UNIVERSITY OF LATVIA

FOTONIKA-LV

LATVIJAS UNIVERISTĀTES NACIONĀLĀ ZINĀTNES PLATFORMA

The 6th International Biennial Conference

Photonics Sciences and Space Research – RIGA 2025

Riga, 22–23 April 2025

BOOK OF ABSTRACTS

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Photonics Sciences and Space Research – RIGA 2025

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Riga, 22–23 April 2025

organised by
ERA Chair project and NSP FOTONIKA-LV of the University of Latvia

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Preface

The National Science Platform FOTONIKA-LV (NSP FOTONIKA-LV) in quantum sciences, space sciences, and technologies at the University of Latvia emerged as an association, FOTONIKA-LV, of three research institutes (strong in quantum sciences, space sciences, and technologies) at the university, based on an the agreement signed by directors on April 24, 2010. Currently, the research community at NSP FOTONIKA-LV is following the roadmap and working diligently to achieve the status of a National Centre of Excellence for Photonics Sciences and Space Research, with an ERA level capacity and worldwide recognition.

The key priority and urgent obligation of the overall mission of the emerging centre: to serve as a national level incubator exclusively for talents intended for academy and "high-tech" SMEs in photonics sciences, space research and related technologies (in response to the acute lack of young researchers with PhD qualification) making maximum efforts in the reversal of a dangerous tendency in Latvia: the total numbers of PhD graduates decreased from 325 (years 2013/2014) to the level close to 100 (years 2023/2024; data from the Central Statistical Bureau Republic of Latvia).

This is the 6th in a row conference in the history of the emerging centre, and the conference book highlights: the achievements of local research teams, results of research efforts performed jointly with colleagues from the abroad and is an opportunity for our close partners worldwide to speak about their scientific interests, from the level of keynote speeches to poster presentations.

The reader of this conference book will envisage the diversity of scientific results incorporated in the form of short or extended abstracts. A few articles are concise reports on high-level studies, while others present results of pilot research and new visions for future research discussed during the conference.

The conference has been an opportunity for the exchange of knowledge and ideas. The organising team is deeply thankful to all the contributors and is ready to hold the 7th conference on April 22–23, 2027.

On behalf of the organising bodies

Dr. Arnolds Ūbelis

NSP FOTONIKA-LV, University of Latvia, Riga, Latvia
e-mail: Arnolds.Ubelis@lu.lv

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Welcome speech

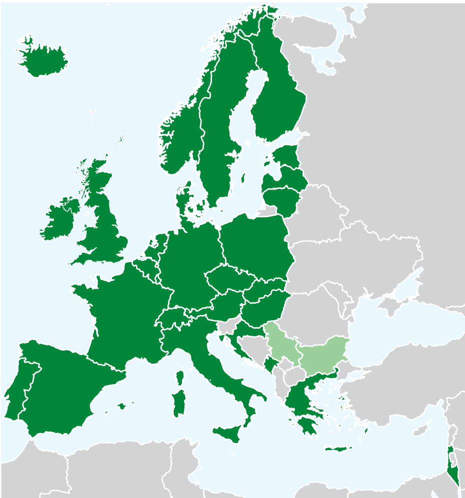
Welcome speech to NSP FOTONIKA-LV 2025 event

Alvis Brāzma

European Bioinformatics Institute, European Molecular Biology Laboratory, Wellcome Genome Campus, Cambridge, UK
and
Biomedical Research and Study Centre, Riga, Latvia
e-mail: brazma@ebi.ac.uk

It was a great honour and pleasure for me to give the welcome words to this important and interesting event – NSP FOTONIKA-LV conference in 2025. I studied at the University of Latvia at the time when Latvia still was on the wrong side of the Iron Curtain (Fig. 1). Although studied applied mathematics and computer science, physics has always been my passion. As an undergraduate, I attended many lectures in physics given by distinguished faculty, Prof. Edvīns Šilters immediately comes to mind. Although geographically we were on the wrong side of the Iron Curtain and were missing out on most opportunities of integrated international science, due to the enthusiasm of the faculty and students, science in Latvia was flourishing. And we had large dreams: to visit and work at the world's most famous science centres and universities, as well as to climb mountains not only in the wonderful Caucasus and Pamirs, but also in the Alps and Himalayas. The Laboratory of Spectroscopy, which sow the seed of photonics in Latvia already during 1980s, was not only a centre of scientific excellence, it became one of the centres of resistance to the Soviet oppression. Only because of these brave people I have been able to spend over half of my scientific career in one of the centres of international scientific excellence and to work the way I was dreaming about as a young student. I am enormously proud to give the opening speech in a conference held in such a historic building.

Figure 1. *The world in which we grow up on the wrong side of the Iron Curtain*



Member states [29]

Austria 1974
Denmark 1974
France 1974
Germany 1974
Israel 1974
Italy 1974
Netherlands 1974
Sweden 1974
Switzerland 1974
United Kingdom 1974
Finland 1984
Greece 1984
Norway 1985
Spain 1986
Belgium 1990
Portugal 1998
Ireland 2003
Iceland 2005
Croatia 2006
Luxembourg 2007
Czech Republic 2014
Malta 2016
Hungary 2017
Slovakia 2018
Montenegro 2018
Lithuania 2019
Poland 2019
Estonia 2023
Latvia 2023

Prospect member state
Bulgaria Serbia

Associate member state
Australia 2008

Figure 2. *EMBL Member States. Latvia joined EMBL in 2023*

In 1997, I was very lucky to join the European Bioinformatics Institute (EBI) of the European Molecular Biology Laboratory (EMBL). EMBL is an international intergovernmental organisation, a centre of excellence in molecular biology research and service provider to scientists around the world. I am immensely grateful to the Latvian scientists with whom we jointly argued for Latvia to join this organisation, which finally happened in 2023 (Fig. 2).

During these almost 30 years at EMBL, I have been gradually transitioning from a mathematician into a biologist, though I have never competed this transition. I have now partially returned to Latvia in a capacity of ERA Chair at the Biomedical Research and Study Centre in Riga, to give my and at establishing the One-health Centre in Latvia and developing of bioinformatics for the Latvian Genome Project.

When Dr. Arnolds Ūbelis invited me to give this opening address, I was very humbled and also a little bit lost, as my work has never been much to do with photonics. But then I realised that this was not entirely true. Not only I have been following the developments in photonics in the literature as an amateur, not long ago I had a brilliant PhD student Maria Theiss (now a postdoc at Harvard), which we supervised jointly with Dr. Virginie Uhlmann at EMBL-EBI (now the Director of BioVisionCenter at the University of Zurich). Maria worked on simulating data from Single-molecule localisation microscopy (SMLM) images of nuclear poor complex (NPC), with the goal to generate synthetic ground truth data to test the limits of SMLM in biology. NPC is one of the most important and one of the larges molecular complexes in a Eukaryotic cell (Fig. 3).

SMLM is a powerful imaging technique, where individual fluorescent molecules are computationally localised from diffraction-limited image sequences, and the localisations are used to generate a super-resolution image. By trading time-resolution for space-resolution, the Abbe diffraction limit is "beaten". To me, as an amateur physicist, this is fascinating. And I think most of you will agree that this is something to do with photonics.

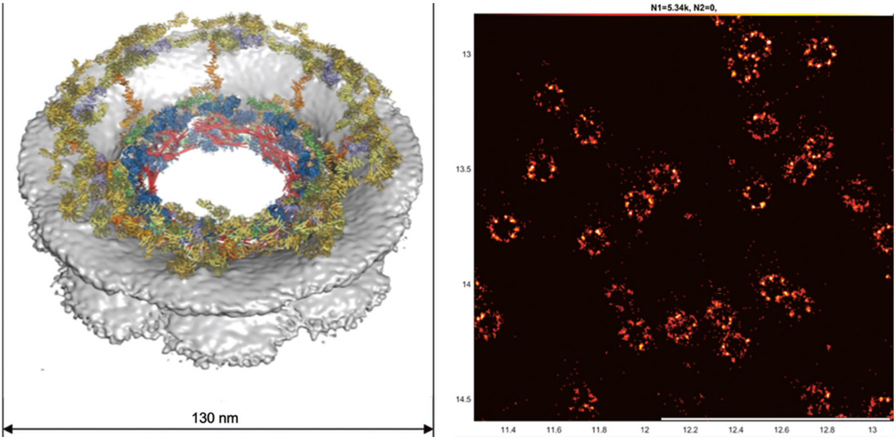


Figure 3. *Left panel, nuclear poor complex (NPC). Composite structure of the symmetric core of the nuclear pore complex, shown in a cartoon representation. The composite structure was generated by sequential unbiased searches for each protein subunit. Distinct subunits are distinguished by different colours. The nuclear envelope is shown as a grey surface. Figure from Hoelz Laboratory/Caltech and Science/AAAS. Right panel, SMLM images of NPC, courtesy of Ellenberg and Ries' lab (EMBL)*

I cannot conclude this address without mentioning my enormous admiration not only for the advances of photonics in Latvia, but also for the tireless drive of Dr. Arnolds Ūbelis to maintain the high level of science in Latva during these difficult times.

Acknowledgments. My work for the last 28 years has mostly been funded by the EMBL Member States, to which I am tremendously grateful.

References

[1] Maria Theiss, Jean-Karim Hériché, Craig Russell, David Helekal, Alisdair Soppitt, Jonas Ries, Jan Ellenberg, Alvis Brazma, Virginie Uhlmann, Simulating structurally variable nuclear pore complexes for microscopy, *Bioinformatics*, Volume 39, Issue 10, October 2023, btad587, https://doi.org/10.1093/bioinformatics/btad587

Profiles of Welcome speakers

Dr. Alvis Brāzma

EMBL's (European Bioinformatics Institute) EMBL Scientist Emeritus
ERA Chair at Latvian Biomedical Research and Study Centre, Riga. Latvia
e-mail: brazma@ebi.ac.uk

Obtained PhD in Computer Science, Moscow State University, 1987. Postdoctoral research at New Mexico State University, USA. At EMBL-EBI since 1997.

Dr. Brazma studied mathematics at the University of Latvia, Riga, before obtaining his PhD in computer science from the Moscow State University. He was a lecturer at the University of Latvia and a visiting Researcher at Helsinki University before joining EMBL-EBI in 1997.

Dr. Brazma was among the first scientists to use microarray data to study gene regulation. In 1999 he founded (together with Alan Robinson) the Microarray Gene Expression Data (MGED) Society (renamed to Functional GEnomics Data (FGED) Society in 2010) which was instrumental in starting ArrayExpress, one of the major international repositories for functional genomics data.

His main research interests concern integrative data analysis to reveal patterns of gene and protein expression in normal and diseased states. He has over 300 scientific publications and served as a Principal Investigator on several large collaborative genomics and biomedical projects, including the kidney cancer project of the International Cancer Genome Consortium.

Since 2025 Dr. Alvis Brazma is an ERA Chair at Latvian Biomedical Research and Study Centre, Riga. Latvia.

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Alvis Brazma – Google Scholar (85 h-index, 75 935 Citations, 185 i10-index)
ResearchGate: Alvis Brazma (86 h-index, 63 527 Citations)

Prof. Andris Vaivads

Rector of Ventspils University of Applied Sciences, Latvia
Professor at Royal Institute of Technology, Sweden
e-mail: andris.vaivads@venta.lv

After graduating from the University of Latvia (1992), Andris Vaivads obtained a doctorate in space physics in Sweden in the Swedish Space Physics Institute in Uppsala, hold a post-doc position at Max Planck Institute for Extraterrestrial Physics in Germany. He worked for the Royal Institute of Technology (KTH) for 20 years, reached worldwide recognition, and outstanding record of scientific publications in the space sciences.

The physics of the cosmic plasma, which leads to the heating of the plasma and the acceleration of charged particles, is a fundamental theme in all future scientific work. Particular scientific interest is magnetic reconnection, shock wave and turbulence processes in the kinematic regime, as well as aurora cosmic source processes.

He is a co-author of the article cited already more than 840 times: S. D. Bale, K. Goetz, P. R. Harvey, *et al*, (2016): The FIELDS Instrument Suite for Solar Probe Plus: Measuring the Coronal Plasma and Magnetic Field, Plasma Waves and Turbulence, and Radio Signatures of Solar Transients. Space Science Reviews V 204, pp. 49–82.

Andris Vaivads has extensive experience in scientific and pedagogical activities, achievements in project development and implementation, international experience, as well as leadership skills. He has headed the Space and Plasma Division at the KTH Royal Institute of Technology in Stockholm and has been a researcher and contributor to various projects internationally.

The repatriation of Prof. Andris Vaivads will result in a substantial boost of the space science domain and relevant technologies nationally across Latvia. The space research community in Latvia will strongly benefit from expected partnership and collaboration of Prof. Andris Vaivads with another outstanding and worldwide visible space scientist, Prof. Bernard Foing (h index 56), starting to act as an ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies, and Space Photonics at the NSP FOTONIKA-V of the University of Latvia.

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Scopus Author ID: 8416866100 (59 h-index, 252 Documents, 11 768 Citations by 5 160 documents)
Web of Science ResearcherID: H-8169-2013 (57 h-Index, 242 Publications, 11 662 Citations by 5 100 articles, 10 646 Citations without self-citations by 4 899 articles)
Andris Vaivads – Google Scholar (64 h-index, 14 128 Citations, 206 i10-index)
ResearchGate: Andris Vaivads (64 h-index, 13 770 Citations)

Keynote speakers

Generation of XUV vector/vortex beams in laser induced plasmas

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Abstract

Experimental generation of vector/vortex high-order harmonic beams is reported. The two-colour-pump is combined with the polarisation-structured vector or vortex beams. In the experiment femtosecond laser pulses propagated through the phase-modifying optical elements (S-waveplate). The propagation of a radially polarised vector beam in the orthogonal polarisation two-colour pump scheme results in the generation of spatially structured odd- and even-order harmonics with variably polarised components. The intermediate states between radial and azimuthally polarised vector beams produce the harmonics with twisted wavefronts.

Keywords: high-order harmonics generation, vector beams, two-color pump, S-waveplate.

The vector beams are characterised by a spatially inhomogeneous distribution of polarisation. The interest in specific spatial polarisation structures is related to influence on the spatio-temporal interaction between matter and laser radiation [1]. The peculiarities of such interaction proposes the prospects in nonlinear optics [2], which extends controlling various processes [3]. The application of vortex wave mixing to a tabletop high-harmonic source and the control of the topological charge of XUV beams was demonstrated in [4] where a technique to produce the first-order orbital angular momentum (OAM) harmonic beams with the smallest intensity along the optical axis. The generation of vector-vortex HHG beams in the XUV was recently demonstrated in [5].

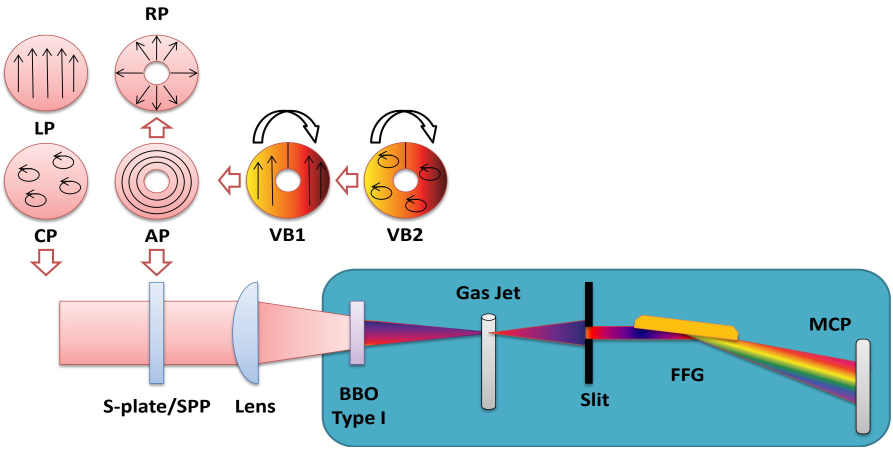

Figure 1. *Schematic of the two-color pumped HHG using vector beams. S-plate/SPP: S-waveplate or spiral phase plate installed in front of the focusing lens (Lens, f = 500 mm); BBO: barium borate crystal; LP: linearly polarised beam; CP: circularly polarised beam; RP: radially polarised vector beam; AP: azimuthally polarised vector beam; VB1: vortex beam produced by SPP; VB2: vortex beam produced in combination of circularly polarised beam and S-waveplate; FFG: flat-field grating; MCP: microchannel plate*

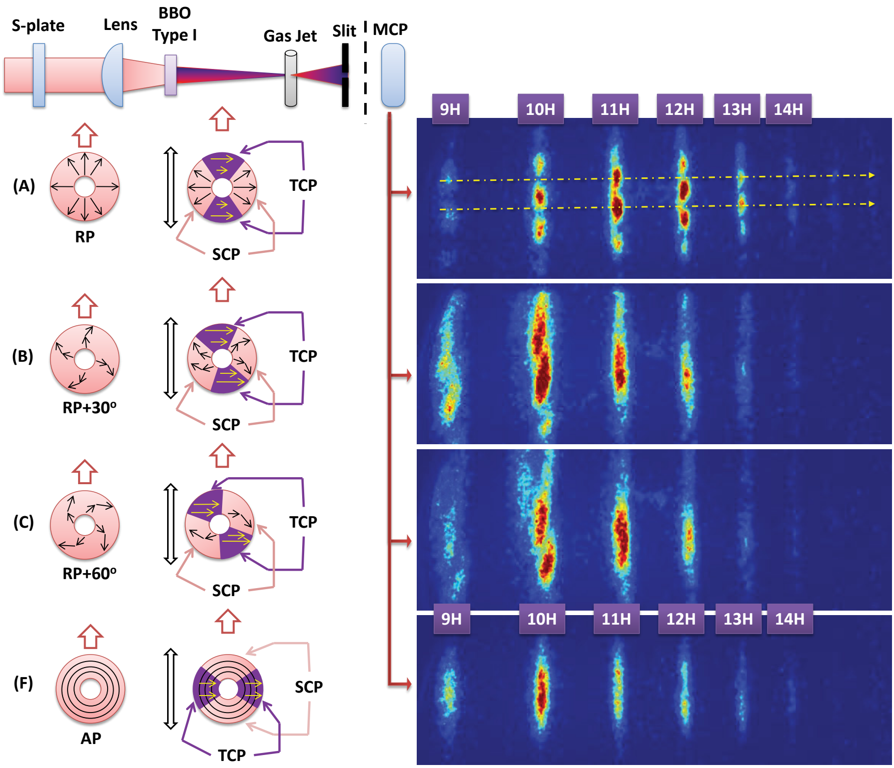

Figure 2. *HHG in argon gas using the SCP and TCP configurations with vector beams produced by the S-waveplate. (A) HHG using SCP; (B) HHG using TCP; (C) HHG using TCP with S-waveplate producing the radial polarisation (RP); (D) HHG using TCP with S-waveplate rotated by 30° with regard to the RP orientation; (E) HHG using TCP with S-waveplate rotated by 60° with regard to the RP orientation; (F) HHG using TCP with S-waveplate rotated by 90° with regard to the RP orientation, which results in the formation of the azimuthal polarisation (AP) of the beam*

Thus, applying driving pulses with spatially variable polarisation and phase (i.e. vector and vortex beams) is useful to generate and control the harmonics of varying spatio-temporal characteristics for various applications. The experimental arrangement is presented in Fig. 1. The pumping pulses at 800 nm wavelength, pulse duration of 60 fs, and energy of 400 µJ were focused by a 500 mm plano-convex lens. Vector beams with radial and azimuthal polarisations were generated with the S-waveplate (RPC-0515-10, Altechna).

The raw images of HHG spectra using the vector beams are summarised in Fig. 2. The vertical contoured bidirectional black arrows (Fig. 2, A–F panels) show the optimal direction of polarisation for the second harmonic (SH) generation. The orientation of the BBO crystal was fixed during the experiment. Below, we address the spatial modulation of the harmonics along the axis of divergence (i.e. vertical axis) shown in Fig. 2 (A–F). Inserting the S-waveplate into the path of the linearly polarised radiation transforms the Gaussian distribution to the vector beam with radial polarisation and doughnut-like spatial distribution. The generation of SH in BBO crystal using radially polarised (RP) beam leads to the formation of the complex ω + 2ω vector beam. The distribution of SH and fundamental beams with polarisation directions is schematically depicted with violet and pink colours, respectively. The areas of the two-colour pump field are identified by the abbreviation TCP. The part of the wavefront with a single-color pump attributed to the non-optimal polarisation direction for SH conversion is designated as SCP (single colour pump) in Fig. 2. The TCP areas are symmetrically distributed in the vertical direction, while SCP is located in the horizontal direction.

As a result of the complex distribution of SCP and TCP areas, the application of the RP vector beam leads to a modulation of odd and even harmonic wavefronts, leading to the appearance of the bright and dark areas changing one after another. The use of the S-waveplate on the path of the linearly polarised laser radiation in the OTC scheme transformed the Gaussian distribution of the pumping radiation to the vector beam with radial polarisation, while the generation of SH in BBO crystal led to the formation of the complex ω + 2ω vector beam. As a result of the complex distribution of polarisation in ω + 2ω areas, the application of the two-colour vector beam led to the different modulations of the odd and even harmonic wavefronts.

References

[1] Wang W.-Y.; Cheng, T.-Y., Bai Z.-X., Liu S.; Lu J.-Q. (2021) Vector optical beam with controllable variation of polarization during propagation in free space: a review. *Appl. Sci.*, **11**, 10664.

[2] Bouhelier A., Beversluis M., Hartschuh A., Novotny L. (2003) Near-field second-harmonic generation induced by local field enhancement. *Phys. Rev. Lett.*, **90**, 013903.

[3] Bouchard F., Larocque H., Yao A. M., Travis C., De Leon I., Rubano A., Karimi E., Oppo G.-L., Boyd R. W. (2016) Polarization shaping for control of nonlinear propagation. *Phys. Rev. Lett.*, **117**, 233903.

[4] Kong F., Zhang C., Bouchard F., Li Z., Brown G. G., Ko D. H., Hammond T. J., Arissian L., Boyd R W., Karimi E., Corkum P. B. (2017) Controlling the orbital angular momentum of high harmonic vortices. *Nature Commun*., **8**, 14970.

[5] Heras A., Pandey A. K., Román J. S., Serrano J., Baynard E., Dovillaire G., Pittman M., Durfee C. G., Plaja L., Kazamias S., Guilbaud O., Hernández-García C. (2022) Extreme-ultraviolet vector-vortex beams from high harmonic generation. *Optica*, **9**, 71–79.

Interdisciplinary Laser Spectroscopy – The interplay between basic and applied sciences and resulting industrial impact

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Laser spectroscopy, enabled by continuing strong advances in quantum electronics and the development of new spectroscopic concepts, is having a profound impact on wide sectors. These include fundamental sciences, applied research and industrial spin-off (see, e.g., [1], Chapters 8–10). Sometimes, and in particular historically, these different aspects have been considered contradictory, but a unified view, that there is a continuous and healthy transition between these different aspects is emerging. Frequently, there appear very important and totally unexpected applications of seemingly exotic basic research [2]. The speaker will illustrate the interplay between basic, applied, and resulting industrial activities based on own experience [3], mostly from the platform of the Lund Laser Centre.

References

[1] Svanberg S., Atomic and Molecular Spectroscopy – Basic Aspects and Practical Applications, 5th edition, *Springer-Nature* (2022), https://link.springer.com/book/10.1007/978-3-031-04776-3

[2] Bergström J., Holm G., Håstad J., Ingelman G., Lindahl U., Norin T. The Unexpected Usefulness, Royal Swedish Academy of Sciences (2012) (*Den Oväntade Nyttan*, in Swedish), https://www.kva.se/app/uploads/2022/06/ovantadenyttan170831.pdf

[3] Svanberg S. Physics – Curiosity and Usefulness, in the Swedish Physical Society Yearbook KOSMOS 2024 (*Fysiken – Nyttan och Nyfikenheten*, in Swedish), https://www.fysikersamfundet.se/wp-content/uploads/Kosmos-sartryck-2024-1-Svanberg72.pdf

Plenary Sessions

Development of NSP FOTONIKA-LV boosted by two ERA Chair projects

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The Association FOTONIKA-LV, comprising the Institute of Atomic Physics and Spectroscopy, the Institute of Astronomy, and the Institute of Geodesy and Geoinformatics at the University of Latvia, was founded in 2010 with a vision to enhance photonics performance at the University of Latvia and to prepare joint EU project proposals. The first large project won by the Association was the FP7 REGPOT project No. 285912 'Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area' (2012–2015, 3.8 million EUR, coordinator: A. Ubelis) [1]. It allowed the recruitment and repatriation of researchers, the upgrade of research infrastructure, active international collaboration and the preparation of new project proposals. In 2018, a National Science Platform FOTONIKA-LV at the University of Latvia was formed, as a successor of the Association FOTONIKA-LV. International Advisory Board, led by internationally visible research leaders Dr. Sune Svanberg (Lund University, Sweden) and Dr. Bernard Foing (Leiden University, Netherlands), monitors the performance and supports the progress of the NSP FOTONIKA-LV.

The 2nd large project of FOTONIKA-LV was the Horizon 2020 ERA Chairs project which was re-funded by the European Regional Development Fund – No. 1.1.1.5/19/A/003 'Development of Quantum Optics and Photonics at the University of Latvia' (Acronym: QUANTUM-LV, 2019–2023, 2.5 million EUR, coordinator: A. Atvars) [2]. The selected ERA Chair was Dr. Rashid Ganeev, who developed the field of nonlinear optics at the University of Latvia. Within the project, several visiting researchers were recruited, including MSc. Vyacheslav Kim (Uzbekistan), Dr. Naresh Kumar Reddy Andra (India), and Dr. Javed Iqbal (Pakistan). The outcomes of the project were outstanding – 69 SCOPUS-indexed publications, 20 pan-European and 28 local project proposals (6 funded, 1 Seal of Excellence received, 2 could be refunded by ERDF), 3 Latvian Patents and 2 international conferences organised.

In January 2025, the 3rd large project of FOTONIKA-LV started, which is Horizon Europe project, re-funded by the European Regional Development Fund – No. 1.1.1.5/2/24/A/004 'ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia' (Acronym: SPACE-LV, 2025–2029, 2.5 million EUR, coordinator: A. Ubelis) [3]. The project's objective is to develop the fields of astrophysics, instrument design, Earth technology, and space photonics at the University of Latvia (LU) under the leadership of the high-level ERA scientist (ERA Chair) Dr. Bernard Foing. Fundamental and applied research will be conducted, scientific articles published, new project proposals submitted, and the results disseminated. The research team will demonstrate excellent scientific performance, establish international collaboration, and enhance LU's global recognition. The project will promote structural changes at LU, ensuring research excellence and student engagement in scientific activities. The main planned results of the project include 21 articles (indexed in SCOPUS or Web of Science), 10 submitted project proposals (Horizon Europe, European Space Agency, and others), 21 seminars/public events, and 83 documents (reports, presentations).

The SPACE-LV project develops three main research directions:

1) Space Photonics Laboratory (led by Dr. B. Foing) – focusing on optical technologies for space missions
2) Baldone Astrophysical Observatory (led by Dr. I. Eglitis) – modernisation and strengthening of astronomical observation capabilities
3) Riga Satellite Laser Ranging Station (led by PhD candidate K. Salmins) – development of advanced satellite laser ranging for space geodesy.

The Project includes the following work packages:

- d1. Recruitment of the ERA Chair group, establishment of the Space Photonics Laboratory (SPL), and ERA Chair missions
- d2. Operations of the Space Photonics Laboratory
- d3. Development of astrophysics observatory instruments and research in astrophysics and planetary science
- d4. Development of a fundamental geodynamic observatory
- d5. Strengthening human resources, career support, and fundraising
- d6. “Laboratory” for Horizon Europe, ESA, and industry projects
- d7. Project management, documentation, and science communication activities.

The SPACE-LV project is currently the main project for NSP FOTONIKA-LV to fund international collaboration, including travel visits, and the organisation of conferences.

FOTONIKA-LV has also submitted a Horizon Europe ERA Chairs project proposal ‘Excellence Group in Advanced Nonlinear Optical Studies’ and achieved a score above the threshold, which could allow the project to be re-funded by the European Regional Development Fund. For this project, the selected ERA Chair was Dr. Rashid Ganeev. The expected results of the project were – 40 articles (indexed in SCOPUS or Web of Science), 10 submitted project proposals (Horizon Europe, European Space Agency, and others), 2 patent applications, and 14 seminars/public events. The ERDF funding for the project was declined due to political reasons. But still, the research direction of nonlinear optics is continued at the University of Latvia in collaboration with R. Ganeev and V. Kim.

For further development of NSP FOTONIKA-LV, a preparation of Horizon Europe Teaming for Excellence Project is of high priority. This project foresees the development of the Centre of Excellence in Photonics FOTONIKA-LV in collaboration with outstanding external partner institutions Lund University (Sweden) and Münster University (Germany). The project foresees the increase of human capital and the update of the research infrastructure by employing a total of 30 million EUR provided by the European Commission and National Funding. Already in 2022, the Teaming Stage 2 project of FOTONIKA-LV was included in the reserve list and was awarded with the ‘Seal of Excellence’. In April 2025, an updated Teaming Stage 1 project proposal was submitted to the Horizon Europe programme, and the results are pending.

Acknowledgments. This report was supported by ERDF project No. 1.1.1.5/2/24/A/004 ‘ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia’.

References

[1] FP7 REGPOT project No. 285912 “Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area” (Acronym: FOTONIKA-LV, 2012–2015, 3.8 million EUR), https://cordis.europa.eu/project/id/285912

[2] Horizon 2020 ERA Chairs project re-funded by ERDF as Project No. 1.1.1.5/19/A/003 ‘Development of Quantum Optics and Photonics at the University of Latvia’ (Acronym: QUANTUM-LV, 2019–2023, 2.5 million EUR), https://www.erachair.lu.lv/

[3] Horizon Europe ERA Chairs project re-funded by ERDF as Project No. 1.1.1.5/2/24/A/004 ‘ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia’ (Acronym: SPACE-LV, 2025–2029, 2.5 million EUR), https://www.erachair.lu.lv/.

The perspectives of research on small bodies of the solar system in Baldone Observatory

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Observations

At the Baldone Astrophysical Observatory, astronomers operate with a Schmidt-type 1.2-meter telescope installed with two similar STX-16803 and Aluma AC4040 cameras in its focal plane. The brightness limit in the visual range of the telescope without a filter is 22 magnitudes at night with good transparency and calm images. CCD parameters: quantum effectivity 80%; the size of one pixel is 9 × 9 microns; and linear size 4096 × 4096 pixels, which corresponds to 53 × 53 arcmin of the field of view.

Achievement

The results from the monitoring of asteroids during 2008–2023 produced 149 new discoveries (Table 1). The most important discoveries were Apollo-type N428694 = Saule (0.058 AU) and Centaur-type N330836 = Orius (12.44 AU).

Asteroid No 635478 has been named "Fotonikalv" in recognition of the achievements of National Science Platform FOTONIKA-LV at the University of Latvia (founded in 2010) towards the consolidation of human capital in quantum sciences, space sciences, and technologies, to boost national progress and to be a strong partner in international consortiums contributing to the implementation of EU space strategy – name awarded in 2024.

Table 1. *The asteroids discovered and named asteroids st the Baldone Observatory*

Asteroid Nr	Name	Year of award the name
274084	Baldone	2011
284984	Ikaunieks	2012
330836	Orius	2013
332530	Canders	2015
352646	Blumbahs	2015
428694	Saule	2016
457743	Balklavs	2017
545619	Lapuska	2021
604750	Marisabele	2022
567580	Latuni	2022
598895	Artjuhs	2023
658787	Alksnis	2024

Asteroid monitoring future prospects

Problem: Observing Near-Earth Objects (NEOs) holds significant importance for planetary defence, solar system formation studies, and resource mining applications. While meter-size or smaller NEOs harmlessly disintegrate in the Earth's atmosphere, larger ones can cause devastating damage. NEOs smaller than 140 m constitute a much larger population, and their smaller sizes require closer proximity to Earth to be sufficiently bright for observations. The associated trailing loss from the faster motion rate becomes a substantial hurdle for surveying small hazardous NEOs.

Solution:

- synthetic tracking method can be implemented by stacking images with an exposure time short enough to prevent significant asteroid, especially NEO, motion relative to the size of the CCD pixels,
- need to determine the ideal exposure time for the number of frames,
- influenced by the system's hardware configuration,
- influenced by the sky background level,
- improve the operational strategies by the different quality of transparency and turbulence of the atmosphere.

Present study of asteroid characteristics

Starting point for research of characteristics of asteroids, especially with small Earth MOID distances:

1. Baldone Observatory observations of selected asteroids in series compounded more than a hundred 180 or 240 second expositions, to achieve a signal-to-noise ratio greater than 20. Baldone observations are consecutively long time (2–4 h), consisting of two-to-four-night series with an accuracy of 0.05 m.
2. Minor Planet Center position/magnitude archive data collected billions of observations from 1934 in different observatories, in different passbands. Collected observations have short brightness measurement series unevenly scattered over a long-time interval with smaller accuracy (often 0.1 mag) but with good statistics (from 1000 to 3000 observations from different observatories per asteroid).
3. The list of observable asteroids has been compiled using the links of the Minor Planet Center MPC checker and MPC light curve database. The list included those NEO and main belt asteroids with Earth MOID distance less than 1.3 and brightness greater than 18 magnitudes without the rotational period data. Observations of selected asteroids are usually made on three to five following nights. Three to five hours long series of observations were made for each asteroid. On average, it takes about more than a hundred observations for each object. Observations were made in the period 2020–2025 mainly with exposures of 180 or 240 sec, to achieve a signal-to-noise ratio greater than 20.
4. A methodology has been developed for determining the rotation period using the short brightness measurement series unevenly scattered over a long-time interval with low accuracy using a statistically large sample of brightness measurements [1]. The main methodological requirements for the data are that the number of observations in the series must be greater than 70, the total observation sample for the asteroid under study must be greater than 1000, the light curve obtained by the Lomb-Scargle (L_S) method must give two maxima and minima in one rotation cycle, and the ratio between the peak and background noise of the power spectra must be larger than three. The rotation periods for 30 main-belt asteroids, mostly with Earth-MOID distances less than 1.1 AU, have been determined using the developed methodology and published brightness data from 19 different observatories.

