LATVIJAS UNIVERSITĀTE

FOTONIKA-LV

LATVIJAS UNIVERISTĀTES NACIONĀLĀ ZINĀTNES PLATFORMA

The 5th International Conference

# Quantum sciences, Space sciences and Technologies – PHOTONICS RIGA 2023

Riga, 20–21 April 2023

# BOOK OF ABSTRACTS

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The 5th International Conference

# Quantum sciences, Space sciences and Technologies – PHOTONICS RIGA 2023

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# BOOK OF ABSTRACTS

University of Latvia Press

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Dr. Arnolds Ūbelis – Scientific secretary of the NSP FOTONIKA-LV

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## SHORT PRESENTATIONS

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# Introduction

# PREFACE. FOTONIKA-LV since 2010

**Arnolds Ūbelis**

*NSP FOTONIKA-LV, University of Latvia, Latvia*

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Until now, only bottom-up efforts made by recognised individual researchers, a few strong research groups, as well top industry leaders have been driving research, technology development, and innovation (RTD & I) in Latvia, relying heavily on "project life" – exclusively on project-related funding. Institutional funding is commonly scarce, largely resulting from serious previous mistakes and wrong priorities of the national RTD and innovation policy and R & I culture. Indeed, in 2014, and more recently in 2021 the Technopolis group stated[1], [2] that the severe lack of institutional funding was significant weakness of R & I policy of Latvia (*'Strongly insufficient institutional funding is the major weakness of R & I policy in Latvia…'* – citation from 2014 report).

The current National Science Platform (NSP) FOTONIKA-LV in quantum sciences, space sciences, and technologies at the University of Latvia (Fig. 1) was also established through bottom-up action and emerged as an association between three research institutes (strong in quantum sciences, space sciences and technologies) at the University, based on an agreement signed by the directors on April 24, 2010. The institutes joined forces to boost the fields of photonics sciences and technology in Latvia, in line with the EC's definition of photonics being among the six key enabling technologies in Europe in October 2009 (see [3], [4]). Re-identified in 2020 in a document considering a new industrial strategy for Europe[5].

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1 Arnold, E., Knee, P., Angelis, J., Giarraca, F., Griniece, E., Jávorka, Z., Reid, A. 2014. Latvia – Innovation System Review and Research Assessment Exercise: Final Report. TECHNOPOLIS, April 20, 2014. https://doi.org/10.13140/RG.2.2.21960.52489.
- Citation from page 27: "Only 17% of research funding is institutional (ERAWATCH Country Report, 2011), making Latvia's one of the most highly 'contested' systems in the world. While there is no clear international benchmark for what the proportion of institutional funding should be, there is some consensus that 50% is the minimal viable level. The Finnish Research and Innovation Council recently observed that the share of competitive funding in the university research system has recently approached that value and that to do any further would be dangerous".
- Citation from page 38. 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.

2 Arnold, E., Knee, P., Vingre, A., International Evaluation of Scientific Institutions Activity, Consolidated report, March 2021, Technopolis group. https://www.izm.gov.lv/lv/media/10721/download.

3 Preparing for our future: Developing a common strategy for key enabling technologies in the EU. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Commission of the European Communities. Brussels (COM(2009) 512 final).

4 Willner, *et al*. (2012). Optics and Photonics: Key Enabling Technologies. Proceedings of the IEEE, Vol. 100.

5 Brussels, 10.3.2020. COM (2020) 102 final. A New Industrial Strategy for Europe.

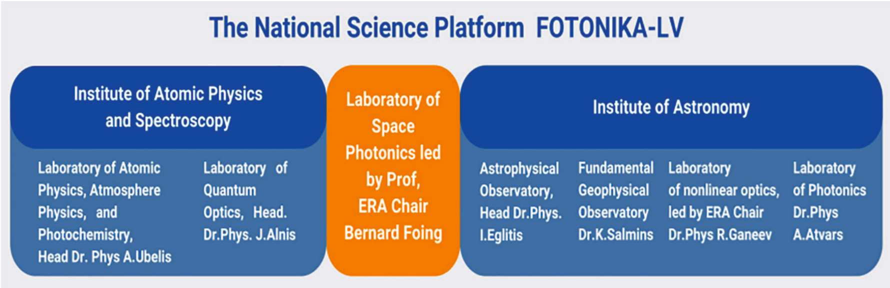


***Figure 1.*** *Current structure of the NSP FOTONIKA-LV*

A specific emphasis was placed on quantum sciences in 2018, when the European Commission decided to finance the Quantum Flagship – the third largest-scale research and innovation initiative for the next ten years[6].

The National Science Platform FOTONIKA-LV[7] at the University of Latvia currently consists of five laboratories dedicated to quantum sciences and photonics, with the Astrophysical Observatory and the Fundamental Geodynamic Observatory hosting an advanced satellite laser ranging station (ILRS code RIGL1884[8]).

The foundation of FOTONIKA-LV was a decisive step forward, prompting remarkable structural changes at the University of Latvia. Since 2010, research teams associated with FOTONIKA-LV have been involved in the implementation of more than 15 large-scale projects including, six European Regional Development Fund projects and 16 projects financed by the 7th Framework Programme for Research (FP7) and the Horizon 2020 (H2020) programme. Among these, five FP7 projects were pivotal for the growth of and structural changes within the University of Latvia (see [9, 10, 11, 12, 13]).

The first remarkable success was achieved through the 3.8 million EUR FP7-REGPOT-2011-1 project No 285912 (Coordinator Dr. A. Ubelis) which allowed the recruitment/repatriation of 18 researchers. Particularly Dr. Phys. Janis Alnis[14], who started his postdoctoral career as a Marie Curie fellow working with Nobel prize winner Theodor Hänsch[15] was repatriated.

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6 https://qt.eu/about-quantum-flagship/: The Quantum Flagship is driving this quantum revolution in Europe.

7 http://fotonika-lv.eu/

8 International Laser Ranging Service: https://ilrs.gsfc.nasa.gov/network/stations/active/RIGL_station_info.html

9 FP7-REGPOT-2011-1. FOTONIKA-LV, No. 285912 (2012–2015), Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area (scored 15 from 15; 3.8MEUR)

10 Final report of FOTONIKA-LV, reg. Nr. 285912 (2012–2015): https://cordis.europa.eu/project/id/285912/reporting/de

11 Arnolds Ubelis. Coordinator. NOCTURNAL ATMOSPHERE – FP7-PEOPLES-2011-IRSES project, contract Nr 294949. "Secondary photochemical reactions and technologies for active remote sensing of nocturnal atmosphere" (01.05.2012–30.04.2016)

12 Arnolds Ubelis. Coordinator FP7-PEOPLES-IRSES BIOSENSORS-AGRICULT. No. 316177 – Development of Nanotechnology Based Biosensors for Agriculture

13 Arnolds Ubelis. PI. FP7-PEOPLES-IRSES-2013. No. 612691. REFINED STEP. An international network on new strategies for processing calcium phosphates (03.11.2013–02.11.2017)

14 Janis Alnis: https://scholar.google.com/citations?user=ZEXK4m0AAAAJ&hl=lv&oi=sra. Full member of Latvian Academy of Sciences

15 https://www.nobelprize.org/prizes/physics/2005/hansch/facts/

Dr. Phys. Roman Viter[16], currently among the most distinguished physicists in Latvia, was recruited from Ukraine.

