaž Fatur, M. Sc.
NLB d. d.
3. OctaGen_Lek
Asst. Prof. Marko Matkovič
M4m Invest d. o. o.
4. Study and technical basis for the development of measures to combat energy poverty
Barbara Petelin Visočnik, M. Sc.
Ministry of Infrastructure
5. Preparation of technical bases regarding the support scheme and implementation of other technical tasks and measures in the field of energy efficiency and renewable energy sources
Stane Merše, M. Sc.
Ministry of Infrastructure
6. Technical basis and selection of the most suitable method for calculating primary energy factors and carbon dioxide emissions for district heating and cooling systems
Stane Merše, M. Sc.
Energy Agency
7. Assessment of the impacts of the legislative package „Fit for 55" on the transport and buildings sectors in the Republic of Slovenia
Matjaž Česen, B. Sc.
Ministry of Infrastructure
8. Professional and technical support in the Comprehensive National Reporting on progress in implementing the National Energy and Climate Plan and preparing its update
Stane Merše, M. Sc.
Ministry of Infrastructure
9. Energy and Climate Plan with Environmental Impact Assessment of Luka Koper d.d. until 2030, with a View up to 2050
dr. Boris Sučić
Luka Koper d.d.

VISITOR FROM ABROAD

1. Ambassador of the Kingdom of the Netherlands in Slovenia, Mr. Johan Verboom, 10 October 2022

STAFF

Researchers
1. Dr. Fouad Al-Mansour
2. Asst. Prof. Marko Matkovič
3. **Stane Merše, M. Sc., Head**
4. Damir Staničić, M. Sc.
5. Andreja Urbančič, M. Sc.
Postdoctoral associate
6. Dr. Matevž Pušnik
Technical officers
7. Matjaž Česen, B. Sc.
8. Jure Čižman, M. Sc.
9. Tomaž Fatur, M. Sc.
10. Edvard Košnjek, M. Sc.

11. Dr. Marko Kovač
12. Marko Pečkaj, B. Sc.
13. Barbara Petelin Visočnik, M. Sc.
14. Dr. Gašper Stegnar
15. Dr. Boris Sučić
16. Luka Tavčar, B. Sc.
17. Ana Marija Udovič, M. Sc.
Technical and administrative staff
18. Marko Đorić, B. Sc.
19. Tadeja Janša, B. Sc.
20. Marija Kavčič, B. Sc.
21. Igor Ribič
22. Katarina Trstenjak, B. Sc.

CENTRE FOR ELECTRON MICROSCOPY AND MICROANALYSIS CEMM

The Centre for Electron Microscopy and Microanalysis (CEMM) is an instrumental centre at the JSI that comprises analytical equipment for electron microscopy and microanalysis. Access to the research equipment within the CEMM is available to the JSI departments as well as other research institutions, universities and industrial partners. The equipment in the CEMM is used by researchers who are interested in the morphology and structural or chemical characterization of materials at the micrometre and atomic level. The CEMM comprises four scanning electron microscopes (JSM-7600F, Verios G4 HP, Quanta 650, JSM-5800), two transmission electron microscopes (JEM-2100 (CO NiN) and JEM-2010F) and the equipment for TEM and SEM sample preparation. In 2022, installation of a new scanning transmission electron microscope Spectra 300 started. Additionally, the IJS is a co-owner (20%) of a JEM-ARM200CF at the National Institute of Chemistry.

Head:
Prof. Miran Čeh

High-resolution scanning electron microscope Verios G4 HP, Thermo Fisher Scientific, (Figure 3) is unique in this part of Europe and provides extremely high imaging resolution at low accelerating voltages. It also features automatic sample insertion and the ability to observe non-conductive specimens with exceptional Z-contrast, even at low voltages. In addition to a highly sensitive EDXS detector, the microscope is equipped with a transmission detector (STEM) as well.

Scanning electron microscope Quanta 650, Thermo Fisher Scientific, (Figure 4) operates in three vacuum ranges that are achieved through differential pumping. This allows us to investigate a wide range of materials, both conductive and non-conductive.

Scanning transmission electron microscope Spectra 300, Thermo Fisher Scientific, (Figure 5) is the most modern research equipment of the last generation of transmission electron microscopes, enabling comprehensive structural and chemical characterization of materials at the atomic and subatomic levels. The microscope has an FEG electron source, a spherical aberration corrector and a monochromator, enabling the following scanning electron microscopy techniques to be performed: observation with a parallel electron beam (TEM, HRTEM), electron diffraction (SAED, CBED, PED), 4D STEM, qualitative and quantitative chemical analyses (EDXS, EELS), all with the ultimate imaging and analysis resolution at the atomic and subatomic levels.

The research carried out using the equipment at the CEMM is diverse due to many different research topics of the JSI departments:

– Scanning electron microscopy is employed to observe the morphology and structure of surfaces and for the microstructural investigation and determination of the chemical compositions of the investigated materials. Samples that are most frequently investigated are ceramics (polycrystalline oxide and non-oxide compositions), nanostructured materials, metallic magnetic materials, metals, alloy glass, etc. All of the scanning electron microscopes in the CEMM are equipped with an energy-dispersion (EDXS) and/or wavelength-dispersion (WDXS) spectrometers for X-rays, allowing non-destructive determination of the chemical compositions of the investigated materials. The JSM-7600F scanning electron microscope is additionally equipped with an electron back-scattered diffraction (EBSD) detector and an electron lithography system. The Verios 4G HP microscope enables the observation of the morphology of nanoparticles and samples that are sensitive to electron doses. The Quanta 650 microscope allows the observation of larger conductive or non-conductive samples.

– Transmission electron microscopy (TEM) provides an insight into the structure of a material on the nano-scale (the atomic

Figure 1: Centre for Electron Microscopy and Microanalysis (CEMM)

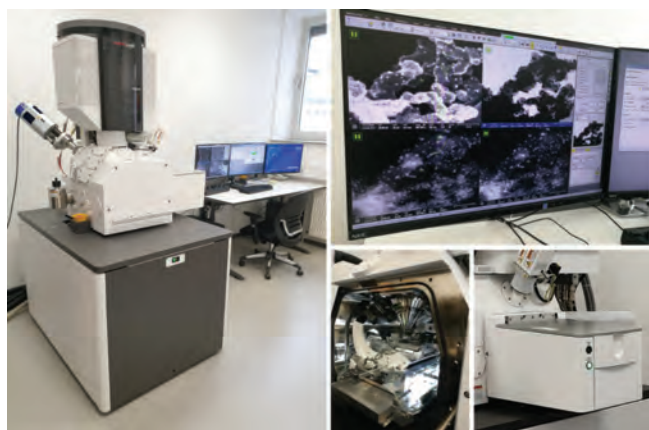*Figure 2: JSM-7600F scanning electron microscope*

Figure 3: Verios 4G HP scanning electron microscope

Figure 5: Spectra 300 scanning transmission electron microscope

Figure 4: ESEM Quanta 650 scanning electron microscope

level). Transmission electron microscopy enables structural and chemical analyses of nanostructured phenomena, such as grain boundaries, precipitates, planar defect, dislocations, etc. Materials that are investigated include thin films on different substrates, alloys, metallic magnetic materials, dielectric materials, ferroelectrics, etc. The JEM-2100 transmission electron microscope is equipped with an EDXS spectrometer and a CCD camera, while the JEM-2010F is additionally equipped with a scanning transmission electron (STEM) unit, EDXS and EELS (electron energy loss) spectrometers, and a CCD camera. The ARM200CF is a dedicated scanning transmission electron microscope with ADF, HAADF, ABF STEM detectors and GIF system.

– The CEMM also manages the necessary equipment for the SEM and TEM sample preparation.

The operation of the centre is managed by the CEMM personnel. Besides the maintenance of the equipment, other CEMM activities include, among others, training of new operators, organization of workshops and conferences on the topic of electron microscopy, providing services for industrial partners and the implementation of new analytical techniques. The CEMM personnel are also responsible for the dissemination of electron microscopy techniques to the general public in the scope of organized visits to the IJS, as well through publications in traditional and digital media.

Examples of microstructural and nanostructural investigations of materials performed with the CEMM equipment
Below are examples of analyses of structural and chemical characterisations of different materials performed by the operators from different JSI departments and the CEMM personnel, using electron microscopy techniques.
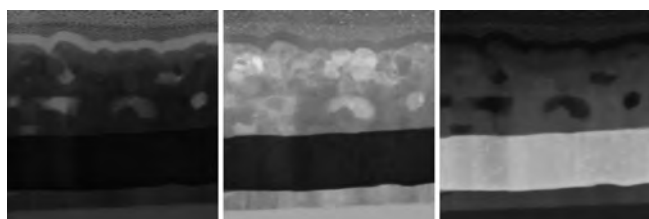
Figure 6: STEM image from left to right: bright field, dark field mode and HAADF image (Katarina Žiberna, K5, Jitka Hreščak, CEMM, Verios G4 HP SEM)

1. Analysis of $0.5(Ba_{0.8}Ca_{0.2})TiO_3 - 0.5Ba(Zr_{0.1}Ti_{0.9})O_3$ layer on $Pt/TiO_2/SiO_2/Si$ base

A STEM image was taken with the Verios G4 HP scanning electron microscope, from left to right: bright field, dark field mode and HAADF image. The layer of $0.5(Ba_{0.8}Ca_{0.2})TiO_3 - 0.5Ba(Zr_{0.1}Ti_{0.9})O_3$ on $Pt/TiO_2/SiO_2/Si$ base was prepared with a solution synthesis. The image was acquired during training on the CEMM equipment (Figure 6).

2. Analysis of Pt nanoparticles on carbon nanospheres

An analysis of Pt nanoparticles on carbon nanospheres at a magnification of 200,000× was made with the Verios G4 HP SEM (Figure 7).

3. Study of diffusion of crystalline ZrO_2 in porcelain after deformation

An EDXS study of ZrO_2 and deposited porcelain layers was performed. A sample was subjected to deformation, i.e., bending under pressure, where the sample was visibly deformed. The study was based on the assumption of diffusion transfer of ZrO_2 into the adjacent porcelain layer or diffusion of porcelain into the ZrO_2 layer. (Figure 8).

4. Nanocrystalline CeO_2 coating

A TEM analysis of the nanocrystalline CeO_2 coating on Fe_2O_3 magnetic nanoparticles was completed (Figure 9).