Obtaining a common phase diagram

Data merging problem:

- brightness from different instruments (observatories),
- magnitudes in different passbands,
- measurements in different sky conditions,
- magnitudes processed using different catalogues,
- brightness bias is obtained using reference stars including those bluer than the Sun.

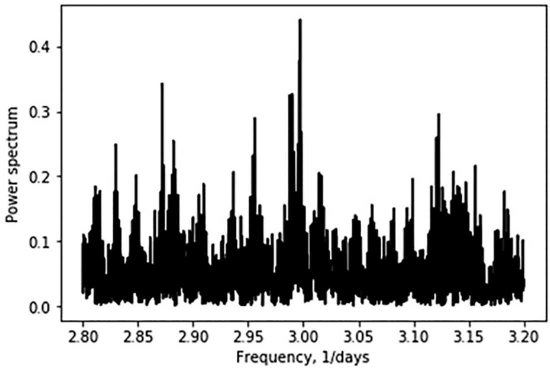

Figure 1. *L_S power spectrum of asteroid N3081 from Mauna Loa Observatory data*

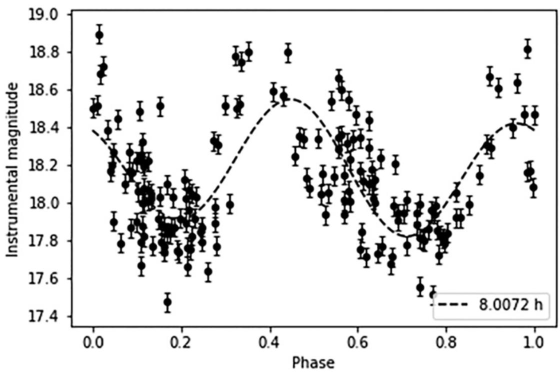

Figure 2. *Light curve for asteroid N3081 from Mauna Loa Observatory data*

To obtain a common phase diagram, the following steps are taken shown in Figure 3:

- all brightness data are reduced to 1 AU, and time delay corrections applied,
- filter bias correction applied with the Hoffman et al.,2025 [3] reported values,
- reference observatory chosen (usually T08o, as it has most data with highest accuracy). Model the phase curve with HG1G2 method, if possible. If not, HG method applied,
- all the other observatory phase curves are matched with the reference observatory one, by shifting them with the corresponding difference.

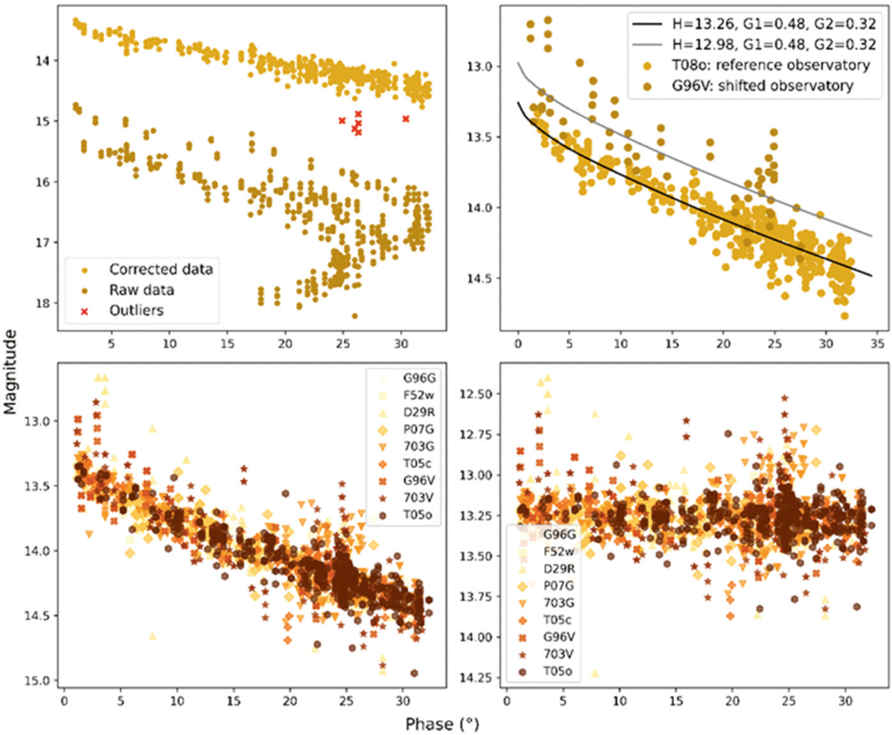

Figure 3. *Methodology for obtaining the common phase diagram from multiple observatory data*

Period calculations from common phase diagrams

Results from Lomb-Scargle analysis of common phase diagram for asteroids with small dispersion (R2 > 0.7) and with average dispersion around phase function (0.4 < R2 < 0.6) can be seen in Table 2.

Table 2. *Comparing rotation periods from previous methodology and common phase curve analysis*

Asteroid	Pcommon, h	Paverage, h	Error, %
3173	45.982	46.008	0.26
3473	9.074	9.074	0.15
3716	10.474	10.456	0.13
2607	2.936	3.015	1.03
2968	4.56	4.585	0.26
2971	4.491	4.495	0.35
3081	8.007	8.007	0

Future perspectives to analyse common phase and light curves:

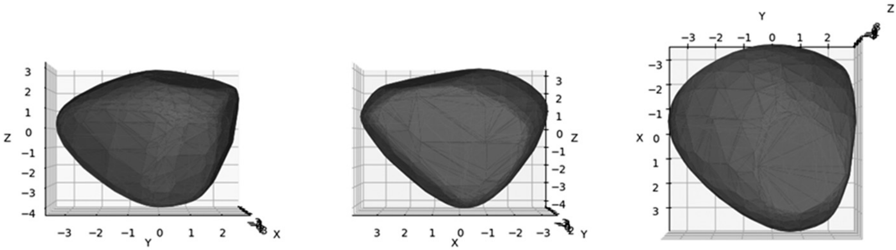

Figure 4. *Illustration of the shape model for asteroid 3081, using Light curve inversion method [4]. The data is combination of many survey observations, applying the previously discussed common phase diagram method*

Light curve inversion enables to obtain the full shape of an asteroid. On top of that, this method outputs the spin state by fitting a parametrised convex polyhedral model to disk-integrated photometry. The surface is described by a convex mesh (facet areas as free parameters) and the rotation by pole orientation and sidereal period. Model parameters are adjusted via a Levenberg–Marquardt minimisation of a χ^2 misfit between observed and synthetic light curves, with an added smoothness regularisation term to enforce convexity and suppress spurious small-scale features. By embedding a coarse grid search in period and pole within the optimisation loop, the global best-fit solution – yielding a unique convex shape and spin vector even from sparse data – is robustly identified.

Acknowledgments. This research was supported by ERDF project Nr. 1.1.1.5/2/24/A/004.

References

[4] Eglitis I., Svincicka D. (2025) Rotation period estimates for 14 asteroids with the Earth MOID less than 1.1 AU. *Icarus* 7, 779

[5] [VanderPlas J. T. (2018) Understanding the Lomb-Scargle Periodogram. *The Astrophysical Journal Supplement* 236, 1

[6] Hoffman T., et al. (2025) Debiasing astro-photometric observations with corrections using statistics (DePhOCUS). *Icarus* 426 116366

[7] Kaasalainen M., Torppa J. and Muinonen K. (2001) Optimization methods for asteroid lightcurve inversion: II. The complete inverse problem. *Icarus*, 153(1), pp. 37–51.

Prospects and Problems of Microwave Observations of the Sun with RT-32 Radio Telescope

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Microwave observations of the Sun and studies of solar microwave polarised emission is still a significant issue of the solar physics and one of scientific activities of Ventspils International Radio Astronomy Centre (VIRAC). The microwave polarised emission (1–10 cm) of the Sun is created in the upper chromosphere and the lover corona depending on frequencies. Studies of its spatial and spectral distribution provides the opportunity of direct localisation emission's sources above the photosphere and direct measurements of plasma parameters and coronal magnetic field inductions in active regions [1].

Nowadays VIRAC implements routine microwave spectral polarimetric observations of the Sun with RT-32 radio telescope equipped by the new multichannel low noise spectral polarimeter LNSP4 [3, 7] (Fig. 1). The spectral polarimeter covers the frequency range 4.1–14.1 GHz (2.1–7.3 cm) divided to 12 frequency channels for right and left circular polarisations. The LNSP4 is integrated into the antenna drive control system and the data acquisition pipeline to provide automatic observations of the Sun, a storage of data into the multilevel archive and some primary processing of data.

The routine observational session of the Sun includes a spiral scanning over the whole solar disk, relative and absolute calibrations of the microwave emission for right and left circular polarisations and a conversion of the time-antenna position domain to heliographic one. The result of the routine observational session is a set simultaneous 2D maps of Stokes I and V distribution over the disk of the Sun for a number of frequency bands with a limited spatial resolution (Fig. 2).

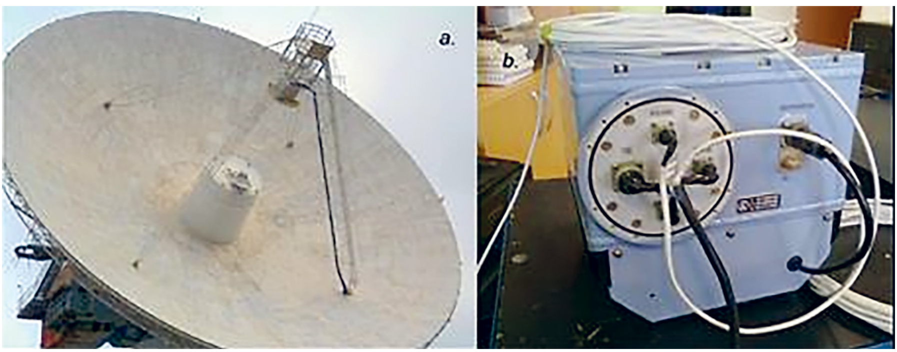

Figure 1. *a) The antenna of VIRAC RT-32 radio telescope after reconstructions of the central cabin and the secondary mirror (2024, February)*
b) the multichannel low noise spectral polarimeter LNSP4

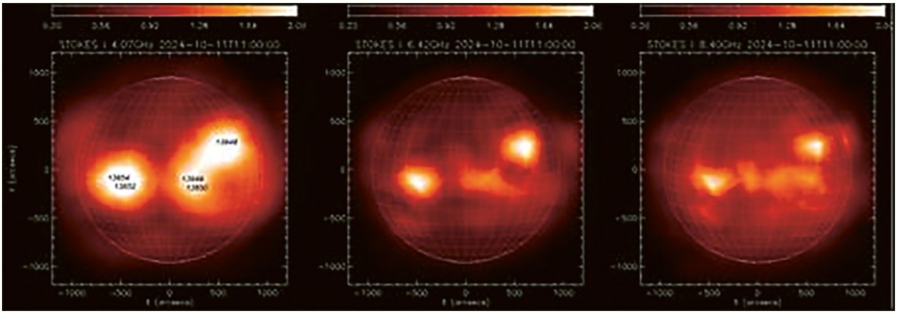

Figure 2. *The simultaneous 2D maps of Stokes I (the spatial distribution of actual brightness temperatures related to brightness one of the quiet Sun) at frequencies 4.07, 6.42, 8.40 GHz observed with RT-32+LNSP4 on 2024, October 11*

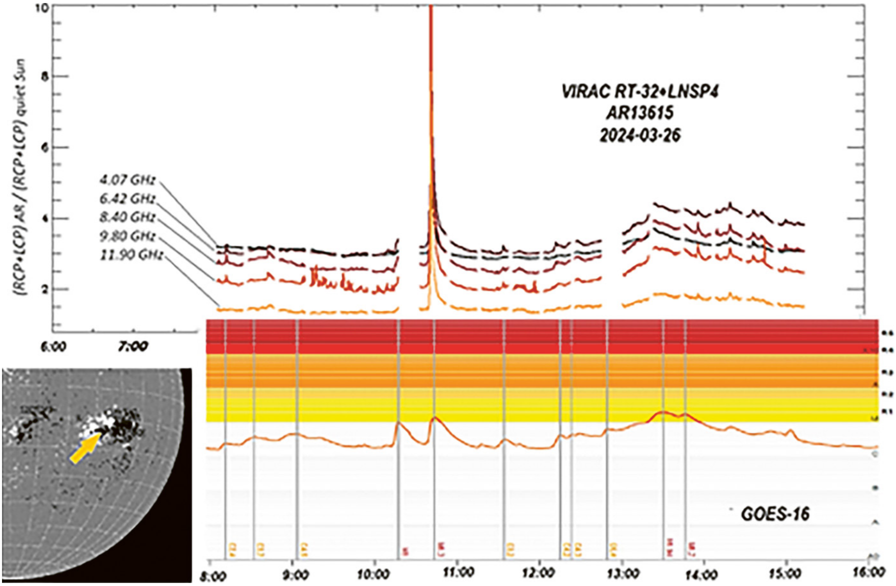

Figure 3. *The long-term monitoring of the microwave flux of AR13615 (flux per RT-32 antenna beam related to quiet Sun) observed in five frequency channels simultaneously (top panel) and the X-ray emission of the whole Sun by GOES-16 (bottom panel). The position of AR13615 and its magnetogram by SDO is shown in bottom left panel. The correlation of microwave bursts with solar flares observed in X-rays clearly visible*

A number of successful test observations for full per beam microwave flux long-term monitoring of separate active regions with a high probability of solar flares were performed also (Fig. 3).

Some feasible problems and tasks of solar physics based on these microwave observations of the Sun could be:

- Studies of radio brightness of the quiet Sun and an absolute calibration methodology [6]

- Analysis of coronal holes and coronal hole-like areas associated with open magnetic fields which could be expected as sources of the slow solar wind [2, 4]
- Analysis of the microwave polarised emission of solar active regions for revealing of coronal magnetic fields based on the quasi-transverse emission's propagation
- Studies of microwave flux fluctuations resulting by magnetic field emergencies in active regions
- Analysis of quasi periodic pulsations (QPP) of the microwave flux as precursors of solar flares [8].

The detailed presentation concerns to technical issues of solar microwave observations with VIRAC RT-32 radio telescope and shows some solutions of relevant solar physics tasks based on it.

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References

[1] Kundu M. R. (1965) Solar Radio Astronomy, New York: *Interscience Publication*
[2] Bezrukov D., Ryabov B., Shibasaki K. (2012) Isolated Sunspot with a Dark Patch in the Coronal Emission, *Baltic Astronomy*, Vol.21, pp. 509–516. DOI: 10.1515/astro-2017-0406
[3] Bezrukovs D. (2013) Spectral Polarimetric Observations of the Sun by VIRAC RT-32 Radio Telescope: First results. *Baltic Astronomy*, Vol.22, N.1, pp. 9–13. DOI: 10.1515/astro-2017-0142
[4] Bezrukov D., Ryabov B. I. (2014) Persistence of Relatively Low Plasma Density in the Atmosphere of Sunspot. *Latvian Journal of Physics and Technical Sciences*, Vol.51, Nr. 2, pp. 65–72
[5] Ryabov B., Bezrukov D., Kallunki J. (2017) Low Brightness Temperature in Microwaves at Periphery of some Solar Active Regions, *Latvian Journal of Physics and Technical Sciences*, vol. 54, No.3, pp. 58–66. DOI: 10.1515/lpts-2017-0021
[6] Bezrukovs D., Kallunki J., Ryabovs B. (2018) Spectral Polarimetric Observations of the Sun by VIRAC RT-32 Radio Telescope: Calibrations. *Space Research Review*, Vol.5, p.16. ISBN 978-9984-648-89-7
[7] Bezrukovs D. (2022) Microwave Observations of the Sun with VIRAC RT-32 Radio Telescope: the Expansion of Possibilities, *Latvian Journal of Physics and Technical Sciences*, Vol. 59, Nr. 3, pp. 5–13. DOI: 10.2478/lpts-2022-0019
[8] Popova E., Bezrukovs D., Bezrukovs V., Suchikova Y., Popov A. I. (2024) Radio-astronomical monitoring of active regions in the microwave range in the service of forecasting solar flares. Modern Physics Letters A, Vol. 39, No. 15, 2450069. DOI: 10.1142/S021773232450069X.

Multi-harmonic and special shape/pattern/template approximations of discrete signals with generally irregular arguments

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"There is no sense to elaborate new methods
for the time series analysis,
As even Ptolemy knew the Fourier Transform"
© The anonymous referee (1996)

Introduction

Phenomenological modelling instead of (or complementary to) the physical one is needed because the parameters of the physical modelling are more numerous, and, typically, need additional data of other types. The simplest example is one equation between two unknowns $a, b = c$, where c is a "phenomenological" parameter (e.g. energy), and a, b – physical parameters (e.g. power, time). So, it is impossible to determine (a, b) separately, if knowing only c. Similarly, sometimes the physical modelling may need, say, dozens of the parameters m, whereas the data may be statistically optimally described by a function with much smaller m. The most common phenomenological models are based on the algebraical or trigonometrical polynomials for approximation of the whole data, and on the Gaussian or rectangular shape of relatively short "pulses". We briefly review more complicated models with special shapes, also known as "patterns" or "templates".

The diversity of the types of deterministic and stochastic signals need adequate methods for the statistically optimal data analysis. Real detected signals are never infinite and are discrete. Often there are large gaps between the observations, which drastically complicate power spectra, cross- (and auto-) correlation functions, functions of the parameters.

Algorithms

The paper, which got the referee report cited in the epigraph, was published in another (much more respectable) journal [1]. There are improved complete expressions which describe statistical properties in the complex case of "running" approximation merging separate algorithms:

- irregularly spaced discrete data;
- an arbitrary covariation matrix w_{kj} of the statistical errors of the measurements, which extends the "diagonal" case of the "Gaussian weights" w_{kj};
- multiplicative "window" function $p(z_k, z_j)$, like in the wavelets.

Despite each of these topics are discussed separately, also with special shapes, the algorithms of the joint improvements are more complicated and have been discussed in [1, 2].

The generalised version of a scalar product of the two vectors $\vec{a}$ and $\vec{b}$, which is used for further analysis, may be expressed as:

$$\left(\vec{a}\cdot\vec{b}\right) = \sum_{kj=1}^{n} p\left(z_k, z_j\right)\cdot w_{kj}\cdot a_k\cdot b_j \qquad (1)$$

Here $z_j = (t_j - t_0)/\Delta t$, where t_j – as a j – the argument of the signal t_j, x_j, $j = 1..\ n$. In the "wavelet" terminology, t_0 is called "shift", and Δt – "scale". Often (but not exclusively), the weight function is symmetrical $p(\pm z_k, \pm z_j) = p(\pm z_j, \pm z_k) = p(\pm z_k)$, then t_0 is the center of the interval of the approximation, in which the data are placed generally asymmetrically.

The test function, may be generally written as:

$$\Phi(x_j; C_\alpha) = (\vec{x} - \vec{x}_C)^2 = \sum_{kj=1}^{n} p(z_k, z_j)\cdot w_{kj}\cdot(x_k - x_{Ck})\cdot(x_j - x_{Cj}) \qquad (3)$$

Here x_{Cj} are "calculated" values at arguments t_j according to the approximating function $x_C(t, C_\alpha)$, where (C_α, $\alpha = 1..m$) are "parameters" or "coefficients" of the mathematical model. Similarly to the basic method of the Least Squares "LS" proposed by Karl Gauss before 1805, one has to determine the set of the parameters C_α, which minimizes the scalar function Φ. This corresponds to m "normal" equations $\partial\Phi/\partial C_\alpha = 0$, $\alpha = 1..m$. Generally, there may be a large number of solutions of these sets of the normal equations, which correspond to different values of Φ. This is typical for "non-linear" basic functions, in which the coefficients are involved inside, e.g, for the mono-periodic multi-harmonic approximation of order s:

$$x_C(t) = C_1 + \sum_{j=1}^{s}(C_{2j}\cos(2\pi jft) + C_{2j+1}\sin(2\pi jft)) = C_1 + \sum_{j=1}^{s} R_j\cos\left(2\pi jf\left(t - T_{0j}\right)\right) \quad (3)$$

the frequency $f = C_{2j+2}$ is also a parameter to be determined. In the periodogram analysis, the test function Φ is computed at a grid of equally spaced values of f with a recommended step $\Delta f = \Delta\varphi/sT$, where $\Delta\varphi \sim 0.05 \ll 1$, and T is duration of observations. The most popular our realisation of the method 'The periodogram' is the software MCV [3,4], which also has a unique function to make a periodogram analysis taking into account a frequency-dependent trend, contrary to popular oversimplified detrending or pre-whitening.

For small number of parameters m, the approximation(=fit) may loose some systematic components of the signal. Such a situation is called "underfit", whereas large m correspond to an "overfit", where the approximation is better, following random fluctuations of the data (e.g. [5]). The statistically optimal number of parameters (of any approximation) is used practically:

- "Aesthetic" ="user-defined"
- ANOVA (=analysis of variances, Fischer's criterion, p-value, FAP=False Alarm Probability)
- Best statistical accuracy of the approximation (mean-squared or at extremum or any point).

The user-defined degree s is commonly used in many computer programs, including different electronic tables. The statistically optimal values using the ANOVA – type criteria are a next step of the analysis. E.g., the catalogues of the photometrical characteristics of long-period pulsating variable stars of different subtypes were published [6,7,8]. The atlas of the phase plane (x, x') curves was presented [9]. The sines and cosines may be combined into basic functions like (scaled and shifted) $\sin(\pi t)/(n\sin(\pi t/n))$.

The cubic polynomial splines were used also for the periodogram analysis and a search of the period changes [11]. The splines are more local and thus sometimes may have better approximations than the trigonometrical polynomial. However, the splines depend not on the number of basic points m, but also on the position (shift). Thus, there may be two improvements – either to find a best shift, or shift-averaged approximation. In this version, the data are still split into equal m subintervals, and the function of the interval is a cubic polynomial. In reality, the argument t may be split into parts, e.g. maxima and quiescence for the outbursts, or eclipses in the binary stellar systems. The simplest "spline of changing order" (1;2;1) is an "asymptotic parabola" (AP) [12]. This function consists of two inclined lines ("asymptotes") connected with a parabola, so the function and its derivative are continuous. This (generally asymmetric) approximation has $m = 5$ parameters, as well as a polynomial of 4-th order. However, AP seems to have smaller systematic deviations for the maxima of majority of pulsating variable stars. For AP, there are two "non-linear" parameters $q = 2$) – the positions of the borders between the parabola and the straight line. This approximation as good for the data in a logarithmic scale (e.f. brightness in stellar magnitudes), as the slopes of the lines may be used for computation of characteristic time scales of the ascending and descending branches of the light curve. This method was used in dozens of papers of our group. The comparison between this kind of spline ($q = 2$), "symmetrical" polynomial ($q = 1$) and ordinary algebraic polynomials ($q = 0$) was presented by [13]. Generally, we use approximations with two "linear" parameters $\tilde{C}_1$, $\tilde{C}_2$, non-linear (shift C_3, scale C_4) and the rest describing the shape of the extremum [2]:

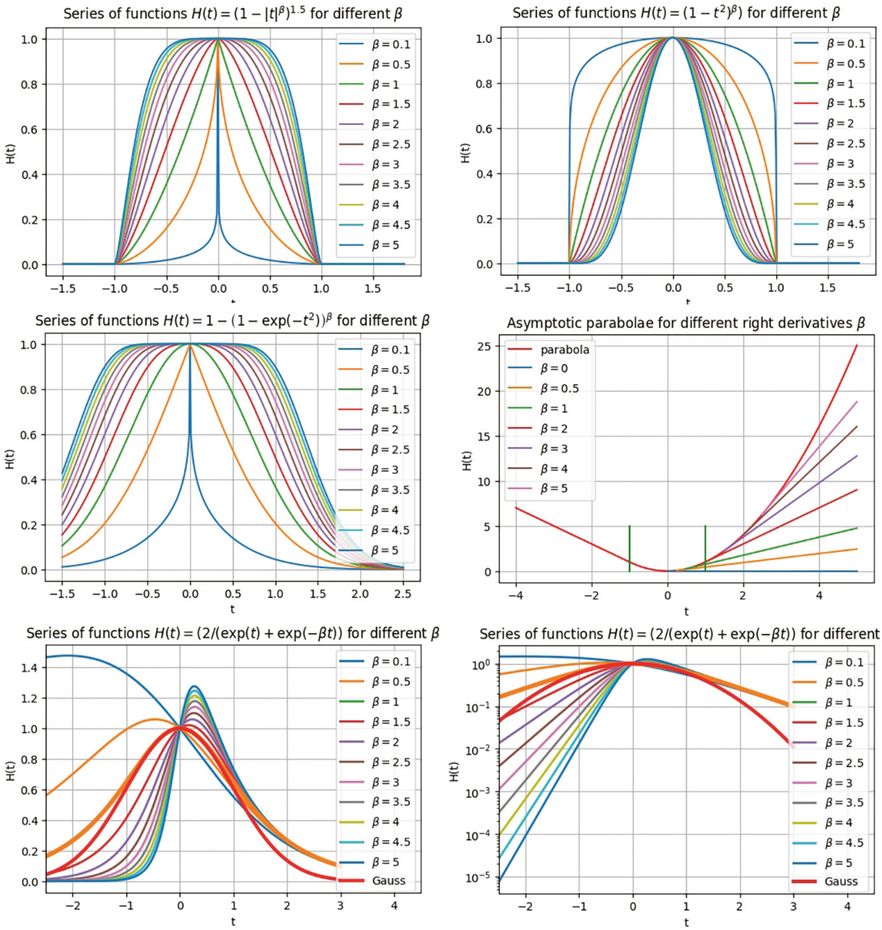
$$x_C[t] = \tilde{C}_1 + \tilde{C}_2 \cdot \tilde{G}\left((t - C_3), C_4, \dots, C_{mp}\right) \tag{4}$$

For non-logarithmic data, the (continuous with all derivatives) asymmetrical approximation for all the hump is $\tilde{G}\left((t - C_3), C_4, C_5\right) = \frac{2}{\exp\,(C_4\cdot(t-C_3))+\exp\,(-C_5\cdot(t-C_3))}$ [14]. This is an extension of the $\mathrm{sech}(z)$ popular symmetrical function. Even complicated function resembling the "log-normal" statistical distribution [15]:

$$\tilde{G}((t - C_3), C_4, C_5) = \exp\left(-\ln\, 2 \cdot C_5 \cdot \left(\ln\left(C_4 \cdot (t - C_3) + 1\right)\right)^2\right) \tag{5}$$

This approximation is useless for nearly symmetrical signals because it does not converge. Another asymmetrical approximation is a second-order polynomial spline with the parameters – the borders between the intervals. For the symmetrical shape, there are symmetrical polynomials with integer and non-integer power, These and other functions (totally, 22 of 11 types) have been involved in the software MAVKA [16], available at http://uavso.org.ua/mavka. One may automatically choose the method, which corresponds to the best accuracy of the moment of the extremum.

Special shapes for the eclipses of binary systems may be split into "all phase curve", "eclipse approximation", "near-extremum parts". Obviously, the wider is the interval compared to the width, the larger m is. Near extrema, the parabolic fit may be enough, with an increasing m for wider intervals. For the "almost" flat minima correponding to transits of exo-planets, or total eclipses, there are three "wall-supported" functions [17]. The most common function for the spectral lines is a Gaussian $\exp(-z^2/2)$ was also used by [18] with some modifications like $\exp(1 - \cosh(z))$. These shapes have infinite width, so it is impossible to determine borders of the minimum which are requested in the official catalogues of variable stars, mainly due to absence of adequate software. Thus, in 2010, we proposed the "New Algol Variable" (NAV) function [19], which is also effective for other types of the eclipsing variables (EA, EW) with smooth curves [20]. There may be minor improvements [18, 21], which increase m often without making significantly better fit. These studies are partially made within the "Inter-Longitude Astronomy" (ILA) project.



References

[1] Andronov I. L. (1997) Method of running parabola: Spectral and statistical properties of the smoothing function. *Astron. & Astrophys. Suppl.*, 125, 207–217. DOI: 10.1051/aas:1997217

[2] Andronov I. L. (2020). Advanced Time Series Analysis of Generally Irregularly Spaced Signals: Beyond the Oversimplified Methods, In: *Knowledge Discovery in Big Data from Astronomy and Earth Observation,* 191–224, DOI: 10.1016/B978-0-12-819154-5.00022-9

[3] Andronov I. L., Baklanov A. V. (2004) Algorithm of the artificial comparison star for the CCD photometry. *Astronomy School Report*, 5, 264–272, DOI: 10.18372/2411-6602.05.1264

[4] Andronov I. L., Baklanov A. V. (2004) Multi-Column Viewer, *MCV,* http://uavso.org.ua/mcv/MCV.zip

[5] Andronov I. L., Marsakova V. I. (2006) Variability of long-period pulsating stars. I. Methods for analyzing observations. *Astrophysics* 49 (3), 370–385, DOI: 10.1007/s10511-006-0037-8

[6] Kudashkina L. S., Andronov I. L. (1996) Fourier coefficients for the light curves of 62 Mira-type stars. *Odessa Astronomical Publications*, 9, 108–111, http://liber.onu.edu.ua/pdf/astro/all/OAP_9/000_pdf/kudash.pdf
[7] Marsakova V. I., Andronov I. L. Catalogue of Main Characteristics of Individual Pulsational Cycles of 18 Long-Periodic Stars. *Odessa Astronomical Publications*, 13, 83–176, http://oap.onu.edu.ua/article/view/97932/93261
[8] Chinarova L. L., Andronov I. L. (2000) Catalogue of Main Characteristics of Pulsations of 173 Semi-Regular Stars. *Odessa Astronomical Publications*, 13, 116–176, http://oap.onu.edu.ua/article/view/97938/93267
[9] Kudashkina L. S., Andronov I. L. (2017) Phase Plane Analysis of the Photometrical Variations of Long Period Variables. *Odessa Astronomical Publications*, 30, 93–97, https://scispace.com/pdf/phase-plane-analysis-of-the-photometrical-variations-of-long-1zuum3su7e.pdf
[10] Andronov I. L., et al. (2008) Idling magnetic white dwarf in the synchronizing polar BY Cam. The Noah-2 project. *Central European Journal of Physics*, 6, 385–401, DOI: 10.2478/s11534-008-0076-3
[11] Andronov I. L. (1987) Smoothing the "smoothing" cubic spline functions. *Publications of the Astronomical Institute of the Czechoslovak Academy of Sciences. 7*0, pp.161–164, URL: https://ui.adsabs.harvard.edu/abs/1987PAICz..70..161A
[12] Marsakova V. I., Andronov I. L. (1996) Local Fits of Signals with Asymptotic Branches. *Odessa Astron. Publ.,* 9, 127–130, http://nbuv.gov.ua/UJRN/oap_1996_9_57
[13] Andrych K. D., et al. (2015) "Asymptotic Parabola" Fits for Smoothing Generally Asymmetric Light Curves. *Odessa Astronomical Publications,* 28 (2), pp.158–160, http://nbuv.gov.ua/UJRN/oap_2015_28_2_17
[14] Andronov I. L. (2005) Advanced Methods for Determination of Arguments of Characteristic Events. *Proceedings of ASP Conference Series*, 335, pp.37–53, https://adsabs.harvard.edu/full/2005ASPC..335...37A
[15] Bódi A., Szatmáry K., Kiss L. L. (2016) Periodicities of the RV Tauri-type pulsating star DF Cygni: A combination of Kepler data with ground-based observations. *Astronomy & Astrophysics,* 596, id.A24, DOI: 10.1051/0004-6361/201629318
[16] Andrych K. D., Andronov I. L., Chinarova L. L. (2020) MAVKA: Program of Statistically Optimal Determination of Phenomenological Parameters of Extrema. Parabolic Spline Algorithm and Analysis of Variability of the Semi-Regular Star Z UMa. *Journal of Physical Studies*, 24, 1902, DOI: 10.30970/jps.24.1902
[17] Andrych K. D., Andronov I. L., Chinarova L. L. (2017) Statistically Optimal Modeling of Flat Eclipses and Exoplanet Transitions. The Wall-Supported Polynomial (WSP) Algoritms. *Odessa Astronomical Publications*, 30, 57–62, DOI: 10.18524/1810-4215.2017.30.118521
[18] Mikulášek Z. (2015). Phenomenological modelling of eclipsing system light curves. *Astronomy & Astrophysics*, 584, id.A8, DOI: 10.1051/0004-6361/201425244
[19] Andronov I. L. (2012) Phenomenological modeling of the light curves of Algol-type eclipsing binary stars. *Astrophysics*, 55, 536–550, DOI: 10.1007/s10511-012-9259-0
[20] Tkachenko M. G., Andronov I. L., Chinarova L. L. (2016) Phenomenological Parameters of the Prototype Eclipsing Binaries Algol, β Lyrae and W UMa. *Journal of Physical Studies,* 2016, 20, 4902, https://arxiv.org/abs/1612.01204
[21] Andronov I. L., Tkachenko M. G., Chinarova L. L. (2017) Comparative Analysis of Phenomenological Approximations for the Light Curves of Eclipsing Binary Stars with Additional Parameters. *Astrophysics*, 60, 57–69, DOI: 10.1007/s10511-017-9462-0
[22] Andronov I. L., et al. Inter-Longitude Astronomy project: some results and perspectives. *Astronomical & Astrophysical Transactions,* 22 (4–5), 793–798, DOI: 10.1080/1055679031000124501

Experimental and First Principles Analysis of Dielectric and Optical Properties of Magnesium Alloys

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Introduction

Additive manufacturing processes are revolutionary in their flexibility and capability to manufacture complex shapes and parts without the need for assembly. Topologically optimised parts can only be economically manufactured, and in a timely manner, by additive manufacturing processes. One of the most useful methods for metal processing is Selective Laser Melting (SLM), which is a type of powder bed fusion additive manufacturing method where a metal powder bed is selectively melted with a laser to form apart from a 3D model in a layer-by-layer manner. Another is Laser Directed Energy Deposition, which uses laser to melt and deposit material from powdered or wire feedstock. Common lasers operate on electromagnetic radiation spectrum spanning the ultraviolet, visible and near infrared ranges denoted by '*UV-VIS-NIR*'. Each metal has different response to interaction with lasers due to their fundamentally different atomic structures, and the response varies as a function of the laser wavelength. For performing laser metal processing, the electromagnetic energy of the laser light needs to be transformed into thermal energy inside the metal, which is determined by the light absorption mechanisms in the metal. It is this absorbed energy, rather than the laser beam itself, that is available for heating the metal.