A professional non-governmental organisation "Riga Photonics Centre" was co-founded, and the membership to the European Photonics Industry Consortium (EPIC)[17] was established through the aforementioned project. Active contacts with Latvian small and medium-sized enterprises (SMEs) within the photonics domain were also established (12 cooperation projects; 11 SMEs were supported in designing proposals for the commercialisation of their disruptive innovation prototypes with a technology readiness level of around 6, financed by the Horizon 2020 SME Instrument or currently by the European Innovation Council "Challenger" calls budget). Numerous FP7 and Horizon 2020 project proposals were prepared (FP7: 16 applications; 10 financed projects. H2020: 23 applications; 6 financed projects) by the recruited /repatriated researchers under the leadership of the scientific secretary A. Ubelis.

The transformation of the association into the NSP FOTONIKA-LV (Fig. 2) was further step of quality and quantity of the structural changes at the University of Latvia, because in addition to the academic activities, cooperation with an excellent group of high-tech SMEs in the domain of photonics had been intensified substantially. The NSP FOTONIKA-LV is currently running 12 projects. These include four ERDF projects, three European Space Agency (ESA) projects, one space project from the European Institute of Innovation & Technology (EIT)[18], three National Council of Science projects, and two strategically very important WIDERA ERA chair projects – QUANTUM-LV[19] and SPACE-LV[20] – ensuring the strategic leadership from two excellent and globally recognised researchers and science managers – Dr. R. Ganeev[21] and Prof. B. Foing[22].

The implementation of foreseen TEAMING project of Horizon Europe during the 2024–2030 will be concluding step in evolution of FOTONIKA-LV, resulting in emergence of the National Centre of Excellence in Quantum Sciences and Photonics in Latvia (Fig. 2) performing worldwide recognised basic research and providing nation-wide services for academia and industry in training highly qualified researchers, professionals and science mangers accordingly.

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[16] Roman Viter: https://scholar.google.com/citations?user=WLVxGWAAAAAJ&hl=lv&oi=sra

[17] European Photonics Industry Consortium (EPIC) – https://epic-assoc.com

[18] European Institute of Innovation & Technology (EIT) "EuroSpaceHub" No 220812. "Increasing space innovation and technology transfer by connecting space academia, industry, and startups" (2022–2024) https://eit-hei.eu/projects/eurospacehub

[19] Refinanced by European Regional Development Fund (ERDF) highly scored Horizon 2020 ERA Chair project No 1.1.1.5/19/A/003 (2,5MEUR) "The Development of Quantum Optics and Photonics at the University of Latvia" (2019–2023), University of Latvia, https://www.erachair.lu.lv. (Horizon 2020 ERA Chair project proposal No. 857624 "ERA Chair in Quantum Optics and Photonics" (QUANTUM-LV))

[20] Will be refinanced in 2023 by European Regional Development Fund (ERDF) highly scored Horizon Europa project proposal No 101087207 – SPACE LV (2.5 MEUR). "ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia" (2023–2028). Call: HORIZON-WIDERA-2022-TALENTS-1, ERA Chair: Prof. Bernard Foing

[21] Rashid Ganeev: https://scholar.google.com/citations?user=r-687_kAAAAJ&hl=lv&oi=sra

[22] Bernard Foing: https://scholar.google.com/citations?user=_fTVp0kAAAAJ&hl=lv&oi=sra

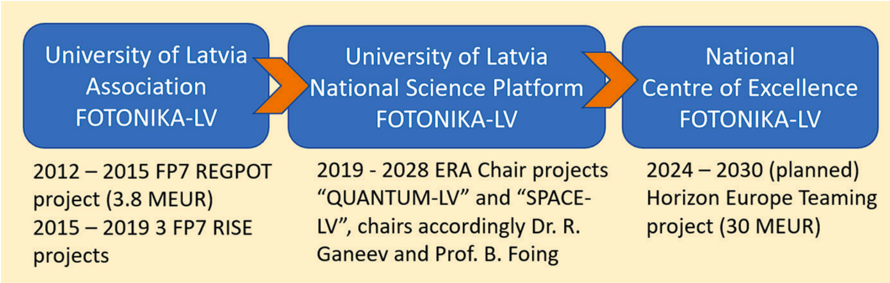


***Figure 2.*** *History and forecast for the evolution of FOTONIKA-LV*

**The NSP originated as an Association and will be upgraded to the scale of an independent National Centre of Excellence – FOTONIKA-LV to become recognised in the European Research Area and visible worldwide research entity of quantum sciences, space sciences, and technologies under umbrella of photonics.**

# Scientific Council of National Science Platform FOTONIKA-LV, in Quantum Sciences, Space Sciences and Related Technologies at the University of Latvia

*also*

# Scientific Council of the 5th Anniversary International Conference 'Quantum sciences, Space sciences and Technologies – PHOTONICS RIGA 2023'

1. **Prof. Sune Svanberg**, *Lund University (Sweden), Department of Physics, professor emeritus, h-index 71 (Google Scholar)*
2. **Prof. Lorenzo Pavesi**, *University of Trento (Italy), Department of Physics, h-index 77 (Google Scholar)*
3. **Prof. Andris Ambainis**, *University of Latvia (Latvia), Faculty of Computing, h-index 51 (Google Scholar)*
4. **Prof. Andrejs Siliņš**, *Latvian Academy of Sciences (Latvia), Division of Physical and Technical Sciences, h-index 12 (SCOPUS)*
5. **Prof. Valdis Segliņš**, *University of Latvia (Latvia), vice-Rector for Natural Sciences, Technology and Medicine, h-index 8 (SCOPUS)*
6. **Dr. Chem. Donats Erts**, *University of Latvia (Latvia), Institute of Chemical Physics, h-index 31 (SCOPUS)*
7. **Dr. phys. Vladimirs Gostilo**, *Baltic Scientific Instruments, Ltd[1] (Latvia), CEO, h-index 19 (Google Scholar)*
8. **Mr. Daumants Pfafrods**, *Light Guide Optics International, Ltd[2] (Latvia), CEO*
9 **Dr. Janis Valdmanis**, *Thorlabs, Inc.[3] (USA), general manager, Ultrafast Optoelectronics Team, h-index 21 (SCOPUS)*
10. **Dr. Phys. Rashid A. Ganeev**, *University of Latvia (Latvia), ERA Chair, National Science Platform FOTONIKA-LV, h-index 58 (Google Scholar)*
11. **Prof. Dainis Draviņš**, *Lund University (Sweden), Lund Observatory, professor emeritus, h-index 34 (Google Scholar)*
12. **Prof. Andris Vaivads, *Ventspils*** *University of Applied Sciences (Latvia), KTH (Sweden), Division of Space and Plasma Physics, h-index 56 (Google Scholar)*
13. **Prof. Bernard H. Foing**, *KU Leuven (Belgium), Euro Space Hub (the Netherlands), h-index 50 (Google Scholar)*
14. **Dr. Alfonso Saiz-Lopez**, *CSIC (Spain), Department of Atmospheric Chemistry and Climate, Institute of Physical Chemistry "Rocasolano", h-index 58 (Google Scholar)*
15. **Prof. Anthimos Georgiadis**, *Leuphana University of Lüneburg (Germany), Institute of Product and Process Innovation (PPI), h-index 11 (Google Scholar)*
16. **Dr. Hab. Phys. Linards Skuja**, *Institute of Solid State Physics, University, of Latvia (Latvia), h-index 37 (SCOPUS).*