5. A study of $H_2Ti_3O_7$ nanotubes (TiNTs)

A TEM image of $H_2Ti_3O_7$ nanotubes (TiNTs) used in a study of the delivery of antibiotic Flumequin by titanate nanotubes for use in aquaculture was taken. The inner diameters of the nanotubes ranged from 2 to 6 nm with the average value of 3.2 nm. The outer diameter varied between 6 and 13 nm with the average value of 8.3 nm (Figure 10).
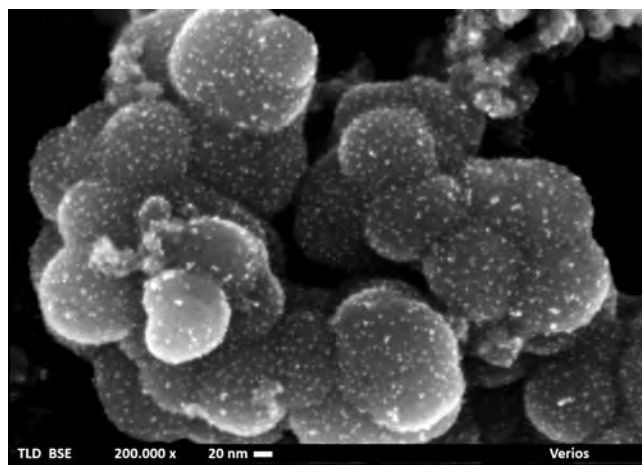
Figure 7: SEM images of Pt nanoparticles (Zoran Samardžija, K7, Kristina Žagar Soderžnik, K7, Verios G4 HP SEM)
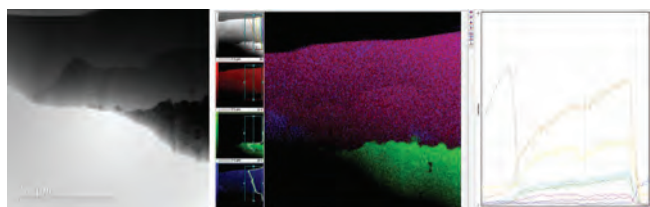
Figure 8: (left) TEM image of the ZrO_2 layer and porcelain, (middle, right) EDS spectrum over the diffusion layer (S. Drev, CEMM, Jeol-ARM200CF)
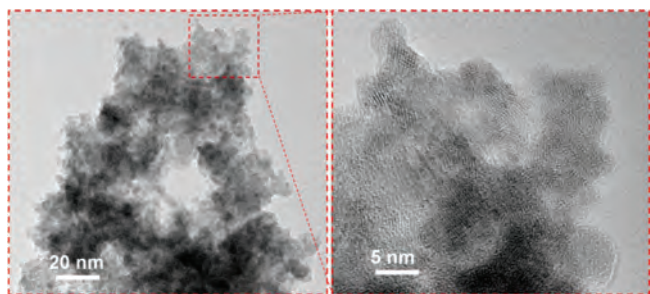
Figure 9: TEM images of nanocrystalline CeO_2 coating (Darko Makovec, K8, JEM-2100)
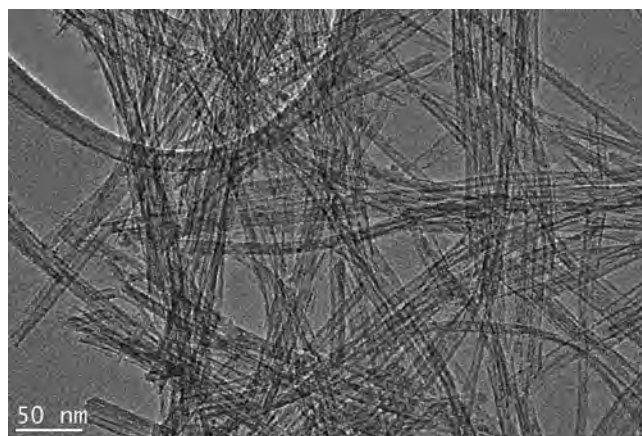
Figure 10: TEM image of $H_2Ti_3O_7$ nanotubes (TiNTs) (Polona Umek, F5, JEM-2100)

Ref: Baati, Tarek, Brahim, Mounir Ben, Salek, Abir, Selmi, Mouna, Njim, Leila, Umek, Polona, Aouane, Aicha, Hammami, Mohamed, Hosni, Karim. Flumequine-loaded titanate nanotubes as antibacterial agents for aquaculture farms. RSC Advances, ISSN 2046-2069, 2022, vol. 12, iss. 10, pp. 5953–5963, illustr., doi: 10.1039/d1ra08533f. [COBISS. SI-ID 102359299], [JCR, SNIP, WoS until 27. 3. 2022: total citations (TC): 0, collaboration index (CI): 0, Scopus until 24. 1. 2023: total citations (TC): 1, collaboration index (CI): 1].

INTERNATIONAL PROJECTS

1. HE - EUROfusion; WP07: ENR-DeHydroc-1,2,3_HE-FU
   Dr. Andreja Šestan Zavašnik
   European Commission
2. HE - EUROfusion; WP18: MAT_HE-FU, IREMEV-MAT-1_HE-FU, IREMEV-MAT-2_HE-FU,
   IREMEV-MAT-3_HE-FU
   Dr. Andreja Šestan Zavašnik
   European Commission

R&D GRANTS AND CONTRACTS

1. Detection of defects and hydrogen by ion beam analysis in channelling mode for fusion
   Dr. Andreja Šestan Zavašnik
2. Formation and Design of AM-processed Fe-Al alloys with self-forming Hydrogen

Permeation Barriers for the harshest of environments
Dr. Andreja Šestan Zavašnik
3. External Services (Export), Electron Microscopy and Microanalysis, Sample Preparation
   and Microscopy
   Prof. Miran Čeh

NEW CONTRACTS

1. BIO1-2020
   Prof. Miran Čeh
   Lek d. d.
2. Characterization of the primary coating, tendency of the primary coating to
   delamination of glass, characterization of contact and non-contact materials
   Prof. Miran Čeh
   Lek d. d.

STAFF

Researcher
1. **Prof. Miran Čeh, Head**
Postdoctoral associate
2. Dr. Sandra Drev
Postgraduates
3. Andreja Šestan Zavašnik, B. Sc.

4. Aleksander Učakar, B. Sc.
Technical officers
5. Petra Drnovšek, B. Sc.
6. Dr. Jitka Hreščak

CENTRE FOR KNOWLEDGE TRANSFER IN INFORMATION TECHNOLOGIES CT-3

The Centre for Knowledge Transfer in Information Technologies performs educational, promotional and infrastructural activities linking researchers and users of their results. Through its successful involvement in European research projects, the centre is also expanding its research and development activities, especially in the field of knowledge management in traditional, networked and virtual organizations. Within the centre, the UNESCO Chair on Open Technologies for Open Educational Resources is active, with a wide range of activities in the field of open education. Among others, we are involved in the implementation of the Master's programme in Open Education Leadership and Planning at the University of Nova Gorica, and in cooperation with the Ministry of Education and Science, we again organised and implemented in 2022 further education and training of education professionals and a UNESCO Consultation with Rectors of Higher Education Institutions on the Future of Higher Education. At both school and national level, we held the 17th ACM Competition in Computer Science and Informatics in the spring. The videolectures.net (VLN) team was involved in the organisation of more than twenty high-profile international and national events, such as the Extended Semantic Web Conference (ESWC 2022), the International Conference on Functional Programming (ICFP 2022) and the 50th anniversary of the Medicine at Work conference in collaboration with UKC Ljubljana.

The centre is involved in a number of international, EU and Slovenian projects. In 2022 we implemented for the fifth time the international mentoring programme Open Education for a Better World and the project OER Dynamic Coalition under the auspices of UNESCO. Thirteen European projects were successfully implemented, including a number of Horizon projects: Horizon Elexis, CyberSANE, NAIADES, Infinitech, Factlog, A-Cinch, Star, Odeuropa, Erasmus+ QA Lead and Bridges, EnRichMyData, EU Japan and the European Statistics Award.

Head:
Mitja Jermol, M. Sc.

Open Education for a Better World – international mentorship programme

In 2022 the 5th year of the international mentoring program Open Education for a Better World was managed by the UNESCO Chair on Open Technologies for Open Educational Resources and Open Learning at the Jožef Stefan Institute and the University of Nova Gorica. We received 62 applications and organized 3 regional hubs, namely North and South America; Africa; Slovenia; and other thematic hubs – Computing; Train the Trainer; Online Learning; Social and Legal Issues; Sustainability and Natural Science; and Youth.

The final event of Open Education for Better World, Eduscope 2022, took place in a hybrid format between the 20th and 22nd September 2022 at the Lanthieri Mansion, in Vipava, and via the MiTeam online platform. At the conference, program participants presented the open educational resources they developed during the program, and received direct feedback on the products from the audience in a panel discussion. The conference was attended by 50 participants live and 138 online; a total of 188 people from 6 continents. The event was co-sponsored by the William & Flora Hewlett foundation. The conference was held together with the BRIDGES symposium where 24 research and practical contributions from the field of open education were presented.

More information about the programme is available at: https://oe4bw. miteam.si/.

Figure 1: OE4BW Eduscope 2022: 20–22 September 2022, Lanthieri Mansion, Vipava (Photo: Simon Marolt)

OER Dynamic Coalition

The UNESCO project OER Dynamic Coalition was launched in 2022 to develop a platform that would provide communication and networking opportunities in addition to content and knowledge management. In line with the principles of the UNESCO Recommendation on OER, we will pursue openness, multilingualism and accessibility on the portal. The portal will bring together national, regional and global platforms and networks in one place,

creating an access point for sharing and promoting knowledge in the field of open educational resources as well as activities and existing or new initiatives.

H2020 - CyberSANE

The project CyberSANE (Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures) started in 2019 and ended in 2022. The aim of the project was to increase the security and resilience of the European Critical Information Infrastructure (CII). As part of the project, we were developing a CyberSANE platform to help professionals in organizations deal with cyber incidents. The platform consisted of several components, and within the project the JSI was responsible for the development of the DarkNET component, used to crawl the data from the dark web and from the media articles in structured and unstructured forms. The DarkNET component then semantically analysed the captured data and extracted relevant information about cyber incidents from it. This gave security analysts an insight into the global state of cybercrime as well as the detection of cyber threat reports on the dark web and in the news. In 2022, the development of the platform was completed and successfully tested in three pilot tests.

> **Within the centre, we hold the UNESCO Chair on Open Technologies for Open Educational Resources, providing a wide range of activities in the field of open education.**

As part of the project, the book *Crash course on cybersecurity: a manual for surviving in a networked world* was also published. The book attempts to explain the complex field of cyber security in a comprehensible manner, highlighting the key information on how to protect yourself and/or your business from cyber attacks and providing technology-neutral advice for implementing cyber attack protection. The book was published under a Creative Commons licence.

H2020 - Infinitech

The EU H2020 project INFINITECH (Tailored IoT & BigData Sandboxes and Testbeds for Smart, Autonomous and Personalized Services in the European Finance and Insurance Service Ecosystem) aims to lower the barriers for BigData/IoT/AI driven innovation and boost regulatory compliance in the financial and insurance sector. Together with the Department for Artificial Intelligence (E3) we are involved in the pilot that developed a platform for the improvement of the effectiveness of the existing supervisory activities in the area of anti-money laundering and combating terrorist financing (AML/ CTF) by processing a large quantity of data (Big Data) owned by the Bank of Slovenia (BS) and other competent authorities. Moreover, INFINITECH established a market platform that provides access to project solutions, along with a Virtualized Digital Innovation Hub (VDIH) that supports innovators (FinTech/InsuranceTech) in their BigData/AI/IoT endeavours.