The purpose of this work is to investigate the optical-material relationships between lasers and magnesium (Mg) alloys. The work is focussed on developing a theoretical and practical understanding of the fundamental absorption and reflection mechanism of lasers with Mg alloys by obtaining spectral absorbance data for Mg alloy feedstock in different shapes and to obtain relationship between optical absorbance and laser beam characteristics. This will help in addressing some important issues that are faced by Mg alloys. Firstly, Mg alloys are reportedly difficult to process with lasers due to high reflectivity and the shortage of basic knowledge, and foundational understanding of their optical-material interactions. Secondly, laser additive manufacturing of Mg alloys has lagged all other structural and/or functional materials due to this problem. And thirdly, there is a significant lack of scientific results and experimental data pertaining to this subject, while copious amounts exist for other metals and alloys.

Materials and Methods

The research consists of a total of 3 materials: commercially pure AZ31, AZ80, and ZK60 alloys. These alloys are the most popular for use in various structural applications. The properties for pure metal are expected to be different from alloys due to the inclusion of alloying elements, as seen in Al alloys and steels [3]. Pure metal is used as a reference for other materials in obtaining the variation in absorbance due to alloying with various elements. A wide selection of materials will be useful to accurately create a property map between absorbance and chemical composition and adequately extract the overall optical behaviour of engineering materials with lasers of varying wavelengths. This information will be extremely important for engineering the Mg alloys for SLM.

The materials were procured in two (2) different forms, bulk shape, and powder feedstock. Bulk material, in the form of sheets & billets was procured from SME Engineering SIA (Riga, Latvia) and powders *(d: 20–10 µm)* were supplied by Nanographi İnovasyon (Ankara, Turkey). Powders of pure Mg and AZ31 were also produced during a visit at Amazement Pvt. Ltd. (Warsaw, Poland)/ Prior to optical characterisation, the surface was be characterised for quality, chemical composition, and roughness using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy, and surface profilometry. The materials were tested for their physical properties to understand their effect on the absorbance spectrum. It is well known that morphology of the incident surface affects the absorbance behaviour [1].

The metallography and sample preparation were performed on Buehler AutoMet 250 Pro at the Institute of Solid-State Physics, University of Latvia. The samples of size $15 \times 15 \times 7$ mm^3 were embedded in epoxy resin molds of cylindrical shapes that are mounted on the polishing machine. The samples were subjected to grinding with 320, 400, 600, and 1200 grit SiC sanding papers until flat. After each step, the samples were cleaned ultrasonically in acetone bath for 60 seconds. After that, oil-based diamond suspensions of sizes 6, 3, and 1 µm were used to polish the samples. The polishing stage was set at 200 rpm and the sample holding head was set at 1.5 N load. Finally, the sample was polished with 0.05 µm colloidal silica suspension.

Optical properties and spectral absorbance of the materials was characterised using UV-VIS-NIR Spectroscopy on Agilent – Cary 7000 Spectrophotometer, and Reflection Electron Energy Loss Spectroscopy was performed on TF-ESCALAB Xi electron spectrometer. Ab-initio calculation using density functional theory (DFT) was performed on DFT package Quantum Espresso [2].

Results

The results of reflectivity measurement using photospectrometry are shown in Figure 1. As can be seen, the reflectivity of the alloys varies slightly in the 500–2000 nm wavelength range but drop sharply below 500 nm. This is an indication that the absorptivity of all the alloys increases for incident laser or light below 500 nm wavelength. The conventionally used IR laser of wavelength 1050 nm is indicated in the plot as well. For these alloys, a reduction of 10–20 % in the reflectivity can be observed at 400–500 nm compared to 1050 nm.

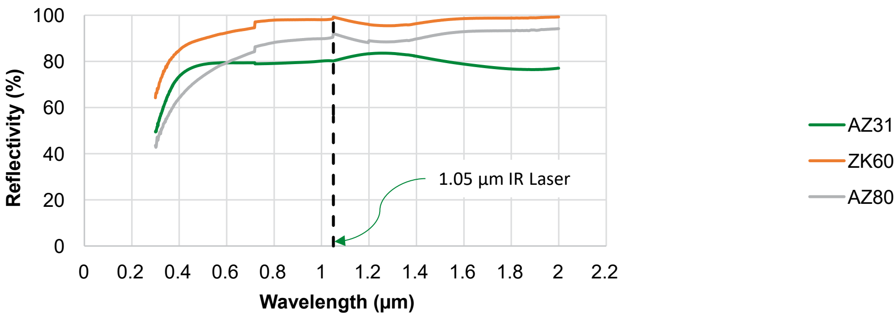

Figure 1. *Reflectivity of polished surface as a function of wavelength of various alloys*

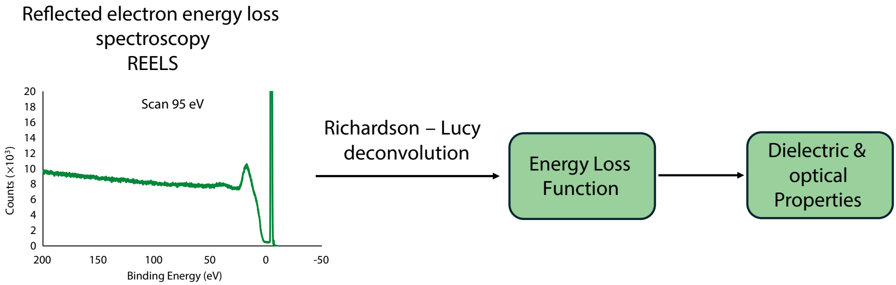

Figure 2. *REELS spectra for AZ31 alloy and the methodology for extracting dielectric and optical properties of the material*

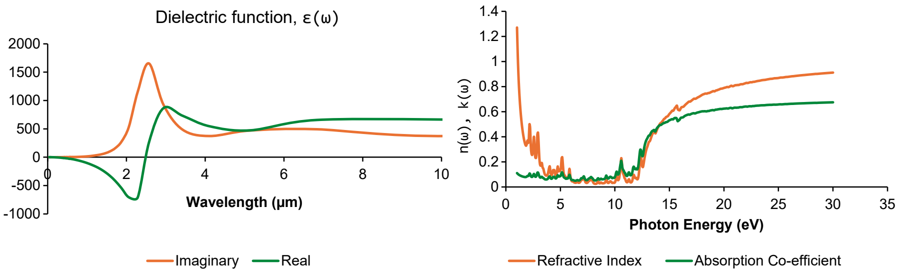

Figure 3. *Results of DFT simulation showing (left) the complex dielectric function and (right) the refractive index and absorption coefficients for pure Mg*

Reflected electron energy loss spectroscopy [3, 4] or REELS is a powerful tool for studying the properties of material at few nanometres depth from the surface. It is used to measure band structure and dielectric properties of the material. REELS was performed on polished AZ31 sample at 95 eV beam energy and the obtained spectrum is shown in Figure 2. The spectrum is processed using Richardson-Lucy deconvolution to deal with elastic interactions and the energy loss function (ELF) can be obtained. Then, the optical and dielectric properties of the material can be obtained.

A supercell of $3 \times 3 \times 1$ was used for the DFT simulation of pure Mg lattice. The supercell contained 72 atoms in HCP structure lattice, 50 k-point were used in the Brillouin Zone, and converged value of 120 bands were used in the calculation of the self-consistent field. The preliminary results are shown below in Figure 3.

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References

[1] Niu C., Zhu T., Lv Y. (2019) Influence of Surface Morphology on Absorptivity of Light-Absorbing Materials. *International Journal of Photoenergy*, 2019: 1476217.

[2] Giannozzi P., Baroni S., Bonini N., Calandra M., Car R., Cavazzoni C., Ceresoli D., Chiarotti G. L., Cococcioni M., Dabo I., Dal Corso A., de Gironcoli S., Fabris S., Fratesi G., Gebauer R., Gerstmann U., Gougoussis C., Kokalj A., Lazzeri M., Martin-Samos L., Marzari N., Mauri F., Mazzarello R., Paolini S., Pasquarello A., Paulatto L., Sbraccia C., Scandolo S., Sclauzero G., Seitsonen A. P., Smogunov A.,

Umari P., Wentzcovitch R. M. (2009) QUANTUM ESPRESSO: a modular and open-source software project for quantum simulations of materials. *Journal of Physics: Condensed Matter*, 21(39): 395502.

[3] Werner W. S. M., Glantschnig K., Ambrosch-Draxl C. (2009) Optical Constants and Inelastic Electron-Scattering Data for 17 Elemental Metals. *Journal of Physical and Chemical Reference Data*, 38(4): 1013–1092.

[4] Deris J., Hajati S. (2017) Reflection electron energy loss spectroscopy as efficient technique for the determination of optical properties of polystyrene intermixed with gold nanoparticles. *Applied Surface Science*, 392: 697–70.

Experimentally induced darkening of dunite, a small step in understanding more about asteroid interlopers

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In the classification of Main Belt asteroids [1], two recognised major asteroid types are the S-type and C-type asteroids. These asteroids possess very different reflectance spectra, which, in the near-infrared, show silicate (olivine/pyroxene) absorption bands for the S-type asteroids and are devoid of these absorption bands for the C-type asteroids. It has been studied that some of these C-type asteroids might be asteroids of the S-type [2], and reference therein] owing to the loss of silicate absorption bands from the darkening of the asteroid material. One major cause for the darkening is the so-called shock-darkening, where iron sulphides and metals melt and migrate between silicate fractures and grain boundaries [2]. Considering that these spectral changes are crucial in correctly classifying asteroids, their extent is yet to be thoroughly investigated. Recent research [3] has tried to understand one of the leading causes of shock-darkening. A dunite cube was doped with troilite (FeS) and placed in a high-temperature furnace. The whole dunite bulk was consequently darkened, which suggests breccia emplacement in a melt of asteroid fragments during asteroid collisions. Although the research needs a profound understanding of the spectral changes, it still marks an essential step in understanding how asteroids can be misclassified from S-type to C-type asteroids.

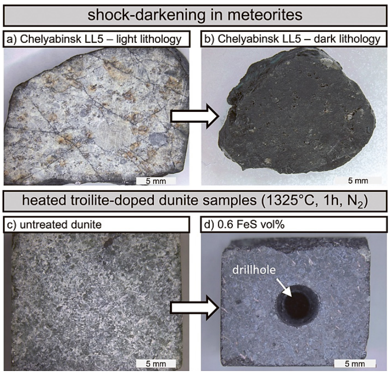

Figure 1. *Induced darkening in a dunite fragment by adding troilite (FeS) into a drillhole*

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References

[1] DeMeo F. E., et al. (2009) Extension of the Bus asteroid taxonomy into the near-infrared. *Icarus* 202: 160–180

[2] Kohout T., et al. (2014) Mineralogy, reflectance spectra, and physical properties of the Chelyabinsk LL5 chondrite – Insight into shock-induced changes in asteroid regoliths. *Icarus* 228: 78–85

[3] Moreau J. G., et al. (2024) Experimentally induced troilite melt pervasion in chondritic analogue materials: a study for FeNi-FeS darkening in chondrites. *Meteoritics & Planetary Science*, 59(12), 3229–3249.

Plasma emission spectroscopy and its role in the study of the heavy elements

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The spectroscopic analysis of the radiation emitted by different light sources is a powerful tool for the study of the atomic structure and the measurement of atomic parameters. Such parameters include, but are not limited to, wavelengths, energy levels, transition probabilities (Einstein coefficients for spontaneous emission), hyperfine and isotope structure constants. The knowledge of these parameters is essential in many fields for the interpretation of different phenomena. In the field of astrophysics, the analysis of stellar chemical abundances or the study of kilonova spectra relies on the availability of atomic data for the identification of the various elements present in the spectra recorded by different galactic surveys. However, despite their importance, experimental data for heavy elements for singly and doubly ionised species remains scarce due to their spectral complexity and the technical challenges associated with producing and diagnosing suitable plasmas.

The Atomic Spectroscopic Laboratory at the University of Valladolid has more than 40 years of experience in the measurement of atomic parameters of neutral, singly and doubly ionised elements using emission spectroscopy. We have performed studies of Stark widths and shifts and measured transition probabilities of a wide range of elements, including He, Ne, Ar, Kr, Xe and more recently heavy elements such as neodymium (Nd).

The experimental setup

We have two different types of discharge sources available in our laboratory. The first is a pulsed-discharge lamp, which is used for the study of spectra of noble gases at pressures of approximately 200 Pa, employing voltages of up to 8 KV [1]. This lamp has been designed to obtain a good approximation to the partial local thermodynamic equilibrium (pLTE) so that the population of the energy levels of the atoms under study can be approximated to the Boltzmann distribution. The plasma produced in this lamp lasts for 200 µs. The configuration of the apparatus enables the acquisition of spectra at various temporal points following the discharge, ranging from 50 µs to 120 µs. The lamp is positioned within the arms of a Michelson interferometer, which allows for the measurement of the electron density evolution during the plasma›s lifetime. At the pressures and electron densities employed in this lamp, the primary broadening mechanism of the spectral lines emitted by the plasma is Stark broadening (Lorentzian profile).

A second type of light source has recently been incorporated for the measurement of spectra of heavy elements [2]. This is a custom-built hollow cathode lamp, modelled on the design of the one used at the Fourier Transform Spectroscopy group at Imperial College London. This lamp uses a cathode composed of the element under investigation (neodymium at present) and features a carrier gas that is flowed at a pressure calibrated to ensure a stable discharge and an optimal signal-to-noise ratio for the spectral lines of interest. The selection of the carrier gas is key in facilitating the population of the energy levels that are the subject of our study. This lamp's primary broadening mechanism is attributed to Doppler broadening (Gaussian profile). The lamp is water-cooled to reduce this broadening as far as possible and to protect the cathode from melting due to the high temperatures it reaches.

To analyse the radiation emitted by our light sources, we use a 1.5 Jobin-Yvon monochromator with a Czerny-Turner configuration equipped with a UV optimised diffraction grating with 2400 lines/mm. This gives as a resolving power of 140 000 at 400 nm. The width of the monochromator´s entrance slit is chosen to maximise the quantity of light, while ensuring that we do not lose resolving power. We have also a Fabry-Pérot interferometer with resolving power of up to 10^8.

Measuring transition probabilities

Accurate experimental transition probabilities (Einstein A coefficients for spontaneous emission) are essential in many fields, from the determination of stellar chemical abundances to laser design, the lighting industry and plasma diagnostics. To measure these parameters, it is first necessary to correctly identify the lines, paying particular attention to blends, a recurring problem when measuring the very line-dense spectra of rare earths due to their complex atomic structure. Secondly, the area under the spectral line profile must be obtained as accurately as possible, since the uncertainty of the transition probability is linked to that of the measured area.

Once the line profiles have been checked for self-absorption (a phenomenon in which part of the emitted light is reabsorbed by the emitting plasma, altering the line profile), special care must be taken to determine the area under the spectral line profile. We perform a careful irradiance calibration that takes into account the different response of our experimental setup with wavelength. We use 3 different standard calibrated lamps to determine the response function of our setup. A calibrated L2D2 Hamamatsu deuterium lamp (model L6566) is used to calibrate the spectral range 190–385 nm, while a FEL QHT Osram tungsten lamp is used for the visible range 380–800 nm. It is well known that the spectral region bridging the UV and visible ranges is problematic due to the appearance of spectral lines in the deuterium lamp and the low emission of the tungsten lamp. To reduce the uncertainty of our response function in this region, we use as a third calibration lamp a Hamamatsu Xe L2273 lamp with emission in the 185–800 nm range.

Following the measurement of the spectrum and its irradiance calibration, the next step is to fit it to a mathematical model. This model incorporates a first- or second-degree polynomial for the background, as well as a sum of functions, either Gaussians, Lorentzians, or a convolution of the previous functions, depending on the predominant broadening mechanism present in the lamp. The calculation of the areas of the spectral lines, along with their respective uncertainties, is then performed using the Loren.py program developed in our laboratory. This program is available for download from our laboratory's Zenodo repository [3]. A comprehensive mathematical exposition of the expressions utilised in this program can be found in [1].

Once the areas of the spectral lines under study are obtained, there are two ways to obtain the transition probabilities depending on the type of our light source. For our pulsed discharge lamp, where the plasma can be described as being in partial local thermodynamic equilibrium (pLTE), we use an exponential fit to the Boltzmann distribution of the population of energy levels. This method, explained in [1], differs slightly from the classical Boltzmann plot method where logarithms are taken. The main disadvantage of this approach, apart from the fact that one must assume at least pLTE, is that the values of the transition probabilities for a set of lines must be known in advance. These lines are referred to as the "reference lines" as they will set the scale. It is therefore very important to choose a good set of lines with accurate transition probability values. This method can be problematic if previous values of transition probabilities are not available in the literature or if the light source used does not fulfil the condition of pLTE.

A second method, known as the "branching ratio method", can be used when if the lifetimes of the upper energy levels of the transitions of interest are known. This method does not require any assumption about the population of the upper energy levels, because it uses the ingenious solution of calculating the ratios of the areas of lines coming from the same upper energy level [4]. The transition probabilities are then obtained combining these ratios with the lifetime of the upper energy level. In this method, the main constraints come from the availability of lifetimes and the fact that we need to measure all the spectral lines coming from a particular upper energy level. This can sometimes be challenging as different lines can lie in very different spectral regions of the spectrum.

Conclusions

Plasma emission spectroscopy remains an indispensable tool in the measurement of atomic parameters of the heavy elements, particularly when high resolution and high sensitivity measurements are required. Our laboratory's approach integrates versatile plasma sources with state-of-the-art detection and calibration methods, facilitating the accurate determination of atomic parameters central to many areas of physics. In this talk, we will give a comprehensive overview of the capabilities and limitations of our experimental setup. The final aim of this contribution is to foster collaboration with other groups working on atomic spectroscopy and with data users in need of new measurements.

Acknowledgments. This work was conducted under the Spanish government through project PID2021-127786NA-100 funded by MICIU/AEI /10.13039/501100011033 and by FEDER, UE. M. T. Belmonte acknowledges the Beatriz Galindo Fellowship from the Ministerio de Ciencia, Innovación y Universidades of the Spanish Government. P. S. Sen Sarma thanks the University of Valladolid for his Ph.D. grant.

References

[1] Belmonte M. T., Mar S., Djurović S., Menéndez J. A., Gavanski L. (2025) Experimental Transition Probabilities and Oscillator Strengths of Singly Ionised Xenon (Xe II) in the Ultraviolet. *Spectrochimica Acta Part B: Atomic Spectroscopy* 202, 107190. DOI: 10.1016/j.sab.2025.107190

[2] Sen Sarma, P. R., Belmonte, M. T., Mar S. (2024). Characterisation of a hollow-cathode lamp to measure accurate branching fractions of rare-earth elements. *The European Physical Journal D*, 78 (76). DOI: 10.1140/epjd/s10053-024-00868-w

[3] Mar S. (2024) Atomic transition probabilities with uncertainties. *Zenodo*. DOI: 10.5281/zenodo.13173712

[4] Belmonte M. T., Pickering J. C., Clear C. P., Concepción Mairey F., Liggins F. (2018). The Laboratory Astrophysics Spectroscopy Programme at Imperial College London. *Galaxies*, 6(4), 109. DOI: 10.3390/galaxies6040109.

Quantum and nonlinear plasmonics on crystalline gold surfaces

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Plasmonics offers unique ways to concentrate and manipulate light in regions of space much smaller than the diffraction limit [1]. Yet, the description based on the classical electromagnetism is valid even for deeply subwavelength plasmonic nanostructures. However, when the nanostructure dimensions approach mesoscopic regime, quantum confinement becomes appreciable, breaking the classical model. For example, this manifests in appearance of the so-called nonlocal response in ultrathin metal-insulator-metal waveguides, resulting in the distortion of the dispersion relation of gap surface plasmon modes [2], as illustrated in Fig. 1.

In this talk, I will discuss recent experimental advances in the field of quantum plasmonics and show why exceptional optical properties of monocrystalline gold flakes [3] are of paramount importance for characterisation of these mesoscopic effects. Atomically smooth surfaces and well-defined morphology make such crystals excellent "sandbox" model for experimental studies of electron dynamics. Furthermore, {111}-type surfaces of such monocrystalline samples exhibit unusual second- and third-order nonlinear optical response [4–6], which is not observable with conventional, polycrystalline gold thin-films.

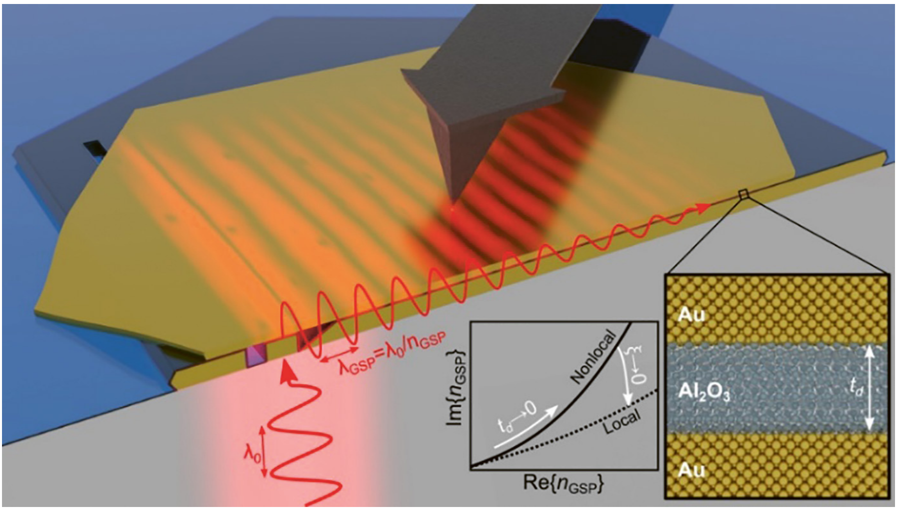

Figure 1. *Schematic illustration of the scanning near-field microscopy experiment probing nonlocal response in metal-insulator-metal heterostructure that ultraconfined gap surface plasmon modes. Reprinted with permission from ref. [2].*

References

[1] Gramotnev D., et al. (2010) Plasmonics beyond the diffraction limit. *Nature Photonics* 4, 83
[2] Boroviks S., et al. (2022) Extremely confined gap plasmon modes: when nonlocality matters. *Nature communications* 13, 3105

[3] Leibsir Y., et al. (2022) Ultimate Limit for Optical Losses in Gold, Revealed by Quantitative Near-Field Microscopy. *Nano Letters* 22, 5759

[4] Boroviks S., et al. (2021) Anisotropic second-harmonic generation from monocrystalline gold flakes. *Optics Letters* 46, 833

[5] Echarri A., et al. (2023) Nonlinear Photoluminescence in Gold Thin Films. *ACS Photonics* 10, 2918

[6] Boroviks S., et al. (2025) Monocrystalline Gold Metasurface to Control Anisotropic Second-Harmonic Generation. *Advanced Optical Materials* 2402525.

Levitation of WGM microspheres: optical, electrodynamic, magnetic

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Whispering gallery mode (WGM) resonators are transparent round objects that can propagate light by total internal reflection and can be very sensitive interference sensors. We have previously demonstrated a humidity sensor based on glycerol microdroplet [1] attached to a thin glass hair. If such a microdroplet could be levitated by some means, then the microdroplet shape could become much rounder and have a simpler transversal mode structure. Levitation of microobjects has always fascinated scientists and has resulted in numerous Nobel prizes.

Optical tweezers

Optical tweezers work by light pressure where photons transfer their momentum to the object upon refraction and scattering. Oil microspheres have been trapped in optical tweezers in air and optical quality Q-factor of 109 has been demonstrated [2]. We have managed to trap about 20 micrometre diameter glycerol microdroplets in air in the focus of a 150 mW green or red laser beam (Fig. 1). Droplets were doped with Rhodamine 6G dye with an idea to make a microsphere dye laser. Unfortunately, the dye immediately bleached in the green trap beam. We think that it might be possible to use infrared light for trapping that would not bleach the dye.

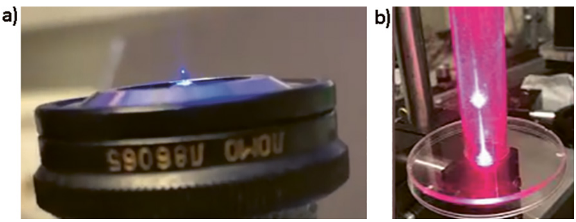

Fig. 1. *Optical tweezers in air:*
a) Levitated diamond microparticle, b) Levitated glycerol microdroplet

Electrodynamic traps

Electrodynamic traps are used to trap ions in vacuum with applications in optical clocks and quantum computers. Ion traps work using alternating (AC) high voltage in megahertz range that creates so called saddle potential. There are many constructional variations based on two main types of such traps namely, electric quadrupole and Paul traps. Trap stability can well be modelled using Mathieu equations. For particles of about 20 microns size the AC voltage is much lower and can be as low as 50 Hz provided by a microwave oven high voltage transformer. We have trapped triboelectrically charged 15 micrometre acrylic plastic PMMA micro-spheres in air using several different electrode configurations (Fig. 2). Such trap allows to trap a single microsphere and micromotion can be minimised by applying DC bias voltages to additional electrodes. In future we would like to trap a glycerol microdroplet doped with dye and demonstrate lasing. A complication is that, for pumping of such microdroplet need a pulsed laser and an achievable output power is quite small for most practical applications.

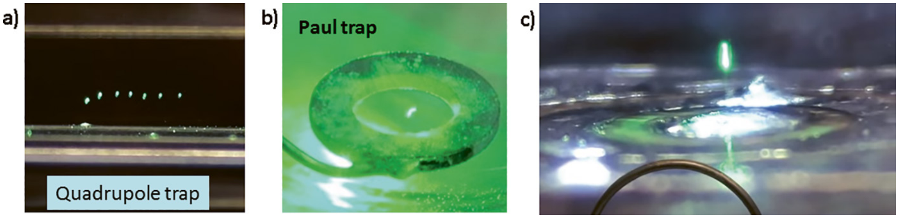

Fig. 2. *Electrodynamic trapping of PMMA microspheres in air using 3 kV AC at 50 Hz; different electrode configurations: a) Electric quadrupole trap made from 3 mm diameter rods connected diagonally together displaying a so-called ion crystal, b) Paul trap using a metal washer, c) trap above a printed circuit board with ring electrodes. The green laser is used for the illumination only*

Electronic magnetic levitation

Electronically controlled magnetic levitation with position sensing and fast feedback coils is used to levitate large objects such as rotors of industrial ultracentrifuges or turbomolecular pumps that turn frictionless and do not require lubricants. Ernshaw's theorem prohibits stable levitation with permanent magnets only. However, it is possible if the permanent magnets are rotating creating a saddle potential similar to case of electrodynamic traps. Fig. 3. shows several examples.

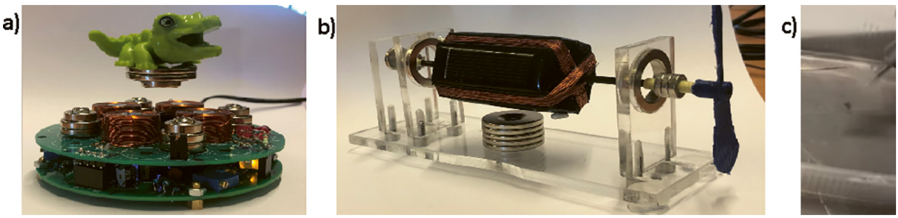

Fig. 3. *Levitation demonstrations in physics education. a) Full levitation using permanent magnets and electronic feedback coils. b) Solar panel Mendocino motor with a quasi-levitation using permanent magnets needs a support in a single point providing low friction and spins much faster compared to Lebedev's light pressure mills where just a part of photon energy is put into mill rotation by the Doppler shift. c) A rotating permanent magnet attached to a motor shaft can lift and trap another permanent magnet in the air*

Diamagnetic levitation

However, a stable levitation with permanent magnets is possible for superconducting or diamagnetic objects like a frog [4]. We successfully levitate pyrolithic graphite above four strong neodymium permanent magnets sticking to each other with opposite polarities and forming a magnetic field minimum. Diamagnetic graphite is pushed towards the place where the field is lower. Such trap is possible also for water microdroplets. If we could levitate glycerol and dye containing microsphere, then such trap would be portable not requiring an external power.

a) b)

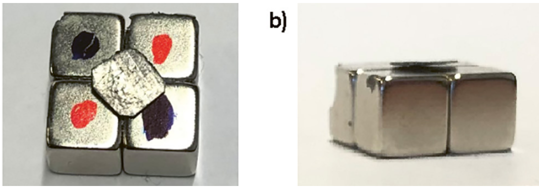

Fig. 4. *a) Diamagnetic levitation of pyrolithic graphite above N52 grade neodymium magnets forming a quadrupole field with a field minimum. b) Levitation height of graphite is less than 1 mm above the permanent magnets*

Summary and conclusions

A brief summary of levitation methods discussed in the present publication is given in Table 1.

We plan in future to levitate glycerol microdroplets for whispering-gallery-mode sensors or doped with dye to demonstrate microsphere lasers. Probably doping the droplet with rare earth elements such as erbium could eliminate bleaching.

Table 1. *Comparison of levitation methods*

Type of levitation	Advantages	Disadvantages
Optical tweezers A. Ashkin 2018 Nobel prize	Need strong laser light, traps transparent particles	Transparent materials Strong laser bleaches dyes
Electrodynamic levitation W. Paul 1989 Nobel prize	no lasers needed, many particles same time	Alternating high voltage
Diamagnetic levitation	Permanent magnets only, no external energy needed	Limited to diamagnetic materials pyrolithic graphite, water
Electronic magnetic levitation	Used in high speed bearings of turbomolecular pumps	Active feedback electronic coils. Ferromagnetic materials

This study has been done at the Quantum Optics Laboratory of the Institute of Atomic Physics and Spectroscopy. A more detailed video documentation on each levitation method is available at the *Youtube* channel managed by Jānis Alnis.

Acknowledgments. This research was supported by the Latvian Quantum Technologies Initiative, Project Nr. 2.3.1.1.i.0/1/22/I/CFLA/001.

References

[1] Reinis P. K., Milgrave L., Draguns K., Brice I., Alnis J., Atvars A. (2021) High-Sensitivity Whispering Gallery Mode Humidity Sensor Based on Glycerol Microdroplet Volumetric Expansion, Sensors **21**, 1746

[2] Kher-Alden J., Maayani S., Martin L. L., Douvidzon M., Carmon T. (2020) Microspheres with atomic-scale tolerances generate hyperdegeneracy, Phys. Rev. X **10**, 031049

[3] Eltony A. M., Gangloff D., Shi M., Bylinskii A., Vuletic V., Chuang I. (2016) Technologies for trapped-ion quantum information systems, Quantum Inf. Process. **15**, 5351

[4] Berry M. V., Geim A. K. (1997) Of flying frogs and levitrons, European Journal of Physics **18**, 307

Laser Spectroscopy of Negative Ions

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I will report on the results and conclusions of the first year of work in the Latvian Science Council project (No. lzp-2023/1-0199): "Negative ion laser photodetachment spectroscopy". The main goal is to obtain more information and better understand the structure and dynamics of atomic systems in them. We do this in collaboration with scientists from CERN [1] in Switzerland and three Swedish universities from Gothenburg [2], Malmö [3] and Stockholm [4]. The basic idea of the project is to conduct high-class experiments during short scientific visits to the large laboratories CERN and DESIREE. Preparatory work and processing of the results are carried out at the Institute of Atomic Physics and Spectroscopy [5].

Top-level research and innovation are most intensively developed in large scientific laboratories. They have access to expensive equipment and complex infrastructure that Latvia cannot afford to purchase and maintain. Conducting research on such modern equipment allows both experienced researchers and young scientists to grow and achieve world-class results.

Work in large centres is very different from the usual routine. In them, we have to pass a competition for access to the facility with our experimental idea. In case of success, such access is given. One or two weeks to carry out the planned experiments. During this time, the operation of the experimental facility is provided by the host laboratory, both financially and with personnel. We only need to find a budget for travel and accommodation. But it is very important to prepare a completely clear work plan, because when the allotted time runs out, the second opportunity may be only after a year, or not at all.

The report will present the results of recently conducted experiments on the lifetime of positive ions and the energies of electron detachment from negative ions. 3 conclusions to be drawn at this time are:

- it is very important that all project participants are able to participate in experimental missions.
- funding for business trips is too little planned
- the problem is the complicated and slow procurement procedure at the University of Latvia.

Acknowledgments. This research was supported by Fundamental and Applied Research Project (No. lzp-2023/1-0199): "The Laser Photodetachment Spectroscopy on Negative Ions", from Latvian Council of Science.

References

[1] https://home.cern/science/experiments/isolde
[2] https://www.gu.se/om-universitetet/hitta-person/daghanstorp
[3] https://mau.se/en/persons/henrik.hartman
[4] https://www.desiree-infrastructure.com/desiree
[5] https://www.lu.lv/par-mums/struktura/instituti/lu-atomfizikas-un-spektroskopijas-instituts.