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[1] www.bsi.lv
[2] www.lightguide.com
[3] www.thorlabs.com

# Agenda

*Thursday, April 20*

## Quantum Sciences and Photonics. *Chair: Prof. Sune Svanberg*

| | | |
|---|---|---|
| **9.30–9.45** | **Welcome speech** | |
| **Alvis Brazma, *EMBL's European Bioinformatics Institute*** – United Kingdom | | |
| **9.45–11.00** | **Keynote lectures 1** | *Chair: Prof. Sune Svanberg* |
| **Rashid Ganeev, *University of Latvia (Online)*** – Recent Developments of Nonlinear Optics in Latvia | | |
| **Jānis Alnis, *University of Latvia*** – Decade of Quantum Optics laboratory | | |
| **11.20–13.20** | **Plenary session 1 (Invited speakers)** | *Chair: Dr. Arnolds Ūbelis* |
| **Lorenzo Pavesi, *University of Trento*** – A platform for Artificial Intelligence: neuromorphic silicon photonics | | |
| **Sune Svanberg, *Lund University*** – Laser Spectroscopy Applied to Environmental Monitoring | | |
| **Katarina Svanberg, *Lund University*** – Some Challenges in Medicine Addressable by Laser Spectroscopy Laser Spectroscopy | | |
| **Henning T. Schmidt, *Stockholm University*** – DESIREE – a tool for studies of atomic, molecular and cluster ions | | |
| **Jyrki Saarinen, *University of Eastern Finland*** – Photonics Flagship and Photonics in Finland | | |
| **Vladimirs Gostilo, Serhii Pohuliai, Rais Nurgalejevs, Igors Krainukovs, Normunds Grundmanis, *Baltic Scientific Instruments*** – Semiconductor Materials and Technologies for Nuclear Radiation Detectors | | |
| **14.20–16.00** | **Plenary session 2 (Invited speakers + Short presentations)** | *Chair: Dr. Aigars Atvars* |
| **Dag Hanstorp, *University of Gothenburg*** – Negative Ions – Fragile Quantum Systems | | |
| **Erich Leistenschneider, *CERN*** – Highly-sensitive negative ion spectroscopy with MIRACLS | | |
| **Miranda Nichols, *University of Gothenburg* et al.** – Studying radioactive negative ion production cross sections | | |
| **Vyacheslav Kim, *University of Latvia*** – High-order harmonics generation in the plasmas containing newly synthesized materials | | |
| **Kishore Babu Ragi, *Riga Technical University*** – Impact of Urban Forest on Heat and Photochemical Pollution in Riga, Latvia | | |
| **Lev Nagli, Michael Gaft, Yosef Raichlin, *Ariel University*** – Laser-Induced Plasma Lasers: Polarization properties | | |
| **Vishwa Pal, *Indian Institute of Technology Ropar (Online)*** – Network of coupled lasers and its applications | | |
| **17.00–18.00** | ***Poster session, Venue: Jelgavas street 3*** | *Chair: Dr. Hab. Uldis Bērziņš* |
| **Aigars Atvars, *University of Latvia*** – Progress of the ERA Chair project | | |
| **Jānis Alnis, Dina Bērziņa, *University of Latvia*** – Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications | | |
| **Viesturs Silamiķelis, Aigars Apsītis, Jānis Sniķeris, Austris Pumpurs, *University of Latvia*** – Development of next generation technology for ultra purity crystal growth based on MHD semi levitation | | |
| **Jānis Blahins, Armāns Bziškjans, *University of Latvia*** – Elaborated universal power supply for ion beam devices controlled by PC | | |
| **Arnolds Ūbelis, Reinis Rotkalis, Austris Pumpurs, *University of Latvia*** – Current status of NSP FOTONIKA-LV infrastructure project QUANTUM & SPACE | | |
| **Uldis Bērziņš, Arturs Ciniņš, Armans Bžiškjans, *University of Latvia* & Dag Hanstorp, *University of Gothenburg* & Paul Martini, Jose Navarro Navarrete, Henning Schmidt, *Stockholm University*** – Lifetime measurements of Ba II metastable ion: preliminary results | | |
| **Ulises Miranda, *Baltic Scientific Instruments* & Ilya G. Kaplan, *Universidad Nacional Autónoma de México* & Uldis Bērziņš, Arnolds Ūbelis, *University of Latvia* –** Computation and vibrational analysis of lower excited states of $Te_2$ dimer | | |
| **Arnolds Ūbelis, Jānis Kļaviņš, Austris Pumpurs, Juris Silamiķelis, *University of Latvia* & Hailey Hardy, *Brigham Young University* –** RF ICP plasma atomic spectra source of Ar, Xe and Kr – for wavelength calibration of lasers in visible – near IR spectral range ensuring accuracy up to 0.001nm | | |

| |
|---|
| **Boriss Janins, *Slicker3D, SIA* –** Lightfield imaging of wide viewing angle for 3D displays and adaptive camouflage using GSL array |
| **Vicor Kärcher, Tobias Reiker, Helmut Zacharias, *University of Münster*** & **Andrea S.S. de Camargo, *University of Sãu Paulo* –** Low order harmonic generation in laser induced borosilicate glass plasma and CdTe quantum dots |
| **Kaspars Miculis**, ***University of Latvia* & Evgenii Viktorov, Pavel Serdobintsev, Nikolay Bezuglov, *St. Petersburg State University, Russia (Online)*** – Modulation of quantum beats signal upon photoionization of Xe isotopes in the magnetic field |
| **Irēna Mihailova, Vjačeslavs Gerbreders, Marina Krasovska, Ēriks Sļedevskis, Valdis Mizers, *Daugavpils University (Online)*** – Fabrication of patterned ZnO nanorod arrays |
| **Arnolds Ūbelis, *University of Latvia*** – Grown in Riga worldwide known photonuclear physicist Michael Danos (1922-1999) |