H2020 Erasmus+: Bridges

We participate as a partner organisation in the Bridges project Bridging Educational Emergency to Digital Pedagogies, which is an Erasmus+ project. As part of the project, we conducted research interviews with pedagogues in the field of higher education about the needs for additional training in the field of open education and distance education. Together with our partners, we prepared a set of educational video content together with the Videolectures.NET team. As part of the Eduscope 2022 event, we co-organized the Bridges project symposium, in which 20 research and practical contributions from the field of open and distance education were presented.

H2020 – EU-Japan.AI

The aim of the EU-Japan.AI project (Advancing Collaboration and Exchange of Knowledge between the EU and Japan for AI-Driven Innovation in Manufacturing) was to establish and stimulate a long-term cooperation between the EU and Japan in the areas relevant for AI-driven innovation in manufacturing and digital industry, by implementing a platform-based approach to connect all the relevant stakeholders and by promoting the use of modern, online-driven awareness approaches to them. As part of the project, we developed an online platform with all relevant information on the use of artificial intelligence in production in the EU and Japan. The platform is also used for connecting partners from both regions and fostering cooperation among them.

As part of the project, we collected data on events, projects, organizations and opportunities for financing projects in the field of artificial intelligence in manufacturing in the EU and Japan. The IJS developed AI Observatory, a web platform that shows various analyses and visualizations of scientific publications in the field of artificial intelligence, media reports on the events related to artificial intelligence, analyses of the job market and demand for skills in the field of artificial intelligence, analyses of the EU research projects and open source projects related to artificial intelligence. We also prepared a report, presenting an analysis of the investments in artificial intelligence technologies and a visualization and analysis of public policies on artificial intelligence. For publication on the online platform, we have also prepared several articles on the advantages and dangers of artificial intelligence in practice.

European Statistics Award

Together with E3 (AiLab) we cooperate in the implementation of a series of competitions in the fields of now-casting and web intelligence where we deal with the promotion and visual appearance of both fields. The main objective is to discover promising methodologies and data sources that can be used to improve the production of European statistics. New approaches based on advanced modelling (possibly using alternative, almost real-time, information) have an important potential to give us accurate estimates of key indicators much faster than before. As part of the program, which will last until the end of 2025, we plan implementations of three competitions in the field of nowcasting and four competitions in web intelligence.

ACM Competition in Computer Science and Informatics

In 2022, after two years of virtual editions, we finally had the opportunity to hold a live competition. Thus, we held the national stage of the 17th ACM Competition in Computer Science and Informatics on the last Saturday in March at the Faculty of Computer Science and Informatics, University of Ljubljana. 125 students from 27 secondary schools competed in programming, 12 students competed in web application development, and 8 students took up the challenge of an off-line task. 4 primary and 14 secondary school entries competed in the production of educational videos. For programming, 52 silver and 7 gold prizes were awarded, while 88 bronze prizes were awarded in the school competitions held in January. As every year, we gave practical prizes to the best competitors in each area.

The results of the whole competition are available at: https://rtk.ijs.si/2022/rezultati.html.

Videolectures.net (VLN)

Videolectures.net (VLN) offers more than 30,000 recorded videos of different scientific events. The main purpose of the video portal is to provide free and open-access video lectures presented by distinguished scholars and scientists at many state-of-the-art events. Videolectures.net is a free knowledge hub, providing online education to everyone. VLN's aims are to share educational content, promote science, give the audience a learning opportunity and connect globally.

The centre is involved in a number of international, EU and Slovenian projects. In 2022 we realised, for the fifth time, the international mentoring programme Open Education for a Better World and project OER Dynamic Coalition under the auspices of UNESCO. Thirteen European projects were successfully implemented, including a number of Horizon projects: Horizon Elexis, CyberSANE, NAIADES, Infinitech, Factlog, A-Cinch, Star, Odeuropa, Erasmus+ QA Lead and Bridges, EnRichMyData, EU Japan and the European Statistics Award.

In 2022 we cooperated with more than 20 Slovenian institutions from the public and private sectors, providing technical support and helping with the organization of events. We worked with many renowned international and Slovenian conferences, most of them being hybrid events. By creating promotional videos, tutorials, workshops and interviews or disseminating information about EU projects, we enabled many events covering more than 30 state-of-the-art topics that were highly recognized by our users. With on-site recording and technical support to many events, we worked for many platforms, such as Zoom, Airmeet, etc. Using technical guidance and covering state-of-the-art topics we published many international and national conferences and events, for which we obtained appropriate consents and enabled the reliability of the prepared video content.

Some of the events with the highest rating that we covered and published in the past year were: ESWC 2022 (Extended Semantic Web Conference), ISWC 2022 (International Semantic Web Conference), ICFP 2022 (International Conference on Functional Programming), Elexis 2022, Euralex 2022, SIKDD2022, ISOFOOD 2022, etc.

We also collaborated with many other Institutions, such as:

–   UKC, Ljubljana, Slovenia – co-organisation of the conference 50th anniversary of Occupational Medi-cineDigital Innovation Centre of Slovenia and the Government Office for Digital Transformation – co-organisation of the conference Women for DigitalisationMinistry of Higher Education, Science and Innovation – co-organisation of the ERA Co BioTech conference
–   University of Nova Gorica – co-organisation of the Eduscope 2022 conference (Open Education for a Better World project)
–   Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften), Vienna, Austria
–   Singular Logic, Athens, Greece
–   Universitat Politecnica de Valencia, Valencia, Spain.

On 21–26 March 2022, we live-streamed the events of the 31st Jožef Stefan Days. We successfully collaborated with the IJS Department of Environmental Sciences (O2), in particular in the organisation and delivery of the monthly online webinars MetroFood (Infrastructure for the Promotion of Metrology in Food and Nutrition).

We also continued to collaborate on European projects such as Erasmus+ QA Lead and Bridges, and fostered long-term partnerships with the Faculty of Architecture of the University of Ljubljana, the University of Nova Gorica, and broadcasted the Science on the Road lecture series, Positive Psychology, and lectures for schools and parents.

We started filming literary evenings with libraries across Slovenia, and continued filming events at the Institute of Biology and the Institute of Chemistry in Ljubljana.

We successfully worked with SNDT Women's University of Mumbai, NCERT – National Council of Educational Research and Training, Digital Infrastructure for Knowledge Sharing (DIKSHA) and the Indian Ministry of Education to host over 10,000 educational videos for primary and secondary education based on online learning as part of Open Education for a Better World.

These video lectures have been used for a successful dissemination of information about numerous projects and for the research and training needs of our centre.

INTERNATIONAL PROJECTS

1. ERASMUS+: QALead - Equipping Institutional Leaders to Maximise Gains from Quality Assurance
   Matija Ovsenek
   European Commission
2. ERASMUS+: BRIDGES - Bridging Educational Emergency to Digital Pedagogies
   Anja Polajnar, M. Sc.
   Agenzia Nazionale Erasmus Plus Indire
3. COST CA19142; Leading Platform for European Citizens, Industries, Academia and Policymakers in Media Accessibility
   Davor Orlić, B. Sc.
   Cost Association Aisbl
4. H2020 - NAIADES; A Holistic Water Ecosystem for Digitisation of Urban Water Sector
   Mitja Jermol, M. Sc.
   European Commission
5. H2020 - CyberSANE; Cyber Security Incident Handling, Warning and Response System for the European Critical Infrastructures
   Mitja Jermol, M. Sc.
   European Commission,the Directorate-general
6. H2020 - INFINITECH; Tailored IoT&BigData Sandboxes and Testbeds for Smart, Autonomous and Personalized Services in the European Finance and Insurance Services Ecosystem
   Mitja Jermol, M. Sc.
   European Commission
7. H2020 - FACTLOG; Energy-aware Factory Analytics for Precess Industries
   Mitja Jermol, M. Sc.
   European Commission
8. H2020 - A-CINCH; Augmented Cooperation in Education and Training in Nuclear and Radiochemistry
   Mihajela Črnko
   European Commission
9. H2020 - STAR; Safe and Trusted Human Centric Artifical Intelligence in Future Manufacturing Lines
   Mitja Jermol, M. Sc.
   European Commission
10. H2020 - ODEUROPA: Negotiating Olfactory and Sensory Experiences in Cultural Heritage Practice and Research
    Mitja Jermol, M. Sc.
    European Commission
11. H2020 - EU-Japan.Ai: Advancing Collaboration and Exchange of Knowledge Between the EU and Japan for AI-Driven Innovation in Manufacturing
    Mitja Jermol, M. Sc.
    European Commission
12. H2020 - ELEXIS; European Lexicographic Infrastructure
    Mitja Jermol, M. Sc.
    European Commission
13. Dynamic Coalition; OER Dynamic Coalition Portal
    Mitja Jermol, M. Sc.
    Unesco

R&D GRANTS AND CONTRACTS

1. Videorecording and Post-Processing
   Mitja Jermol, M. Sc.
2. Management of the European Statistics Award for Web Intelligence - LOT 1
   Anja Polajnar, M. Sc.
   European Commission
3. Management of the European Statistics Award for Nowcasting - LOT 2
   Anja Polajnar, M. Sc.
   European Commission
4. TIDES: Connect AI
   Mitja Jermol, M. Sc.
   Tides Foundation

STAFF

Postgraduate
1. Anja Polajnar, B. Sc.

Technical officers
2. **Mitja Jermol, M. Sc., Head**
3. Dr. Matej Kovačič
4. Simon Marolt, B. Sc.
5. Dr. Tanja Zdolšek Draksler

Technical and administrative staff
6. Aleš Buh
7. Ana Fabjan, B. Sc.
8. Adis Krečo, B. Sc.
9. Monika Kropej, B. Sc.
10. Matija Ovsenek
11. Kim Sevšek, B. Sc.
12. Špela Sitar, B. Sc.

MILAN ČOPIČ NUCLEAR TRAINING CENTRE ICJT

The mission of the ICJT training centre is training in the field of nuclear technologies and radiation protection. In addition, ICJT is actively informing the public about these technologies.

The beginning of 2022 was still impacted by the Covid-19 pandemic. The training and the information activities (visits of school groups) were performed by implementing protective measures – face masks, ventilation, hand sanitation, a limited number of participants, and sufficient distance between tables. We are proud that there was not a single case of infection transfer during the training process at the ICJT.

Training in nuclear technologies is our primary mission. The *Nuclear Technology* (TJE) course is the first, theoretical phase of the training of future control-room operators and was held from September 2021 to February 2022. In the spring (May and June) we ran a course entitled *Basics of Nuclear Technology* (OTJE). In addition to these established courses there were also four courses for Slovenian nuclear-safety administration (*Selected Chapters of Nuclear Technology*, *Nuclear Technology Fundamentals*, and *Radioactive Waste*) and two courses called *Nuclear Energy in Short*.

There were 26 **radiological protection training** courses for medical, industrial and research use of radioactive sources. Furthermore, there were 3 courses on the use of radiation portal monitors at scrap-metal processing facilities.

In collaboration with the Reactor Physics Division and the Reactor Infrastructure Centre four **international courses** were organized.