Advances in Application of Hybrid system: Hollow Cathode and Low Pressure Inductively Coupled Plasma for Spectroscopic Investigation of Basic Properties of Atoms and Ions of Hardly Volatile Elements

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The advancement of hybrid plasma technology (hollow cathode discharge & inductively coupled radiofrequency plasma: RF-ICP & HC) in UV, VUV spectroscopy research will open the game-changing potential to address the pressing need for novel insights and expertise in pertinent fields via studies of resonance spectra of atoms of hardly volatile elements, as well as ions of many elements, particularly:

a) Valuable for astrophysics in the treatment of spectroscopic data captured by the emerging "after Hubl" fleet of space telescopes [1], [2], [3], [4].
b) Response to the urgent need, faced by modern atomic physics and its theoretical frameworks, for new and/or improved empirical data on UV, VUV spectroscopy, and basic properties of scarcely investigated atoms and ions [5].

The utilisation of **game-changing hybrid plasma system featuring sophisticated geometry** – inductively coupled RF plasma conjoined with hollow cathode discharge (HC & RF-ICP, see principal sketch in Fig. 1), produced using top level "know-how" of glass and silica glass technologies (see Fig. 2) relevant high vacuum systems, and manipulation skills with high purity noble gases and small quantities of elements. Atoms and ions (sputtered in plasma by HC discharge from the solid phase of the used element) face diffusion out from the volume of hollow cathode discharge, and are effectively excited in ICP plasma generated by the coil of inductor positioned nearby to the cathode (Fig. 1) in the presence of 1–2 Torrs of noble gas (the pressure of Ne, Ar, Kr, or Xe on choice will be accordingly fixed via selection of optimal parameters for the relevant element).

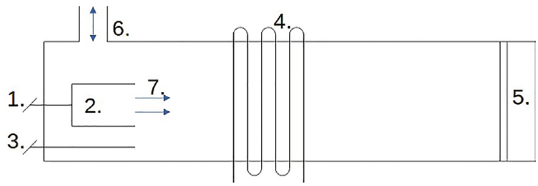

Figure 1*. Conceptual drawing of the geometry of a hybrid plasma system.*
2 – hollow cathode; 3 – Anod: 4 – RF- ICP inductor; 5 – ultrasil window; 6 – Vacuum pumping and gas supply: 7 – diffusion of sputtered by HC discharge atoms into the area of ICP-RF plasma

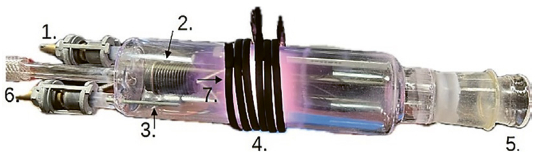

Figure 2. *Laboratory-produced fully silica glass, powerful hybrid plasma light source.*
Numbers in Fig. 2 indicate the same elements, like in the drawing in Fig.1

Low-pressure inductively coupled RF plasma[1] is known as an exclusively ideal source to obtain intensive atomic resonance spectra of various elements [7]. Since 1970, our research teams in Riga collected valuable experience and IPR assets in designing, manufacturing and application of RF-ICP-based sources of main resonance lines (Na I, Rb I, Cs I, Zn I, Cd I, Hg I, Sn I, Pb I, S I, Se I, and Te I) for analytical spectroscopy and research on basic properties of atoms. Up to now, Tellurium is an atom whose atomic properties have been persistently studied by the team in Riga using an RF-ICP plasma source [8, 9]. To the best of our knowledge, such a comprehensive approach has not been applied to other elements, highlighting the need for this project. Moreover, the atomic spectroscopy findings from the study of Te I have proven valuable in Astrophysics research, as demonstrated by a team from the Massachusetts Institute of Technology (USA) in analysing data recorded by the Hubble Space Telescope, as detailed in [10]. This is an example highlighting an opportunity to utilise the novel approach for similar endeavours for the large number of atoms (including hardly volatile) and their ions using the hybrid plasma technique, similarly to what has been done for the Te I.

Besides that, up to now, no one has succeeded in studies of the spectra of ions of atoms excited in RF-ICP plasma. Recently, we conducted the pilot research and demonstrated the possibility to study resonance spectra of ions of B II [11], Gd II [12], and Pb II [13]. Further progress with the hybrid plasma technique will open plenty of opportunities to study resonance spectra of ions.

References

[1] Anil K. Pradhan, Sultana N. Nahar. Monography. Atomic Astrophysics and Spectroscopy. *Cambridge University Press*; 2011. 376 pages

[2] Uldis Bērziņš. Combination of 3 Different Measurements: Branching Fractions, Radiative Lifetimes, and Absorption Oscillator Strengths – a Good Opportunity for the Analysis of the Presence of Elements in Astrophysical Objects. *Conf. paper. Measurement 2021 Conference*. 17–19 May 2021, Slovakia

[3] After Hubble: This Canadian telescope could fill coming 'ultraviolet gap'. News, by Elizabeth Howell, published December 11, 2023: https://www.space.com/hubble-space-telescope-ultraviolet-gap-canada-castor-telescope

[4] PLAnetary Transits and Oscillations of stars (PLATO) is a space telescope under development by the ESA for launch in 2026: https://www.esa.int/Science_Exploration/Space_Science/Plato_factsheet

[5] Advances in Atomic Physics: An Overview, by Nobel Prise Laureate Claude Cohen-Tannoudji, and David Guery-Odelin. (2011) *World Scientific Illustrated*, Kindle Edition, 794 pages

[6] Maher I. Boulos. The inductively coupled radio frequency plasma. Pure & Appl. Chem., V.57(9), pp.1321–1352,1985

[7] Kazantsev S. A., Khutorshchikov V. I, Guthohrlein G. H., Windholz L., Practical Spectroscopy of High-Frequency Discharges, *Plenum Press, New York, and London*, 1998, 2013

[8] Ubelis A. P., Berzinsh U. V. (1983). Transition probability measurements of Te I spectral lines by methods of emission and absorption of radiation. *Physica Scripta*, 28(2), 171

[9] Ubelis A. P., Berzinsh U. V. (1991). $5s^2 5p^3 6s$-$5s^2\ 5p^4$ transition probabilities of Te I. *Physica Scripta*, 43(2), 162

[10] Roederer I. U., Lawler J. E., Cowan J. J., Beers T. C., Frebel A., Ivans I. I., et al (2012). Detection of the second r-process peak element tellurium in metal-poor stars. *The Astrophysical Journal Letters*, 747(1), L8

[1] Basic principles and the main design features were comprehensively reviewed by M.I. Boulos in 1985, see [6]

[11] Ūbelis A., Pumpurs A., Kļaviņš J., Bzhishkian A., Gabrusenoks J, Measurement of atomic and ionized (B I and B II) spectra of hardly volatile Boron using a unique technique – hybrid plasma system. *The 6th International Biennial Conference 'Photonics Sciences and Space Research* – Riga 2025', Book of Abstracts, pp. 103–104

[12] Čakšs M., Ūbelis A., Kolesniks A., Silamiķelis J. Spectroscopic studies of Gd I and Gd II using hybrid plasma source. *The 6th International Biennial Conference 'Photonics Sciences and Space Research* – Riga 2025', Book of Abstracts, p. 118

[13] Ūbelis A., Mētra Z., Kolesniks A., Rupkus J., Measurement of atomic and ionised (Pb I and Pb II) spectra of Lead hybrid plasma system. *The 6th International Biennial Conference 'Photonics Sciences and Space Research* – Riga 2025', Book of Abstracts, pp. 105–106

Laboratory Atomic Spectroscopy for stellar and kilonova astrophysics

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Astronomical spectra provide the vast majority of information that we know of the objects in the universe. These diagnostics are possible from detailed knowledge of the structure of the atomic species involved. In addition, the line strengths must be accurately known to use astronomical spectra for quantitative analyses, such as the determination of stellar and nebular temperatures, ion and electron densities, and ultimately chemical abundance. Spectral regions provide insight to different processes, but also different objects, since the emission and absorption have various spectral imprints. In recent years, the near-infrared wavelength region, 1–5 μm, is becoming more important thanks to its smaller interstellar extinction and several new spectrographs are coming online matching these needs. The planned European Extremely Large Telescope (E-ELT) will observe predominantly in the infrared domain. The lack of atomic data for the near-infrared region will appear in this case. Stellar surveys in the optical region rely on accurate transitional data to fully exploit the expensive observations.

Our research program on Laboratory Atomic Astrophysics focuses on the needs atomic data, both line identification and measurements of intrinsic line strengths, the oscillator strengths. This includes both the infrared and optical transitions.

We will review the branching fraction and lifetime technique to measure line strengths, using the high-resolution Fourier spectrometer at Edlen Laboratory at Malmö university, in combination with radiative lifetimes. The measurements are combined with calculations using the GRASP and ATSP2k codes, providing a high-accuracy data set for astrophysical analysis.

In the present contribution, I will discuss infrared transitions from an atomic structure point of view and as a base for the astronomical analysis as well as for laboratory and theoretical priorities. Examples are given from recent studies on Sc I, Mg I, Al I, Si I and La I for the stellar studies. In addition, I will present our project on high-precision lifetime measurements of metastable states, performed at the DESIREE storage ring.

A more recent application is the detection of a kilonova, the afterglow from a binary neutron star merger, in 2017. To decipher these spectra, atomic data for the heavy neutron-capture elements is needed. I will present our work in this area.

Probing molecular mutual neutralisation reactions of atmospheric importance using the ion storage facility DESIREE

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The evolution of many cool molecular plasma environments is defined and governed by intricate balances between ionizing processes, chemical rearrangements, and neutralisation reactions such as mutual neutralisation (MN). Measuring and explaining these processes in detail is crucial to modelling and understanding non-local thermal equilibrium (non-LTE) environments, such as atmospheric plasmas [1–5].

Until recently, experimental studies of MN involving molecular ions in flow tubes and merged-beams experiments were limited to measurements of overall reactivities without detailed information of the mechanism or of the final states formed, see e.g. [6–10]. The Double ElectroStatic Ion Ring ExpEriment (DESIREE) facility [3–5, 11–15] – see Fig. 1 for a schematic over the whole facility – with its combination of stored and merged ion beams and coincident imaging detection, has now made studies on mutual neutralisation involving molecular ions possible [5,14,15].

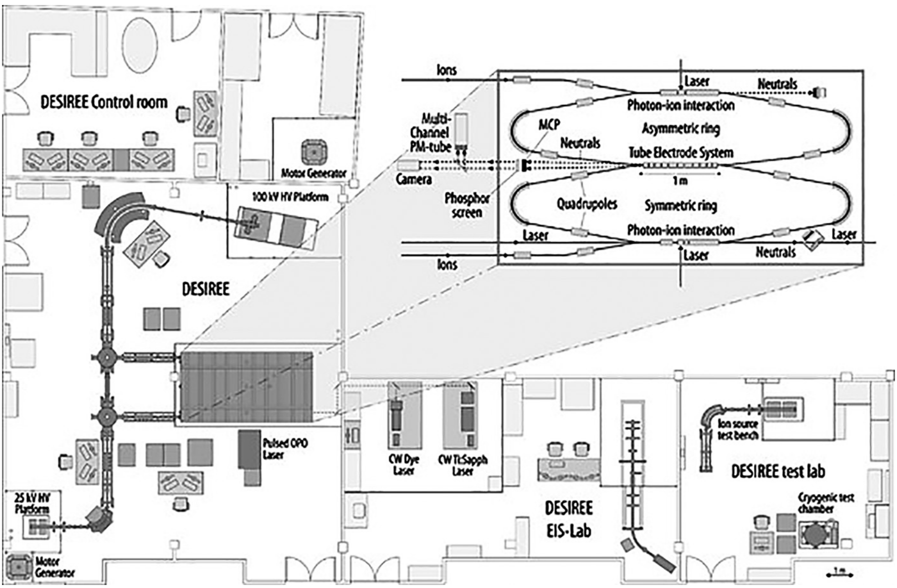

Figure 1. *The Double ElectroStatic Ion Ring ExpEriment (DESIREE) facility*

Using this facility, we aim for a better understanding of how small and large molecules are formed and processed in astrophysical, atmospheric, and combustion plasmas, where we combine several novel experimental methods to build a fundamental picture of the transfer of charge-, energy- and mass in collisional reactions. Control over the reaction environment, e.g., the ion-ion collision energy may be fine-tuned in small steps, and the ability to manipulate the internal energies of the ions before they react, see e.g. [13]. means that desired information, e.g., identify the reaction products and the states they are in [3–5,14,15], can be obtained over many of the conditions needed to accurately model plasmas where these processes are important.

Identification of the products from the MN reactions has been possible by two generations of time- and position-sensitive detector systems. In the first-generation detection system that was in operation previously installed at DESIREE, the position and time information of each event were recorded separately. Light from the particles striking the MCP-phosphor screen detector was taken out of the vacuum chamber and focused via a beam-splitter onto a CMOS camera and a 16-anode PMT, as illustrated in Fig. 1. Differences in the arrival time of the particles at the detector are extracted from the PMT, and positions were recorded from images taken with the camera. The two detectors were controlled independently, and data then had to be matched during analysis using absolute time-tags. This significantly limits multi-particle detection efficiency as there is the strict requirement that particle events trigger different anodes of the PMT, as once an anode is triggered it is vetoed and cannot be re-triggered for 200 ns. These issues are addressed by a newly installed time-resolved and event-driven camera with a 256 × 256 pixel array, where each pixel in the sensor possesses its own signal processing circuit (Amsterdam Scientific Instruments, TPX3CAM). Multi-particle coincidence events can be detected with much greater efficiency than realisable in the previous system, as each pixel is individually addressable and not vetoed after triggering, as illustrated in Fig. 2.

Here, I focus on MN relevant to atmospheric non-LTE phenomenon such as sprites [16,17], looking at reactions involving molecular oxygen and nitrogen ions, e.g., $O^- + NO^+$ [5] and $O^- + O_2^+$. For example, in the MN of NO^+ with O^- at low collision energies ($E_{c.m} < 1$ eV), two different classes of reaction products are energetically available:

$$NO^+ + O^- \rightarrow \text{N+O+O} + E_K \; vs \; NO^* + O + E_K$$

Here, the products share E_K of kinetic energy. On capturing the electron from O^-, the neutralised NO^* either stabilises by fragmentation yielding three atomic products or by photon emission, yielding two neutral products. At low $E_{c.m.}$, the only open three-body channel (2a) produces ground- state products sharing E_K = 1.3 eV of kinetic energy whereas several molecular pathways are available with E_K varying from 0.1 to 7.8 eV.

***Figure 2**: The MCP-phosphor TPX3CAM time-and-position sensitive detection system at DESIREE*

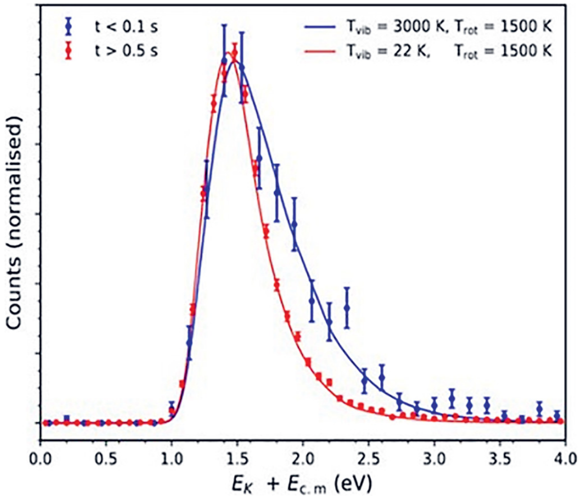

***Figure 3**: EK distributions from two storage time intervals. Full lines are fits assuming a constant rotational distribution (T_{rot}= 1500 K), and a vibrational distribution described by: (blue) T_{vib} = 3000 K, and (red) T_{vib} = 22 K*

By measuring the positions and differences in arrival times of the MN reaction products on the detector, we are able to determine for each event the kinetic energy, E_K, of the products, and construct a distribution of E_K values for many such MN events, as illustrated in Fig. 3.

Analysis of the experimental E_K distribution reveals that the low-collision-energy MN of NO^+ with O^- is completely dominated by dissociation into three ground-state atomic products, and that the process proceeds in a two-step mechanism via a Rydberg state of NO [5].

In addition, due to the unique possibilities offered by the DESIREE facility, we are able to follow reactions as a function of the storage time of the ions. During storage, the hot molecular ions radiatively couple to the cryogenic environment [13], and cool away internal energy. The radiative lifetimes of the first ten vibrational levels of NO^+ are ~100 ms [18], and a beam of pure NO^+ $(\nu = 0)$ will be present after less than one second of storage.

The effect of ion-cooling is observed in the kinetic energy E_K given to the three atomic fragments. The E_K distribution plotted by the blue points in Fig. 3. are obtained from events which are measured in the first 0.1 s of storage, while the data plotted by the red points are obtained after 0.5 s of storage. The distribution obtained at short storage times is broader, as the molecular ions have not yet cooled sufficiently and their internal rovibrational energy ends up being given to the atomic fragments as additional kinetic energy. As the ions cool, this "available" energy decreases, as indicated by the significantly narrower red data points.

We are then able to demonstrate the power of the techniques available at DESIREE to elucidate competition between two- and three-body product channels, unravel effects of rovibrational energy on the reaction, and provide high-quality experimental data to both benchmark and drive better cool molecular plasma modelling.

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References

[1] Capone L. A., et al. (1981) *Nature* **293**, 45
[2] Shuman N. S., et al. (2015) *Chem. Rev*. **115**, 4542
[3] Poline M., et al. (2021) *Phys. Chem. Chem. Phys*. **23**, 24607
[4] Poline M., et al. (2022) *Phys. Rev. A* **105**, 062825
[5] Poline M., et al. (2024) *Phys. Rev. Lett.* **132**, 023001
[6] Miller T. M., et al. (2012) *J. Chem. Phys.* **136**, 204306
[7] Shuman N. S., et al. (2014) *J. Chem. Phys*. **140**, 044304
[8] Shuman N. S., et al. (2014) *J. Chem. Phys*. **140**, 224309
[9] Peterson J. R., et al. (1971) *Phys. Rev. A* **3**, 1651
[10] Padget R., Peart B. (1998) *J. Phys. B: Atom., Mol. Opt. Phys*. **31**, L995
[11] Thomas R. D., et al. (2011) *Rev. Sci. Instrum*. **82**, 065112
[12] Schmidt H. T., et al. (2013) *Rev. Sci. Instrum*. **84**, 055115
[13] Schmidt H. T., et al. (2017) *Phys. Rev. Lett.* 119, 073001
[14] Bogot A., et al. (2024) *Science* **383**, 285
[15] Bogot A., et al. (2024) *Science* **383**, 285
[16] Liu N., et al. (2015) *J. Atmos. Terr. Phys*. **136**, 98
[17] Malagón-Romero A., et al. (2024) *Geophys. Res. Lett*. **51**, e2023GL107990
[18] Werner H.-J., P. Rosmus P. (1982) *J. Mol. Spectros*. **96**, 362.

The prospects of the application of laser-induced breakdown spectroscopy for analysis in ores from deep boreholes in Latvia

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The aim of reported research agenda, to clarify the potential to enrich knowledge base on the presence of various elements and precious metals [1] up to trace level in geological structures of Latvia via renewed studies of deep (up to 1.2 km) boreholes using the advanced and very sensitive LIBS methodology and the experience obtained by the applicant and the team of colleagues in the first pilot studies [2], [3], [4]. The methodology is particularly valuable for trace-level identification as it eliminates the need for intermediate steps or time-consuming preconcentration procedures. LIBS is a simple, straightforward, versatile, and highly sensitive form of atomic emission spectroscopy that focuses a rapidly pulsed laser beam onto a sample to form a micro torch plasma containing its constituent elements, followed by spectral analysis of the emitted light to detect the elements present. The LIBS technique, up to now, has been rarely used in geological material studies, despite its advantage of directly and rapidly identifying trace elements in samples. It requires no intermediate steps or time-consuming preconcentration procedures.

The proposed application of the LIBS technique will be a valuable pioneering effort to start **microscale geochemical mapping** within Latvia's crystalline geological structures, laying the foundations for large-scale follow-up projects. This will mark the first nationwide application of LIBS technologies for deep boreholes (207 boreholes across the territory of Latvia), with the potential for game-changing outcomes that could shed light on the finer details of Latvia's still underexplored geological structures and the relevant economic potential.

The crystalline basement rocks of Latvia have been considered unpromising for practical use [5] due to significant depth, 300–1900 m (iron ores 400–1000 m). However, nowadays, valuable metals such as gold, silver, platinum, and even copper and nickel are mined in shafts reaching a depth of 2–4 km. Manganese (to 18% in Staicele deposit) and cobalt (to 0.7% in Gārsene deposit) were previously found in the iron ores in the 1980s–1990s today is in the list of critical materials of the European Union, see [6]. If the quantity of metals reaches mineable limits and the ore quality is good, the depth of up to kilometres is not an obstacle for their practical use.

The response to the societal demand in Latvia and the EU is an important objective of the foreseen research. Planned efforts align with the EU Green Deal, indicating possibilities for more focused mining, reducing environmental impact, and associated "carbon footprint".

To achieve the objectives of the foreseen research, the following roadmap is proposed by the authors of this presentation:

- Revision of studies of geological samples performed since the 1980s-1990s when drilling was made, and studies on the current "state-of-the-art" in the application of LIBS technique for deep borehole studies.

- Targeted experimental search for traces of precious metals and valuable minerals in the geological samples from deep boreholes, for mapping the location of various elements across the depth of each borehole.
- Development of calibration methodology for the selected metals of elements to move from qualitative studies to quantification.
- Efforts of further advancement of application of LIBS technologies in geology research, particularly hybrid coupling of laser-produced & RF-ICP plasma.
- The development of a knowledge base for the **microscale geochemical mapping** of the crystalline basement of Latvia and the design of research programs for future comprehensive large-scale studies.

References

[1] List of Critical Raw Materials is named for 2023 in the European Union report: *European Commission*, Study of Critical Raw Materials for the EU 2023 – Final Report

[2] Ganeev R. A., Kim V. V., Vorobyov D., Gross U., Ubelis A., Ozols D., Sarakovskis A. (2024). The First Application of Laser-Induced Breakdown Spectroscopy: A Fast-Analytical Technique in Targeted Search for Elements in Geological Samples from Deep Boreholes in Latvia. *Latvian Journal of Physics and Technical Sciences*, 61(2), 23–32

[3] Rashid A. Ganeev, Vyacheslav V. Kim, Jelena Butikova, Aigars Atvars, Jurgis Grube, Anatolijs Sarakovskis, Arnolds Ubelis, (2023). High-order harmonics generation in Cd and Pd laser-induced plasmas, *Opt. Express* 31, 26626–26642

[4] Kim V. V, Grube J., Butikova J., *et al*. (2022) Influence of chromium plasma characteristics on high-order harmonics generation, *Appl. Phys. B* 128, 217

[5] Brangulis J. A., Kuršs V., Misāns J., Stinkulis Ģ. (1998). Latvijas ģeoloģija (*Geology of Latvia*). *State Geological survey of Latvia*, Riga

[6] Vetrennikov, V. (1991) Zhelyezisto-kremn'istye formacii dokembriya Latvii i ih prognoznaya ocenka (Ferruginous and siliceous formations in the Precambrian of Latvia and their forecasting evaluation). Riga, *Zinatne* (*in Russian*).

Four-level Generation in Laser-Induced Plasma Lasers

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Laser-induced plasma lasers (LIPL) have been extensively studied in the Laser Spectroscopy Lab of Ariel University. We demonstrate that stimulated emission and lasing occur under appropriate resonant and **linearly polarised** optical pumping of a pre-formed laser-induced plasma (LIP) plume. It manifests as the emission of intense, collimated, and **polarised** beams. A relatively small external magnetic field governs the polarisation of the LIPLs generation. We call this effect Laser-Induced Plasma Lasers (LIPLs). We investigated LIPLs generated according to the 3-level scheme (the 13th group elements) [1–4] and according to the quasi-three-level scheme, which we nominate as a Direct Generation (**DG**) scheme (mostly elements from the 14th group) [5, 6].

The present talk explores the four-level generation in LIPLs, where lasing occurs between intermediate energy levels. The upper generation level Eu is inversely populated from the pumped level E_p through fast electron impacts (**IP**) and IR radiative transitions. The two cases are distinguished based on the energy difference $\Delta E = Ep - Eu$: (i) a large $\Delta E \approx$ 1 eV, and (ii) a small $\Delta E \approx$ 0.1 eV. In this case of $\Delta E \approx$ 1 eV, there are numerous intermediate energy levels between E_p and E_u. Achieving population inversion at the E_u level requires collisional processes to transfer population effectively through these intermediate levels. The mechanism of these collisional processes and the potential role of direct infrared (*IR*) generation transitions from E_p to E_u are discussed in the presentation. When the energy gap is small, there may be few or no intermediate levels between E_p and E_u. This leads to an effective coupling of E_p and E_u to one level simplifying the population inversion process. In this scenario, the generation process is discussed within the framework of the direct generation (DG) scheme as outlined in reference [6].

The experimental setup is presented in [7]. Here we only emphasize that the pumping OPO generation is vertically polarised, and the polarisation of the LIPL was measured relative to the OPO polarisation vector $\boldsymbol{E_p}$. The degree of generation polarisation (DOP) was used as a measure of polarisation, defined as:

$$\boldsymbol{DOP} = \frac{(I_{II} - I_{\perp})}{(I_{II} + I_{\perp})}, \quad (1)$$

where $\boldsymbol{I_{II}}$ and $\boldsymbol{I_{\perp}}$ represent the generation-line intensities with the electric vector $\boldsymbol{E_g}$ parallel and perpendicular to $\boldsymbol{E_p}$, respectively.

Fig. 1 a presents *Ti* LIPL under pumping at 230.27nm as a typical four-level generation with large ΔE (≈ 0.7 eV). Under this pumping, the DG is observed at 1688 nm ($E_p = E_u =$ 5.404 eV), alongside four-level generation lines at 548.14 nm and 622.04 nm (with E_u = 4.669 eV for both). The generation lines at 1688 nm and 547.77 nm are strongly polarised with a positive DOP, while the 622.04 nm line is polarised with a negative DOP. The external magnetic field of 280 mT parallel to the direction of the generation strongly diminishes generation polarisation. Fig. 1b presents these generations' transitions scheme.

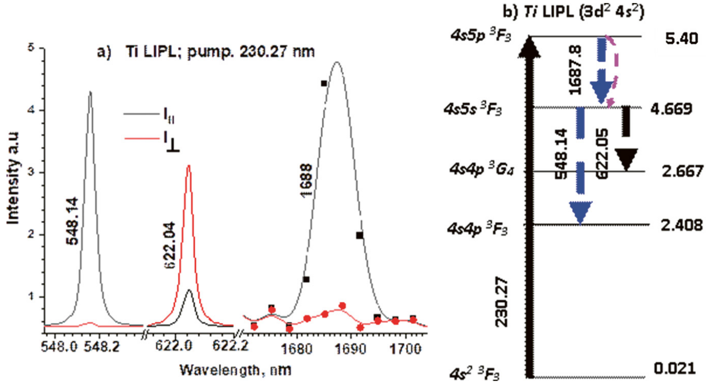

Figure 1. *a) Four-level polarised generation spectra for Ti LIPL under pumping at 230.27 nm; b) Energy scheme for these generations. The black upward-pointing arrow represents the pumping transition. Violet curved arrows indicate collisional transitions. Dashed blue and black arrows pointing downward represent lasing with positive and negative DOP, respectively. The numbers along the arrows correspond to the pumping and generation wavelengths, and the numbers to the right of the levels represent energy in eV*

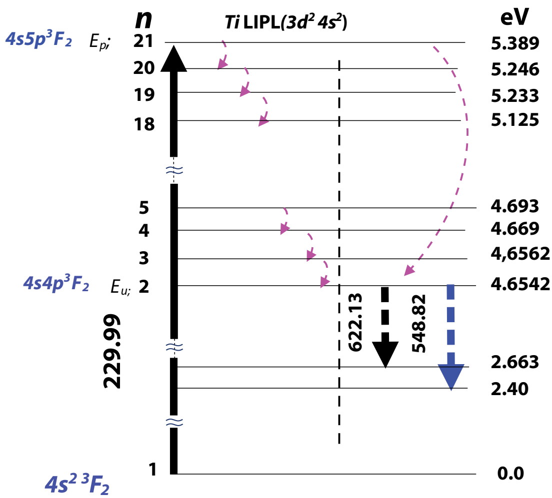

Figure 2. *The scheme of the Ti LIPL under pumping at 229.99 nm*
The left part presents the cascade of the allowed collisional transitions; the right part is the one-step collisional jump from the E_p *level to the VIS generation* E_u *level*

Two pathways for the creation of the inversion population on the E_u level due to collisionally assistant transitions are discussed in the example of the Ti LIPL pumped at 229.99 nm: The first is the cascade El energy loss involving **all** intermediate levels between E_p and E_u levels. The second one is the one-step collisionally assistant jump from the E_p level to the E_u level.

Fig. 2 presents the energy scheme of the Ti LIPL pumped at 299.99 nm, which was used for estimating models of the E_u inverse population. The left section illustrates the cascade of allowed collisional transitions, while the right section represents the one-step collisional jump from the $\boldsymbol{E_p}$ level to the $\boldsymbol{E_u}$ level. The variable *n* denotes the ordinal number of the transitions: for the ground level, ***n* = 1**; ***n* = 2** corresponds to the $\boldsymbol{E_u}$ level for the 548.82 nm and 622.13 nm generations, and so on. The last transition ***n* = 21**, represents the $\boldsymbol{E_p}$ level. EI collisions involving energy loss of excited atoms are discussed. In the first case, the cascade transitions follow the sequence ***n* = 24 → *n′* = 23**, ***n* = 23 → *n′* = 22**, continuing down to ***n* = 3 → *n′* = 2**.

The rates coefficient $\beta_{n,n'}^{mix}$ (in cm³/sec) for transitions between states *n* – *n′* (*n* > *n′*) is determined as follows [8, 9]:

$$\beta_{n,n'}^{mix} = 4\pi\alpha_0^2 \upsilon_e \left(\frac{I_H}{k_B T_e}\right)^2 \; 3 f_{n,n'} \Psi_{n,n'} \frac{I-E_n}{I-E_{n'}} \; e^{-\frac{\Delta E_{n,n'}}{k_B T_e}}, \tag{2}$$

where indices *n* and *n′* denote the upper and lower states respectively, $\Delta E_{n,n'} = E_n - E_{n'}$. a_0 is Bohr radius, υ_e is the average electron velocity (proposing the υ_e Maxwellian distribution). I_H is the hydrogen atom ionisation energy. $I = I_H Z^2$ is an atom ionisation potential; Z is the atomic number.

$$\Psi_{n,n'} = \frac{e^{-x_{n,n'}}}{x_{n\,n'}} - E_i(x_{n,n'}), \; x_{n,n'} = \frac{\Delta E_{n,n'}}{k_B T_e}, \; E_i(x_{n,n'}) = \int_{x_{n,n'}}^{\infty} \frac{e^{-t}}{t}\, dt, \tag{3}$$

where $E_i(x_{n,n'})$ is the exponential integral function.

The oscillator strength $f_{n\,n'}$ is determined through the dipole moment matrix element, which depends on the initial and final states of the atom

$$f_{n,n'} = \frac{2m_e}{3\hbar^2} \frac{\Delta E}{e^2} \, |\langle \psi_n | \boldsymbol{d} | \psi_{n'} \rangle|^2, \tag{4}$$

where m_e is the electron mass, *ħ* is the reduced Planck constant, *e* is the electron charge, and $\langle \psi_n | \boldsymbol{d} | \psi_{n'} \rangle$ is the dipole moment matrix element for the transition between the initial (ψ_{n}) and final ($\psi_{n'}$) wave functions.

Cascade collision rates Ac (probability in sec⁻¹) are:

$$A_c = N_e \prod_{j=21}^{2} \beta_{n=J,n'=J-1}^{mix} = N_e \left[\beta_{n=21,n'=20}^{mix} \, x \, \beta_{n=20,n'=19}^{mix} \, x \cdots x \, \beta_{n=3,n'=2}^{mix}\right], \tag{5}$$

where N_e is the electron density; $\beta_{n=J,n'=J-1}^{mix}$ is the coefficient for collisional transitions between levels *n* = *j* and *n′* = *j* – *1*.

Jump-like probability A_{jump} are:

$$A_{jump} = N_e \, \beta_{n,n'}^{mix}. \tag{6}$$

The results of the numerical estimation show that the probability of achieving the inversion population in the cascade of 21 transitions Ac **is about 0**, while the one-step jump probability between level ***n* = 21** and level ***n′* = 2 (A_{jump}) is about 3.7 10^{10} sec⁻¹. This indicates that the jump-like collisions may dominate in the creation of the inversion population on the E_u level.**

This estimation is supported by the absence of the generation from intermedia levels which are populated during the cascade of collisions (see Fig. 3). The polarisation observed in the 4-level generation with a large ΔE may further support the one-step collision process for populating the E_u level, as it is difficult to imagine.

References

[1] Nagli L., Gaft M. (2015) Lasing effect in laser-induced plasma plume, *Opt. Comm.*, **354,** 330–332

[2] Nagli L., Gaft M., Gornushkin I., Glaus R. (2016) Stimulated emission and lasing in laser-induced plasma plume, *Opt. Comm*. 378 41–48

[3] Nagli L., Stambulchik E., Gaft M., Raichlin Y. (2021) Polarization effects in laser-induced plasma lasers based on elements from the 13th group, *J. Appl. Phys*. 129, 013103-1-6

[4] Gornushkin I., Glaus R., Nagli L. (2017) Stimulated emission in aluminum laser-induced plasma: kinetic model of population inversion, *Appl. Optics*, 56 695-70

[5] Nagli L., Gaft M., Raichlin Y. (2022) Hanle effect in Ti Laser-Induced Plasma Lasers, *Optics Communications* 517 128292-1-7

[6] Nagli L. (2024) Polarization properties of the Laser-Induced Plasma Lasers generating according to the quasi-three-level scheme, *Optics Communications* 559 130423-1-8

[7] Nagli L., Kulikov K. (2025) Four-level generation in Laser-Induced Plasma Lasers, *Optics Communications* 583 131665 1–11

[8] Zel'dovich Ya., Raizer Yu. (2002) Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, Dover Publications*, Mineola, NY, pp. 382–421, 264–269

[9] Gornushkin I., Kazakov A. (2017) Kinetic Model of Stimulated Emission Created by Resonance Pumping of Aluminum Laser-Induced Plasma, *J. Appl. Phys*. 121 213303-1-11.