*Friday, April 21*

Space Sciences and Space Photonics. *Chair: Dr. Valdis Avotiņš*

| **9.30–9.45** | **Welcome speech** | |
|---|---|---|
| **Andris Vaivads, KTH Royal Institute of Technology,** Sweden **& *Ventspils University of Applied Sciences***, Latvia | | |
| **9.45–11.00** | **Keynote lectures 2** | *Chair: Dr. Valdis Avotiņš* |
| **Andris Vaivads, *Ventspils University of Applied Sciences*** – Space science at Ventspils University of Applied Sciences | | |
| **Bernard Foing, *Leuven University*** **& Arnolds Ūbelis, *University of Latvia*** – The project SPACE-LV: "ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia" | | |
| **11.20–13.20** | **Plenary Session 3 (Invited speakers)** | *Chair: Dr. Ilgmārs Eglītis* |
| **Kalvis Salmiņš, Jorge Roberto del Pino Boytel, Jānis Kauliņš, *University of Latvia*** – The Hybrid Photodetector (HPD) as a detector for Satellite Laser Ranging, first results | | |
| **Jara Pascual, *Collabwith-EuroSpaceHub*** – EuroSpaceHub, how to digitise the space and aviation ecosystem to leverage funding, talent, innovation and entrepreneurship | | |
| **Ilgmārs Eglītis, *University of Latvia*** – Projects in Baldone Astrophysical Observatory | | |
| **Vidvuds Beldavs, *Riga Photonics Centre (Online)***<br>1. Space compacts as a means to implement Space2030 Agenda linking space sciences and technologies to UN Sustainable Development Goals<br>2. ChatGPT and other AI tools to accelerate development at the community level in Sub-Saharan Africa | | |
| **Naresh Kumar Readdy Andra, *University of Latvia*** – Diffractive phase elements to form new class of optical fields are driving with versatile spatial distributions | | |
| **Sergey Kravchenko, *Cryogenic and Vacuum Systems (Online)*** – Capabilities of space industry test systems | | |
| **14.20–15.20** | **Plenary session 4 (Short presentations)** | *Chair: Kalvis Salmiņš* |
| **A. Kalinovskis, V. Stepanovs, A. Ancāns, Dans Laksis, Atis Elsts, *Institute of Electronics and Computer Science*** – Event Time and Amplitude Meter: High-Precision Measurement Device Based on Enhanced Event Timing Principles | | |
| **Serhii Matviienko, *National Technical University of Ukraine* & Arnolds Ūbelis**, ***University of Latvia*** – Next Generation's Relativistic Radio-Physical Gravimeter for Geology, Seismology and Geodesy | | |
| **Krišjānis Krakops, Valdis Avotiņš, Arnolds Ūbelis, *University of Latvia*** – The Progress of the EU supported Project "EuropeanSpaceHub" at the University of Latvia | | |
| **Juulia-Gabrielle Moreau, Argo Jõeleht, *University of Tartu*** **& Bernard Foing, *Leuven University*** **& Arnolds Ūbelis, *University of Latvia (Online)*** – Shock metamorphism, a cause for spectral changes in meteorites: from Tartu to Riga, a cooperation | | |
| **Vladislavs Bezrukovs, *Engineering Research Institute Ventspils International Radio Astronomy (Online)*** – Properties of the variability of active galactic nuclei Perseus A, MRK 421, MRK 501 according to joint radio-optical observations in Latvia, Ukraine and Slovakia | | |

# Welcome speeches

**Dr. Alvis Brazma**

Senior Team Leader and Senior Scientist at the EMBL's European Bioinformatics Institute
Brazma@ebi.ac.uk
0000-0001-5988-7409 (h-index 79, citations > 58 500)
https://scholar.google.se/citations?hl=lv&user=4QnYN1sAAAAJ

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

Dr. A. 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. A. Brazma was among the first scientists to use microarray data to study gene regulation. In 1999 he founded the Microarray Gene Expression Data society was instrumental in starting ArrayExpress, one of the major international repositories for functional genomics data.

Dr. Alvis Brazma oversees the development and services for several major resources, including ArrayExpress, the Gene Expression Atlas and the BioStudies Database. His main research interests concern integrative data analysis to reveal patterns of gene and protein expression in normal and diseased state. He has over 100 scientific publications and is a Principal Investigator on several large collaborative genomics and biomedical projects, including the kidney cancer project of the International Cancer Genome Consortium.

**Prof. Andris Vaivads**

The Rector at Ventspils University of Applied Sciences
Andris.Vaivads@venta.lv
0000-0003-1654-841X (h-index 56, citations > 10 950)
https://scholar.google.ca/citations?user=ixBaPtEAAAAJ

*He is a co-author of the article (2016) cited already more than 500 times*: Bale, S. D., Goetz, K., Harvey, P. R. *et al*. (2016). The FIELDS Instrument Suite for Solar Probe Plus. *Space Sci Rev* 204, 49–82. https://doi.org/10.1007/s11214-016-0244-5.

He obtained MSc degree in Physics at the University of Latvia (1992), and Doctoral degree in Space Physics working in the Swedish Space Physics Institute in Upsala. He worked for the institute for 20 years, reached worldwide recognition and outstanding record of scientific publications in the space sciences.

Return/repatriation of Prof. Andris Vaivads will result in a substantial boost of space science domain and relevant technologies nationally across Latvia.

Space research community in Latvia will strongly benefit from expected partnership and collaboration of Prof. Andris Vaivads with other outstanding and worldwide visible space scientist Prof. Bernard Foing, starting to act as an ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the NSP FOTONIKA-LV of the University of Latvia.

Compiled by Arnolds Ūbelis

# Keynote speeches

# Recent Developments of Nonlinear Optics in Latvia

**Rashid Ganeev**

*Institute of Astronomy, University of Latvia, Latvia*

e-mail: rashid.ganeev@lu.lv

Nonlinear optics (NLO) is the study of how intense light interacts with matter. NLO is essential in the development of broad-bandwidth light sources, pulse compression techniques, generation of coherent extreme ultraviolet radiation, and other areas of optoelectronics and photonics.

In this talk, I describe the most recent studies of NLO properties of small and large molecules, quantum dots, and nanoparticles of different materials carried out at the University of Latvia and the Institute of Solid State Physics. Among the topics of my talk are the variation of the nonlinear refraction and absorption of spectrally tunable femtosecond pulses in carbon disulfide, nonlinear absorption and refraction of picosecond and femtosecond pulses in HgTe quantum dot films, exfoliated $Bi_2Te_3$ nanoparticle films, and mercury sulphide quantum dots, plasma dynamics characterisation for improvement of resonantly-enhanced harmonics generation in chromium, indium, and tin laser-induced plasmas, third harmonic generation in the thin films containing various quantum dots, etc. [1–8]. The perspectives of further development in the NLO studies will be discussed.

## Acknowledgments

This research was funded by the European Regional Development Fund (project No. 1.1.1.5/19/A/003).

### References

[1] Bundulis, A., *et al.* (2021). Nonlinear refraction and absorption of spectrally tunable picosecond pulses in carbon disulfide. *Optical Materials* 122(11), 111778. https://doi.org/10.1016/j.optmat.2021.111778.

[2] Bundulis, A., *et al.* (2021). Nonlinear absorption and refraction of picosecond and femtosecond pulses in HgTe quantum dot films. *Nanomaterials* 11(12), 3351. https://doi.org/10.3390/nano11123351.