Public information remains an important part of our activities. In the first months of the year it was partially done using a videoconference system, while later the majority of visits were in person. The lectures covered the electricity from nuclear energy, sources of electricity in Slovenia, fusion, isotopes, energy in general, and the use of radiation in industry, medicine and research. In 2022, a lecture on the safety of nuclear power plants was added. For younger visitors, a workshop on energy was offered. Altogether, there were 97 groups with a total of 4002 participants this year. Since 1993, there were 196,707 pupils, teachers and others, visiting our information centre. In the summer, an elevator that will allow visits by persons with disabilities was installed in our building. In parallel, a thorough reconstruction of the permanent exhibition on nuclear energy was started. We have continued monitoring and analysing media reports on nuclear energy.

Head:
Dr. Igor Jenčič

In 2022 extensive construction works started in the building of the training centre. These works include installation of an elevator and a thorough upgrade of the permanent exhibition on nuclear energy.

Figure 1: Radioactivity workshop on the Open Day of the Jožef Stefan Institute

Figure 2: Experimental training session of the Basics of Nuclear Technology Course

STAFF

Researcher
1. **Dr. Igor Jenčič, Head**
2. **Technical officers**
3. *Sara Gregl, B. Sc., left 01.04.22*
4. Matjaž Koželj, M. Sc.
5. Urban Pompe, B. Sc.
6. Tomaž Skobe, M. Sc.
7. Vesna Slapar Borišek, B. Sc.
Technical and administrative staff
8. Saša Bobič
9. Matejka Južnik, M. Sc.
10. Borut Mavec, B. Sc.

Table of training activities at the Nuclear Training Centre in 2022

Date	Title of the course	Partici-pants	Lecturers	Weeks	Participants × weeks
(13.9.21) - 4.2.	Nuclear technology, theory	12	18	5	60
(15.12.21) - 14.1.	Basics of nuclear technology, systems	7	8	2	14
19. - 21.1.	Radiation protection for RP department staff – refresher course	4	3	0.6	2.4
28.1.	Energy literacy training	18	10	0.2	3.6
28.2. - 2.3.	Radiation protection for industrial and other practices (measurement of roadway density and humidity)	1	3	0.6	0.6
28.2. - 2.3.	Radiation protection for handheld XRF spectroscopy	9	3	0.6	5.4
28.2. - 4.3.	Radiation protection for industrial and other practices (radiography)	3	3	1	3
7. - 8.3.	Radiation protection for industrial and other practices (unsealed sources)	2	4	0.4	0.8
7.3.	Radiation protection for baggage screening systems	3	3	0.2	0.6
7.3.	Radiation protection for industrial and other practices	8	3	0.2	1.6
10. - 11.3.	Radiation protection for industrial and other practices (radiography) – refresher course	6	3	0.4	2.4
10.3.	Radiation protection for industrial and other practices – refresher course	9	3	0.2	1.8
10.3.	Radiation protection for industrial and other practices (measurement of roadway density and humidity) – refresher course	3	3	0.2	0.6
10.3.	Radiation protection for handheld XRF spectroscopy – refresher course	7	3	0.2	1.4
10.3.	Radiation protection for industrial and other practices (unsealed sources) – refresher course	3	4	0.2	0.6
23.3.	Radiation protection for baggage screening systems	8	2	0.2	1.6
7.4.	Use of radiation portal monitors at scrap-metal processing facilities	5	0	0.2	1
12.4.	Radiation protection for industrial and other practices	10	2	0.2	2
19. - 22.4.	Nuclear technology fundamentals	8	7	0.8	6.4
3.5. - 2.6.	Basics of nuclear technology, theory	7	14	4.4	30.8
16. - 20.5.	Selected chapters of nuclear technology	7	5	1	7
23.5.	Use of radiation portal monitors at scrap-metal processing facilities	2	1	0.2	0.4
2. - 24.6.	Basics of nuclear technology, systems	7	8	3.4	23.8
13.6.	Radiation protection for industrial and other practices	6	2	0.2	1.2
21.6. - 1.7.	Activities of nuclear instrumentation and research reactor within the framework of the MOBIL-APP project (A*Midex Project) for the virtual mobility period	9	6	1.8	16.2
28.7.	Nuclear core design predictions of cycle 33 assuming shorter cycle 32	3	1	0.2	0.6
20.9.	Use of radiation portal monitors at scrap-metal processing facilities	3	2	0.2	0.6
26. - 30.9.	Uppsala University dedicated practical course Experimental Reactor Physics	11	4	1	11
26. - 28.9.	Radiation protection for handheld XRF spectroscopy	4	3	0.6	2.4
26. - 28.9.	Radiation protection for industrial and other practices (measurement of roadway density and humidity)	1	3	0.6	0.6
26. - 30.9.	Radiation protection for industrial and other practices (radiography)	3	3	1	3
26. - 28.9.	Radiation protection for high-activity sealed sources – refresher course	1	3	0.6	0.6
3. - 14.10.	17th EERRI Research Reactor Group Fellowship Training Course	11	14	2	22
3.10.	Radiation protection for industrial and other practices	10	2	0.2	2

Table of training activities at the Nuclear Training Centre in 2022

Date	Title of the course	Partici-pants	Lecturers	Weeks	Participants × weeks
3. - 4.10.	Radiation protection for industrial and other practices (unsealed sources)	2	3	0.4	0.8
6.10.	Radiation protection for handheld XRF spectroscopy – refresher course	3	3	0.2	0.6
6.10.	Radiation protection for industrial and other practices (unsealed sources) – refresher course	5	4	0.2	1
6.10.	Radiation protection for industrial and other practices – refresher course	10	3	0.2	2
6. - 7.10.	Radiation protection for industrial and other practices (radiography) – refresher course	1	3	0.4	0.4
8. - 10.11.	Selected chapters of nuclear technology	6	2	0.6	3.6
11.11.	Radioactive waste	22	3	0.2	4.4
18.11.	Pulse experiment exercise for students	32	6	0.2	6.4
7.12.	Radiation protection for industrial and other practices	10	2	0.2	2
14.12.	Update of the FAR and SHUFFLE codes within the frame of the NEK dry-storage project SFDS	1	2	0.2	0.2
TOTAL		303	187	33.6	253.4

Figure 3: Trainees at the written exam during the Basics of Nuclear Technology Course, June 2022

Figure 4: Visit from the Ministry of Finance to the exhibition in the Nuclear Training Centre, March 2022

INTERNATIONAL PROJECTS

1. Implementation of the 17th EERRI Research Reactor Group Fellowship Training Course, from 3 October 2022 to 14 October 2022
   Dr. Igor Jenčič
   IAEA - International Atomic Energy Agency

R&D GRANTS AND CONTRACTS

1. Strengthening the Competence of Entrepreneurship and Promoting Flexible Transition between Education and the Environment in Primary and lower Secondary Schools
   Tomaž Skobe, M. Sc.
   Ministry of Education, Science and Sport
2. Strengthening the Competence of Entrepreneurship and Promoting Flexible Transition between Education and the Environment in Secondary Schools
   Tomaž Skobe, M. Sc.
   Ministry of Education, Science and Sport
3. Assessment of the justification for the use of items of general-use containing added radionuclides and radiation protection assessment for minerals or rocks with naturally occurring radionuclides

Matjaž Koželj, M. Sc.
Ministry of the Environment and Spatial Planning
4. Services
   Dr. Igor Jenčič
5. Training Courses TJE and OTJE - For Foreign Participants
   Dr. Igor Jenčič

NEW CONTRACTS

1. Implementation of public information and awarenes activities about energy and nuclear energy in central Slovenia
   Dr. Igor Jenčič
   Gen Energija, d. o. o.
2. Trainings of the Radiation protection
   Matejka Južnik, M. Sc.
3. ICJT Training Programme implementation in the year 2022
   Dr. Igor Jenčič
   Krško Nuclear Power Plant
4. Basic Training Course on Nuclear Technology and Nuclear Power Plants
   Dr. Igor Jenčič

RADIATION PROTECTION UNIT

SVPIS

SVPIS has been involved in ionizing-radiation measurements and radiation protection since the commissioning of the TRIGA MARK II Research Reactor in 1966. SVPIS is responsible for the radiation control of all the activities at the Institute dealing with ionizing radiation. Our main task is the supervision of work in the reactor with the Hot-Cell Facility and we are authorised by the regulatory authority to perform environmental monitoring.

SVPIS also controls 17 laboratories that use sources of ionising radiation in their research work. There are different sources of radiation used at the JSI, which need regulatory control. Furthermore, we are involved in radioactive-waste management.

SVPIS is authorized by the Slovenian radiation-protection administration and nuclear-safety administration to perform control in industrial and research institutions, using sources of radiation. The measurements of dose rates, contaminations and radon activity concentrations as well as gamma spectrometry are performed using accredited methods (LP-022, EN ISO/IEC 17025).

Head:
Matjaž Stepišnik, M. Sc.

Personal dosimetry

Personal doses of 135 workers that regularly or occasionally deal with ionizing radiation were monitored with Thermo Luminescent Dosimeters. The maximum individual yearly dose was 0.32 mSv. This is 2 % of the regulatory limit for occupational exposure (20 mSv per year). The collective dose at the JSI in 2022 was 2.7 man mSv.

Supervision of the Research Reactor and laboratories

The controlled area of the Research Reactor, the Hot-Cell Facility and the Department of Environmental Sciences was monitored on a weekly basis. During certain activities, the constant presence of a radiation-protection worker was needed (i.e., for the opening of activated samples or radioactive-waste management). Measurements of dose rates, surface contamination, contamination of different objects and personal contamination were performed routinely. In most cases, no or very low contamination levels were measured. Locally elevated radiation levels were mostly measured in the reactor's controlled area.

At present, more than 100 radioactive sources (open and sealed) and 15 devices with ionizing radiation (X-ray units and accelerator TANDETRON) are in use, requiring regulatory control and additional 450 low-activity sources in different laboratories. In 2022, a total of 21 detailed radiological surveys were performed in JSI laboratories. An independent inspection by an external authorized institution was performed in the SVPIS laboratory and two other laboratories at the JSI. No deficiencies that could be important for radiation protection were identified.

Environmental monitoring of the reactor

The environmental monitoring of the Reactor Center was performed according to the existing program. The program consists of effluent measurements and measurements of samples in the environment. Activity concentrations of gamma emitters in water samples, filters, noble gases, soil samples and sediment samples were measured periodically. About 500 different samples for the reactor and different laboratories have been measured with gamma spectrometry. Environmentally passive dosimeters have been used to monitor the radiation levels in the surroundings of the reactor.

Based on the effluent measurements and a conservative environmental transfer model, the effective dose to the reference group of the public was estimated to be less than 1 μSv/year. **In 2022 the public exposure due to activities at the Reactor Center was insignificant**.

Expert assessments and measurements for outside customers

The Radiation Protection Unit is authorized for supervision measurements and expert assessments in the field of radiation protection. In the past year several radiological control investigations were carried out in industrial and research institutions (in total 41). Our group has participated in the evaluation of the radiological monitoring of Krško NPP, research reactor TRIGA and storage for low- and intermediate-level waste in Brinje.

Jožef Stefan Institute

STAFF

Technical officers
1. Dr. Tinkara Bučar
2. Mitja Eržen, B. Sc.
3. **Matjaž Stepišnik, M. Sc., Head**

Technical and administrative staff
4. Thomas Breznik, B. Sc.
5. *Jasna Kopač, B. Sc., left 01.09.22*
6. Tanja Murn, B. Sc.
7. Nina Udir, B. Sc.