Towards the use of organic materials in the terahertz range

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Functional materials used in terahertz (THz) range photonics and optoelectronics include traditional semiconductor materials such as silicon, germanium, gallium arsenide, gallium nitride, etc., which are used to generate and detect THz radiation; dielectric optical materials such as zinc telluride, gallium selenide, and barium borate, which are used to filter and modulate THz waves; and plasmonic metallic materials such as gold and silver, which are used to focus and amplify THz signals [1–3]. Recently, non-traditional materials such as organic ones have been applied in THz technology. This is caused by the need for more efficient THz devices for integrated THz systems. Organic materials for THz applications have the advantages:

- flexibility,
- light weight,
- low cost,
- scalability,
- tunability.
- At the same time, there are some challenges:
- low efficiency,
- material stability,
- charge carrier mobility [4, 5].

In this paper, we review possible organic materials for prospective optoelectronic THz generators, THz detectors, and other THz devices. One potential candidate is heterocyclic amines, such as indoles, pyrroles, and quinolines, which are sometimes used in organic photo-conductors for THz generation and detection. These materials can be applied in photo-conductive antennas that convert optical pulses into THz radiation. Their electrical properties can be easily tuned to optimize their performance in the THz range. Some of them have potential for use in THz waveguides. Another good candidate is carbazole and its derivatives, which show great promise due to their high carrier mobility, nonlinear tunability, and easy functionalisation. For instance, carbazole derivatives such as 3,6-diphenylcarbazole and biscarbazole are being studied for their potential for THz applications. Their wide band gap and high electron mobility make them suitable for fast and efficient optoelectronic THz generators and THz detectors. Carbazole derivatives are also being explored for use in THz modulators, which can control the amplitude, phase, and polarisation of THz waves. Their ability to change their optoelectronic properties under the external electric field makes them useful for THz modulating in communication systems. They can also be used for THz sensing in detection systems, where organic optoelectronics offer advantages of flexibility and low cost. Both heterocyclic amines and carbazole derivatives can be easily modified to tune their optoelectronic properties, making them highly versatile for a variety of THz applications. Challenges related to efficiency and stability need to be addressed before these functional organic materials can be widely used in practical THz devices and systems.

References

[1] Freeman J., Linfield E., Davies A. G. (2025) Terahertz frequency electronics and photonics: materials and devices. *Phil. Trans. R. Soc. A* 383, 20230378

[2] Ukirade N. A. (2025). A review on advancement of materials for terahertz applications. *Next Mater*. 6, 100479

[3] Leitenstorfer A., et al. (2023) The 2023 terahertz science and technology roadmap. *J. Phys. D: Appl. Phys*. 56, 223001

[4] Kim S.-J., et al. (2021) Nonlinear optical organic crystals for efficient terahertz wave generation, detection, and applications. *Adv. Opt. Mater*. 9, 2101019

[5] Jazbinsek M., et al. (2019) Organic crystals for THz photonics. *Appl. Sci*. 9, 882.

Plasmonic crystals for THz applications

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In the area of fundamental and applied condensed matter physics, there is a significant interest in the research related to the development of THz technologies focused on the elaboration of core elements of optoelectronic systems: generators, emitters, detectors, and modulators of electromagnetic radiation capable to operate in the frequency range of 0.1–10 THz. The relevance of this direction is primarily associated with the applied aspects of the widespread use of THz radiation in various fields, such as spectroscopy, including astrophysical measurements, 6G communications, medicine, environmental monitoring, security systems, explosives detection, etc. [1, 2]. Among the various areas of development of THz technologies, THz plasmonics is a new field with great prospects and achievements. This field studies the wide class of phenomena relating to the peculiarities of interaction of electromagnetic (em) waves of THz frequency range with collective oscillations of electron gas (plasmons) in low-dimensional structures and nanodevices on their basis [3, 4].

One promising platform for THz plasmonic systems is the plasmonic crystals (PCs) fabricated in the form of quantum well heterostructure covered by grating-gate metasurfaces (Fig. 1). Such PC structures provide essential enhancement of THz light-matter interaction with particular resonant properties associated with different plasmonic modes excited in low-dimensional electron gas. PCs have shown enhanced performance as THz detectors [5] and hold potential for applications as THz emitters/amplifiers [6], and modulators [7, 8].

This thesis addresses to overview of recent experimental and theoretical studies of resonant interaction of plasmon excitation of 2D electron gas (2DEG) with THz electromagnetic waves in PCs. Particularly, several effects concerning a formation of different resonant-plasmonic phases of PC structures, 2D plasmon instabilities under metallic grating, magneto-plasmons, including non-linear effects of self-induced transparency of PCs by high-power picosecond pulses will be highlighted.

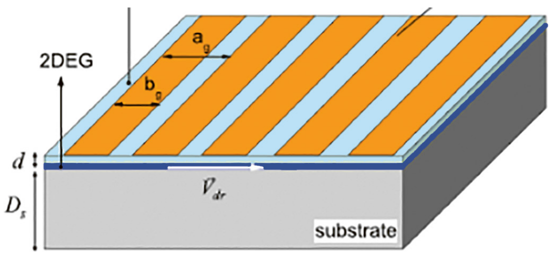

Figure 1. *Sketch of metallic grating-based PC structure with 2DEG*

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References

[1] Tonouchi M. (2007) Cutting-edge terahertz technology, *Nature photonics* 1(2), 97–105

[2] Federici J., Moeller L. (2010) Review of terahertz and subterahertz wireless communications, *J. Appl. Phys*.107, 111101

[3] Otsuji T., Shur M. (2014) Terahertz Plasmonics: Good Results and Great Expectations, *IEEE Microw. Mag*. 15, 43

[4] Shur M. S. (2021) Terahertz Plasmonic Technology, *IEEE Sens. J.* 21, 12752

[5] Popov V., Fateev D., Otsuji T., Meziani Y., Coquillat D., Knap W. (2011) Plasmonic Terahertz Detection by a Double-Grating-Gate Field-Effect Transistor Structure with an Asymmetric Unit Cell, *Appl. Phys. Lett.* 99, 243504

[6] Boubanga-Tombet S., Knap W., Yadav D., Satou A., But D. B., Popov V. V., Gorbenko I. V., Kachorovskii V., Otsuji T. (2020) Room-Temperature Amplification of Terahertz Radiation by Grating-Gate Graphene Structures, *Phys. Rev. X* 10, 031004

[7] Sai P., Korotyeyev V. V., Dub M., Słowikowski M., Filipiak M., But D. B., Ivonyak Y., Sakowicz M., Lyaschuk Y. M., Kukhtaruk S. M., Cywiński G., Knap W. (2023) Electrical Tuning of Terahertz Plasmonic Crystal Phases, *Physical Review X*, 13, 041003

[8] Sai P., Korotyeyev V. V., But D. B., Dub M., Yavorskiy D., Łusakowski J., Słowikowski M., Kukhtaruk S., Liashchuk Y., Han J. W., Böttger C., Mittendorf M. Extreme Terahertz Nonlinearity of AlGaN/GaN-based Grating-Gate Plasmonic Crystals. preprint arXiv:2503.02562.

A New Industrial Facility for Gold Ore Gamma-Activation Analysis

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Abstract

The results of development and research of the characteristics of a new gamma-activation analysis (GAA) facility, created for quantitative analysis of gold-bearing ores in real conditions of a gold-mining enterprise, are presented. The values of gold detection limit (3σ), measured from the spectra of certified reference samples with an ultra-low background level, were 0.025–0.028 ppm with a single irradiation. In this case, the root-mean-square measurement error for a gold concentration of 1 ppm did not exceed 8%, and 4% for a concentration of 10 ppm. The GAA facility provides the analysis of coarse-ground samples (1–3 mm) with a capacity of at least 65 samples per hour.

Keywords: gold ore analysis; gamma activation analysis; photon activation analysis.

Introduction

Gamma activation analysis (GAA) has a great potential to replace traditional gold assay analysis in mining industry in the future [1–6]. This work is devoted to the results of the development and study of the characteristics of "Au-Isomer", a new industrial GAA facility for mining industry.

Facility design

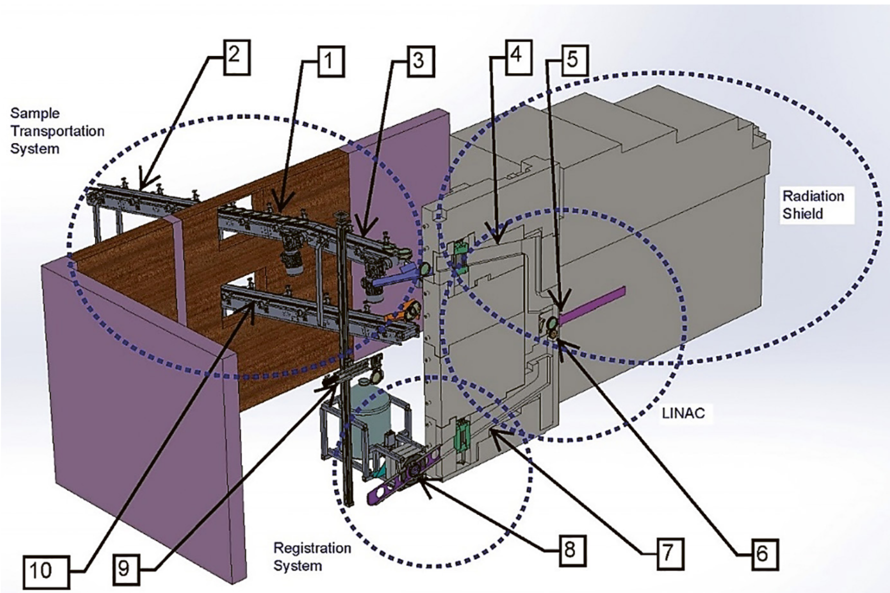

Figure 1. *The GAA facility sketch drawing*

The facility has dimensions of 7.1 x 4.5 m and a height of 4.1 m together with a crane, designed for assembly and disassembly of the radiation shield (Fig. 1). The installation works in a fully automatic mode; the algorithm of its operation is presented below (Fig. 2). Containers with ore samples 1, installed on the receiving conveyor 2 of the GAA facility's Sample Transportation System, are fed through the conveyor 3 to channel 4, along which the containers are rolled to the target 5 of the LINAC. During irradiation, containers are rotated by the drive 6 to ensure uniform distribution of the dose in the container volume.

Channels 4 and 7, like the LINAC, are surrounded by Radiation Shield. After irradiation the containers are rolled down channel 7 to precision spectrometers 8 of the Registration System to measure the induced activity. After measurement the containers are lifted by a lifting mechanism 9 of the Sample Transportation System for unloading onto a containers' return conveyor 10 or loading into channel 4 for re-irradiation. The decision to re-irradiate is carried out by a computer program at a low signal level in the energy range of radiation of the gold isomer. The containers measured for the second time will alternate in channels 4 and 7 with the containers measured for the first time, and the barcode system of the containers at the entrance to channel 4 will inform the computer control system of which container went to irradiation.

At present, time specifications for the developed GAA facility's operating procedure are as follows: moving the container to the barcode reader area – 10 sec; to the irradiation area after reading the barcode – 2 sec; irradiation – 10 sec; moving the container to the detectors of the registration system after irradiation – 2 sec; measurement – 15 sec; making a decision on re-irradiation – 0.5 sec, unloading – 12 sec. Thus, the total time of one analysis is about 52 seconds, which provides an analysis throughput of at least 60–65 analyses per hour. It is planned in the near future to reduce the time of samples feed to the reader, starting from the second sample to 3 seconds, and the time of unloading – to 9 seconds. Thus, the total time of one analysis will be about 47 seconds, which will provide an analysis throughput of at least 75 analyses per hour.

The GAA facility's characteristics research and discussion

The metrological characteristics of the newly developed GAA facility for gold have been investigated and confirmed during acceptance tests, during which more than 2000 analyses were carried out. According to calculations, the DL values determined from the spectra of certified ultra-low background samples MST SG147f, MST Gq157d, and 27006101 with a single irradiation for 10 s and a spectrum acquisition time of 15 s were 0.028, 0.025, and 0.027 ppm (3σ), respectively. The achieved DL level exceeds the DL levels in previous works on the GAA of gold-bearing ores [7–11].

An equally important characteristic of GAA is the measurement accuracy, that would provide gold concentration values. We conducted a study of statistical errors in the analysis of samples with a gold content in the concentration range from 0.312–24.3 ppm. Each sample was tested six times with a single irradiation. The results obtained were used to determine the average value of gold concentration and a relative standard deviation (SD) from the passport value of the concentration. The test results show that for gold concentration of about 1 ppm the root-mean-square deviation does not exceed 8%, and for a concentration of 10 ppm – 4%.

To study the stability of the results of determining the gold concentration in our experiments, we used samples MST209 with a gold concentration of 24.3 ppm, VIMS212GO with a gold concentration of 0.4 ppm and MST SGBlank10 with a gold concentration of less than 0.005 ppm. The measurements were carried out for 6 consecutive days, 5 measurements per day at different times, with constant calibration coefficients and irradiation modes. Based on the test results, the deviation of the measured concentration from the reference for the sample of 0.4 ppm was less than 6.5% and less than 1.0% for the sample of 24.3 ppm. Studies have shown high stability of the results.

In the course of characteristics studies, more than 2000 analyses were carried out on the developed "Au-Isomer" GAA facility. The facility demonstrated excellent DL values – (0.025–0.028 ppm) with a single irradiation for 10 sec and a spectrum acquisition time of 15 sec. In this case, the root-mean-square measurement error for a gold concentration of 1 ppm did not exceed 8%, and for a concentration of 10 ppm – 4%. Studies have shown that with re-irradiation of the sample (4÷5 times), the concentration of gold in the sample at the DL level can be measured with sufficient accuracy. The "Au-Isomer" provides an analysis capacity of at least 65 samples per hour with the possibility of further increasing the productivity up to 75 samples per hour.

References

[1] Hoffman E. L., Clark J. R., Yeager J. R. Gold Analysis-Fire Assaying and Alternative Methods. *Explor. Mining Geol.*, Vol. 7, No. 1&2, pp. 155–160, 1998

[2] Morse J. G. Nuclear Methods in Mineral Exploration and Production. *Elsevier*, 1977

[3] Bourmistenko Yu. N. Photonuclear Analysis of Materials Composition-M.: *Energoatomizdat*, 1986. p. 200 (in Russian)

[4] Bourmistenko Yu. N., Ivanov I. N., Sviridova V. V., Feoktistov Yu. N. Computer-selected optimization of activation analysis methods. *J. Radioanal. Chem.*, 1977, v.40, p. 147–153

[5] Sammut D. Gamma Activation Analysis. A New Gold Standard? *Chemistry in Australia*, February 2016. p. 18–21

[6] Tickner J., Ganly B., Lovric B., O'Dwyer J. Improving the sensitivity and accuracy of gamma activation analysis for the rapid determination of gold in mineral ores. Applied radiation and isotopes: including data, instrumentation and methods for use in agriculture, industry and medicine 122:28-36. 2017.

[7] Navoi Mining and Metallurgical Combinat. https://www.ngmk.uz/en [accessed 06.10.2021]

[8] Sokolov A. D., Burmistenko Y. N., Gostilo V. V., Titov V. L. Industrial Gamma-Activation Assay Systemfor Gold Ore Analysis. *Minerals Engineering*, Vol. 117, 15 January 2018, pp. 179–181.

[9] Sokolov A. D., Demsky M. I., Gostilo V. V., Hasikova E. I., Titov V. L. Gold Ore Analysis Using Industrial Gamma-Activation Assay System. *ALTA Au* 2017, pp. 146–153, Perth, WA May 20–27, 2017. www.altamet.com.au/conferences/alta-2017 [accessed 06.10.2021]

[10] Sokolov A., Gostilo V., Demsky M., Hasikova E. Optimization of an industrial gamma-activation assay system for the analysis of gold and rare earth metal ores. *ALTA 2018 Gold-PM Proceedings*, p. 61–71. ISBN: 978-0-9946425-4-7

[11] Sokolov A., Gostilo V., Demsky M., Hasikova E. Performance optimization of an industrial gamma activation assay system for analysing gold and rare metal ores. *The Journal of the Southern African Institute of Mining and Metallurgy* (SAIMM), Vol.119, May 2019, p. 509–513.

On-Line XRF Analysis of Elements in Minerals on a Conveyor Belt

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Abstract

Determination of the elemental composition of minerals and their derivatives at mining enterprises is important at all stages of materials processing. This paper is devoted to the results of development and application of an online XRF analysis method for monitoring mineral elements on a conveyor of mining enterprises. The paper gives an overview of mining applications in which we have successfully implemented the online analysis based on the CON-X industrial XRF analyser in lump, ore, charge feed, cake and slag materials on conveyor belt. An evaluation of metrological characteristics achieved in these applications is presented.

Keywords: XRF analysis of minerals; elemental analysis; on-line ore analysis on conveyor belt

Introduction

Determination of the elemental composition of minerals and products of their technological processing at mining and refining facilities is important at all stages of material processing (for example, mining and beneficiation). Many analysing techniques have been developed that allow to accurately determine the chemical composition of prepared samples [1–3]. Such an analysis requires setting up special laboratories that have quite a complex and expensive analytical equipment, specially trained and highly qualified personnel. When analysing materials on such an industrial scale, the main difficulties are related to delivering the representativeness of these materials' samples and the speed of analysis, the results of which often become known only after a few hours.

Operational analysis of materials on the conveyor of mining enterprises in most cases does not require sample preparation, which excludes the influence of a human factor and unpredictable accidents on the results of the analysis [4]. Such operational analysis can be based on various nuclear physics methods (e.g., radiometric, neutron activation, gamma activation, and X-ray fluorescence (XRF)) [4–7]. Of course, online analysis methods are usually less sensitive and precise than chemical ones. However, they provide analysis results in real time, which allows to quickly adjust technologies, automate technological processes and eliminate significant human labour costs. Each of the nuclear physics methods has its advantages and disadvantages and solves a certain range of applications [4–7]. X-ray fluorescence analysis (XRF) is one of the most accurate and simplest analytical methods for studying a matter in order to obtain its elemental composition [5, 7]. With the help of this method, various elements from aluminium (Al) to uranium (U) can be detected.

This paper is devoted to the results of development and application of an online XRF method for monitoring elements in minerals at conveyors of mining and processing enterprises. The paper also reviews those mining technological applications where we have successfully implemented the online method and presents an analysis of metrological characteristics achieved in these applications.

Results and discussions

The Chromite lump (Cr_2O_3 or $FeCr_2O_4$) content determination

Control of the chromium content in chromium-iron ore was provided to control the quality of the initial products on the conveyor of a mining company. The online XRF analyser [8] was mounted above a conveyor belt on a standard suspension on four legs with shock absorbers to reduce the vibration of the analyser (Fig. 1.a). The distance between lower surface of the analyser and the surface of ore pieces was 150 mm. The conveyor belt speed was 1 m/s, and the measurement time in this application was t = 60 sec.

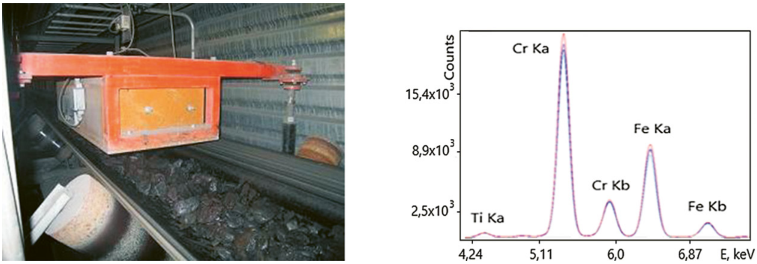


Figure 1. *a) Online XRF analyser on a standard suspension on four legs above the conveyor belt of a mining enterprise; b) Spectrum of chromium-iron ore on the conveyor*

The typical spectrum of chromium-iron ore flowing through the conveyor recorded online by the XRF analyser, used to calculate the concentrations of elements in it and the calculation errors, is presented in Fig. 1.b. The spectrum clearly shows the peaks of chromium and iron, the concentrations of oxides of which in the ore range from 29–40% and 25–30%, respectively. The detection limits of chromium and iron in the ore were 0.07 and 0.08% abs. The accuracy of XRF analysis is confirmed by the data of chemical analysis of more than 300 ore samples, which were taken from the conveyor synchronously with the operation of the spectrometer. The standard deviation of the results of the two methods was 1.1 % abs for Cr_2O_3 and 0.8 % abs for Fe_2O_3.

Analysis of chemical composition of the charge feed

For the production of cast iron from iron ore, agglomerate is used, the raw material for which is an iron-ore mixture (IORM) and limestone. The main task of managing the process of the agglomerate charge preparations to ensure the required chemical composition. The system for automatic continuous monitoring of the chemical composition of charge components (limestone and IORM) was developed on the basis of the XRF online method [4].

The iron-ore charge feed moves on a conveyor belt at a speed of 1 m/s (Fig. 2.a) and has the following granulometric composition: the content of 0–1 mm size class material in IORM is 68–83%, 1–3 mm – 12–23%, the remaining part of IORM consists of larger particles with a 3–8mm size. The IORM level on the conveyor belt is very uneven. To equalise the IORM level and ensure a constant distance between the analyser detector and the IORM layer on the conveyor (40 mm), a floating suspension with a protective cover was developed. In case of heavy loads of the conveyor belt, the spectrometer is automatically lifted above the conveyor by command from the emergency level sensors. The expressiveness of the method for analysing IORM directly in the process flow depends on the time of spectrum measurement and is 6 minutes.

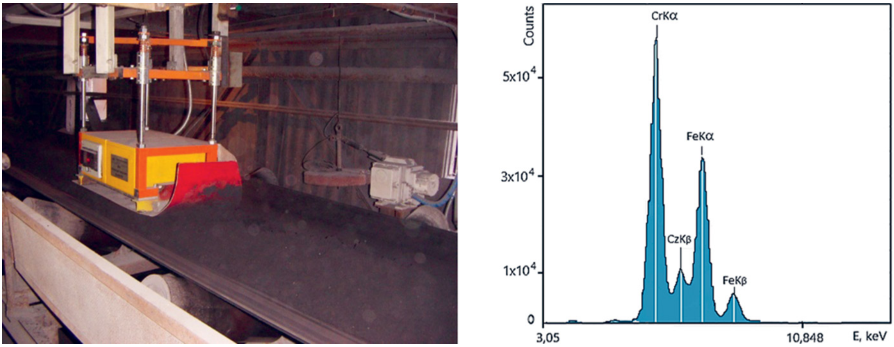


Figure 2. *a) Online XRF analyzer on an iron-ore mixture conveyor;*
b) X-ray fluorescence spectrum of iron-ore mixture

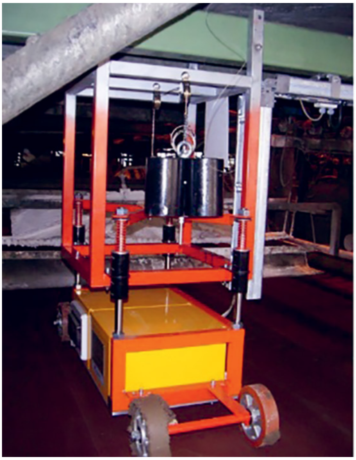
The spectrum of X-ray fluorescence of IORM is shown in Fig. 2.b. The spectrum contains lines of iron, calcium, argon (in the composition of air), manganese, peaks of iron escape, total peaks of iron superposition, peaks of coherent and incoherent scattering of characteristic radiation of the tube (molybdenum line). The range of element concentrations in IORM during the industrial test period was 57.5–60.5; 3.58–4.96; 0.24–2.19 % for Fe, CaO, MnO, respectively. The reproducibility of the results of CaO, MnO and Fe determination was 1.8; 12.0 and 0.2% rel., accordingly. For a sample with a CaO content of 2.56 and MnO content of 1.02 %, the detection limits were 0.33 and 0.21%, respectively. The resulting detection limit for Fe was 0.16%. The error of the X-ray fluorescence determination of CaO, MnO and Fe in IORM directly in the process flow was: 6.4; 19.0 and 0.9% rel., accordingly.

The results of XRF analysis on the conveyor were controlled by comparing these with the results of chemical analysis of 500 simultaneously taken samples [4]. A mechanised sampler was used for sampling IORM on the conveyor. The volume of the sample taken every 6 minutes was 0.6–0.8 kg. Experimental studies showed that the discrepancy between the results of iron determination in the samples and in the flow is characterised by a standard deviation of 1.6% rel. The XRF in the flow methodology is far superior to the IORM analysis technique with one-off samples selection in terms of accuracy, expressiveness, productivity, efficiency and the possibility of participation in the automated process control system (APCS).

Cobalt (Co) content determination in iron-cake

Concentration control of cobalt iron-cake is necessary for an enterprise to control the quality in the technological process. Such control was carried out directly on a belt filter with a cake moving at a speed of 0.3 m/s (Fig. 3.a). The distance from the lower plane of the analyser to the surface of the cake was 50 mm, which was provided by the diameter of wheels supporting the analyser on the surface of the cake. To prevent the wheels from falling into the cake, a dynamic suspension with a balancer has been developed, that kept the analyser in a fixed position above the surface of cake.

The spectrum of the iron cake for the measurement time t=300 sec is shown in Fig. 3.b. The spectrum clearly shows the lines of all elements present in the cake. The task of determining the cobalt concentration is complicated by the fact that the intense Fe-Kβ line overlaps with the weak Co-Kα line. This creates difficulties in determining the Co concentration, but the analyser performs the task due to the sufficiently high energy resolution of the detector.



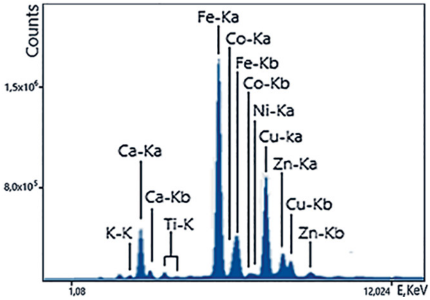


Figure 3. *a) Online XRF analyzer on the belt filter with iron-cake;*
b) Spectrum of the iron-cake during the measurement t=300 sec

To measure the cobalt content in the required concentration range of 0.23–0.36%, the empirical coefficients method was used. This method uses standard samples of different concentrations, close in composition to the real ore. To determine the cobalt concentration, we used a calculation option in which the cobalt peak area is normalised to the peak area (Fe-Kα), using the fundamental value of the Fe-Kα to Fe-Kβ ratio. The best results were obtained when the calibration curve was plotted directly from the ratio of Co/Fe intensities to the incoherent scattering intensity of the radiation. The average result received by the analyser differs from the average result for the same samples in chemical laboratory: – for Co – 0.023% abs. (2.695% rel.); – for Fe – 0.642% abs. (6.766% rel.); – for Cu – 0.091% abs. (6.058% rel.)

Conclusions

Despite the many fundamental problems and technological limitations in the online XRF method, which hinder its wider implementation, its use in the technological processes of mining enterprises continues to grow. As the results of this paper show, the online XRF method allows to solve rather non-standard problems of controlling the content of elements in ore materials (lump, ore, change feed, cake, slag) on conveyors of mining and processing enterprises. This conclusion is supported by the results of applying the online XRF method to determine the composition of minerals on a conveyor in the operational analysis of potassium [9] and phosphate [10] materials, copper-nickel [11] and uranium-thorium materials [12–14].

During the latest years such applications were developed as: the Analysis of iron and other trace elements in quartz sand; – Iron ore analysis; – Chromite ore analysis; – Copper ore analysis; – Zinc analysis in concentrated product; – Cobalt content analysis in iron matrix; – Rutile analysis; – Zircon analysis; – Sylvinite analysis; – Nickel analysis in concentrated product; – Silver ore analysis; – Limestone analysis. A number of projects that the company is currently carrying out and preparing for implementation, will certainly expand the list of applications of the online XRF method on conveyors of mining and processing enterprises.

References

[1] Whiten B. Calculation of Mineral Composition from Chemical Assays. *Mineral Processing and Extractive Metallurgy Review*. Vol.29, issue 2, 2007. p. 83–97

[2] Coomber D. Radiochemical Methods in Analysis. *Springer*, 1975

[3] Gandhi S. M., Sarkar B. C. Essentials of Mineral Exploration and Evaluation, *Elsevier*, 2016

[4] Volkov A. I., Alov N. V. Automated systems for determining the chemical composition of bulk and lump materials on a conveyor (overview). *Problems of Ferrous Metallurgy and Material Science*, 2011, No. 2, 75–88 (in Russian)

[5] Beckhoff B., Kanngießer B., Langhoff N., Wedell R., Wolff H. Handbook of Practical X-Ray Fluorescence Analysis. *Springer*, 2006

[6] Molnar G. Handbook of Prompt Gamma Activation Analysis. *Springer*, 2004

[7] X-Ray Spectrometry: Recent Technological Advances / edited by Tsuji K., Injuk J., van Grieken R. *John Wiley & Sons Ltd*., 2004

[8] Baltic Scientific Instruments. On-line XRF conveyor analyzer CON-X. https://bsi.lv/en/products/ndt-analyzers/-line-xrf-conveyor-analyzer-con-x

[9] Hasikova J., Titov V., Sokolov A., Gostilo V. On-Line XRF Analysis of Potash Materials at Various Stages of Processing. *Canadian Institute of Mining, Metallurgy and Petroleum – CIM Journal*, 2014, Vol.5, No.4, p.256–260

[10] Hasikova J., Sokolov A., Titov V., Dirba A. On-Line XRF Analysis of Phosphate Materials at Various Stages of Processing. *Procedia Engineering* 83 (2014), 455–461

[11] Hasikova E. I., Sokolov A. D., Titov V. L. Real-Time X-Ray Fluorescence Analysis of Copper-Nickel Materials Flow on Conveyor Belt. *ALTA Ni-Co-Cu* 2017, pp. 326–333, Perth, WA May 20–27, 2017

[12] Hasikova E. I., Sokolov A. D., Titov V. L. Quantitative Analysis of Uranium and Thorium Containing Materials Using Industrial On-Line XRF Analyser. *ALTA 2017 U-REE Proceedings*, pp.289–299

[13] Hasikova J., Sokolov A., Titov V. On-Line X-Ray Fluorescence Analysis of Uranium and Thorium Materials in Mining and Processing Industry. "Uranium – Past and Future Challenges", *Proceedings of the 7th International Conference on Uranium Mining and Hydrogeology*, Springer, 2014, p.793

[14] Docenko D., Gostilo V., Sokolov A., Rozite A. On-Line Measurement of Uranium in Ores Using. 3rd International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM- 2009) *Proceedings*, Vienna. Ref. No. IAEA-TECDOC-CD--1739 Available: http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1739_CD/PDF/Session_4.pdf.

Lightguide fiber bundles

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Lightguide has developed an innovative fiber bundle end treatment technology – a stacked fiber bundle (SFB) that facilitates the efficient transmission of the laser light in the deep UV region and does it with minimal losses. Light delivery from a source to a destination can be achieved in several ways using fiber bundles. Lightguide has developed clad fused bundle (CFB) technology that allows high power (up to 6 kW) transmission with low losses in wide spectral regions; while also enabling shaping the bundle ends (the ends can be the same shape or different) in virtually any 2D shape. However, certain applications necessitate the transmission of shorter wavelengths, specifically in the deep UV spectrum (Nd:YAG IV and V harmonics), where existing bundle end technologies have limitations – mainly degraded performance over time and lower transmission.

A stacked fiber bundle uses carbon coated hydrogen loaded fibers, known for their solarisation resistance, formed in a way that enables high transmission and durability when exposed to deep UV light over extended periods. SFB technology could be used in a number of applications requiring transmission of light at deep UV spectral regions. These applications are found in medicine, quality control, UV curing, process analysis, etc.

Keywords: Fiber bundles, deep UV, laser application, carbon coated fibers, hydrogen loaded fibers, deuterium lamp, Nd:YAG harmonics.

References

[1] Klein K. F., Schliessmann P., Smolka E., Belz M., Boyle W. J. O., Grattan K. T. V. (1997) UV-stabilized silica based fiber for application around 200 nm wavelength, *Sensors and Actuators B*, Vol. 38–39, pp. 305–309; DOI: 10.1016/S0925-4005(97)80224-9

[2] Huebner M., Meyer H., Klein K.-F., Hillrichs G., Ruetting M., Veidemanis M., Spangenberg B., Clarkin J., Nelson G. (2000) Fiber-optic systems in the UV-region, *SPIE-Proc. BiOS'00*, Vol. 3911, pp. 303–312; DOI: 10.1117/12.384918

[3] Alps K. (2023) Innovative fused end fiber bundle technology for high-brightness, irregular beam profiles, *Proc. SPIE 12403*; DOI: 10.1117/12.2648342

[4] Alps K., Brūvers I., Grūbe J., Narels M. (2024) Cutting-edge fused end fiber bundle technology for multi kW range applications, *Proc. SPIE 12866*, Components and Packaging for Laser Systems X, 1286603; DOI: 10.1117/12.3000484

[5] Klein K.-F., Gonschior C. P., Beer D., Eckhardt H.-S., Belz M., Shannon J., Khalilov V., Klein M., Jakob C. (2013) Silicabased UV-fibers for DUV applications: current status, *SPIE-Proc.,* Vol. 8775, paper 8775–10; DOI: 10.1117/12.2020993

[6] Heimann J., Klein K.-F., Gonschior C. P., Klein M., Hillrichs G. (2013) Optical fibers for 355 nm pulsed lasers and high-power broadband light sources, *SPIE-Proc. BiOS'13*, Vol. 8576, paper 8576–19; DOI: 10.1117/12.2005146.