[3] Kim, V. V. *et al.* (2022) Third-order optical nonlinearities of exfoliated $Bi_2Te_3$ nanoparticle films in UV, visible and near-infrared ranges measured by tunable. femtosecond pulses. *Optics Express* 30(5), 6970–6980. https://doi.org/10.1364/OE.449490.

[4] Kim, V. V., *et al.* (2022). Investigation of nonlinear optical processes in mercury sulfide quantum dots. *Nanomaterials 12(8),* 1264. https://doi.org/10.3390/nano12081264.

[5] Kim, V. V., *et al.* (2022). Variation of the sign of nonlinear refraction of carbon disulfide in short-wavelength region. *Optical Materials Express* 12(5), 2053–2062. https://doi.org/10.1364/OME.451733.

[6] Kim, V. V., *et al.* (2022). Plasma dynamics characterization for improvement of resonantly-enhanced harmonics generation in indium and tin laser-produced plasmas. *Photonics* 9(3), 600. https://doi.org/10.3390/photonics9090600.

[7] Ganeev, R. A., *et al.* (2022). Third harmonic generation in the thin films containing quantum dots and exfoliated nanoparticles. *Applied Physics B* 128(2), 202. http://dx.doi.org/10.1007/s00340-022-07923-7.

[8] Kim, V. V., *et al.* (2022). Influence of chromium plasma characteristics on high-order harmonics generation. *Applied Physics B* 128(2), 217. http://dx.doi.org/10.1007/s00340-022-07937-1.

# Decade of Quantum Optics laboratory

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Laboratory of Quantum Optics was established a decade ago in 2013 during the FOTONIKA-LV project[1], acquiring a femtosecond optical frequency comb metrology laser, tuneable diode lasers, rubidium saturation spectrometer and laser stabilisation resonators. Afterwards, the laboratory won three research projects on optical whispering gallery mode microresonators (WGM). WGM resonators confine and circulate light within a circular cavity, offering high sensitivity to changes in the surrounding environment. Due to their low optical losses, high quality factor (Q-factor), and excellent thermal stability, silica microsphere resonators are particularly suitable for frequency comb generation. Below is a summary of the Quantum Optics laboratory's publications in the last 5 years grouped in two categories: sensing applications and microresonator frequency combs.

### Whispering gallery mode resonator and glucose oxidase based glucose biosensor

This paper discusses the development of a novel glucose biosensor that uses whispering gallery mode (WGM) resonators and glucose oxidase ($GO_x$) enzyme [1]. The research aims to provide a more sensitive, selective, and reliable method for glucose detection, which is crucial for diabetes management.

### Whispering gallery mode resonators coated with Au nanoparticles

The deposition of Au nanoparticles onto WGM resonators can enhance their performance by introducing new properties, such as localised surface plasmon resonance (LSPR) to exploit the enhanced properties for light-matter interactions [2].

### Whispering gallery mode resonators covered by a ZnO nanolayer

The paper presents a comprehensive investigation of the properties of ZnO nanolayer-covered WGM resonators, including their fabrication process, the influence of the nanolayer thickness, and the resulting changes in the resonator's performance [3]. The study also discusses the potential applications of these modified resonators in various fields, such as sensing and optoelectronics.

### Computer modelling of WGM microresonators with a zinc oxide nanolayer using COMSOL multiphysics software

The addition of a ZnO nanolayer to the silica surface can enhance the performance of WGM resonators, as ZnO is known for its unique optical, electrical, and piezoelectric properties. The paper [4] describes the computer modelling process using COMSOL Multiphysics software, which enables the simulation and analysis of various physical phenomena in WGM resonators with a ZnO nanolayer. This approach allows for a comprehensive investigation of the effects of the ZnO nanolayer on the resonator's performance, including factors such as mode profiles, mode coupling, and quality factor (Q-factor).

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[1] https://cordis.europa.eu/project/id/285912

**Whispering gallery mode resonator temperature compensation and refractive index sensing in glucose droplets**

This paper [5] presents a temperature compensation technique for WGM resonators, by coating silica microsphere with a thin layer of PMMA that has an opposite sign of thermo-refractive coefficient. Second part explores drying of glucose droplets where refractive index increases in time.

**High-sensitivity whispering gallery mode humidity sensor based on glycerol microdroplet volumetric expansion**

High-sensitivity whispering gallery mode (WGM) humidity sensor is demonstrated [6]. Glycerol is a hygroscopic substance, meaning it readily absorbs moisture from the environment, causing its volume to expand or contract depending on humidity levels. Expansion results in shifts in the resonant frequency of the WGM resonator.

**Selectivity of glycerol droplet microresonator humidity sensor**

In this paper [7], researchers investigate the selectivity of a glycerol droplet microresonator humidity sensor. Humidity sensors are essential for various applications, such as environmental monitoring, industrial processes, and biomedical devices. Glycerol droplet microresonators, a type of whispering gallery mode (WGM) resonator, have shown potential for high sensitivity and selectivity in humidity sensing applications. In contrary to polymer-based humidity sensors, glycerol droplets are insensitive to other volatile organic compounds.

**Wavelength Sensing Based on Whispering Gallery Mode Mapping**

In this paper [8], R. Berkis and co-authors present a study on laser wavelength sensing based on whispering gallery mode (WGM) mapping. It is based on WGM imaging of more than 10 PMMA microspheres attached to a tapered optical fiber. Paper demonstrates that this setup can be used for precise unknown laser wavelength determination.

**Quality factor measurements for PMMA WGM microsphere resonators using fixed wavelength laser and temperature changes**

A study on the quality factor (Q-factor) measurements of polymethyl methacrylate (PMMA) whispering gallery mode (WGM) microspheres, using a fixed-wavelength laser and temperature changes [9].

**Scattering loss analysis in PMMA WGM micro resonator from surface irregularities**

This paper investigates scattering loss in polymethyl methacrylate (PMMA) whispering gallery mode (WGM) micro resonators resulting from surface irregularities [10]. The research aims to provide a better understanding of the factors affecting the performance of PMMA WGM resonators, which is crucial for optimising their applications in various fields.

**Mode family analysis for PMMA WGM micro resonators using spot intensity changes**

The resonant modes within the cavity can be classified into different mode families, which determine the resonator's characteristics and performance [11]. Polymer PMMA microsphere is used as the resonator material in this study. This approach offers a simple, non-invasive, and cost-effective method for investigating the mode characteristics of WGM resonators.

**Frequency comb generation in WGM microsphere-based generators for telecommunication applications**

Silica microsphere-based optical frequency generators were fabricated, focusing on their potential applications in telecommunications [12]. Frequency combs are a set of equally spaced frequency lines, which can be used for optical communications. In the context of telecommunications, frequency combs generated by WGM microsphere-based generators can be used for advanced modulation schemes, data encoding, and multiplexing, leading to improvements in data transmission rates, channel capacity, and spectral efficiency.

**Frequency comb generation in whispering gallery mode silica microsphere resonators**

The research demonstrates the potential advantages of using WGM silica microsphere resonators for frequency comb generation, such as their high efficiency, broad spectral coverage, and tenability [13]. These features make them promising candidates for optical communications.