CENTER FOR TECHNOLOGY TRANSFER AND INNOVATION CTT

The Technology Transfer Office was established in 1996 and transformed in January 2011 when an independent Center for Technology Transfer and Innovation (CTT) was created to continue within the third-pillar mission at the Jožef Stefan Institute (JSI). We assist in the process of technology and knowledge transfer from the JSI to industry, which includes licensing, spin-out creation and associated procedures for the protection of intellectual property. We assist companies by finding suitable local and international research partners for contract and collaborative research. We also support knowledge transfer from science to the school system and promote the recognition of the JSI as well as science in general among young people and the wider public.

The center's success is based on 13 professionals, 7 of whom hold degrees in natural sciences and engineering, 6 in economics, 1 in law and 2 in social sciences. One of the experts is also qualified as a patent attorney, one as a Registered Technology Transfer Professional (RTTP), while three team members hold a U. S. Certified Licensing Professional certificate. The head of the center is a member of the first European Innovation Council steering board, which is a great achievement. We are members of the ASTP (Association of Science and Technology Professionals), the LES (Licensing Executives Professionals), the Association of Technology Transfer Professionals and the Slovenian Association of Patent Attorneys.

Head (until 31. 3., 1. 6.–31. 8. 2022):
Dr. Špela Stres, MBA, LLM

Our main activity is the transfer of technologies and knowledge into the economy where the main asset is the created network of contacts from enterprises and other organizations in Slovenia and abroad. Our clients are primarily JSI researchers, although numerous companies and other research organizations also procured our services in 2022. Our services, fine-tuned towards individual needs, include analyses of the requirements, preparation, registration and protection of intellectual property, marketing of intellectual property (including the secret know-how), identification of negotiation points, carrying out negotiations, drafting of various agreements, creation of spin-out companies, access to information and research infrastructure, and support in establishing financial measures.

In 2022 the Center for Technology Transfer and Innovation was funded through the following European and national projects: the Enterprise Europe Network (EEN) Slovenia (COSME scheme), Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation (ARRS CRP), Consortium for Technology Transfer – KTT (MIZŠ), WASTELESS, INDUSAC, ExSACT (ATTRACT – Phase 2), DIGI-SI, SmartFlex-Cell and AMULET. Project activities were merging with and complementing our core TT activities. Within the KTT project, we coordinate the work of the Consortium for Technology Transfer from PROs to industry, including the largest Slovenian public research organizations. Within the EEN project, we coordinate the Slovenian branch of the Enterprise Europe Network.

Acting Head (1. 4.–31. 5., since 1. 9. 2022):
Dr. Levin Pal

CTT is divided into five groups whose activities interact with and complement each other.

GROUP FOR THE PROTECTION AND MARKETING OF INTELLECTUAL PROPERTY processes IP protection and marketing cases, based on introductory meetings with researchers (17) and prepares patentability assessments, including in-depth state-of-the-art analyses (14). The group also conducts detailed market potential analyses (14), helps develop the invention description for disclosure within the Institute (7), helps fulfill the terms for patent application filing, prepares agreements on the ownership of intellectual property (10), searches for suitable patent attorneys for filing and processing the applications (12), and advises about the strategy of international and national expansion of the patent protection. Group members prepared and published new technology profiles within the Enterprise Europe Network and received expressions of interest from companies.

The above-mentioned and other technologies were promoted directly (10) to more than 700 companies and other organizations, with 41 expressions of interest received. Moreover, group members arranged signatures of nondisclosure agreements (26), took part in negotiations, and prepared and closed research and development agreements (32) where 28 of them included intellectual property exploitation.

> **Preparation, protection and marketing of 17 JSI technologies; 225 identified RR topics; 32 research-and-development agreements signed with domestic and foreign companies where 28 of them included intellectual property exploitation.**

Group members also provided individual consulting for all the phases of a spin-out company's creation (7). They helped with the preparation of business plans, defined interest for the use of intellectual property, equipment and facilities at the JSI, contacted external mentors and supporting programmes, informed and contacted financing sources, managed discussions on the arrangement of the relationship between the JSI and researchers within entrepreneurial teams, prepared documentation for spin-out creation, helped valorize the intellectual property, prepared agreements for access to the infrastructure and prepared license agreements for the use of technology within a spin-out company.

The Proof-of-Concept Innovation Fund call was published to increase the TRL of the JSI research project in the amount of 20,000 euros.

Figure 1: Dr. Špela Stres (far left) and Dr. Marko Perdih (far right) with the winners from Slovenia and Poland, of the Prize for the best innovation from public research organizations (left to right): Blaž Zdovc, Maja Grdadolnik, Dr. David Pahovnik, Paweł Kołakowski M. Sc., and Dr. Ema Žagar (photo: M. Verč)

Organization of the 15th International Technology Transfer Conference (ITTC). More than 140 visitors. The competition for the best innovation; two ITTC best innovation awards, two WIPO awards – the WIPO Medal for inventors, recognizing researchers for their impact on society, and the WIPO IP Enterprise Trophy for a company most efficiently utilizing and promoting intellectual property.

Figure 2: World Intellectual Property Organization Award (photo: M. Verč)

For the fourteenth time in a row, we awarded researchers from public research organizations with the Prize for invention or innovation with the best market potential, having used a total amount of more than 60,000 euros for all the awards since the first award ceremony.

The group actively sets up and plans collaboration with actors that are setting up a regional venture capital fund in excess of 40 million euros, which is being built by the European Investment Fund in collaboration with the Slovenian and Croatian investment banks (SID and HBOR, respectively). The fund will represent an important addition to the financial sources for spin-out companies from Slovenian and Croatian PROs, which previously have not had this opportunity.

The collaboration with the Ljubljana MBA Programme was re-established, within which a spin-out team with members from the JSI spin-out Particulars, d.o.o., collaborated with a group of 10th generation MBA students and mentors from the School of Economics and Business at the University of Ljubljana in a consulting project resulting in a business plan for introducing a new product into the market.

Cooperation with the Euro-Mediterranean University – EMUNI was established; we offer support and mentoring services at the Euro-Mediterranean Innovation Camp for young candidates (students, researchers, innovators with business ideas) from the Euro-Mediterranean area. We connect young innovators with mentors, researchers from the Jožef Stefan Institute, who will help the candidates to develop and present their innovation and innovative ideas as part of the competition and connect them to the business sector.

The group also prepared and published a call of the innovation fund Proof-of-Concept CTT at the JSI. With €20,000 of our own resources we supported a research project at the JSI and a successful research group for the development of the technology to a higher TRL for the market.

GROUP FOR PROMOTION, EDUCATION AND PROJECT MANAGEMENT

In 2022 the research groups presented their innovations and business models at the 15th International Technology Transfer Conference (ITTC), 6 researchers/research groups applied for the call for innovation with the greatest commercial potential; in addition to Slovenian applications, two were also received from Poland and Italy. The expert committee recognized the greatest potential for a market breakthrough in the solutions from Slovenia and Poland. Also, the World Intellectual Property Organization (WIPO) awards were presented for the third time in a row at the ITTC: (1) the WIPO Medal for Inventors as a recognition of researchers at Slovenian public research organizations who contribute patent-protected inventions to the development and well-being of the Slovenian economy and society; (2) the WIPO IP Enterprise Trophy as a recognition of Slovenian companies for a systematic use of the intellectual property system, cooperation with public research organizations and methodical use of intellectual property in business activities. The conference took place in a hybrid format, which enabled participation and cooperation from the countries like Lithuania, Poland and Mexico.

Among the more visible events, in addition to the 15th International Conference on Technology Transfer, the group organized the traditional workshop Young Hopes in a virtual format, during which all the key steps from an idea development and intellectual property protection to the preparation of a business model and marketing activities were presented. On the last Saturday of March, the Open Day was, after two years, once again organized at both JSI locations at Jamova cesta and Reaktor Center Podgorica where approximately 500 visitors visited us. While at the beginning of the year school visits took place in a virtual mode, visits in a classic, physical, format with visits to research sections

and laboratories began again in the spring months. In 2022 we organized 36 visits, during which nearly 1150 visitors visited us (mostly remotely). The organization of virtual meetings between the researchers of the JSI and internationally established research institutions – from Japan, Austria and Lithuania – continued.

Among the central promotional activities was the organization and filming of four new videos on the opportunities for cooperation between companies and the JSI in the fields of health, digital and green technologies. The publication Modrosti iz inovacijskega podpornega okolja v javnih raziskovalnih organizacijah (Wisdom from the innovation support environment in public research organisations) was reprinted. A database of the research equipment at the JSI was established.

Informing about relevant events, education courses, projects and other relevant content was carried out by preparing and sending out CTT newsletters (Opportunities for Cooperation, Spin-Out News), lists of European, Slovenian and other calls for project applications in the IJS fields, and other notifications like international partner searches for research/industrial partners, which contributed to applications for new projects with new international partners. The group also coordinated the preparation of a promotional video about the IJS.

GROUP FOR CONTRACTUAL COLLABORATION WITH INDUSTRY

The group visits both large and small companies (53), organizes their (virtual) return visits to the JSI (22), sectorial and regional tours of companies to the JSI and collaborates with the other entities from the support environment. This group's members regularly find new topics for cooperation within the development projects amongst companies and researchers (225 identified R&D topics), prepare technology offers, arrange the signing of non-disclosure agreements, and acquire written consents for further international cooperation (1) with business or technology-research goals, along with supporting the closure of license and research-and-development contracts.

The colleagues from the three groups jointly helped close license and research-and-development contracts with different companies and research organizations. Last year, the activities of the CTT increased significantly in the area of contracting, regarding both domestic and international contracts.

HORIZONTAL GROUP FOR SUPPORTING PROJECT PROPOSALS AND EXECUTION

Since the establishment of the Center for Technology and Innovation Transfer on 1 January 2011, this group has, along with its partners, submitted a number of successful applications to various national and European tenders. In 2022 we acquired the following projects: DIGI-SI, WASTELESS, INDUSAC, DIH4AI, ExSACT (Attract) and RITIFI. Group members are evaluators of Slovenian and international project applications. They work in different committees for the preparation of guidelines and calls at different levels. For example, they participated in the working group of the European Commission, which set the guidelines for the operation of the European Innovation Council. The group was later even named the EIC National Champion. The group is a member of the European Enterprise Network, which provides important tools for its work. The group has gained important and vast experience in the field of project preparation and implementation, on the basis of which its experts can competently advise and help the researchers at the Institute.

The group offers assistance to interested JSI departments in preparing project applications by updating the call search database on a monthly basis (1800 calls in 2022); it provides assistance with individual tender schemes, interpretation of tenders, the search for project partners (16) and the preparation of individual sections of project applications (14) (e.g., management, communication & dissemination, impact). JSI researchers can also contact the group experts if they need help in preparing legal documents related to project applications, e.g., NDA between partners, and in preparing consortium agreements, especially in reviewing background IP and foreseeable, i.e., foreground IP, as well as

We informed the employees of the JSI about national and international invention and innovation competitions and helped them apply to these competitions, at which they won 5 awards.