Short communications

Towards random UV lasing in 2D ZnO nanopowders

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Zinc oxide (ZnO) is known today as one of the best photoactive wide-bandgap n-type metal-oxide semiconductor nanomaterials belonging to the group II-VI compounds, whose excellent functional optical and electronic properties are of great interest for modern nanophotonics, quantum electronics and optoelectronics [1, 2]. In particular, photoexcited ZnO nanoparticles (NPs) exhibit strong UV excitonic photoluminescence (PL) at room temperature (RT) with a low excitation threshold [3]. This provides good prospects for practical ZnO-based UV light emitters [4, 5]. But despite all the advances in ZnO nanophysics and nanotechnology, some features of RT excitonic PL of ZnO NPs are not so clear, especially in disordered micro- and nano-structured photonic systems with random light scattering at nanoscale [6]. Here we tried to study this issue in more detail for the case of micro- and nanocrystalline 2D ZnO powders.

The experiments were carried out with fine-dispersed ZnO nano-powder of high-grade quality obtained by the classical hydrothermal method. Characterisation was performed by available means of XRD, SEM, Raman and UV-Vis spectroscopy. The measurements showed that randomly oriented polycrystalline ZnO NPs of wurtzite structure have a nodular shape with sizes from 100 nm to 1 µm and crystallites of ~20 nm. The optical bandgap was close to ~3.4 eV. The samples for PL studies were prepared as a ~100 µm thick 2D powder layer packed between thin quartz plates. In the PL spectra excited in ZnO powder at RT conditions by a nanosecond-pulsed N2 laser at a wavelength of 337 nm, we observed two main emission bands: strong excitonic near-band-edge (NBE) PL emission in the blue-UV region at a wavelength of 387 nm (arising from the recombination of free excitons caused by band-to-band transitions) and broad-band deep-level (DL) PL emission in the visible (green-red) region at a wavelength of 500 nm (caused by native defects, i.e., VZn, VO, Oi). The exponential amplification in the peak intensity of the NBE PL band and its FWHM narrowing simultaneously with the attenuation (up to disappearance) of the weak DL PL band during the increase in the excitation power (pumping) clearly indicates the stimulated emission of ZnO NPs in the powder medium. This regime is realised in the entire excitation range due to the non-resonant diffusion mode of light amplification, similar to random laser generation in multiple scattering photonic media of Letokhov type [6]. The emission spectra varied with the observation angle from sample to sample, but the transition from spontaneous to stimulated emission in the samples could be observed in all directions. According to our theoretical estimates, the critical volume for random lasing in 2D powder with ZnO NPs is sufficient. The estimated UV gain is high as ~100 cm^{-1}, the threshold power is low as ~1 mJ/cm^2. The results look promising. Research is in progress.

References

[1] Tashiro A., Adachi Y., Uchino T. (2023) *J. Appl. Phys*. 133, 221101
[2] Sharma D. K., et al. (2022) *Mater. Today Proc*. 49, 3028–3035
[3] Lytovchenko V. G., et al. (2021) *Ukr. J. Phys*. 66, 612–617
[4] Gomes A. S. L., et al. (2021) *Prog. Quant. Electron*. 78, 100343
[5] Ma R.-M., Oulton R. F. (2019) *Nat. Nanotechnol*. 14, 12–22
[6] Cao H., et al. (2019). *Nat. Rev. Phys*. 1, 156–168.

Towards modelling and monitoring of near-earth space debris pollution for the safety of the future lunar missions

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The near-Earth space debris problems are considered serious for the safety of the future lunar missions [1–4]. Over the past 60 years, more than 6,900 rocket launches have put into orbit more than 21,600 objects: 70% of them are still in space and 20% of them are debris. Most of the tracked debris is fragments from explosions and breakups of satellites and space vehicles. Besides, there is a huge amount of debris that is untraceable: ~1.2 million pieces of 1 cm and 130 million pieces of 1 mm or less. Due to the high speed and impact energy, even the smallest objects are dangerous for spacecrafts, and random collisions with objects larger than 10 cm will cause catastrophic destruction, releasing clouds of new debris, followed by cascading collisions (*Kessler effect*). Debris fragmentation follows a power law, when the number of pieces increases dramatically with decreasing size. The total mass of debris exceeds 10,000 tons. To avoid the threat, many active and passive methods for debris mitigation and remediation have been proposed [2]. These measures, if done properly, help reduce space pollution. But single actions may not be enough to prevent the debris re-growth, which reaches 6–9% per year. This requires a comprehensive approach. In addition to regular measurements and characterisation of debris by ground-based and space-based observations (radars, telescopes, sensors, etc.), appropriate modelling and monitoring are needed for correct prediction and assessment.

There are various space debris models to describe contamination in near-Earth orbits from 200 to 36,000 km (i.e. LEO and GEO), developed by NASA, ESA and others. They are divided into two types: engineering models to assess current risks and evolutionary models to predict future risks. Both are used in R&D, but all have uncertainties:

1) changing characteristics of debris objects from past launches,
2) uncertain data from future launches,
3) instability of debris after cascade collisions,
4) vagueness of long-term degradation in different orbits,
5) indefiniteness of gravitational, electromagnetic and radiation effects of cyclic changes in the Earth's atmosphere.

The latter seems to be particularly important to take into account:

a) population of space debris at the Earth-Moon liberation centres (Lagrange points) and
b) expansion of the Earth's upper atmosphere to capture debris in low orbits and aerodynamic removal upon re-entry.

Therefore, the next adjustments are proposed to improve the reliability of the models:

- modelling of space debris accumulation at the Earth-Moon L-points,
- modelling of self-cleaning in low-Earth orbits during 11- and 22-year cycles of solar activity,
- modelling of atmospheric density changes with seasonal variations,

- identification of space debris by statistical pattern recognition,
- correlation of the eco-state of the near-Earth space and the Earth's biosphere [5].

Such simulation models of space debris are currently being developed using computer methods in R&D centres in Ukraine with partners. The results are promising. Research is in progress.

References

[1] United Nations Office for Outer Space Affairs (2025), http://www.unoosa.org/oosa/osoindex/index.jspx

[2] ESA Annual Space Environment Report (2025), http://www.esa.int/space_safety/space_debris

[3] NASA Orbital Debris Program Office Quarterly News 29, 1 (2025), http://orbitaldebris.jsc.nasa.gov

[4] Beldavs V. et al. (2018) Towards the international lunar decade, *EPSC Abstracts 12*, EPSC2018-268

[5] Frolov V. F. (2015). Ecological Safety of the Biosphere of Earth and Space. Kyiv: *Interservice*. 220 p.

Staff Dynamics at the University of Latvia

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This paper is a result of the author's individual 'desk research' and analysis of the data obtained by surfing open resources – it does not represent the official view of the University of Latvia (UL).

UL Strategy reads 'The University of Latvia (UL) is a university of science of a high international standing … The UL contributes to the global science, higher education, knowledge, technology transfer and innovation … Scientific achievements and their integration into studies form the basis of the international reputation and competitiveness of the University of Latvia' [1].

Scientific Activity Development Plan envisages to [2]:

- identify priority research areas and formulate priority directions for the long-term development of scientific activity,
- define the key resources required for the implementation and development of scientific activities, and the most efficient form of their funding and management,
- strengthen research capacity by developing the UL Academic Centre, by promoting the sharing of research infrastructure both within the UL and in cooperation with other scientific institutions of Latvia, by investing in human resources through providing professional development opportunities for researchers, by developing and continuously maintaining a balanced remuneration system.

Let's have a look at numbers available on the University of Latvia websites: Annual reports (open source) [3], University of Latvia statistics (open source; data as of 1 November each year) [4], data provided by the Research department (available on-demand for project managers). Since a number of employees work only part-time or have both academic[1] and general staff[2] positions, some data are provided in full-time-equivalent units (FTE)[3] only. A drawback for the data availability should be mentioned: along with the University of Latvia restructuration, also the structure of the portal 'University of Latvia statistics: Facts and Figures' has been changed – no open-source data are available before 2022 and no open-source data for the structural units before they were merged in large faculties in July 2024. Therefore, it is hardly possible to draw any trusty trends since the reference period is too short (3 years only).

Traditionally, the field of education in Latvia is 'dominated' by women including also employed at universities. In 2024, 55.1% of the academic staff were female and 44.9% were men [5]. This is confirmed also for the UL by University of Latvia statistics: Key indicators [4], (Tab. 1). Although UL has adopted the 'Gender Equality Policy' promoting equal opportunities at work [6], the numbers for professorship are the other way around (Tab. 1) since less women are elected as professors; however, the percentage of women-professors is gently increasing.

1 academic staff – staff elected to academic positions: professors, associate professors, docents, lead researchers, lecturers, researchers, research assistants

2 general staff – administrative staff, auxiliary training staff, technical, economic and all other staff, except academic staff

3 FTE – average number of hours worked to the average number of hours of a full-time worker

Table 1. *Key indicators; source: University of Latvia statistics [4]*

	2022	% women	2023	% women	2024	% women
Academic staff, FTE	785		764		685	
including women	405	52%	392	51%	382	56%
Professors	147		149		172	
including women	57	39%	59	40%	77	45%
Students	14 992		15 056		15 276	
including women	10 812	72%	10 884	72%	11 024	72%
Graduates	3 159		3 270		3 439	
including women	2 432	77%	2 547	78%	2 650	77%
International students	7.3%		7.6%		7.9%	

Staff Dynamics

By comparing data in Tab. 2 and Tab. 3 one can observe unconformity – number of employees (headcount) is different in the Annual reports [3] and the University of Latvia statistics [4]. However, data in both tables show similar trend: number of employees including administration is increasing, also, student population is growing, but the number of the academic personnel, the ones responsible for qualitative teaching, is decreasing (see Fig. 1). Over the 10 last years (Tab. 2) the ratio of academic staff at the University of Latvia has dropped from above 50% (in 2015–2016) to below 40% (in 2024).

Even more agitating trend is emerging: the new framework of the restructured UL is active form 1 July 2024 (data in Tab. 3 for 2024 are as of 1 November 2024, 4 months after restructuring): one can see that the employment intensity (i.e., FTE to number of the respective employees: FTE/no) has decreased for the academic staff and substantially increased for the administration – average employment of the academic staff is about half-time (52%), but for the administration it is almost full time (90%).

Table 2. *Number of Employees (headcount); source: University of Latvia Annual reports [3]*

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Academic personnel	1 446	1 445	1 541	859	1 404	1 404	1 461	1 432	1 410	1 305
General personnel	1 668	1 428	1 634	1 811	1 714	1 687	1 709	1 655	1 745	2 176
Total	**2 714**	**2 873**	**3 175**	**2 670**	**3 118**	**3 091**	**3 170**	**3 087**	**3 155**	3 481
% of Academic pers.	53%	50%	49%	32%	45%	45%	46%	46%	45%	37%
Students	13 055	13 100	15 500	15 200	15 250	15 260	15 590	15 250	15 350	15 600
Graduates	3 052	3 092	2 833	3 466	3 360	3 144	3 292	3 159	3 270	3 439

Table 3. *Number of Employees (headcount and FTE); source: University of Latvia statistics [4]*

	2022			2023			2024		
	no	*FTE*	*FTE/no*	*no*	*FTE*	*FTE/no*	*no*	*FTE*	*FTE/no*
Academic personnel	1 314	785	60%	1 278	764	60%	1 305	685	52%
General personnel	2 081	1 164	56%	2 162	1 247	58%	2 176	1 194	55%
incl. Administration	176	146	83%	185	154	83%	192	172	90%
Total	**3 395**	**1 949**		**3 440**	**2 011**		**3 481**	**1 879**	

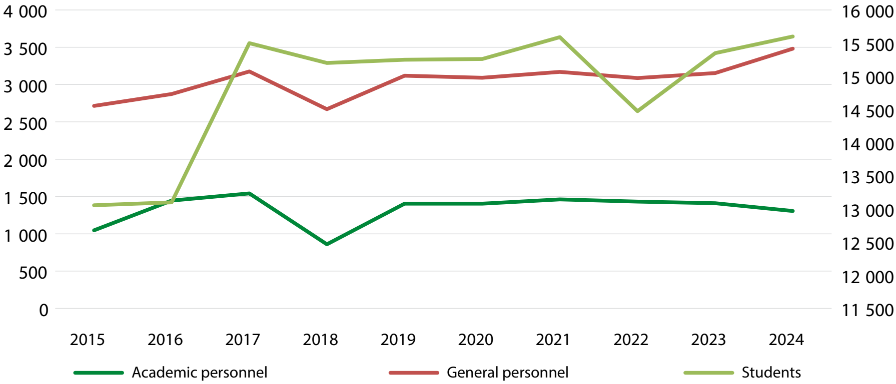

Figure 1. *Dynamics of staff and students; source: University of Latvia Annual reports [3]*

Table 4. *Dynamics of research and research supporting personnel 2016–2024; source: University of Latvia Research department*

	2016	**2017**	**2018**		**2019**		**2020**		**2021**		**2022**		**2023**		**2024**	
	FTE	*FTE*	*nr*	*FTE*	*nr*	*FTE*	*nr*	*FTE*	*nr*	*FTE*	*nr*	*FTE*	*nr*	*FTE*	*nr*	*FTE*
Research personnel	503	653	1154	544	1154	591	1388	579	1386	565	1165	476	1034	450	999	385
Research supporting personnel	171	175	757	187	1180	229	956	247	474	166	467	161	512	165	875	293
Total	**674**	**828**	**1911**	**731**	**2734**	**820**	**2344**	**826**	**1860**	**731**	**1632**	**637**	**1546**	**615**	**1874**	**678**

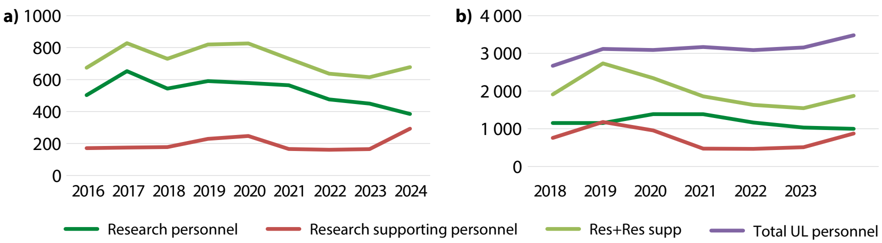

Figure 2. *Dynamics of research and research supporting personnel: a) FTE, b) headcount; source: UL Research department and University of Latvia Annual reports [3]*

Data collected in Tab. 4 and Fig. 2 show opposite trend to the University of Latvia Strategy defining UL as a science university [1] and Scientific Activity Development Plan envisaging investing in research human resources [2] – the number of research and research supporting personnel is decreasing (both in FTE and headcount) with each subsequent year, although the total number of UL employees is growing. Number of the research personnel has dropped down both in FTE and absolute numbers (headcount); total research-related personnel in 2024 has increased due to research supporting staff only.

Table 5. *THE World University Rankings for category 'Research' and Academic personnel in UL; source: [7] and University of Latvia Annual reports [3]*

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
THE Research	10.2	12.0	9.3	11.1	19.3	24.8	27.1	27.6	40.3	45.0
Academic personnel	1 445	1 541	859	1 404	1 404	1 461	1 432	1 410	1 305	

One can argue that according to the Times Higher Education World University Rankings [7], the score for 'Research Quality' (untill 2023 called 'Research') is constantly rising for the University of Latvia (Tab. 5) reaching 45 (of 100) in 2025. But the 2025 data were published in June 2024 and cover period 2018 - 2022 when the growth of research (and academic) personnel followed the overall increase in the number of personnel.

Remuneration

The goal of the Gender Equality Policy of the University of Latvia claims observing the principle of equality – to ensure equal working conditions and equal remuneration for the same quantity and quality of work performed [6]. From data collected in Tab. 6 one can derive conclusions oneself: the average salary for male employees has increased in almost all unit groups, the average salary for women has decreased in almost all unit groups with exception of 'Faculties/academic' where in majority cases the remuneration is project based. Does it mean that women in 'Administration' and 'Other units' are employed on less paid jobs while men take better paid positions?

Table 6. *Average salary4 depending on employment position; source: University of Latvia statistics [4]*

unit group	staff group	gender	2022	2023	2024	growth 2023 → 2024
Administration	general	M	2264	2634	2921	11%
		F	2096	1961	1851	-6%
Faculties	academic	M	2264	2453	3098	26%
		F	2096	2321	2842	22%
	general	M	1599	1689	1699	2%
		F	1571	1757	1632	-7%
Other units	academic	M	1830	2301	2352	2%
		F	1573	2269	2292	2%
	general	M	1346	1609	1523	-5%
		F	1125	1331	1220	-8%

Conclusions

This paper is an attempt to play with open-source numbers available on different University of Latvia webpages and does not represent the official survey on the UL staff dynamics. For in-depth study full data sets should be examined over longer period, not only 3 last years available on the open-source 'University of Latvia statistics: Facts and Figures'. UL is currently undergoing a comprehensive assessment, to be finished fall-2025; hopefully the conclusions and recommendations will be more encouraging for research-related and academic staff.

[4] average salary = total salary / total hours × monthly work hours

References

[1] University of Latvia Strategy 2021–2027 (with amendments). *University of Latvia Council,* 28.06.2021. https://www.lu.lv/fileadmin/user_upload/LU.LV/www.lu.lv/Dokumenti/Dokumenti_LV/1._VISPAREJIE_DOKUMENTI/LU_strategija_buklets_2025_03_03.pdf

[2] Scientific Activity Development Plan 2030. *University of Latvia Senate*, 26.06.2023. https://www.lu.lv/fileadmin/user_upload/LU.LV/www.lu.lv/Dokumenti/Dokumenti_EN/2/SCIENCE_DEVELOPMENT_PLAN_2030.pdf

[3] Annual reports. https://www.lu.lv/en/about-us/documents

[4] University of Latvia statistics: Facts and Figures. https://statistika.lu.lv/dashboards/lu-statistics-dashboard

[5] Key indicators – Gender equality: education and science. Official Statistics Portal (2025), GGE05, https://stat.gov.lv/en/statistics-themes/indicators-well-being-and-equality/gender-equality/6301-gender-equality-education

[6] Gender Equality Policy of the University of Latvia (in Latvian). Adopted 29.10.2021. https://www.lu.lv/fileadmin/user_upload/LU.LV/www.lu.lv/Dokumenti/Dokumenti_LV/2._POLITIKAS/LU_dzimumu_lidztiesibas_politika.pdf

[7] Times Higher Education World University Rankings. https://www.timeshighereducation.com/world-university-rankings/latest/world-ranking.

Poster presentations

Coherent manipulation of quantum states using the Autler-Townes effect

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I will report on the scientific results of my PhD dissertation work. The research focuses on achieving high-fidelity coherent control of quantum states in multilevel atomic systems using the Autler-Townes effect [1]. In contrast to model few-level systems, where various coherent control schemes can be implemented with relative ease, multi-photon excitation schemes in real atoms often involve multiple non-degenerate sublevels. For example, fine structure levels of many atoms exhibit hyperfine structure. The hyperfine interaction scales as $1/n^3$ and is usually negligible for highly excited states, therefore individual addressing of hyperfine sublevels is restricted to low-lying excited states at low laser coupling strength. Adiabatic coherent control methods, on the other hand, require strong laser couplings to avoid losses. Efficient coherent population transfer between the ground state and Rydberg states then inevitably involves multiple excitation pathways, and their mutual interference can lead to very complicated excitation dynamics.

Hyperfine splitting of alkali metal atom ground state can span several GHz, while already in the first excited state it reaches only tens to a few hundred MHz. When the laser coupling strength reaches hundreds of MHz, one can only address individual hyperfine components in the ground level. Excitation of two hyperfine ground level components via an intermediate manifold to a Rydberg state resembles a tripod excitation scheme, where three (meta) stable levels are all coupled to a single fast decaying level. Total or partial adiabatic population transfer between the stable levels can be performed with high fidelity [2].

Decomposition of two-photon excitation schemes in alkali metal atoms into bright and dark states using the Morris-Shore transform [3] reveals intricate interplay between coherent laser coupling and intra-atomic hyperfine interactions. The perturbation introduced by the hyperfine interaction leads to the observation of "chameleon" states — states that change their appearance in the Autler-Townes spectrum, behaving as bright states at small to moderate coupling, and fading from the spectrum similarly to dark states when laser coupling strength exceeds the hyperfine mixing in the excited manifolds [4]. The chameleon states can be further classified as "slow" or "fast", depending on their divergence rate relative to the bright components of the Autler-Townes spectrum [5].

Analysis of bright and dark states formation in two-photon excitation schemes in alkalis has revealed orthogonal excitation pathways, each coupled to a different hyperfine component of the ground state. While the hyperfine interaction mixes the two pathways, this mixing can be disrupted by introducing a specifically tuned control laser, which couples the intermediate excitation manifold to an unpopulated level. Application of the control laser allows $\Delta F \equiv 0$ excitation with fidelity exceeding 99.99% [6].

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References

[1] Autler S. H., Townes C. H. (1955) *Phys. Rev. 100*, 703, DOI: 10.1103/PhysRev.100.703
[2] Cinins A., Bruvelis M., Bezuglov N. N. (2022) *J. Phys. B: At. Mol. Opt. Phys*. 55 234003, DOI: 10.1088/1361-6455/ac9a90

[3] Morris J. R., Shore B. W. (1983) *Phys. Rev. A* 27, 906, DOI: 10.1103/PhysRevA.27.906

[4] Kirova T., Cinins A., Efimov D. K., Bruvelis M., Miculis K., Bezuglov N. N., Auzinsh M., Ryabtsev I. I., Ekers A. (2017) *Phys. Rev. A* 96, 043421, DOI: 10.1103/PhysRevA.96.043421

[5] Cinins A., Bruvelis M., Dimitrijević M. S., Srećković V. A., Efimov D. K., Miculis K., Bezuglov N. N., Ekers A. (2022) *Astron. Nachr*., 343, e210081, DOI: 10.1002/asna.20210081

[6] Cinins A., Efimov D. K., Bruvelis M., Miculis K., Kirova T., Bezuglov N. N., Ryabtsev I. I., Auzinsh M., Ekers A. (2024) *Phys. Rev. A* 109, 063116, DOI: 10.1103/PhysRevA.109.063116.

Application of resonance atomic spectra lines of Se I and Te I in the measurement of the transmittance of optical fibers in far UV

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Introduction

This research investigates the application of Selenium and Tellurium atomic spectral lines to evaluate the transmittance of high-quality optical fibers in the far ultraviolet region, specifically below 200 nm. Due to commercially available solutions, using Deuterium lamps that nearly cut off at 200nm [1], this method using atomic spectral lines offers a practical solution.

Methods

Our team used Se and Te electrodeless low-pressure lamp that were powered by an RF-ICP generator, producing intensive resonance spectra of Se I and Te I [2],[3]. Two experimental systems were created, both using Princeton instruments SpectraPro 2300 monochromator and 1200-line grating. One of these systems used 5 meters long optical fiber, while the other one used a quartz tube filled with weak nitrogen flow to eliminate atmospheric oxygen's absorption of UV spectrum, allowing us to detect spectra under 180nm.

Results

The results show intense Se I, Te I spectra lines, such as Se I at 196.09nm and 203.98 nm, and Te I at 214.72 nm and 226.55 nm, as well as one C I line at 193.09 nm [4]. Comparison of two detection methods acquired data reveals reduced transmittance at shorter wavelengths. A logarithmic graph was used as a model to visualize the relation between transmittance and wavelength. In the results, used optical fiber showed relatively high transmittance till 200nm with a steep decline till 190 nm (Fig. 1.)

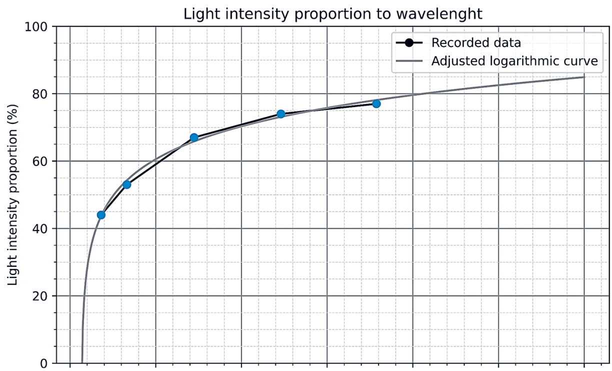

Figure 1. *Light transmittance depending on wavelength, with a logarithmic curve to predict transmittance in different wavelengths*

Conclusions

This method of measuring transmittance is efficient, cost-effective and suitable for applications both in research and industry. There is a potential to expand this method by combining other elements in lamps, such as As and Sb.

References

[1] https://www.flickr.com/photos/bob_81667/35443318076/in/photostream

[2] Ubelis A. P., Berzinsh U. V. (1986). Transition probability measurements of Se I spectral lines by emission method. *Physica Scripta*, 1986, 34 (6B), S. 805–806

[3] Ubelis A. P., Berzinsh U. V. (1983). Transition probability measurements of Te I spectral lines by methods of emission and absorption of radiation. *Physica Scripta*, 28(2), 171–178

[4] https://physics.nist.gov/PhysRefData/ASD/lines_form.html.

Dirac Delta pulse generator – powerful tool for diagnostics in electronics

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A single spike pulse function e^(ikx) or Dirac delta function is convenient for diagnostics because its Fourier transform in time axes is 2πδ(k) or a flat, monotonic, constant wave function. Although such an idealised spike pulse function cannot be obtained by electronic methods, its equally effective narrow bell-shaped function can be easily obtained, which is handy tool for practical work, as long as the pulse width is significantly narrower than the time constant (respectively, the reciprocal passband) of the semi-resonant medium under study. Sending the next pulse before at least 20 pulse widths have passed is undesirable. The most important thing is to achieve such a Delta pulse "train" (pulse train) or pulse comb (Dirac comb), because its transformation on the time scale is an infinite horizontal band from zero to infinity [1]. That is, the system under test (DUT = device under test) receives all possible frequencies simultaneously in one short action and refers to those in which it can resonate. Thus, with one short action, the full frequency characteristic curve of the DUT can be recorded.

How to implement it practically? Back in the eighties, it seemed that the fastest pulse could be obtained from two logic elements, one of which is powered by the other, so only a needle created by the transition process of the logic elements runs through. By slightly extending it with the help of an RC circuit, debouncing buttons were built at that time. However, the maximum operating frequency of the USSR 155/133 series chips did not reach 100 MHz, and even the 500/100 series did not reach 1 GHz. In this regard, the theory and even the element base for avalanche transistors are well developed today, and in avalanche mode it is able to achieve a pulse several orders of magnitude shorter than one might think from semiconductor passband data. In avalanche mode, the transistor is orders of magnitude faster than f(T). The Edaboard electronics discussion forum [2] recommends a scheme. If the FMMT413TD transistor is used, then a supply voltage of about 100 V is required to induce the avalanche mode, and the resulting needle has a length of approximately 0.35 nanoseconds and an amplitude of about 2 kV, which is more than enough for all kinds of tests: for determining VSWR in antennas, for measuring the length or wave shortening factor in antenna cables, for determining the location of a transmission line break, for finding a coil break (reflects a positive pulse) or a short circuit (reflects an inverted pulse), for measuring the gain factor, for measuring the passband of a probe, for EMI immunity tests udc [3]. This specialised avalanche transistor is quite hard to find, and there are also ones that are less than 100 times cheaper than the 2N2369A, which I tried and managed to get 2 ns spikes at 80 V and 2N3904 at 180 V for about 1.7 ns. Even with the BC337-25 or the BC548B, you can get pulses of about 7 ns or shorter, which can be almost sufficient in many cases. The resistance value and capacitor capacitance depend on the transistor: for the 2N2369A, 10K and 27 p to 33 p or 1M and 4p7; for the BC337 and BC548, 4k7; for the FMMT413, 4k7 to 10K and 200 p. To some extent, such transistors as 2N2222, 2N4441, MPSA44, BC107, BC337, S9014, S8050, etc. can also be forced to enter the avalanche mode. For very short pulses, it should be noted that BNC connectors paired with RG58 cannot work above 4 GHz, but SMA with RG405 can work up to 12 GHz.

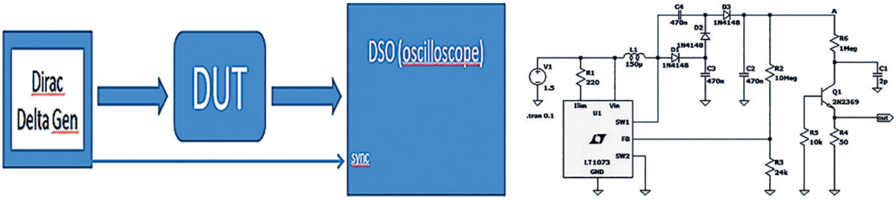

Figure 1. *Typical Delta generator circuit*

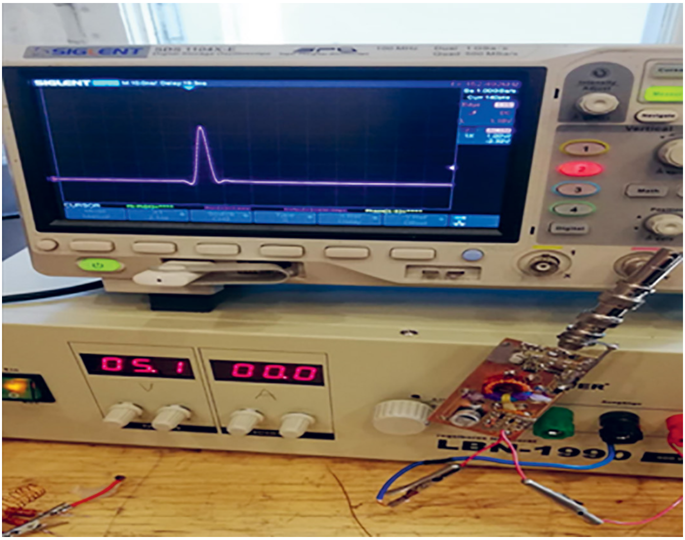

Figure 2. *Typical DUT connection to the test set and the obtained oscillograms on our soldered pcb*

There are at least several publications with corresponding circuits: [4] have created a rather complicated solution using a multi-stage FMMT417, which reaches 300 V and 0.7 ns. [5] recommends 2N3904. With 2SC5773, in [6] it was possible to obtain a rise time of 0.7 ns and a decay time of 1.3 ns. A fairly high-level study can also be found in [7] with a photopulse output to a fiber, which can be very useful for research in the field of photonics. To obtain the avalanche-causing high voltage, any design of power supply circuit can be used, even if it is as clumsy as [8], but the most common are direct conversion with a multi-winding blocking-generator [9], which with a 2N3904 reaches 1.7 ns and 200 V, or with the help of a Step-Up chip [10] and its LT-Spice computer simulation, for example, the LT1073, which can operate even from a single finger battery, with a 2N2369 reaching 0.35 ns and 90 V. The circuit [11] is also very similar. In [12] this circuit is supplemented and even the printed circuit board topology can be found. A lot of good theoretical insights and practical information about this design can be found in [13], although reaching only 7 ns.

References (all internet links last accessed on 01.03.2025)

[1] https://dsp.stackexchange.com/questions/35475/what-is-the-fourier-transform-of-deltat-a
[2] https://www.edaboard.com/threads/avalanche-pulse-generator.402966

[3] Bas ten Have, Tom Hartman, Niek Moonen, Frank Leferink (Sept.2019). Why Frequency Domain Tests Like IEC 61000-4-19 Are Not Valid; a Call for Time Domain Testing. *Proc. of the 2019 International Symposium on Electromagnetic Compatibility*. DOI: 10.1109/EMCEurope.2019.8872070

[4] Pavitra Krishnaswamy, Andras Kuthi, P. Thomas Vernier, Martin A. Gundersen (August 2007). Compact Subnanosecond Pulse Generator Using Avalanche Transistors for Cell Electroperturbation Studies. *IEEE Transactions on Dielectrics and Electrical Insulation* Vol. 14, No. 4, 857.pp

[5] https://www.codrey.com/electronic-circuits/avalanche-pulse-generator-an-introduction

[6] https://hackaday.io/project/169376-avalanche-breakdown-pulse-generator-tdr-g1/details

[7] Joan Canals, Nil Franch, Oscar Alonso, Anna Vilā, Angel Diéguez (Jan 2019). A Point-of-Care Device for Molecular Diagnosis Based on CMOS SPAD Detectors with Integrated Microfluidics. Sensors 19(3): pp. 445, DOI: 10.3390/s19030445

[8] https://hackaday.com/2016/10/04/a-quickly-hacked-together-avalanche-pulse-generator

[9] https://tefatronix.g6.cz/display.php?page=avgen&lang=en

[10] https://electronics.stackexchange.com/questions/638895/simulating-an-avalanche-pulse-generator-in-ltspice

[11] https://entangledwaves.wordpress.com/2013/07/15/avalanche-pulse-generator

[12] https://hackaday.io/project/169376-avalanche-breakdown-pulse-generator-tdr-g1/details

[13] LT Application Note AN-72. www.analog.com/media/en/technical-documentation/application-notes/an72f.pdf.

Measurement of atomic and ionised (B I and B II) spectra of hardly volatile Boron using unique technique – hybrid plasma system

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The measurement and studies of resonance spectra of hardly volatile chemical elements like Boron (melting point 2076 °C, boiling point 3927 °C) is an experimental challenge caused by difficulties of atomisation. Therefore, the knowledge base of basic properties of B I and B II is not rich at all. Currently, to respond to increasing demand from atomic physics and astrophysics especially, and various technology disciplines, like analytical spectroscopy and advancement of implantation technologies of Boron ions (B II) in high purity germanium crystals [1], the key material used for high energy radiation sensors, currently demands development of handier and cost-effective apparatus [2]. Particularly, a determination of the solar photosphere boron abundance was studied and published in 1999 [3]. An article appeared in 1997 reporting on the measurement of B II 1362 Å. resonance line by Goddard High Resolution Spectrograph of Hubble Space Telescope, observing four B-type stars from the Orion association [4]. A growing number of Space telescopes and advances in ground-based telescopes mean a need for a richer knowledge base on the spectroscopy on atoms and ions, including hardly volatile elements.

The latest data on Boron spectroscopy were published in 2009 [5], in 2010 [6], and are collected in a widely known database [7]. A critical compilation of energy levels and spectral lines of Boron atom was made in [8]. Overall, there are many theoretical studies, and one research study based on high-power hollow cathode technologies with current up to 3 A [9].