**Kerr optical frequency combs with multi-FSR mode spacing in silica microspheres**

Research paper [14] explores the potential advantages of using WGM silica microsphere resonators for generating Kerr optical frequency combs with multi-FSR mode spacing, such as their high efficiency, broad spectral coverage, and tunability. These features make them promising candidates for various applications, including optical communications, precision metrology, and high-resolution spectroscopy.

**Demonstration of a fiber optical communication system employing a silica microsphere-based OFC source**

This paper [15] demonstrates a fiber optical communication system employing a silica microsphere-based optical frequency comb (OFC) source, highlighting the potential benefits of using silica microsphere resonators for frequency comb generation in optical communication systems. The research provides valuable insights into the properties and performance of these frequency combs, which could contribute to the advancement of optical communication technologies and systems.

**Optical frequency combs generated in silica microspheres in the telecommunication C-, U-, and E-bands**

The paper focuses on generating optical frequency combs in the C-, U-, and E-bands, which are significant for telecommunication applications [16]. The author discusses the fabrication techniques, experimental setup, and results obtained from the study. By understanding the factors influencing the performance of the frequency combs, such as the resonator's Q-factor, mode spacing, and pump power, it becomes possible to optimize the performance of the devices in various applications.

**Silica Microsphere WGMR-Based Kerr-OFC Light Source and Its Application for High-Speed IM/DD Short-Reach Optical Interconnects**

In this paper researchers investigate a silica microsphere whispering gallery mode resonator (WGMR)-based Kerr optical frequency comb (OFC) light source and its application for high-speed intensity modulation/direct detection (IM/DD) short-reach optical interconnects [17]. Optical interconnects are crucial for high-speed data transmission and communication systems, and employing Kerr-OFC light sources can lead to improved performance in these applications.

## Nonlinear absorption and refraction of picosecond and femtosecond pulses in HgTe quantum dot films

In this paper, authors investigate the nonlinear absorption and refraction of picosecond and femtosecond pulses in mercury telluride (HgTe) quantum dot films [18]. Quantum dots (QDs) are semiconductor nanocrystals with unique optical and electronic properties, making them attractive for various applications in optoelectronics and photonics. The research contributes to the understanding and optimisation of HgTe QD films for ultrafast optical applications, paving the way for the development of novel photonic devices and systems.

## Acknowledgments

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### References

[1] Brice, I., *et al.* (2020). Whispering gallery mode resonator and glucose oxidase based glucose biosensor. *Sensors and Actuators B: Chemical* 318, 128004.

[2] Brice, I., *et al.* (2019). Whispering gallery mode resonators coated with Au nanoparticles. Nanoengineering: Fabrication, Properties, Optics, Thin Films, and Devices. *SPIE* 110891T.

[3] Brice, I. *et al.* (2020). Whispering gallery mode resonators covered by a ZnO nanolayer. *Optik* 219, 165296.

[4] Draguns, K., *et al.* (2021). Computer modelling of WGM microresonators with a zinc oxide nanolayer using COMSOL multiphysics software. *Proceedings of SPIE 11672. Laser Resonators, Microresonators, and Beam Control* XXIII; 1167216.

[5] Brice, I., *et al.* (2021). Whispering gallery mode resonator temperature compensation and refractive index sensing in glucose droplets. *Sensors* 21, 7184.

[6] Reinis, P. K., *et al.* (2021). High-Sensitivity Whispering Gallery Mode Humidity Sensor Based on Glycerol Microdroplet Volumetric Expansion. *Sensors* 21, 1746.

[7] Milgrave, L., *et al.* (2022). Selectivity of glycerol droplet microresonator humidity sensor. *Proceedings of SPIE, Optical Sensing and Detection* VII; 121390F.

[8] [8] Berkis, R., *et al.* (2022). Wavelength Sensing Based on Whispering Gallery Mode Mapping. *Fibers* 10, 90 (2022).

[9] Berkis, R., *et al.* (2019). Quality factor measurements for PMMA WGM microsphere resonators using fixed wavelength laser and temperature changes, *2019 IEEE 9th International Conference Nanomaterials: Applications & Properties (NAP)*. Odessa, Ukraine, pp. 01P05-1-01P05-4.

[10] Berkis, R., *et al.* (2021). Scattering loss analysis in PMMA WGM micro resonator from surface irregularities, in OSA Optical Sensors and Sensing Congress 2021. OSA Technical Digest, paper JTu5A.26.

[11] Berkis, R., *et al.* (2021). Mode family analysis for PMMA WGM micro resonators using spot intensity changes. Laser Resonators, Microresonators, and Beam Control XXIII 11672, 1167217.

[12] Braunfelds, J., *et al.* (2020). Frequency comb generation in WGM microsphere based generators for telecommunication applications. *Quantum Electronics* 50, 1043.

[13] Brice, I., *et al.* (2021). Frequency comb generation in whispering gallery mode silica microsphere resonators. *Proceedings of SPIE* 11672, Laser Resonators, Microresonators, and Beam Control XXIII; 1167213.

[14] Anashkina, E. A., *et al.* (2021). Kerr optical frequency combs with multi-FSR mode spacing in silica microspheres. *IEEE Photonics Technology Letters* 33, 453–456.

[15] Salgals, T., *et al.* (2021). Demonstration of fiber optical communication system employing silica microsphere-based OFC source. *Optics Express* 29, 10903–10913.

[16] Anashkina, E. A., *et al.* (2021). Optical frequency combs generated in silica microspheres in the telecommunication C-, U-, and E-bands. *Photonics* 8, 345.

[17] Salgals, T., *et al.* (2022). Silica Microsphere WGMR-Based Kerr-OFC Light Source and Its Application for High-Speed IM/DD Short-Reach Optical Interconnects. *Appl. Sci*. 12, 4722.

[18] Bundulis, A., *et al.* (2021). Nonlinear absorption and refraction of picosecond and femtosecond pulses in HgTe quantum dot films. *Nanomaterials* (Basel) 10, 335.

# The project SPACE-LV: "ERA Chair in Astrophysics, Instrumentation, Ground Segment Technologies and Space Photonics at the University of Latvia"

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The National Science Platform (NSP) FOTONIKA-LV at the University of Latvia including the fields of quantum sciences, space sciences, and related technologies has designed ERA Chair project proposal SPACE-LV to boost astrophysics, space sciences, and observation technique research and innovations building on the significant capabilities of the space research community at the University.

The mission of the **ERA Chair** project proposal "SPACE-LV" also called HORIZON-WIDERA-2022-TALENTS-01 is to make significant contributions to further structural changes which have started by bottom-up initiatives and the decision taken on April 24, 2010, by the directors of three research institutes at the University of Latvia (the Institute of Atomic Physics and Spectroscopy, the Institute of Astronomy, and the Institute of Geodesy and Geodynamics). This was the founding the association FOTONIKA-LV, with the goal to rise jointly and to implement large scale projects in two scientifically interlinked domains of modern sciences: quantum sciences, and space sciences within the frame of photonics, one of the 6 key-enabling technologies in the EU [1].