Figure 3: Matjaž Žagar (left) and Leon Korošec, M. Sc. (right), from Elan d.o.o. - recipients of the World Intellectual Property Organization Award – WIPO Enterprise Trophy, and Ana Krstov from the Slovenian Intellectual Property Office (photo: M. Verč)

JSI research capacities and technologies were presented at 53 company visits.
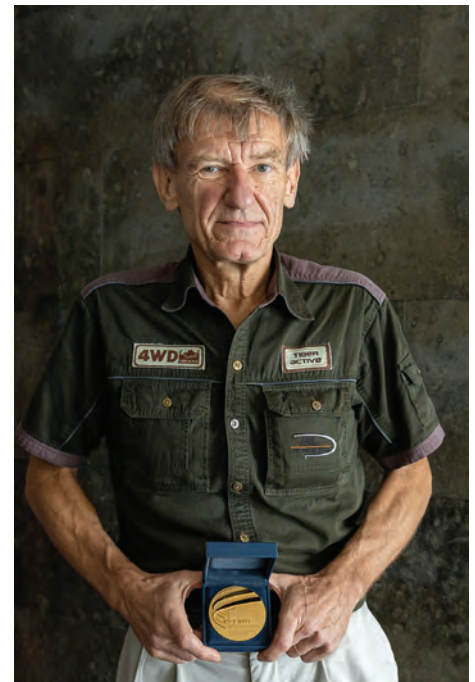

Figure 4: Prof. Miran Mozetič, recipient of the World Intellectual Property Organization award – WIPO Medal for Inventor (photo: M. Verč)

Information about 1800 calls for national and international projects and programmes was disseminated within the JSI. Partner search for 16 project applications. Content support for 14 project applications.

in giving advice on the management of IP for an annex to a consortium agreement. They also advise on the legal aspects of European research programs (e.g., state aid, intellectual property, open access, FAIR, open science). In the SmartFlexCell project, co-financed by EIT Manufacturing, we participated in the role of a legal advisor and coordinator for intellectual property and support for the establishment of a spin-off company based on the intellectual property of the project partners. Last year, the activities of the CTT increased significantly in the area of contracting, regarding both domestic and international contracts.

HORIZONTAL GROUP FOR TECHNOLOGY TRANSFER AND INNOVATION RESEARCH

Experts from this group operate as evaluators and external experts in Slovenia and within the European Commission, as well as different respectable international institutions (EC ERC, EUREKA, RRI). They were recognized by the JRC as one of the most propulsive technology transfer offices in the EU and were included into the TTO Circle, a group of PROs most active in the field of knowledge and technology transfer (including the institutes Max Planck, Weitzman, Fraunhofer, VITO and VTT). They collaborate with the United Nations, as a member of the 10-member Group for Support of the Technology Facilitation Mechanism (10MG TFM), and with the World Intellectual Property Office (WIPO) in the context of its international worldwide activities. The group is a member of the Expert Group DG Research & Innovation in the European Innovation Council (Management Group for Establishing European Innovation Council Mechanism). Group members participated in the plan preparation for a smart use of intellectual property (Community for the practice of a smart use of IP). Being a member of the Enterprise Europe Network (EEN), as a support provider for small and medium-sized companies, the group actively participated (as a sector group) in the fields of digitalisation, electronics, renewable energy and energy Intensive Industries.

We are a member of the European Innovation Council (EIC) steering board, the advisory group of the Director of the DG R&I of the European Commission, Economic and Societal Impact of Research and Innovation; we lead the working group for establishing the EIC Marketplace for the European Commission; we are national delegates in the CERN Knowledge Transfer Forum. We collaborate with the World Intellectual Property Office (WIPO) within their worldwide international activities. We preside over the Association of Technology Transfer Experts of Slovenia. For the stakeholders in the innovation system, we prepared a proposal for a long-term sustainable state-aid model for cooperation between science and industry, including also the critical points of the transfer of intellectual property from research to industry.

Members participate in the steering board of the European Innovation Council, and the HL Advisory Group of the Director of DG R&I Economic and Societal Impact of Research and Innovation. The group presides over the Association of Professionals for Technology Transfer of Slovenia, as well as the Committee for Spin-Out Creation at the Jožef Stefan Institute. In 2022, within the CRP (ARRS) project, the group finalized the proposal for a long-term sustainable state-aid model for promoting cooperation between science and industry on the basis of intellectual property evaluation.

Organization of Conferences, Congresses and Meetings

1. Young Hopes 2022 – Entrepreneurial and innovation workshop for young researchers (virtual), 7 April 2022
2. Virtual cooperation meeting between RIKEN (Japan) and Jožef Stefan Institute (virtual), 25 May 2022
3. Virtual cooperation meeting between Lakeside Science & Technology Park, Fraunhofer Institute and Jožef Stefan Institute (virtual), 9 June 2022
4. Final conference of the KTT project, Ljubljana, 23 June 2022
5. Round table on the European Chips Act and opportunities for semiconductors in Slovenia and EU, Ljubljana, 29 June 2022
6. 15th International Technology Transfer Conference – 15th ITTC (live + virtual), 12 and 14 October 2022
7. Technology Park Meeting, Jožef Stefan Institute, Ljubljana, 21 October 2022
8. Virtual Cooperation Meeting, Center for Physical Sciences and Technology from Lithuania – Jožef Stefan Institute (virtual), 1 December 2022
9. Infineon Austria at the Jožef Stefan Institute, Ljubljana, 21 December 2022

INTERNATIONAL PROJECTS

1. H2020 - AMULET; Advanced Materials and Manufacturing Technologies united for LightwEight
Dr. Levin Pal
European Commission
2. H2020 - ExSACT; Enable State Administration to be an Active Contributors in Process of Risk Absorption and Risk Reduction Through IPR and State Aid
Dr. Levin Pal
European Commission
3. H2020 - SurfBio; Innovation Hub for Surface and Colloid Biology Research
Dr. Levin Pal
European Commission

4. EIT M - Smart Flex Cell; Smart Reconfigurable Manufacturing Cell
Dr. Špela Stres
Eit Manufacturing
5. SMP-COSME-2021-EEN; EEN Slovenia; Support SMEs in Slovenia to innovate, grow and scale with the Enterprise Europe Network
France Podobnik, B. Sc.
European Commission
6. DIGITAL EU; DIGI-SI - Digital Emergency Responce for Slovenia
France Podobnik, B. Sc.
European Commission

R&D GRANTS AND CONTRACTS

1. Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation
Dr. Špela Stres
Ministry of Education, Science and Sport
2. JSI Share of License Revenues related to Exploitation of Inventions - Abroad (JSI License Revenue Share - Abroad)
Dr. Špela Stres
3. HEP2023 - Particle Physics from Early Universe to Future Colliders, Portorož, Slovenia, 11 April 2023 to 14 April 2023
Marjeta Trobec, M. Sc.
4. Evaluation of IP as a basis for proposing a long-term sustainable state aid model to promote science-business cooperation
Dr. Špela Stres
5. The consortium for technology transfer from the PRO to the economy
Dr. Špela Stres
Ministry of Education, Science and Sport

NEW CONTRACTS

1. DIH4AI-Senso4S
Dr. Špela Stres
Senso4s d. o. o.

VISITORS FROM ABROAD

1. Marija Gutauskienė and dr Linas Eriksonas, Center for Physical Sciences and Technology, Lithuania, 13 October 2022

STAFF

Researchers
1. Dr. Urška Florjančič
2. Dr. Marijan Leban
3. Dr. Duško Odić
4. **Dr. Levin Pal**, Head
5. *Dr. Špela Stres, Head, 01.09.22, transferred to Department U1*

Postgraduate
6. Robert Blatnik, M. Sc.

Technical officers
7. Tomaž Justin, B. Sc.
8. Tomaž Lutman, B. Sc.
9. Urška Mrgole, B. Sc.
10. France Podobnik, B. Sc.
11. Marjeta Trobec, M. Sc.

Technical and administrative staff
12. Matej Mrak, B. Sc.
13. Robert Premk, B. Sc.

CENTER FOR SMART CITIES
AND COMMUNITIES
CSC&C

The Center for Smart Cities and Communities (CSC&C) was established at the beginning of 2017. On 1 January 2019, Nevenka Cukjati, Ph. D., took over the management of the center.

The main task of the center is to coordinate and operate the Strategic Research and Innovation Partnership for Smart Cities and Communities (SRIP SC&C). In addition, the center also promotes cross-sectoral cooperation within the Jožef Stefan Institute, thus supporting the partnership in the field of state-of-the-art technologies and, at the same time, actively participating in the creation of national R&D policies for the coming years.

Head:
Dr. Nevenka Cukjati

Strategic Research and Innovation Partnership for Smart Cities and Communities

Strategic Research and Innovation Partnership for Smart Cities and Communities is a form of partnership, in which stakeholders have joined forces to develop and sell solutions, raising the quality of life in the cities of the future.

The aims of SRIP SC&C are to bring together companies and research institutions in a particular field to form value chains, prioritise **development investments** and coordinate R&D activities. We are building a **good support environment** for sharing knowledge and experience in the forms of workshops, seminars and joint events; we offer access to test environments, laboratories, databases; and we provide assistance in market analysis, human-resources development, intellectual-property protection and internationalization.

SRIP SC&C currently has 96 members (as of end of 2022) comprising 26 % of micro-enterprises, 31 % of small enterprises, 10 % of medium-sized enterprises, 8 % of large enterprises, 16 % of faculties or institutes and 9 % of municipalities or associations. The following open-source online SRIP SC&C platforms are available to SRIP SC&C members: **Technology Casino** and **Solution Market**. In the Technology Casino they can learn about and try out different technologies and platforms (playground) for developing innovative solutions in the field of smart cities and communities. They can share and promote their solutions in a common digital marketplace.

On 21 September 2022, at a meeting, SRIP coordinators submitted a mutually agreed document to the Minister of the SVRK with a **proposal of measures** that could significantly contribute to even better functioning of the SRIP and its cooperation with the relevant ministries.

During the year, as part of the Entrepreneurial Discovery Process (EDP), we held several meetings with representatives of the SVRK and ministries, on the basis of which a document called Slovenian Strategy for Sustainable Smart Specialisation S5 was prepared. On 16 December 2022, we received confirmation from the SVRK of the European Commission's successful completion of the coordination of the European Cohesion Policy Program for the period 2021–2027. At the same time, the thematic enabling condition linked to the Slovenian Sustainable Smart Specialization Strategy S5 was also confirmed. Its confirmation is the result of the successful work of all those involved in the creation of S5, including our center within the SRIP SC&C.

We were a co-organizer of the **Data Analytics Forum 2022** entitled Towards Modern Trends, which took place on 21 April 2022 at the Four Points by Sheraton Ljubljana Mons hotel and online. Participants gained insights into all areas and steps of effective data management. Various experts and concrete examples were used to present how to bridge the gap between modern concepts and concrete problems in organizations.

We were a co-organizer of the **Cyber Security Conference** – Challenges for Users of Digital Services, which took place on 10 May 2022 at the Brdo Congress Center. Experts in the field, politicians and a representative of Microsoft, an internationally renowned company, shared their experiences on cyber security.