The report highlights the first results of applying a hybrid plasma system ensuring atomisation of hardly volatile elemental Boron: hollow cathode discharge combined with low-pressure inductively coupled radiofrequency plasma (HC & RF-ICP) in studies of spectroscopy of atomic boron. The light, coming from such a source where a Boron hollow cathode is incorporated into a silica glass cell and the inductor of RF generator is positioned in front of the hollow cathode, is dominated by the group of intense resonance spectra line duplets of B I, and several resonance lines of B II are also present. Our pilot studies demonstrated the value of such novelty, in studies of branching ratios of spectral lines B I in the spectral region 160–250 nm and particularly to measure with maximum accuracy branching ratios for the following duplets of B I: 1666.850, 1667.272; 1817.843, 1818.348; 1825.894, 1826.400; 2088.889, 2089.570; 2496.769, 2497.722 and to study resonance spectra of Boron ion B II diffusing from hollow cathode into the area RF-ICP plasma where excitation of the resonance spectra is 10 times or even more effective.

References

[1] Fair R. B. (1998). History of Some Early Developments in Ion-Implantation Technology Leading to Silicon Transistor Manufacturing. *Proc. of the IEEE*, 86(1), 111–137

[2] Blahins J., Ubelis A. (2022). Towards Next-Generation Small-Size Boron Ion Implanting Apparatus. In *Proceedings of the Latvian Academy of Sciences*, 76(2), 198–203

[3] Katia Cunha, Verne v. Smith (1999) A Determination of the Solar Photospheric Boron Abundance. *The Astrophysical Journal*, 512: 1006È1013

[4] Katia Cunha, David Llambert, Michael Lemke, Douglas R Ges, Lewis C. Roberts. (1997) A Boron Abundance of B Stars of the Orion Association. *The Astrophysical Journal*, 478:211È224

[5] Zhang Tian-yi, Zheng Neng-wu. (2009) Theoretical Study of Energy Levels and Transition probabilities of Boron Atom. *Acta Physica Polonica A.m* Vol. 116 (2), 141–153

[6] Fuhr J. R., Wiese W. L. (2010) Tables of Atomic Transition Probabilities for Beryllium and Boron. *J. Phys. Chem. Ref. Data*, 39 (1), 141–153

[7] Kramida A. (2006). NIST Atomic Energy Levels and Spectra Bibliographic Database

[8] Odintzova G. A., Striganov A. R. (1979) The Spectrum and Energy Levels of the Neutral Atom of Boron (BI). *Journal of Physical and Chemical Reference Data 8* (1), 63–67 (1979); DOI: 10.1063/1.555592, Published Online: 15 October 2009

[9] Kramida A. E., & Ryabtsev A. N. (2007). A critical compilation of energy levels and spectral lines of neutral boron. *Physica Scripta*, 76(5), 544–552.

Measurement of atomic and ionised (Pb I and Pb II) spectra of Lead hybrid plasma system

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The report is highlighting the first results of application of hybrid plasma system: hollow cathode discharge combined with low pressure inductively coupled radiofrequency plasma (HC & RF-ICP) in studies of spectroscopy of atomic lead. The experimental measurements and analysis showed the potential of substantial increase of knowledge base on the spectroscopic properties of atomic Pb I and eventually for ion Pb II. Current advances in atomic physics envisage that the data on atomic spectroscopy of Pb I and Pb II need to be substantially enriched, to open new opportunities for the studies of basic properties of atoms and ions of lead. The limiting factor for that, until now, were insufficiently intensive sources of emission needed for such research in case of lead, having low volatility. Substantial progress in theoretical atomic physics and growing needs of astrophysics indicate that new experimental data on atomic spectroscopy of atomic (Pb I) and ionic (Pb II and more) will lead towards increased accuracy theoretical calculations and broader use in astrophysics. Additionally, there is growing need to improve sensitivity, and to make more user-friendly methods, used in detection of traces of lead containing pollutants in the environment. Possible breakthrough – application of resonance fluorescence, which could be effectively used in case of presence of intensive sources of basic resonance lines. The best evidence of that, is the case of mercury, for which sophisticated resonance florescence techniques where developed, and standardised during the last decades increasing the sensitivity substantially [1]. Our research aims to move toward similar results in the case of lead.

The presentation and extended abstract of the conference will report the results of this pilot experiment indicating very promising outcomes for follow up research and future applications of such hybrid source of resonance spectra of atomic and ionic lead:

- The possibility to produce intensive source of resonance lines of lead with profiles of lines without reabsorption which means ideal case for both version (absorption and resonance fluorescence) of analytical spectroscopy.
- The presence of large number of spectral lines in the spectrum will allow branching ratio studies for many groups of spectral lines similar to our studies in case of Se I, [2], Te I [3] and As I [4].
- The presence of spectral lines of Pb II in the spectra from hybrid plasma indicates on broad opportunities to study ion spectra of lead for the first time, using RF-ICP & HC plasma.

References

[1] Telliard W. A., Andersson M. (2005). Method 245.7 Mercury in Water by Cold Vapor Atomic Fluorescence Spectrometry. *US EPA Office of Science and Technology*, 1–33

[2] Ubelis A. P., Berzinsh U. V. (1986). Transition probability measurements of Se I spectral lines by emission method. *Physica Scripta*, 1986, 34 (6B), S. 805–806

[3] Ubelis A. P., Berzinsh U. V. (1983). Transition probability measurements of Te I spectral lines by methods of emission and absorption of radiation. *Physica Scripta*, 28(2), 171–178

[4] Berzins U., Ubelis A., Bziskjans A. (2021). Branching fraction measurements of arsenic $4p^25s$-$4p^3$ transitions. *Journal of Quant. Spectr. and Radiative Transfer*, 276, 107943

[5] Zhang Tian-yi, Zheng Neng-wu (2009) Theoretical Study of Energy Levels and Transition probabilities of Boron Atom. *Acta Physica Polonica A.m* Vol. 116 (2), 141–153.

Exploring optoplasmonic doped whispering gallery mode microspheres

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Whispering gallery mode (WGM) resonators are well suited for wide variety of potential applications: filters, passive resonators, sensors, lasers, optical frequency combs (OFC). Due to their high quality (Q) factors, light beams are confined and sustained inside the resonator with small reflection losses thus enhancing light-matter interaction. This allows to reach high sensitivity to any perturbations of the surrounding environment or generating nonlinear effects at relatively low powers. The material, geometry and surface of the WGM resonator can be tailored to enhance desirable optical properties.

Silica doped with erbium is widely used for optical amplification. When erbium ions incorporate into silica sharp and temperature-stable transitions at 1530–1570 nm can be generated [1]. Adding gold nanoparticles on the resonator surface leads to localised surface plasmon resonances that extend the evanescent field and further enhance the sensitivity [2] while being highly chemically and photostable. The possibilities to combine the material doping and adding optoplasmonic metal nanoparticles to create a hybrid active/passive system has not been widely explored.

Lasing of erbium doped microspheres

We have fabricated silica microspheres doped with erbium ions. When pumped with 1470–1500 nm source emitted at 1530–1560 nm at a threshold of 1.6 mW [3]. Optimal concentration of Er ions is vital for generation of lasing signal, as both too high and too low concentration of Er ions incorporated into silica microspheres will not generate any lasing signal. Lasing was also observed when gold nanoparticles were deposited on the surface of the doped microsphere (see Fig. 1).

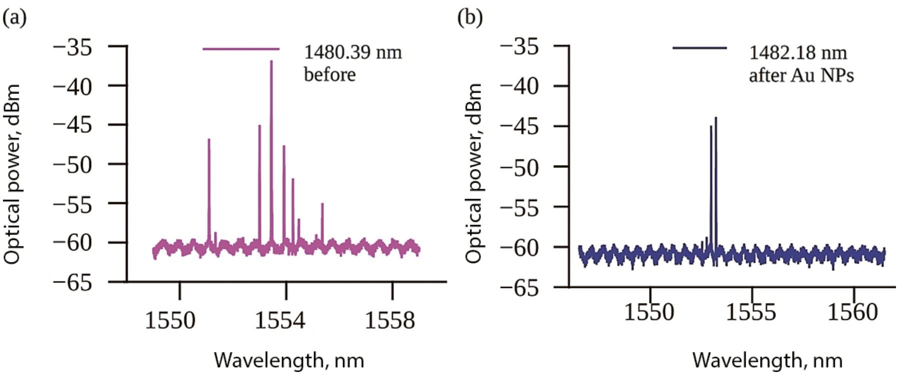

Figure 1. *Lasing signal of Er-doped microsphere (a) before and (b) after additional deposition of gold nanoparticles*

Deposition of gold nanoparticles for optiplasmonics

Multiple depositions of gold nanoparticles using colloidal nanoparticles solution was performed. Comparing the case of no Au NPs (Fig. 2a) to each additional time sample is dipped into the Au NPs (Fig. 2c-d), it can be seen that number of supported modes inside the microsphere decreases. Looking at transmission scan spectra, 3–5 dip-coating cycles into 1:10 diluted Au NP colloidal solution appear to have strong nonlinear broadening during red detuning Similarly, when observing the third harmonic green emission excited with CW 1550 nm laser for a sample doped with high concentration of erbium before (Fig. 2e) and after gold nanoparticle deposition (Fig. 2f–i), emission becomes more intense as Au NPs are added on the surface until disappearing completely after 4th dipping cycle. Further research into these hybrid doped optoplasmonic resonators is necessary with different types of dopants and plasmonic nanoparticles.

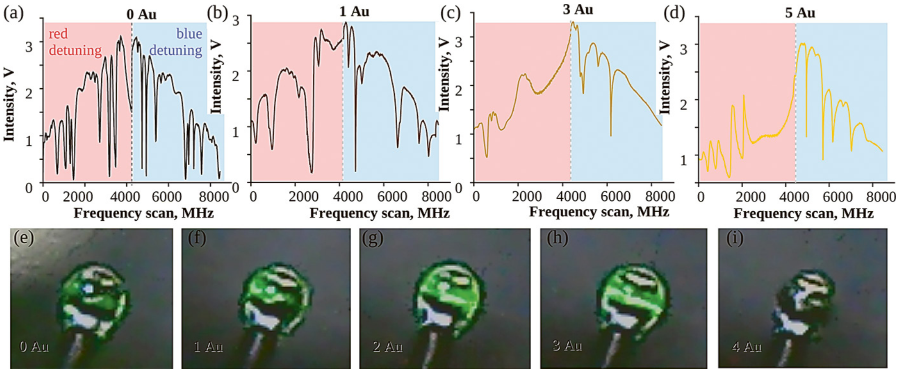

Figure 2. *Er doped microsphere sample for different number of dip-coating cycles into 1:10 Au NP solution (a)-(d) transmission spectra and (e)-(i) third harmonic generation*

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References

[1] Kalkman J., et al. (2006) Erbium-implanted silica microsphere laser. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 242, 182–185

[2] Bozzola A., et al. (2017) Hybrid plasmonic–photonic whispering gallery mode resonators for sensing: a critical review. *The Analyst*, 142(6), 883–898

[3] Brice I., et al. (2025) Tailoring whispering gallery mode resonator for a wide range of potential applications: optoplasmonic erbium doped microspheres. *Journal of Physics: Conference Series 2978*, 012004.

On current status of small sized innovative boron ion implantation apparatus

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4 years ago, FOTONIKA-LV won the ERDF competition for the development and testing of an innovative low-cost implantation device concept. Currently, the Project is completed and has received a 96% rating for scientific quality. The innovations of the device are based on the following technical solutions:

Since pure boron is a high-temperature material, but boron compounds are highly toxic, ions are obtained from pure boron, but with the help of a Hollow Cathode (HC) discharge, by gently heating boron to a temperature at which it rapidly loses its electrical insulator properties. Accordingly, HC allows obtaining a relatively large ion current without complex technical equipment.

1. Boron is filled into a cavity of purified carbon, which is a particularly convenient material that solves the problems of boron fixation on the walls.
2. Immediately behind the HC is a radiofrequency inductively coupled plasma (ICP) discharge coil, which provides a significant improvement in the ionisation yield, behind which ions are extracted by the interaction of two mechanisms – a differential vacuum drop, which drives them towards the vacuum pump, and an electrostatic field created by a conical electrode. Behind the electrode is a stack of plate shaped electrodes, which allows focusing and minimal acceleration of the ion beam.
3. The vacuum system is made of quartz glass, which, firstly, is a material that is easy to manufacture or modify in laboratory conditions, and secondly, costs much less than the massive molybdenum metal vacuum recipient classically used in high-purity implantation apparatuses, and also provides, with a condition if surface degassing with ICP plasma is applied, slightly better vacuum purity than molybdenum and significantly better than stainless steel.
4. Further, instead of the usual technological double-focusing magnetic mass separator, the beam is cleaned of impurities by a quadrupole mass selector (QMS) radiofrequency mass separator, which we managed to order from the rod manufacturer for a relatively reasonable price, which guarantees such high manufacturing accuracy that beam losses in the mass filter are small.
5. The main accelerator is a linear multi-plate electrode system with a constant pitch, to which voltage is supplied through a resistive divider. It was found that for reasonably high exposure doses, a target wafer anti-charging system is not necessary. The target is, however, housed in a stainless-steel housing to prevent bremsstrahlung escaping into the environment, and the QMS circuit is also made of this metal to implement the grounding point.
6. All the Electronics around mentioned parts are made for occasion of our laboratory, using an original modern-day solutions like switched mode power supplies (SMPS), direct digital synthesis (DDS) generators, Cocroft-Walton circuit for 100 kV obtaining, devices-to-computer links etc.

7. Based on this work, a textbook was written in Latvian as part of the planned PhD Dissertation on ion technologies and technological equipment assemblies used in ion beam manipulation, their construction, calculations, alternatives and use. In total, 145 pages of text, 131 drawings, 9 tables, 127 formulas and 630 references were collected in it. Still is not yet quite clear how to publish this work if the images in it are the work of other authors, because there is no much experience in requesting the multiple author's permission. The dissertation is expected to be defended in the summer or early autumn of 2025.

Current Status of 120 kW 30 kV SMPS Power Source for e-beam

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Some time ago, within the framework of a low-budget short-term Project, an apparatus was created to supply a high-power electron gun for applications in high-temperature metallurgy. The task of the work was 30 kV and 5 Amperes. The device was created at a level satisfying the Project, but its launch was hindered by the size of the Project deadline and budget, however, recently the interest in completing the Project has noticeably increased, because it seems that a similar device could have a prominent application in medium-power energy, small renewable resources (solar and wind) power plants for direct power injection into High Voltage Networks.

Questions that were successfully completed:

1. The 120 kW power rectification was based on an innovative thyristor rectifier, which initially charges the capacitor bank with a half-cycle regulator, thus avoiding overloading the fuses, then slowly increases the voltage to a certain level, when the rectifier switches to a full-wave three-phase rectifier mode until it is turned off. This method not only allowed for significant cost savings but also proved to be gentler on network overloads in operation as an alternative to operating a short-term additional resistance and its short-circuiting magnetic contactor.
2. The capacitor bank leads were formed with the help of bifilar layers of opposing current located close to each other, which reduced the lead inductance by approximately 95%, and the remaining unwanted inductance was compensated by smaller MKP capacitors directly on the ends of the igbt transistors.
3. A large-sized transformer was made by gluing together I-shape ferrite rods with very high magnetic quality. This method can be used for fast making ferrite cores of any size. The transformer windings were designed by leading out both ends of each layer so that they could be connected non-consecutively, let the voltage drop between the layers was a single-layer voltage, not a two-layer voltage, as is usually used in transformers. In leakage inductance tests and saturation current tests, the transformer proved to be correctly designed.
4. The rectifier was made by connecting in series many 1 kV 5 A TO-220 high-speed diodes, mounting them on individual radiators, which are screwed into nests of two pancake-shaped plastic plates, between which a fan blows air from the centre to the edges. During testing, a few assembly errors were identified and were promptly corrected, so the infrared thermography control verified that the Graetz rectifier is stable up to a current of 5 A.
5. Since the e-gun is prone to sporadic short circuits at times, the protection mechanism was built on the basis of a large rod-shaped solenoid, the Q-factor of which was adjusted to an aperiodic mode with the help of massive array of multiple SMD resistors. Such an implementation turned out to be much more miniature and reliable than other possible alternatives. The delay created by the coil was sufficient for the electronic protection circuit trigger during the delay.

Issues that were not solved well enough:

1. The giant transistor gate control chip tended to give unmotivated false opening pulses in some rare modes resulting in through-shoot, which led to the need to replace burned-out 1200 Volt and 700 Ampere transistors several times. The circuit was implemented with increasing complexity and improvements, but today it is clear that the H-bridge specific ZVS control chip must be found other – more resistant to interference.
2. Significant difficulties were caused by the fact that the laboratory does not have an optocoupled probes that would allow for simultaneous viewing of Vds, Vgs and Id on each of the 4 transistors. Since such probes cost from 30 kEUR per piece, and at least 12 pieces are needed, for now We are thinking about producing them on our own, based on the AFBR opto-transmitter and opto-receiver. This would allow for a much better understanding of what exactly the bridge control chip is doing wrong.

A scientific publication was published about the work done.

Formation of LIPSS on GaAs in water using radially and azimuthally polarised laser beams

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In this study, we demonstrate the fabrication of laser induced periodic surface structures (LIPSS) on gallium arsenide (GaAs) immersed in water. Ripples were inscribed in lines by moving the sample on the focal plane of the laser beam, which produced 532 nm, 30 ps pulses. An S-waveplate was used to convert the initially linearly polarised Gaussian beam into helical beam with either radial or azimuthal polarisation, depending on the waveplate's orientation. Formed structures were analysed with the use of scanning electron microscopy to define the optimal parameters for LIPSS formation. These findings provide a foundation for further studies of LIPSS formation using vector beams with varied polarisation states. The modified GaAs surfaces exhibit distinct functional properties that could be used across a variety of applications.

Acknowledgments. Work was supported by Fundamental and Applied Research Project (Nr. lzp-2023/1-0199): "The Laser Photodetachment Spectroscopy on Negative Ions". We would like to express our sincere gratitude to K. Salmins and A. Sarakovskis for the help with acquiring the necessary equipment for experiments.

Machine learning solution for enabling cosmological analysis with the matter anisotropic three-point correlation function

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The recent DESI results from the analysis of the DR2 [1] have significantly challenged the established LCDM model. Together with other Stage IV spectroscopic surveys, these missions will provide large volumes of data. They will probe the large-scale structures (LSS) of the Universe to a depth corresponding to when the Universe was only around 2 Gyr old. This allows to analyse the evolution of the Universe, including the components of it, such as dark matter and dark energy.

The most common way to analyse the LSS is to utilise the N-point correlation functions. The well-established two-point correlation statistics have proven to be a robust method for cosmological parameter constraints [2], exploiting the cosmic ruler: Baryonic Acoustic Oscillations (BAO). However, with the increase of the available data, two-point statistics are reaching their accuracy limits. Furthermore, they cannot distinguish non-gaussianity and suffer from parameter degeneracy. All of this can be alleviated by the inclusion of three-point statistics in the analysis.

The three-point correlation function (3PCF) has not been explored as well as the Fourier counterpart, the bispectrum. Nonetheless, it offers a significant advantage – it is not impacted by the survey footprint. One of the most recent theoretical advancements is the anisotropic 3PCF [3]. It is based on the Tripolar spherical decomposition, enabling to separate the anisotropic signal coming from the redshift space distortions and Alcock-Paczyński effect.

Although it is a very useful theoretical model, it takes a significant amount of computational resources to obtain it: approximately 30 CPU hours. Consequently, to constrain cosmological parameters with the Markov Chain Monte Carlo (MCMC) method, it could take years to finish the computation. To enable the cosmological analysis, I created an emulator, based on neural networks, that can speed up the computation by more than 10 million times, while maintaining competitive accuracy.

Furthermore, my MCMC analysis shows that including the anisotropic component yields more than 20% better constraints. This is only true when squeesed triangles are included in the analysis, thus $r_{min} = 20\ Mpc\ h^{-1}$. Otherwise, there is no significant improvement over the isotropic multipole constraints.

References

[1] Karim M. A., Aguilar J., Ahlen S., Alam S., Allen L., Prieto C. A., Alves O., Anand A., Andrade U., Armengaud E., Aviles, A., 2025. DESI DR2 Results II: Measurements of Baryon Acoustic Oscillations and Cosmological Constraints. https://arxiv.org/abs/2503.14738

[2] Aghanim N., Akrami Y., Ashdown M., Aumont J., Baccigalupi C., Ballardini M., Banday A. J., Barreiro B., Bartolo N., Basak S., Battye R., 2020. Planck 2018 results-VI. Cosmological parameters. *Astronomy & Astrophysics*, 641, p. A6. [3] Atomic Spectra Database | NIST

[3] Sugiyama N. S., Saito S., Beutler F., Seo, H. J., 2021. Towards a self-consistent analysis of the anisotropic galaxy two-and three-point correlation functions on large scales: application to mock galaxy catalogues. *Monthly Notices of the Royal Astronomical Society*, 501(2), pp.2862–2896.

Tantalum pentoxide microring resonators

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We present our ongoing work on the design and development of high-quality-factor (Q) microresonators based on tantalum pentoxide (Ta_2O_5) [1], a CMOS-compatible material with high refractive index and wide bandgap, offering significant potential for nonlinear and quantum photonic applications. Our research focuses on the systematic optimisation of microresonator geometries to tailor dispersion properties and enhance light confinement. The device design is carried out in-house, in collaboration with several international partners. Nanofabrication is performed at the University of Münster, ensuring precise control over waveguide and resonator dimensions. Measurement and characterisation of the optical properties are conducted in collaboration with Riga Technical University, while dispersion characterisation is performed in cooperation with the Max Planck Institute for the Science of Light. We report on recent advancements in resonator Q factors, modal analysis, and dispersion engineering strategies, laying the groundwork for efficient frequency comb generation and other nonlinear optical phenomena in the Ta_2O_5 platform.

Acknowledgments. The research was funded by the European Commission Recovery and Resilience Facility project Latvian Quantum Technologies Initiative (Grant No. 2.3.1.1.i.0/1/22/I/CFLA/001).

References

[1] Splitthoff L., Wolff M. A., Grottke T., Schuck, C. (2020). Tantalum pentoxide nanophotonic circuits for integrated quantum technology. Optics Express, 28(8), 11921. DOI: 10.1364/oe.388080.

The firms that break light. A summary of statistics of the Photonics and Optics industry in Latvia in the last 5 years

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Photonics and Optics, two fields in physics that once held little interest about them beyond that of scientists and researchers, have both become key in modern advancements in technology. Their influence is pervasive, impacting nearly every facet of modern existence, from daily life and entertainment to critical sectors like medicine, defence, communications, and manufacturing. The mastery of light-based technologies is becoming inextricably linked to national progress and competitiveness. For small nations, often characterised by limited domestic market sizes, constrained natural resources, and the need for specialised economic niches, the photonics and optics industry present a unique and compelling strategic opportunity.

While large economies with substantial domestic markets and manufacturing scale often dominate high-volume segments of the global photonics and optics markets, the unique characteristics of this industry offer distinct strategic advantages and opportunities for smaller, more agile nations. The sectors high knowledge intensity, rapid pace of innovation, and diverse application landscape create avenues for specialisation where smaller countries can achieve global leadership in specific niche markets. Success for small economies in these fields typically hinges on focusing on high value-added products, services, and intellectual property, rather than attempting to compete on cost or volume in commoditised segments. This approach aligns well with the need for smaller economies to move up the global value chain and generate sustainable economic growth based on innovation rather than solely on resource exploitation or low-cost labour.

Central to harnessing these opportunities is the cultivation of a vibrant and supportive national innovation ecosystem. This requires a multi-faceted approach encompassing several key elements. **Strong foundational research capabilities**, typically housed within universities and public research institutes with specialised expertise in optics, photonics, materials science, and related engineering disciplines, are essential for generating new knowledge and seeding innovation. However, research alone is insufficient; **effective mechanisms for technology transfer are critical to bridge the gap between laboratory discoveries and commercially viable products**. This often involves dedicated tech transfer offices, incubators, science parks, and collaborative research programs designed to connect academic researchers with industry needs and entrepreneurial ventures.

Finally, targeted and consistent government support is often a crucial catalyst and enabler for developing a competitive photonics sector in smaller economies. This can take various forms, including direct funding for R&D programs, investments in shared research infrastructure, incentives for private sector R&D and innovation, support for skills development, facilitation of cluster initiatives, and the development of national strategies that prioritize photonics as a key sector.

Photonics and Optics in Latvia

What follows below is a summary of the key figures and trends in Latvia from the Photonics and Optics industries. Dated from 2014 till 2023 (data for 2024 is still largely unpublished) and encompassing a total of 54 firms, the figures show consistent growth in the 2 industries, in terms of people employed, turnover and overall profitability. Although some slowdown is observed in 2023, this can largely be attributed to macroeconomic factors outside the control of the industry and the overall trend remains positive.

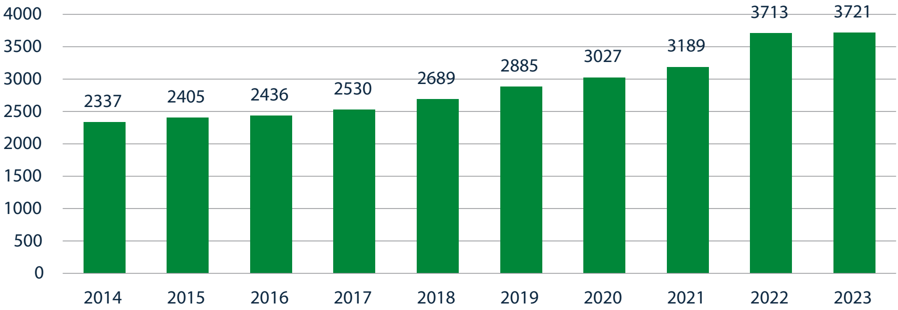

Figure 1. *Number of employees in the Photonics and Optics sector in Latvia from 54 firms sampled*

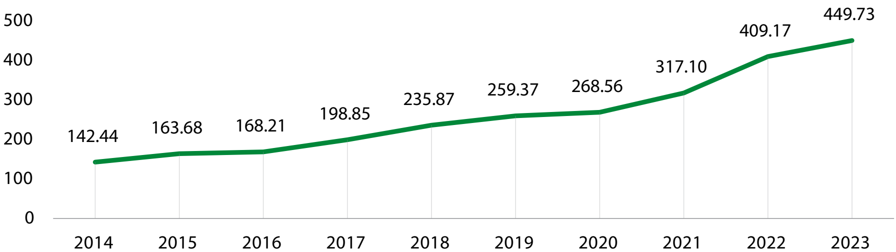

Figure 2. *Total Turnover in the Photonics and Optics sector in Latvia from 54 firms sampled*

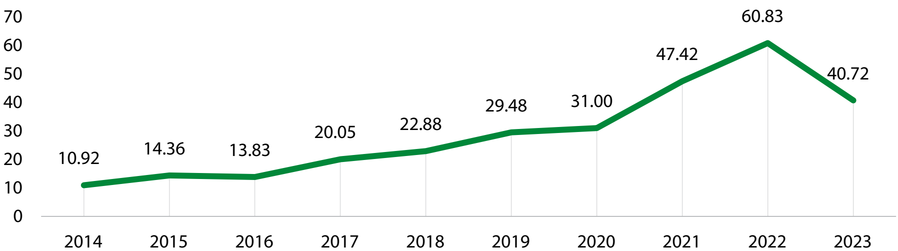

Figure 3. *Total Profit in the Photonics and Optics sector in Latvia from 54 firms sampled.*

References

[1] Latvijas Republikas Uzņēmumu reģistrs | https://info.ur.gov.lv/?#/data-search.

Spectroscopic studies of Gd I and Gd II using hybrid plasma source

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This report shows results of spectroscopic studies of neutral gadolinium (Gd I) and ionised gadolinium (Gd II). A hybrid plasma source was used in this research: hollow cathode (HC) discharge combined with radiofrequency inductively coupled plasma (RF-ICP). Using this system plasma spectra from samples of Gd and Gd_2O_3 were produced and recorded. Analysis of recorded spectra indicate that both Gd I and Gd II are generated in the hybrid plasma source.

Investigating the Impact of Hollow Cathode Lamp Geometry on Neodymium Emission Spectra

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Introduction

Spectroscopic investigations of rare earth elements, such as neodymium, are essential to a broad range of fields, including astrophysics [1], quantum information science [2], and advanced lighting technologies [3]. Laboratory-generated plasmas, when operated under controlled conditions, serve as reliable sources for the precise determination of atomic parameters, including transition probabilities. In our laboratory, we utilise a hollow cathode lamp (HCL) – a well-established plasma source in high-resolution spectroscopy [4] – to experimentally determine transition probabilities for doubly ionised neodymium (Nd III). Such measurements are particularly important for refining astrophysical data, where Nd III lines play a critical role [5].

Since plasma conditions affect the signal-to-noise ratio (SNR), the accuracy of these measurements is strongly dependent on the discharge parameters, which are, in turn, influenced by the geometric configuration of the lamp – particularly the anode design.

Experimental Setup

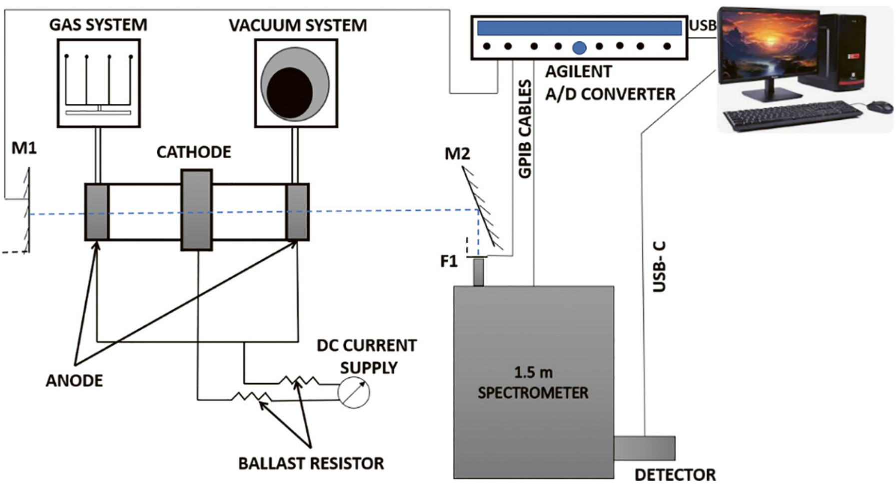

Figure 1. *Schematic diagram of the experimental setup*
Mirror M1 positioned at the back of the lamp is used to reconstruct the self-absorbed spectral lines [4]. Flap F1 is positioned to block light from reaching the spectrometer during background signal measurements, otherwise, it is retracted to the position indicated by the dotted lines. The motorised movements of M1, F1, and the spectrometer grating are synchronised and controlled by an Agilent analogue-to-digital (A/D) converter connected to the computer via GPIB

The Atomic Spectroscopy Laboratory at the University of Valladolid (Spain) has a long history in plasma spectroscopy [4, 6–8], initially focusing on noble gases [4] and more recently expanding to rare earth elements such as neodymium. This expansion is driven by the element's significance in stellar abundance studies and the lack of accurate atomic data for neodymium in the NIST Atomic Spectra Database [9].

A schematic of the experimental setup is shown in Fig. 1. At the heart of the system is a hollow cathode discharge lamp, featuring a cylindrical neodymium cathode (10 mm outer diameter, 20 mm length). The discharge is sustained in an argon buffer gas environment, introduced at pressures between 30–50 Pa, following evacuation to a base pressure of approximately 10–2 Pa. A DC power supply (0–1000 V, up to 1 A), coupled with ballast resistors, maintains a stable discharge. The emitted light is collected and directed into a 1.5 m Jobin-Yvon HR1500 Czerny–Turner spectrometer equipped with a 2400 lines/mm diffraction grating. Spectral detection is performed using a PCO.edge 4.2 CMOS camera with a pixel size of 6.5×6.5 μm². Plasma emission is imaged onto the spectrometer entrance slit using an alignment mirror (labelled M2). Inside the spectrometer, optics guide the spectral emission to the CMOS detector, where the spectra are recorded [10] for subsequent analysis.

The mechanical components of the experiment are controlled via a computer interface using an Agilent A/D converter and GPIB cables. Detailed descriptions of the experimental setup can be found in references [11] and [12].

This study investigates the effects of anode geometry on the plasma characteristics and emission behaviour of Nd III. In this poster we will present modifications to the lamp design, an updated voltage–current discharge profile, and comparative analyses of emission spectra and plasma glow images to visualise the impact of these geometric changes.

Acknowledgments. This work was conducted under the Spanish government through project PID2021-127786NA-100 funded by MICIU/AEI /10.13039/501100011033 and by FEDER, UE. P. R. Sen Sarma thanks the University of Valladolid for his PhD grant. M. T. Belmonte acknowledges the Beatriz Galindo Fellowship from the Ministerio de Ciencia, Innovación y Universidades of the Spanish Government.