We were a partner of the international **World Future Verse Conference**, which took place from 29 September to 1 October 2022 at the Festival Hall in Bled. The conference presented blockchain technologies in relation to the green transition and digital transformation, virtual and augmented reality technologies, NFTs, web3.0 and DAO.

The partnership integrates the current content of the new Financial Perspective Europe 2021–2027, the Carbon Neutral Cities Mission and the guidelines of the "GREEN DEAL" document. The European Commission identified the importance of carbon-neutral smart cities as one of the five key areas supported with the mission's financial mechanism. The EU Missions represent a new way to tackle important social challenges. The following missions have been identified under **Horizon Europe** (2021-2027): fighting cancer; adapting to climate change; living in greener cities; looking after soil health to provide for healthy food, people, nature and climate; and protecting the oceans. The Ministry of Education, Science and Sports, which coordinates the European Commission's **Climate Neutral and Smart Cities Mission**, appointed Nevenka Cukjati, Ph. D., the head of SRIP SC&C, who is also the

national delegate for the mission, as one of the external experts of the sub-group. At the monthly meetings of the sub-group, the experts contributed to the preparation of the strategic orientations of the EU Mission on Climate-Neutral and Smart Cities under Horizon Europe 2021-2027.

On 28 April 2022, the European Commission published a list of 100 EU cities that will participate in the **EU Mission for 100 Climate-Neutral Cities** by 2030. The list includes Slovenian Municipalities of Kranj, Ljubljana and Velenje, with which, in addition to the Ministry of Education, Science and Sport, we have been negotiating the implementation of the Climate-Neutral Cities Program within the framework of the SRIP SC&C operation, which we worked on in two workshops. **The first workshop called Climate-Neutral Cities** – What are they, how to design them, what are the pathways to them, took place on 30 May 2022 at the EU House in Ljubljana. **The second workshop called Climate-Neutral Smart Cities** – The role of ministries in the process of implementing climate-neutrality measures, was held on 4 October 2022 at Villa Bianca in Velenje. Together with relevant stakeholders from Slovenia, we addressed the needs of cities and defined the role of ministries in the process of supporting cities in the implementation of the Climate-Neutral and Smart Cities Mission. The third workshop is planned for April 2023.

SI4CARE Project

The Interreg ADRION SI4CARE project – Social innovations for the integrated care of the ageing population in the ADRION regions started on 1 December 2020 and will run until 31 May 2023. The project is co-funded by the Interreg ADRION Programme (European Regional Development Fund – ERDF), with the total amounting to just over 2 million euros. The lead partner of the project is the University of Ljubljana, cooperating with eight partners from seven countries. Within the JSI, we are working with the Computer Systems (E7) and Intelligent Systems (E9) sections.

The aim of the project is to ensure that the ageing population in the ADRION regions is provided with health care. The main purpose of the project is to introduce strategies and action plans to each country (Slovenia, Italy, Croatia, Bosnia and Herzegovina, Greece, Montenegro, and Serbia) and to put them into practice to help the elderly, especially in remote places. In 2022, SI4CARE meetings were held on 23–24 June 2022 in Athens and from 30 November to 1 December 2022 in Sarajevo. The project partners were introduced; wish lists, best practices, pilot activities, the action plan and transnational strategy were reviewed.

We participated in the organization of the Consultation on the Measures to Improve Long-Term Care in Slovenia, which took place on 14 October 2022 at the JSI and online. Several experts from the field of health and social care participated. Potential actions to improve long-term care that we have identified so far in the project as relevant for Slovenia were presented.

WEFE4MED Project

The PRIMA WEFE4MED project – WEFE Nexus for the Mediterranean Community started on 1 October 2022 and will run until 30 September 2026. The project is supported and funded by Horizon 2020 – the European Union's research and innovation programme, with the total amount of just under 2 million euros. The Cyprus Institute is the project's lead partner, cooperating with 10 partners from 8 countries. Within the JSI, we are working with the Computer Systems (E7) and Knowledge Technologies (E8) sections.

The overall objective is to promote the adoption of the Water-Energy-Food-Ecosystems (WEFE) Nexus approach in the Mediterranean through the Nexus Community of Practice to address the climate and environmental challenges of the societies and agro-ecological systems. The community will bring together practitioners, scientists, policy makers, civil society, media, entrepreneurs, innovators and investors. It will gather and share knowledge, build capacity by introducing best practices, science-based policies and innovative solutions inspired by demonstration sites, and demonstrate the benefits of integrated natural-resource management for sustainable and climate-resilient development in the Mediterranean.

ReConSTruCt-EU Project

As one of 11 partners, we applied for the Interreg Central Europe ReConSTruCt-EU project, whose lead partner was Technology Park Ljubljana, a member of the SRIP SC&C. The application contained all the necessary documentation, but the project was ultimately not selected for funding. The work within the project would focus on 3 priority areas: digital modelling, new materials and recycling and reuse.

We will continue to liaise with the JSI Sections with the aim of winning new projects.

INTERNATIONAL PROJECTS

1. PRIMA; WEFE4MED - Towards a Mediterranean WEFE Nexus Community of Practice
   Dr. Nevenka Cukjati
   Prima Foundation
2. Social Innovation for Integrated health CARE of ageing population in ADRION Regions-SI4CARE
   Dr. Nevenka Cukjati
   The Emillia-Romagna Region
3. Support for Strategic Research and Innovation Partnerships (SRIP) in priority areas of

Smart Specialization
Dr. Nevenka Cukjati
Ministry of Economic Development and Technology

R&D GRANTS AND CONTRACTS

1. Support for Strategic Research and Innovation Partnerships (SRIP) and Priority Areas of Smart Specialization (SRIP PMiS)
   Dr. Nevenka Cukjati

STAFF

Technical officer
1. **Dr. Nevenka Cukjati, Head**
Technical and administrative staff
2. Mojca Kristl, B. Sc.
3. Jan Kunc, B. Sc.

CENTER FACTORIES OF THE FUTURE

CFoF

On 1 January 2022, the leadership of CFoF was temporarily assumed by Asst. Prof. Dr. Igor Kovač. The centre was established in early 2017. The main task of the centre is to coordinate and operate the Strategic Development and Innovation Partnership of Factories of the Future (SRIP FoF). In addition, CFoF also encourages cooperation and the creation of research and business synergies between research and industrial partners within Slovenia, in particular integrating the competences and capacities in the field of cutting-edge technologies of the Jožef Stefan Institute and other members of the SRIP, as well as focusing on internationalisation, entrepreneurship and familiarisation with intellectual property in cooperation with the units within the IJS. CFoF contributes to supporting the latest technology partnership and, at the same time, actively participates in the development of R&D policies in the coming years, in collaboration with industry and the state.

Head:
Asst. Prof. Igor Kovač

What does the Factory of the Future Strategic Development Innovation Partnership offer?

The SRIP Factory of the Future (SRIP FoF) strategy is to gather and integrate Slovenian research and innovation knowledge and experience from the industrial and academic spheres and highlight the priority breakthroughs of new products, technologies and services for Factories of the Future. We have established a supportive environment with expert services for industry and research organizations, with an emphasis on developing new cutting-edge technologies that combine and build on the existing Slovenian research and innovation achievements.

The key functions of the strategic long-term interconnectivity are the definition and upgrade of the strategic action plan for Factories of the Future, activities in the scope of the development of joint services, internationalization, developement of human resources and entrepreneurship, representation of joint interests to the state, etc. Part of the services will be done in cooperation with other institutions.

The SRIP FoF **creates and supports** business and research synergies in the area of smart factories for new products, services and technologies, and helps businesses enter the global market by focusing on niche areas. The members of the SRIP FoF come from various companies, associations or institutions from Slovenia. The operation of the SRIP FoF focuses on a greater integration of knowledge and joint presentation of stakeholders in domestic and international markets. The primary goals are to increase the share of high-tech industrial products in exports and increase the added value and productivity of the Slovenian industry.

Key areas of activity

By November 2022, the SRIP ToP organisation scheme included eight domains (vertical value chains – VVC) through which six horizontal networks with key enabling technologies (KET) were interconnected. However, following the focusing exercise, the organisational structure has slightly changed recently (Figure 1).

In a two-dimensional matrix structure where enabling technologies and vertical value chains are intertwined, the IJS manages the following: VVCs – Robotic and laser systems and components, Advanced green technologies, and KETs – Robotics, Photonics, Plasma technologies, Modern production methods for materials and nano and quantum technologies.

By effectively directing R&D and introducing knowledge and technologies that enable the production of better-quality products, reducing energy and raw materials, reducing environmental pollution, improving human involvement, etc., the SRIP FoF also indirectly contributes to accelerating the transition to a low-energy, energy-efficient economy and greenhouse-gas emissions, thus intensively promoting the transition to a low-carbon society

Figure 1: Scheme of SRIP FoF domains

and a green circular economy. The essence of the concept of factories of the future is mainly reflected in a greater potential for the reuse of raw materials, made possible by a more flexible and optimally managed production.

In the field of **internationalization**, we organised a high-profile international event called Innovation Day, in Ljubljana in December 2022, where we presented the content together with EIT Manufacturing. Some members of the SRIP FoF participated in the event, while others were present as attendees. We also participated in the Circular Economy event in Bled in September 2022.
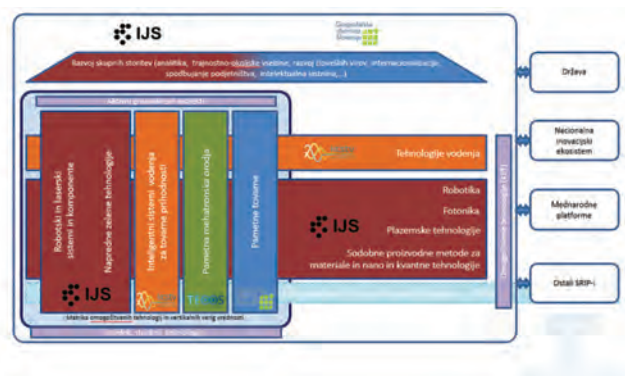
In order to expand and consolidate its activities in the field of innovation at home and abroad, the JSI, as the coordinator of the SRIP FoF, is actively involved in various European initiatives. One of these is the **European Institute of Innovation and Technology (EIT)**, which enables innovators and entrepreneurs to develop solutions for creating growth and jobs.

Thus, the SRIP FoF has been actively involved in the field of manufacturing through the JSI since the beginning of the creation of the **EIT Manufacturing - EITM community** (https://eitmanufacturing.eu/), and in 2021 it became a full core member. To support the implementation of the EITM program at the JSI, the institute incorporated this program into its operations. It sent an informative invitation to all the sections and centres at the JSI in the development phase, to which seven departments responded; in addition to the Centre Factory of the Future, they are all members of the SRIP FoF. In doing so, the rules for joining the EITM were concluded and adopted. Based on this, the JSI as a member and coordinator of the SRIP FoF worked in the EITM innovation ecosystem, participated in the development of key topics of production technologies and processes, participated in the decision-making on global issues, exchanged industry experiences at the European level, defined key requirements and applied to calls for EITM projects. As a core member, the JSI was also able to invite external partners that are not members of the EITM to participate in the projects but, of course, the SRIP FoF members had priority.

In 2022 the following units were involved in the EITM as members of the SRIP FoF:
–   IJS, Department of Automation, Biocybernetics and Robotics (E1),
–   IJS, Department of Systems and Control (E2),
–   IJS, Artificial Intelligence (E3),
–   IJS, Thin Layers and Surfaces (F3),
–   IJS, Surface Technology and Optoelectronics (F4),
–   IJS, Nanostructured Materials (K7),
–   IJS, Advanced Materials Research (K9),
–   IJS, Centre Factories of the Future (CFoF).

We presented our activities to the EITM Advisory Board. The JSI members participated at networking events (EITM MatchMaking Events), short presentations of project ideas (Idea Pitch) and workshops to help prepare project applications. We were also active in the preparation of project applications. During the last EIT call for innovation based projects, the JSI as the lead partner submitted one project. Let us stress that these are projects at a Technology Readiness Level (TRL) of 5 to 6. Therefore, the need for the commercialisation of results and a go-to-market strategy is very clear. In the future, we want to encourage as many partners as possible, other members of the SRIP ToP, to participate in our projects and win as many projects as possible in the field of innovation, business and education, especially in the area of RIS calls.

The year 2022 was marked by **the 3rd phase of the SRIP FoF project**, where we further intensified our activities, but our activities were still marked by the COVID 19 epidemic and related measures, both at home and abroad. In implementing the activities, we followed the action plan for the 3rd phase of the SRIP operation, met with the coordinators of individual vertical value chains and horizontal networks and encouraged them to connect with members in preparing joint projects, and preparing and implementing events of interest to the members, research sector and industry. We continued to cooperate with other SRIPs, key ministries that are important for our work (the ministries responsible for the economy and education) and the Government Office for Development and Cohesion Policy (SVRK). For the Government Office we also prepared, presented and submitted a jointly signed document called PROPOSAL FOR THE IMPLEMENTATION OF MEASURES TO SUPPORT RESEARCH AND DEVELOPMENT IN THE ECONOMY AND AN EFFECTIVE IMPLEMENTATION OF S5, in which the IJS, in cooperation with two SRIPs coordinated by the IJS, played a major role. We established contacts with new teams in the key ministries and actively participated in the discussion and preparation of the operational programs for the next financial period.

In cooperation with SVRK, we made changes to the process of entrepreneurial discovery in certain product and development areas, which will be included in the renewed strategy of smart specialization for the period 2021–2027. We highlighted the importance and inclusion of key enabling technologies, the development and financing of which are crucial for the success of the entire Slovenian smart specialization, as well as for the JSI.

We conducted SRIP FoF presentations at various events and presented the SRIP FoF and our activities at various meetings at home and abroad. We were active in collecting and preparing news for members; our website is constantly updated and has been well visited as it is a hub of news from the field of technology and our activities. Due to social networks, an increasing circle of followers can become acquainted with our activities. We regularly published weekly news that was well read by the recipients.

To encourage companies and organizations to join the SRIP FoF, **we conducted several presentation events** in 2022. Among the most resounding events were the following: Intelligent and Robotic Autonomy in Smart Factories

co-organised with a member of the SRIP FoF, Kolektor, and the Chamber of Commerce and Industry of Slovenia. The event Steps to a Smart Factory was organised in cooperation with Kolektor Sisteh where experts shared their practical experience with the participants. This event proved to be a big success and the interest was so high that we decided to organise a series of events covering various topics in the field of smart factories, which will follow in the next year. In May 2022, we held the Sensor Systems for Flow and Vibration Measurement event. We participated in various training events. We cooperated with the Novo mesto Development Centre in the implementation of the Robotics for Children Course. With the Slovenian Society for Vacuum Technique (DVTS), we ran a course on the basics of vacuum technology.

We maintained the connection we had developed with KOC-FoF in the past, giving our members access to the workshops and conferences organized by KOC-FoF.

In 2022, 11 new members joined the SRIP FoF: Airnamics, d.o.o.; Elvi, d.o.o.; the Association of Chemical Industries of Slovenia at the Chamber of Commerce and Industry of Slovenia; Imas, d.o.o.; Qlector, d.o.o.; Marsi Group, d.o.o.; Renn Solutions, d.o.o.; Sick, d.o.o.; Titus Technologies, d.o.o.; Laboratory for Production and Operations Management of the Faculty of Mechanical Engineering, University of Maribor; Zlatorog oprema, d.o.o.

Throughout the year we actively participated in **the QU4LITY project** in the scope of the H2020 inititaive, which is expected to demonstrate, in a realistic, measurable and replicable way, an open, certifiable, highly standardised, SME-friendly and transformative shared data-driven ZDM (Zero Defects Manufacturing) product and service model for Factory 4.0. In the scope of the project, the SRIP FoF has been working with the JSI Department of Automation, Biocybernetics and Robotics as one of the leading partners in Work Package 8 and collaborating with a consortium of partners to design and implement a virtualized platform, which will consist of a project marketplace where all the ZDM equipment will be listed and marketed, and a digital innovation hub, which will offer innovation management services. The SRIP FoF was involved in the coordination of the virtual platform implementation. The project was completed in Q1 2022.

We joined the Interreg Mediterranean **project Panoramed**, as a co-leader in the field of innovation. We regularly met with the Slovenian representatives of two selected strategic projects in the field of innovation. Project BlueBioMed promotes the transformation of the development and improvement of the sustainable goals in the field of inovation for blue bio-technologies in the Mediterranean. The project focuses on the development of inovation policies in corelation with the transnational governance programmes of the Mediterranean Region. Project B-Blue, however, focuses on connecting communites of the Mediterranean, bringing together the key figures from the blue bio-technologies with the goal of increasing their capacities and coordination as a means of maximising the inovation potential through common transnational initiatives. They are planning to include the organizations from the Southern Mediterranenan as well. Both strategic projects work alongside one another in pursuit of better results. With presentations of the past and participation in the planning of future work, we participated in all project meetings. In cooperation with the leaders of strategic projects in the field of innovation, we prepared follow-up questionnaires, collected data and prepared the first and second follow-up report. We also participated in several international online events in the field of blue biotechnologies, as well as events associated with the organization of strategic projects within the framework of innovations, and presented our work so far at two events. We are also in regular contact with the representative of SVRK, who are engaged in the Panoramed project. The project was successfully completed in April 2022.

At the beginning of 2020, Center FoF launched the project "Digital technologies as an incentive for the transition to a circular economy by small and medium-sized enterprises in the Alps" – **CIRCULAR 4.0**. The project was funded by the Interreg Alpine Space program. The aim of the CIRCULAR 4.0 project was to accelerate the transition of small and medium-sized enterprises from the Alpine Region from a linear to a circular business system through digitalization and Industry 4.0.

As part of the second work package aimed at establishing circularity and digitality assessment tools and a training program for companies and support organizations, Center FoF prepared and tested a training program for intermediary organizations with an active cooperation of two JSI research departments and an external contractor. Project partners and test companies from the whole Alpine Region focused on the development of new and review of the existing tools for assessing the circularity, assessing the degree of digitalization of companies, and collaborating with SRIP FoF members that also tested the applicability of the proposed tools.

The project started in september 2019 and was successfully completed in June 2022. The total value of the project was 2,560,692 euros. Fifteen project partners from five Alpine countries were participating – Austria, Italy, France, Slovenia and Germany: Amt der Salzburger Landesregirung, Associazione Fabbrica Intelligente Lombardia, Austria Wirtschaftsservice Gesellschaft, Auvergne-Rhône-Alpes Enterprises, Bundesministerium fur Digitalisirung und Wirtschaftsstandort, poslovni Zgornja Avstrija, BWCON, Camera di Commercio Industria Artigianato e Agricoltura di Venezia Rovigo, Chambre de Commerce et d'Indsutrie du Var.

In 2021, we were successful with our proposal for a new project within the Horizon Innosup program for small and medium-sized enterprises in **the field of digital data management in enterprises**. The result of the project will be a handbook of tools for managing digital data in enterprises and examples of business practices from three innovation systems. The duration of the project is 13 months. The cooperating partners are HIT – Hub Innovazione Trentino Fondazione, Italy and Haute Ecole Specialisee de Suisse Occidentale / HES-SO-INNOSQUARE Freiburg, Switzerland.

In 2022 we were successful in applying for a new Horizon Europe project. In October 2022, Centre FoF launched **a ZOOOM project – 3Os and IP awareness raising for collaborative ecosystems**. The project aims to raise awareness about the importance of IP creation and management in collaborative innovation ecosystems which rely on three key assets: software, hardware and data. In practice, there is a perceived lack of competence in the companies creating products based on the three O's (open software, open hardware, open data). Companies therefore want to offer their services/products openly, for free, but have difficulties in aligning their business models with the relevant IPR licences. This prevents further development and expansion of innovation potential. The project will develop tools (videos, web platforms, educational models, etc.) for promoting open licensing in industry. These models will include both the legal and business aspects of open licensing.

We are working with prestigious European institutions on this project. Our partners are from Belgium, Finland, Bolgaria, Denmark, Austria, Germany and Italy: Katholieke Universiteit Leuven, Teknologian tutkimuskeskus VTT OY, Fondatsiya LiBRE, EIT Manufacturing South Srl, AALBORG University, Innovations und Technologietransfer Salzburg Gmbh, Free Software Foundation Europe E.V., Hub Innovazione Trentino – Fondazione, Universita degli Studi di Trento.

The aims of the project are to provide business solutions and useful tools for business and, in particular, industry, and make appropriate decisions on which open-licensing strategies best fit certain business models.

INTERNATIONAL PROJECTS

1. H2020 - QU4LITY; Digital Reality in Zero Defect Manufacturing
   Asst. Prof. Igor Kovač
   European Commission
2. H2020 - Go-DIP; Managing Digital Intellectual Property in Manufactoring SMEs Digitalization Processes
   Asst. Prof. Igor Kovač
   European Commission
3. HE - ZOOOM; 3Os and IP Awareness Raising for Collaborative Ecosystems
   Asst. Prof. Igor Kovač
   European Commission
4. EIT M East - JSI; Sponsorship for Operation of the SRIP FoF
   Asst. Prof. Igor Kovač
   Eit Manufacturing East GmbH

R&D GRANTS AND CONTRACTS

1. MED Governance Platform
   Asst. Prof. Igor Kovač
   Government Office for Development and European Cohesion Policy
2. Circular 4.0: Digital technologies as enabler to foster the transition to the circular economy bythe SME in the Alpine Space area
   Asst. Prof. Igor Kovač
   Government Office of the Land of Salzburg
3. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
   Asst. Prof. Igor Kovač
   Ministry of Economic Development and Technology

STAFF

Researcher
1. **Asst. Prof. Igor Kovač**, Head
Technical officers
2. *Živa Antauer, B. Sc., 01.09.22, transferred to Department E8*
3. Petra Hauschild, B. Sc.

4. *Bojana Omersel Weeks, B. Sc., left 16.05.22*
5. Nataša Vertot Rakun, B. Sc.
Technical and administrative staff
6. *Tina Mrak Maržić, B. Sc., left 22.07.22*
7. Nataša Pibernik, B. Sc.