References

[1] Banerjee S., Cassisi S., Colgan J., Fontes C. J., Frey H. M., Kelley K., Lippuner J., Miller R. H. (2022). Opacity of the highly ionized lanthanides and the effect on the early kilonova. *The Astrophysical Journal*, 934(2), p.117

[2] Goldner P., Ferrier A., Guillot-Noël O. (2015). Rare earth-doped crystals for quantum information processing. In: J.-C. G. Bünzli and V. K. Pecharsky, eds. *Handbook on the Physics and Chemistry of Rare Earths*. Vol. 46. Amsterdam: Elsevier, pp.1–78

[3] Song X., Chang M.-H., Pecht M. (2013). Rare-earth elements in lighting and optical applications and their recycling. *JOM*, 65, pp.1276–1282

[4] Belmonte M. T., Aparicio J. A., Mar S. (2014). Improved and expanded measurements of transition probabilities in UV Ar II spectral lines. *Monthly Notices of the Royal Astronomical Society*, 445(4), pp. 3345–3351

[5] Hasselquist S., Shetrone M., Cunha K., Smith V. V., Holtzman J., Lawler J. E., Prieto C. A., Beers T. C., Chojnowski D., Fernández-Trincado J. G., García-Hernández D. A. (2016). Identification of Neodymium in the Apogee H-Band Spectra. *The Astrophysical Journal*, 833(1), p.81

[6] Belmonte Sainz Ezquerra M. T. (2016). Experimental transition probabilities and stark parameters of singly ionized noble gases. *Doctoral Thesis, University of Valladolid*

[7] Mar S., Aparicio J. A., Calisti A., Ćirišan M., de La Rosa M. I., del Val J. A., Djurović S., Fuentes L. M., Gigosos M. A., González M. Á., Gonzalo A. B. (2011). Research areas of the Plasma Spectroscopy Group at the University of Valladolid. *Óptica pura y aplicada*, 44(3), pp.433–445

[8] Peláez R. J., Mar S., Aparicio J. A., Belmonte M. T. (2012). Integration of an intensified charge-coupled device (ICCD) camera for accurate spectroscopic measurements. *Applied Spectroscopy*, 66(8), pp.970–978

[9] Kramida A., Ralchenko Y., Reader J. and NIST ASD Team (2024). NIST Atomic Spectra Database (version 5.12) [online]. Gaithersburg MD: National Institute of Standards and Technology. Available at: https://physics.nist.gov/asd [Accessed 8 Apr. 2025]. DOI: 10.18434/T4W30F

[10] Sen Sarma P. R., Belmonte M. T., Mar S. (2024). Analysis of Slit Curvature Using Image Processing. Zenodo. DOI: 10.5281/zenodo.14002840

[11] Sen Sarma P. R., Belmonte M. T., Mar S. (2024). Characterisation of a hollow-cathode lamp to measure accurate branching fractions of rare-earth elements. *The European Physical Journal D*, 78(6), p.76

[12] Sen Sarma P. R., Belmonte M. T., Llorente S., Mar S., Integration of a CMOS camera for accurate high resolving power spectroscopic measurements. SSRN. Available at: https://ssrn.com/abstract=5018907 [Accessed 8 Apr. 2025].

Measurements of metastable ion lifetimes

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We will report on a series of works measuring the lifetimes of metastable levels for astrophysical interesting metastable ions. These experiments were carried out in close collaboration with the research group of Professor Henrik Hartman at Malmö University and the group led by Professor Henning Schmidt using the ion ring DESIREE [1] at Stockholm University.

Metastable levels are responsible for parity forbidden lines occurring in many low-density astrophysical plasmas, found in e.g. gaseous nebulae, planetary nebulae, protostars, stellar chromospheres. Line ratios from forbidden lines are the most reliable tools for diagnostics of temperatures and density of these regions. Measurements of metastable lifetimes is of direct importance for the use of forbidden lines.

We are using the laser probing technique what was derived by Mannervik [2] and his group at the CRYING storage ring and successfully applied to a number of ions of varying complexity [3]. For several complex ions the measured lifetimes can be combined with measured line ratios to derive experimental transition rates like it was done in our previous work [4].

We will report on preliminary results for Barium, Calcium, Nickel and Iron ions.

Acknowledgments. This research was supported by Fundamental and Applied Research Project (Nr. lzp-2023/1-0199): "The Laser Photodetachment Spectroscopy on Negative Ions", from Latvian Council of Science.

References

[1] Schmidt H. T., et al. (2013) First storage of ion beams in the Double Electrostatic Ion-Ring Experiment: DESIREE, *Review of Scientific Instruments* 84, 055115. DOI: 10.1063/1.4807702

[2] Mannervik S. (2002) Studies of Metastable Levels in Singly Charged Ions by Laser Techniques in an Ion Storage Ring, *Physica Scripta*, Volume 100, pp. 81–87

[3] Hartman H., Johansson S., Lundberg H., Lundin P., Mannervik S., Schef P. (2005) Experimental Oscillator Strengths for Forbidden Lines in Complex Spectra, *Physica Scripta*, Volume T119, pp. 40–44

[4] Berzins U., Ubelis A., Bziskjans A. (2021) Branching Fraction Measurements of Arsenic $4p^25s$-$4p^3$ Transitions, *JQSRT* 271, 107943.

Coherent control in size selected semiconductor quantum dot thin films

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Quantum interference [1] is a cornerstone phenomenon in quantum mechanics, arising when the probability amplitudes associated with different quantum pathways combine, leading to patterns of constructive or destructive interference. Coherent control [2] leverages this phenomenon by using external optical or electromagnetic pulses to steer the outcome of quantum interference. Through careful adjustment of the phase, amplitude, and frequency of these external pulses, it is possible to selectively enhance or suppress specific quantum transitions. This selective manipulation enables researchers to direct quantum pathways toward desired outcomes, making coherent control a powerful tool for exploring and utilising quantum systems.

In this study [3], we present a novel approach to coherent control by exploiting resonant, internally generated fields within CdTe quantum dot (QD) thin films at the L-point in the Brillouin zone (see Fig. 1. CdTe is chosen for its favourable electronic properties, including a bulk band gap of 3.6 eV at the L point, where transitions are strongly influenced by Coulomb interactions. Third harmonic generation (THG) is employed, with a third harmonic wavelength of λ 3 = 343 nm (hν = 3.61 eV) driven by a fundamental wavelength of λ 1 = 1030 nm. This resonant condition allows precise control of three-photon pathways connecting the valence and conduction bands. The experimental setup leverages CdTe QD films of varying thicknesses to finely tune the phase relationship between the fundamental external field and the internally generated third harmonic field. This tuning enables the suppression or significant enhancement of resonant third harmonic signals (see Fig. 2), while the non-resonant harmonic contributions remain largely unaffected.

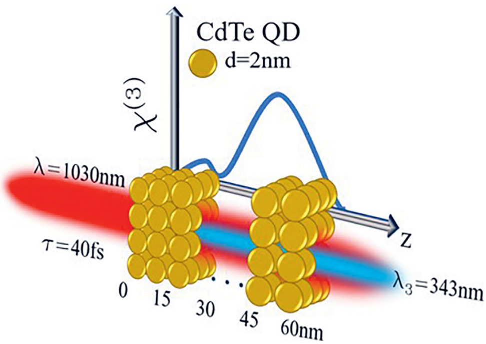

Figure 1: *Schematic representation of the experiment. In order to coherently control the resonant nonlinear susceptibility different CdTe QD film thicknesses are used*

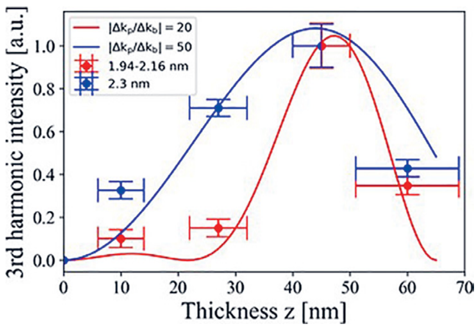

Figure 2: *Coherent control of the resonant third harmonic intensity at hω 3 = 343 nm is demonstrated.*

Such control is achieved by modifying the quantum interference patterns between different photon pathways. By using high peak intensities, we induce an increased population of conduction band electrons, which alters the refractive index of CdTe. This change enhances the phase mismatch between the fundamental and third harmonic fields, reducing the coherence length from the micrometre to the nanometre scale. This technique introduces an additional layer of control over quantum interference through phase manipulation at ultrafast timescales. The implications are far-reaching, offering potential applications in ultrafast switching, quantum cryptography, and the development of next generation nanophotonic devices. By bridging the gap between fundamental quantum mechanics and practical device applications, this work underscores the potential of quantum interference as a foundational tool in the rapidly evolving field of quantum technologies.

References

[1] Manykin E. A., Afanas’ev A. M. (1967) On one possibility of making a medium transparent by multiquantum resonance, *J. Theor. Phys*., 52, pp. 1246–1250 & *Sov. Phys. JETP*, 25, no. 5, p. 828

[2] Dong D., Petersen I. R., Quantum control theory and applications: a survey, (2010) *IET Control Theory Appl*., 4, pp. 2651–2671

[3] Kärcher V., Reiker T., da Costa P., de Camargo A., Zacharias H. (2025) Quantum control in size selected semiconductor quantum dot thin films, *Nanophotonics*, 14, no. 2, pp. 229–239.

The effect of EM levitation, pressure and temperature combination on synthesising the Magnesium – high Titanium alloys

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Magnesium metal is widely used – the World`s third most applied metal – both in the form of ingots or in mechanical processing [1]. Currently, it is the lightest technological metal resistant to corrosion under normal conditions, with a 5% increase in use yearly [2]. In alloys with aluminium, it can be easily produced in very wide proportions [3]. With zinc, it can be achieved as an additive to zinc alloys, since pure magnesium alloys are characterised by low thermal stability [4].

In alloys with titanium, only 0.2% titanium allows for a noticeable improvement in mechanical properties. There are known experiments with powder technologies with up to 99% titanium, where an increase in hardness is observed, however, it is strongly harmed by the brittleness inherent in ceramics however, thermal safety is significantly increased [5].

The melting point of pure titanium is 1670°C, but magnesium is a chemically very active metal and, when molten, reacts rapidly with oxygen, nitrogen, carbon dioxide, water, and also with other materials found in crucibles. This makes melting magnesium at temperatures above 1000°C problematic [6].

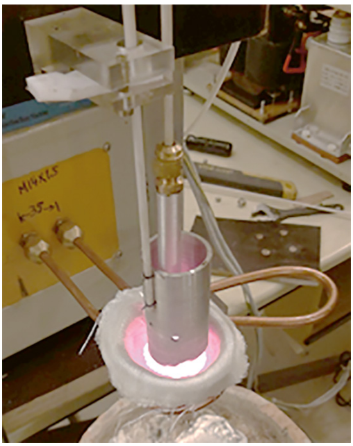

Figure 1.1. *Experiment setup for our patent LVP2023000104 "A method for supplementing molten, levitating material during the growth of monocrystalline, polycrystalline, or other solid-state structures under electromagnetic levitation conditions. This patent lets us get a crystal with unlimited mass as long as we keep adding more material to the system*

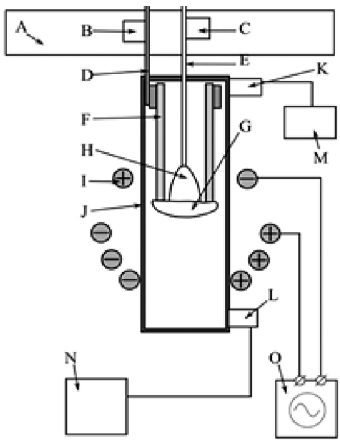

Figure 1.2. *Technical diagram: A - control block, B & C – stepper motors, D & E – movement rods, F – material for adding, G – melted metal in levitation, H – crystal being pulled out, I - induction coil with a counter turn, J – casing, K – connection for vacuum system, L – gas inlet, M – vacuum pump, N – inert gas, O – generator*

Figure 1.3. *Melted levitating magnesium*

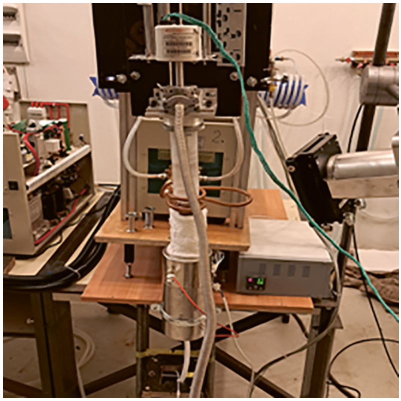

Figure 1.4. *Full picture of the setup used*

Under normal conditions (at 1 bar pressure), it is impossible to achieve the formation of an alloy, because as soon as the addition of titanium exceeds 0.2%, the melting point of the alloy increases above 1090°C and all magnesium boils away due to its boiling point. This has slowed down the research of Mg-Ti alloys with higher titanium concentration, shifting the emphasis to powder metallurgy and other technologies [5].

Due to our previous research, ERDF project: Nr. 1.1.1.1/20/A/070, there exists a little-known fact that gives strong hope for synthesising a new type of magnesium – titanium alloy without any ratio restrictions [7].

1. We do not use a crucible at all in electromagnetic levitation (EML) – the molten metal is held by the electromagnetic field.
2. High-pressure melting solves the problem of magnesium boiling; the partial pressure of magnesium vapor at the melting point of titanium is 18 bar.
3. It is possible to build a box for pressure up to 50 bar in which to implement EML.

We have already implemented magnesium melting in levitation in an argon protective atmosphere in previous works. We have also implemented the levitation of titanium melts.

Under normal pressure conditions, two modifications can be made to the titanium – α and β (Fig. 2), with a transition at 882°C, which could grant the alloys the ability to be thermally treated afterwards.

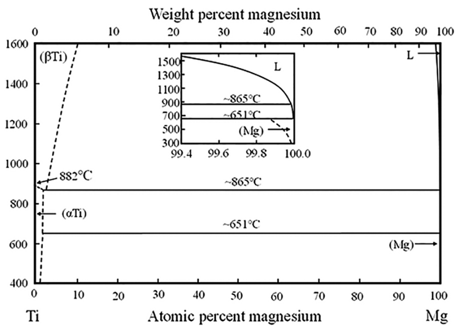

Figure 2. *α and β modifications of the Titanium;*
source: Villars P, Prince A. Handbook of ternary alloy phase diagrams. Cleveland: ASM International, 1995

Benefits and potential uses of Mg-Ti alloy

This type of alloy would represent the lightest known metallic material – approximately twice as light as aluminium. Due to the presence of titanium, it would also exhibit high atmospheric stability [8]. Given that magnesium is abundant in nature, the production costs of such an alloy could remain relatively low. In addition to its lightweight nature, the alloy would be expected to demonstrate significantly greater durability compared to the aluminium. These properties make it a strong candidate for advanced applications in the aerospace and aviation industries, as well as in the medical technologies.

The development and utilisation of this alloy could offer substantial benefits to the national economy, particularly through high-value technological innovation and export potential.

Latvia possesses extensive reserves of dolomite, a carbonate rock with the chemical formula $CaMg(CO_3)_2$, in which nearly half of the mass consists of magnesium carbonate ($MgCO_3$). Multiple established technologies enable the extraction of magnesium from dolomite [9]. While the refinement process is energy-intensive and generates by-products such as calcium compounds, chlorine, and carbon dioxide (CO_2), these by-products can be recycled or converted into commercially valuable materials with sufficient investment in research and development [10].

With its rich dolomite resources and the global demand for lightweight, high-performance metals, Latvia holds the potential to position itself as a leader in sustainable magnesium production – bringing innovation to aerospace, energy, and medical industries, while contributing to economic growth and technological advancement.

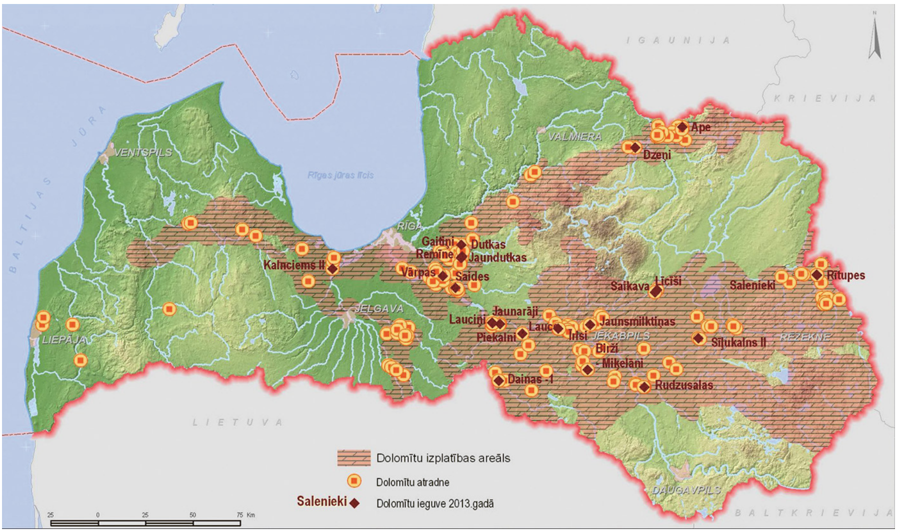

Figure 3. *Dolomite deposits in Latvia; source: Latvian Environment, Geology and Meteorology Center.*

References

[1] Friedrich H., Mordike B. L. (2006). Magnesium Technology: Metallurgy, Design Data, Applications. *Springer*

[2] Zeng X. Q., Ding W. J., Peng L. M. (2008). Recent development and applications of magnesium alloys. *Transactions of Nonferrous Metals Society of China*, 18(4), 820–827. Elsevier

[3] Luo A. A. (2004). Magnesium casting technology for structural applications. *Journal of Magnesium and Alloys*, 2(2), 75–85. Elsevier

[4] Singh R., Chauhan A., Kumar P. (2021). Development of magnesium-zinc alloys and their biomedical applications: A review. *Journal of Magnesium and Alloys*, 9(3), 871–885. Elsevier

[5] Jinfeng L., Sha J. (2014). Effect of titanium powder addition on the properties of magnesium-based alloys. *Materials Science Forum*, 765, 277–281. Trans Tech Publications

[6] Ghosh M., Chattopadhyay A. K. (2011). Intermetallic phase formation in magnesium–titanium systems: A microstructural study. *Materials Science and Engineering: A*, 528(9), 3484–3491. Elsevier

[7] Sniķeris J., Apsītis A., Pumpurs A., Lācis U., Kravchenko S., Silamiķelis V. (2023) Experimental observation of the vertical displacement between heating and levitation regions in an electromagnetic levitation coil. *Journal of Physics D: Applied Physics* 57 (9), 095002

[8] Polmear I. J., StJohn D., Nie J. F ., Qian M. (2017). Light Alloys: Metallurgy of the Light Metals (5th ed.). *Butter-worth-Heinemann*

[9] Toleikienė M., Zvanutė J., Zubrickaitė R. (2015). Dolomite as raw material for magnesium production. *Environmental and Climate Technologies*, 15(1), 20–30. Riga Technical University Press

[10] Friedrich H. E., Schumann S. (2001). Research for a “new age of magnesium” in the automotive industry. *Journal of Materials Processing Technology*, 117(3), 276–281. Elsevier.

Round Table Discussion: Towards the Repatriation of Researchers from the Research Community of Latvian Diaspora

Dangerous shortage of top-level professionals in the ecosystem of photonics sciences and technology fields in Latvia

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The presence and reproduction of a community of top-level professionals, contributing to the well-functioning innovation ecosystem in the country, particularly to satisfy the growing demand from academia and "high-tech" industry in the photonics domain, is sustained by the state's ability to increase the concentration of respective talent in geographically limited urban territories. Traditionally, the talent policy of small but highly developed and worldwide competitive EU countries incorporates the following key assets:

- the capacity of the domestic education system to teach and produce talented individuals a quality of graduates "per capita" higher than average in the EU,
- the knowledge base of secondary school graduates should have a strong natural science background,
- possesses the ability to react flexibly, therefore benefiting from changes in the EU and global market needs.

This article aims to highlight the main factors of acute shortage of talent pull in Latvia in areas of the photonics sciences, space research, and related technologies, comparing with the well-known breakthrough case of South Korea's achievements based on accents on physics education and quality of STEM studies, indicating the steadily growing number of students in relevant disciplines in EU countries and refer to history lessons comparing South Korea, Latvia and Finland.

The historical experience of South Korea, among similar others, is an outstanding example. *To use physics in industry, Korea first needed to train a new generation of physicists. In 1952, the Korean Physical Society (KPS) consisted of only 34 members, but by 1995, its membership had grown to 4,536. Much of that increase came from the growing number of students in physics majors graduating from Korean universities. During 1964–1994, the number of students receiving BSc degrees in physics grew from 217 to 2,777, the number of MSc graduates increased from about 25 to 326, and the number of PhD. graduates rose from a few to 76. As such, Korea's physics community consists largely of young scientists. In the Korean Physical Society, 2,064 members (45%) are in their 30s, citation, see [1]*).

The massive industrial development of Riga city historically had been fuelled by steady growth in physics and engineering education in quality and quantity, much earlier than Korea, since the second half of the 19th century. Riga was the leading Imperial Russia by the establishment of Riga Polytechnicum (1862–1918), the first polytechnic institute. The institute was transformed into the University of Latvia in 1919 (Latvia declared independence on November 18, 1918). During the first period of independence between the two World Wars, the Institute of Physics was founded by Dr. Fricis Gulbis in 1919 and experienced steady growth, employing 20 PhD-level physicists on its staff. Besides local training, several have opportunities for secondment research visits abroad (*including A, Apinis, and R. Siksna receiving research training in the labs of Nobel Prize laureates Nils Bors and Johannes Stark accordingly*) [2].

In comparison, Korea counted only 2 doctors in physics in 1945, see [3], was involved in a devastating war from 25 June 1950 to 27 July 1953, and was split into two parts afterwards.

Currently, South Korea is ranked as the 12th highly developed economy, whose success was based on the development of an effective education system, and it's not surprising that in 1997 the Ministry of Science was headed by a physicist and experienced science manager, Prof. Sook-iL Kwun [4], [5] and [6].

The devastating Second World War and 50 years of Soviet occupation failed to overcome the nation's wisdom to keep the education of its younger generation as a key for national survival!

The nation's wisdom played a decisive role in ensuring the recovery of technological intelligence, largely based on physics education. On the other side USSR wanted to be successful in competition with Western countries, particularly with the USA in nuclear physics, space technology, radio physics, material sciences, and military technologies. Therefore, the secondary school system was based on a natural sciences background, and according to that, obligatory secondary school education was introduced across the USSR and also in Latvia in 1959.

The authorities tried to massively increase the number of creative physicists, engineers, and technology development managers. That was the message to smart talents among secondary school graduates about the opportunity to escape the necessity to deal with stupid ideology. Many secondary school graduates moved for studies in physics, chemistry, technology disciplines, and mathematics to have employment in the institutes of the newly founded Latvian Academy of Sciences and to become teachers of STEM disciplines in secondary schools. The revival of basic physics research was promoted at the University of Latvia and partly at the Riga Technical University.

As a result, after the reestablishment of independence in 1990 Latvia was proud to have 8 physics-related large research institutions employing more than 2000 physicists: The Institute of Polymer Mechanics, The Institute of Physical Energetics, The institute of Physics, The Institute of Solid State Physics, The Nuclear Research Centre, Radio astrophysical observatory, Department of Spectroscopy and Astrophysical observatory at the University of Latvia. All of listed received very positive comments from the international experts from the first evaluation of Latvian science, organised by the Danish Academy of Sciences (*...the panels recommend that the Latvian authorities, when planning the necessary adjustments of the research system to the present economic realities, have the balance between the long range basic science and the short range applied science in view, remembering that the foundation of a part of future development of the Latvian society is created by the activities of a stable, high quality research base, citation, see [7] and [8]*), with advice to sustain them as engines for the emerging worldwide competitive high-tech industry.

Many physicists were employed by other institutes, e.g., the Institute of Mathematics and Computer Sciences, the Institute of Inorganic Chemistry, the Institute of Organic Chemistry, the Institute of Wood Chemistry, as well as working in various laboratories of Physics-related faculties in the eight largest universities or high schools. Industry centres and specialised applied research centres employed graduates in physics. The total number of researchers in Latvia was nearly 45,000 (30,000 in academic research, 15,000 in industry), and more than 2500 graduates in physics among them. Currently well-recognised leader of RTD and innovation, Finland in 1990 counted only 15,000 researchers [9]. Finland employs nearly 40,000 researchers in the private and public sectors of the economy.

Unfortunately, political decision makers in Latvia failed to follow such smart advice provided by the first comprehensive evaluation of Latvian science made by independent international experts and received the first serious warning on dangerous tendencies in human resource development already in 2008, monitored in the benchmarking report of EU Lisbon strategy milestones among EU member states [10]. The EU Commission set the benchmark of the Lisbon Strategy: The total number of graduates in Mathematics, Science, and Technology (*MST includes life sciences, physical sciences, mathematics and statistics, computing, engineering and engineering trades, manufacturing and processing, architecture and building*) in the European Union should increase by at least 15% from 2000 to 2010. With growth of over 37% in the number of MST graduates in the period 2000–2008, the EU has already progressed at more than twice the rate foreseen by the EU benchmark for 2010 in this field. In the period 2000–2008. Romania, Portugal, and Slovakia showed the highest growth rates (>14%), followed by the Czech Republic and Poland (>10), Finland (6%), Estonia (5,8%), Germany (5,5%), and Lithuania (4.0 %). **Latvia, already having drastically lower numbers per capita, instead of growth, demonstrated a stagnation followed by a decrease (–2.8%)**.

The share of the population qualified to university degree level in mathematics, science, or technology is an important predictor of the availability of human resources qualified to carry out research and development activities in the public and private sectors of the economy. In 2008, 1.39% of Europeans aged 20 to 29 received a tertiary degree in mathematics, science, or technology [10], the best performers, Finland, Portugal, France, Ireland, and Lithuania, counted 2.43, 2.07, 2.01, 1.95, and 1.78, respectively.

The negative MST benchmark for Latvia in 2000–2010 painfully played back later for the country in general (the total number of PhD annual graduates fell from already smaller than necessary 315 in 2013 to 100 in 2020). Especially unacceptably low are the annual numbers for graduates in physics, constituting about 30-% of the numbers given in Fig. 1 for STEM disciplines.

Latvia counts about 100 research-driven SMEs active in the fields under the MST “umbrella”. In addition, about 10 companies reached an annual turnover of 100 MEUR and even more. All the communities of the mentioned Latvian companies face an extreme shortage of high-quality professionals in comparison with their partners in Finland and Sweden, where the annual number of graduates is around 1600 and 3500, respectively (*around 300 per million of population*).

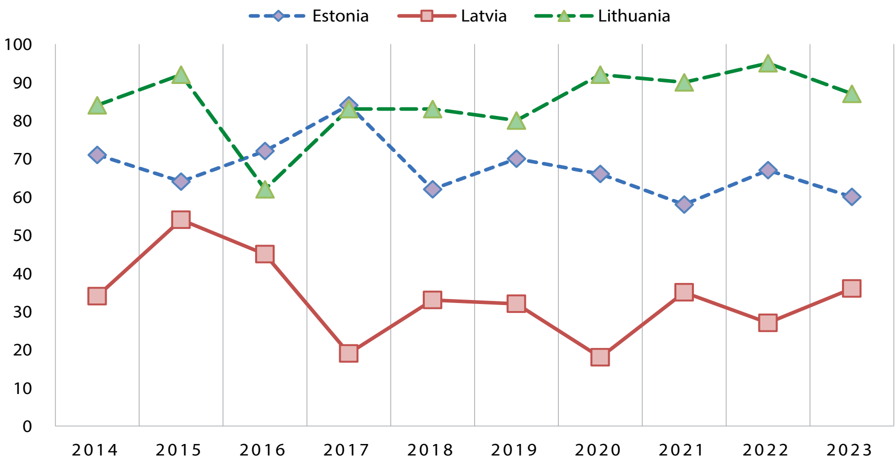

Figure 1. *Doctoral graduates of natural sciences, mathematics, and statistics in the Baltic states, Source: Eurostat [11]*

A shortage of highly qualified human resources in MST disciplines means a weakness of the relevant ecosystems, resulting in limited productivity of scientific and applied research and production of high-added-value commercial assets by industry. Especially painful for the development is the low number of physicists in the country, particularly making Latvia risky for investors looking forward to the development of disruptive innovation technologies demanding well-trained professionals with a strong background in physics.

Today, we have in Latvia only one independent research institute in physics (*instead of the former 8*) – the Institute of Solid State Physics – a highly internationally recognised and strong player in the European Research Area. Other former institutes of the Academy of Science family were lost or are incorporated into large faculties of the two mentioned universities, having the status of small, strongly subordinated units. The reasons for such "*progress*" are as follows: For decades, keeping public institutional funding around 10–15% of what is needed for sustainable and competitive operations; Absence of targeted, not bureaucratic, financial instruments to finance disruptive innovation prototypes, particularly the project proposals awarded with the "*Seals of Excellence*" from the European Innovation Council; Lack of proactive promotion and financial support for studies in physics; Insufficient allocation of national budget and EU Structural funding for RTD and higher education, particularly ensuring fellowships for MSc and PhD studies; Policy failure in repatriation and recruitment of young talents and experienced researchers from abroad. Unfortunately, decision makers prefer "*bricks instead of brains*" contrary to the EU Commission's recommendation to invest 25% of Structural funds into RTD and Innovation was not followed during the previous planning period and is not the case for the current one.

In 2014 Latvia received another strong warning: TEHNOPOLIS expert group stated the following in their report [12] already in 2014 "*The difficult financial climate, short-term planning within the state, insufficient administrative capacity and the low political priority of innovation and research, and a heavily bureaucratic tradition all make it hard to implement research and innovation policy in Latvia ...*"

Low political priority of innovation and research in the country for decades means a weak, low-productive economy, causing:

Emigration. Since the early 1990s, Latvia has experienced a steady population decline primarily due to net emigration, when many Latvians are seeking better economic opportunities abroad [13], and elite children and graduates of the best state gymnasiums move for studies at the best universities in the Baltic Sea region, the UK, and the USA.

Economic Challenges. The Latvian economy has faced growing bureaucracy, a changing fiscal environment, corruption, and rising energy prices on one side, and a shortage of top-level professionals on the other side. Latvia counts only 3–5 research-driven "high-tech" companies with annual turnover around or slightly above 100MEUR. The brain drain and outflow of talents is limiting competitiveness, resulting in an ability of the company to grow.

Chaotic Educational System reforms have resulted in a gradual deterioration of the quality of teaching in MST disciplines, strongly linked to a shortage of teachers in mathematics and natural science subjects.

Lowest in the EU investments in RTD and Innovation.

Low ranking of Latvian universities. Only the two best ones are ranked 800–1000 among the world's leading universities in international rankings.

Conclusions

Exceptional crisis management measures are needed in search of solutions. Evidently: in the short-term perspective – massive repatriation of researchers; in the midterm perspective, drastic improvement of studies in physics in quality and quantity; in the long-term perspective, restoration of obligatory secondary education and drastic increase of the quality of teaching MST disciplines and particularly physics in secondary schools with a massive awareness campaign on the necessity to the welfare of society basing on experience on Finland particularly and Nordic Countries in general.

We want to note that massive repatriation and recruitment of research talents from abroad will face allocation problems. Therefore, RTD and the innovation ecosystems in various fields of the "high-tech" economy need to be improved as follows: the legal status of existing research institutes at the universities needs to be improved; their independence in decision making ensured, and new EU-level centres of excellence created.

This limited in size, short article highlights the extraordinarily complicated problems Latvia will face in the future in its unavoidable and necessary efforts to overcome its current backwardness based on strong ecosystems for the relevant MST fields, with strong interplay between academia and industry.

Besides academia and industry shortage of professionals is an acute problem for the ministry departments in the Government. Frequently, opinions or even senseless advice and demands from the ministries, concerning research problems in strong institutes or university units, having on their staff many researchers with a Hirsch index above 10 and experienced science managers, are produced by MSc and sometimes even BSc level "professionals" without any research experience in academia or management private sector companies producing high added value goods for worldwide market.

Evidently, in the current landscape of research and innovation in the country, the research structures in Latvia need much more independence in decision-making, keeping in mind that the previous avalanche of "*top down*" reforms resulted in millions of EUR in damage to the state economy and in "*bottle necks*" and substantial slowdown in the growth of export oriented "high-tech" industry.

Possibly, the forums of research institutes in physics, chemistry, and other MST fields can emerge as an effective "task force" for strategy development and decision-making concerning advancements of basic and applied research and contribution to industry development.

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References

[1] Sook-iL Kwun. Physics, big science, and modern industrialization in Korea. Sook-Il Kwun (President of Korean Physical Society). *Korean Physical Society Series* No 97–06

[2] Jānis Jansons, Latvijas Universitātes Fizikas institūts (1919–1944) un tā sagatavotie fiziķi (*Institute of Physics of the University of Latvia (1919–1944) and the physicists it trained*, in Latvian). *Latvijas Universitātes akademiskais apgāds*.2008. gads 219 lpp.

[3] Sook-iL Kwun (1999). Physics in Korean Industry. *The Industrial Physicist*. pp 26–27

[4] Kumagai Jean (1997). A physicist now heads South Korea's science ministry. *Physics Today*, 1997, 50.5: 53–54

[5] Swinbanks D. (1997). Physicist takes top Korean science post. *Nature*, 386(6621)

[6] Sook-iL Kwun. Physics, big science, and modern industrialization in Korea. Sook-Il Kwun (President of Korean Physical Society). *Korean Physical Society Series* No. 97–06

[7] Latvian Research: an International Evaluation (Copenhagen: The Danish Research Councils, 1992)
[8] Juris Ekmanis (1993). Latvijas zinātnes starptautiskā ekspertīze*: International Evaluation of Latvian Research*, in Latvian), A daļa, 3: 39–40
[9] Husso Kai, Sakari Karjalainen, Tuomas Parkkari (2000). The state and quality of scientific research in Finland: a review of scientific research and its environment in the late 1990s. Mon ila Oy / Erikoisp a in o Oy, Helsinki 138 pages
[10] Richard Deiss, Lars Bo Jakobsen, Margot Kuzma, Mikaël Le Bourhis, Cristina Marcone, et al (2011) Progress Towards the Common European Objectives in Education and Training: Indicators and Benchmarks 2010/2011. Commission of the European Communities: Commission staff working document, ⟨hal-03245597⟩ 191 pages
[11] Graduates by education level, programme orientation, sex and field of education (2025). Eurostat. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/educ_uoe_grad02$dv_443/default/table?lang=en&category=scitech.hrst.hrst_fl.hrst_fl_te
[12] Arnold E., Knee P., Angelis J., Giarraca F., Grinice E., Jávorka Z., Reid A. (2014). Innovation System Review and Research Assessment Exercise, https://doi.org/10.13140/RG.2.2.21960.52489
[13] European Immigration. A Sourcebook, Book Chapter (2016), pp. 199–210. Šūpule Inese. *Baltic Institute of Social Sciences*, Latvia. DOI: 10.4324/9781315580920-15, https://www.scopus.com/pages/publications/85106466085

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