The growth of FOTONIKA-LV in quality, quantity, and structural changes started already in 2011 when efforts of a joint "task force" resulted in the financing of the FP7 REGPOT project "Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area" (3,8 M€, 2012–2015) [2]. This was a highly competitive (success rate of 7%), but valuable FP7 financial instrument supporting excellence in countries of convergence regions. On June 18, 2018, by the Decree of the University of Latvia Rector (No 1/215) the status of FOTONIKA-LV was increased to the level of National Science Platform (NSP) reflecting the efforts to support national industry in the photonics domain.

Prof. Bernard Foing a recognised researcher (h-index 50 [3], citations >10000), who is very experienced in space research, technology development, and science management [4,] agreed to become the ERA Chair holder in space part of NSP FOTONIKA-LV. Prof. B. Foing is joining the space research community of NSP FOTONIKA-LV to become a strategic advisor in the field, and will recruit his ERA chair team to establish the Space Photonics Laboratory to be the engine at the heart of developing "state-of-the-art" research, basing on the capacities of two observatories of the Platform. The challenge is to meet the growing dynamics in astrophysics, astrobiology, planetary sciences, and lunar studies as well as the need for further developments of technologies used for space science and space industry needs.

The SPACE-LV project will substantially increase the capacity of personnel via recruitment and repatriation. The SPACE-LV project will provide maximum freedom to the ERA Chair holder in decision-making. He will serve also as a national spokesperson for space science influencing national policy from one side and will boost the attractiveness of research activities in the domain of space sciences and technologies for STEM students. The Astrophysical observatory of the Platform performs excellent research on Carbon stars in is well-known in Asteroid science counting more than 50 discovered asteroids. Fundamental Geodynamic Observatory is a member of NASA-led ILRS service network and is supposed to contribute to the space surveillance program of ES and ESA. Challenging are laser ranging of Moon as well as laser ranging of space debris and asteroids.

The SPACE-LV ERA Chair WIDERA project will make multifold impact, and boost RTD and innovation capacity in space science and technologies of NSP FOTONIKA-LV in synergetic interplay with ERA Chair project [5] of quantum sciences led by world-wide recognised Dr. Rashid Ganeev (h-index 58, citations >11000 [6]). The Project will vastly improve the innovation ecosystem and entrepreneurial environment in the country in tangible and intangible ways, e.g.:

- Space sciences and technologies related SMEs which are seeking NSP FOTONIKA-LV counsel and research support will have the opportunity to communicate and receive qualified advice from Prof. Bernard Foing and his talented ERA Chair team;
- The research community of NSP FOTONIKA-LV will have more opportunities to communicate with entrepreneurs and SMEs communities serving for European Space Agency needs;
- The implementation of the SPACE-LV, ERA CHAIRS project constitutes the coherent efforts of project team where researchers and science managers of the NSP FOTONKA-LV units will work together with Prof. Bernard Foing, the ERA-CHAIR holder, and his team to ensure maximum effective usage of the resources provided by the ERA-CHAIRS project and research potential available in NSP FOTONIKA-LV.

The work plan of the SPACE-LV project consists of 7 Work packages and specific relevant tasks for each WP. WPs form logical structure (see charter below) to achieve the main aim – ensure maximum of operational and scientific freedom to Prof. Bernard Foing and his ERA-CHAIR team in their efforts to ensure effective advancements NSP FOTONIKA-LV as such and the units targeting the field especially.

The first WP1 deals with the selection of ERA chair team, establishing a Space Photonics Laboratory, and specific planning activities. The WP 1 will start with about 2 months of a pre-project phase to ensure a smooth start to the project. The implementation of WP1 will be guided by Prof. Bernard Foing. He will also lead WP 2 and WP 5. WP 2 deals with activities of Space Photonics Laboratory, a new unit of the NSP FOTONIKA created for the implementation of scientific ambitions of the ERA Chair and his team and to promote synergies in partnership with the labs and 2 observatories, representing both areas space sciences and technologies and quantum sciences. WP3 and WP4 will be led by experienced researchers who will foresee relevant advancement of both observatories having targeted support from the ERA Chair project. WP5 is dedicated to human resources and career development planning and will be led by the ERA Chair to benefit as much as possible from his experience as well as to ensure implementation of his innovative approaches and visions. WP6 will oversee widening participation, developing and activating roadmaps of project proposals to Horizon Europe calls, European Space Agency and industry related projects and contracts, specifically for national scale disruptive innovation projects and eventually large scale RTD projects for the transnational companies in the EU and worldwide. The implementation of the work package WP6 will be led by experienced researcher who was the coordinator of many EU Framework projects including mentioned FP7 REGPOT project – Dr. Phys Arnolds Ūbelis, who is also scientific secretary and the Leader of the NSP FOTONIKA-LV. He will also take leadership of the management work of package WP7 and will serve as a project coordinator. WP 7 will start already in the pre-project phase; will deal with kick-off activities and events of the project to ensure wide publicity. WP7 will cover management, documentation, publicity, policy development and outreach activities including actions ensuring synergy with EU Structural funds via ex-ante conditionality of National smart specialisation strategies.

The project will be supported and advised by the internationally visible Scientific Council (including recognised researchers and entrepreneurs from Latvia and USA) of the NSP FOTONIKA-LV [7]. The ERA Chair Prof. B. Foing, at least twice in a year, will offer to the Council to discuss the current problems of project implementation, as well as issues of long-term sustainability, strategy and policy developments on an ERA scale. He and the project coordinator Dr. Arnolds Ūbelis will provide presentations accordingly.

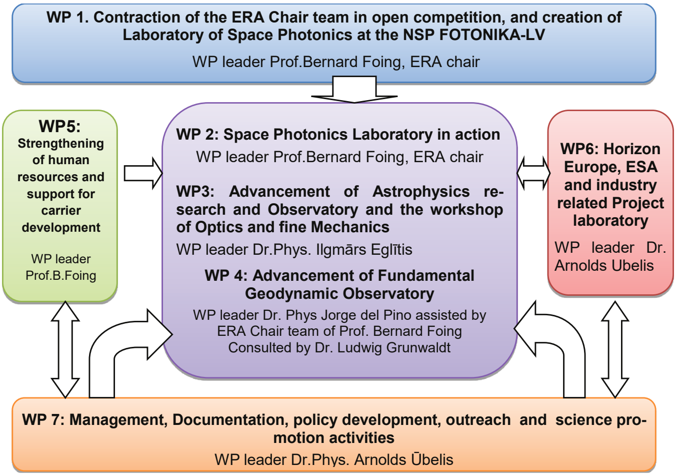


***Figure 1.*** *The work plan of the SPACE-LV project*

The Project will facilitate the increase of the following, key performance indicators via:

- A 50% annual increase in the l number of high-level publications in the field and reports at the large-scale conferences resulting from productive research of substantially stronger team of scientists, effective management of knowledge and IPR assets via implementation of WP2-WP4;
- An increased number of and better quality of Horizon Europe and ESA project proposals due to contribution of the ERA Chair and his team (WP7). Up to five MSCA fellowship project proposals will be designed to attract new talents to the NSP FOTONIKA-LV. At least two MSCA Staff Exchanges project proposals will be submitted to finance international (research units in third countries), inter-sectoral, interdisciplinary secondments leading to knowledge transfer;
- Raising TWINNING and TEAMING (Horizon Europe WIDERA calls) project proposals;
- Raising challenging project proposals to: European Research Council calls; research infrastructure calls; European Innovation Council calls;
- Annually doubling the increasing number of MSc and PhD students and theses in the domain. 5 PhD candidates linked to the project will finalise and will defend their thesis. At least 8 MSc students and four PhD students and candidates will implement their career development plans having high quality research training from ERA Chair team (WP2-WP5) (impact on human resource development);

- Substantially increasing overall human capacity of the NSP FOTONIKA-LV in the domain (in demand by academia and industry in Latvia), particularly by increasing the probability to attract 2-4 post-doc fellows financed by EU Structural funds. The project will be bottom-up booster of space science and related technologies under umbrella of photonics as a regional smart specialisation in Latvia and eventually as a transregional Pan-Baltic smart specialisation in Estonia and Lithuania accordingly (economical and societal outcomes and impacts);
- Efforts towards strategic planning for the space science and technologies innovation ecosystem in Latvia will be made using foresight and strategic intelligence methodology exposed in accordance with available resources (contribution to national wide capacity of long-term planning).

There is an **acute need for greater prevalence of forward thinking mentality in the country,** and lack of such experience is among the major reasons why Latvia is failing to improve its competitiveness. The NSP FOTONIKA-LV has developed capabilities in foresight and futures research as a result of the REGPOT project including courses and secondments at Fraunhofer ISI [8] and Austrian Institute of Technology leading the Foresight Academy.

Generally speaking, the implementation of this SPACE-LV project will have a substantial impact on the NSP FOTONIKA-LV, and nationwide in the domain of space science and space technologies. The impact on the University of Latvia – substantial increase of research and research training capacity in astrophysics, space science and space technologies – in the fields where the University of Latvia has world-wide recognised capacity since the second part of the last century, which was partially damaged due to low national financing, brain-drain, and ageing of the personnel. The impact will result in several levels:

- On national scale the impact will result in emergence on the institution which is strong player in spaces science and technologies in European Research Area able to boost basic research and very needed applied research activities in the context of pending partnership of Latvia in the European Space Agency and in the context relevant industry developments;
- National SMEs community in photonics and space sectors face acute shortage of advice and cooperation with experienced professionals in the field. The ERA-CHAIR and his team will bring relevant expertise and needed awareness;
- The implementation of the ERA Chair project will result in increased efforts to attract industrial contracts to the labs from large scale industry in the EU (particularly linked to the European Space Agency) and in the world. The ERA Chair and his team evidently will bring relevant expertise, contacts and needed awareness.

**References**


[1] https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies_en

[2] FP7-REGPOT-2011-1. FOTONIKA-LV, No. 285912 (2012–2015). Unlocking and Boosting Research Potential for photonics in Latvia – Towards Effective Integration in the European Research Area

[3] Bernard Foing: https://scholar.google.com/citations?user=_fTVp0kAAAAJ&hl=en

[4] www.erachair.lu.lv

[5] Rashid Ganeev: https://scholar.google.com/citations?user=r-687_kAAAAJ&hl=lv&oi=sra

[6] http://fotonika-lv.eu

[7] Georghiou, L., *et al*., eds. (2008). The Handbook of Technology Foresight: Concepts and Practice, Edward Elgar Publishing. FP7-PEOPLE-IRSES-GA-2011-294959-IFA – International Foresight Academy.

# Plenary Sessions

# A platform for Artificial Intelligence: neuromorphic silicon photonics

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The interest in Artificial Neural Networks (ANNs) has considerably increased in recent years due to their versatility, which allows for dealing with a huge class of problems [1]. Nowadays, ANNs are mostly implemented on electronic circuits, in particular, on von Neumann architectures in their different specifications such as the general purposes CPU (Central Processing Units), the massively parallel GPU (Graphical Processing Units) or the specialised integrated circuits used to accelerate specific task such as the TPU (Tensor Processing Units) [2–4]. Very-large-scale ANN models have been elaborated which outperform human minds in given tasks [5, 6] at the expense of large training times and huge power consumption [7–9]. Other intrinsic limits of electronic ANNs are related, for example, to the ease in interference between electrical signals, the difficulty in handling a large number of floating point operations and a low parallel computing efficiency [10–12].

A possible solution to these limitations is provided by Photonic Neural Networks (PNNs) which enable high-speed, parallel transmission (Wavelength Division Multiplexing, WDM) and low power dissipation [10, 11]. PNNs have the same overall architecture as an ANN, namely, they are made by several interconnected neurons where each neuron receives multiple inputs and feeds multiple other neurons (Fig. 1). The received inputs are weighted, combined, and processed by each neuron, which through a nonlinear activation function feeds its interconnected neurons. When optics comes into play, some of these operations are very easy to implement. For example, large matrix multiplication becomes very fast and energy-efficient [13], giving PNNs a great advantage compared to electronic ANNs. These advantages lead to the development of photonic accelerators for electronic ANNs [14]. On the other hand, in integrated PNNs, the inter- and intra-neurons connections are easily established through waveguides in an on-chip optical switching network [10, 15] where the propagating optical signal can be modified using tuneable waveguide elements (e.g., phase shifters or Mach Zehnder interferometers MZI [16]).

The complexity in operations achievable by a PNN depends on multiple factors. These include the network topology, namely how the single processing units (neurons or nodes) are interconnected. Artificial neurons are combined in a huge variety of networks, from basic structures (e.g., the single perceptron shown in Fig. 1 right [17]) to very complex ones [18]. Potentially, any topological organisation of neurons can be achieved, the optimal structure depending on the specific task to be solved and on the amount and format of data to be analysed [19]. Problems that require low latency and fast reconfigurability fit with PNNs of the feed-forward type, where the data flows only in one direction (from the input neurons to the output neurons) through different layers of nodes [20]. On the contrary, high-complexity tasks where long short-term memory plays a key role require recurrence where the information flow back and forth between the neurons [21]. A model that is easily implemented in PNNs is the photonic reservoir computing, where random fixed connections between the nodes are established, with training only performed in the output layer [22]. Finally, the readout strategy is another key element since it provides direct access to the information elaborated by the network itself. The readout can be

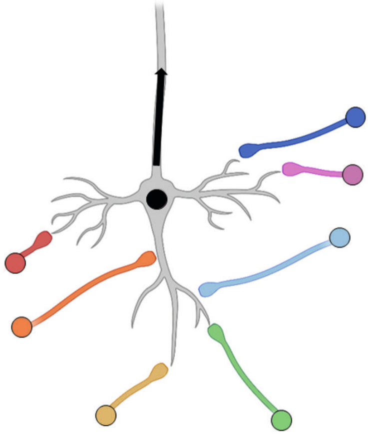

***Figure 1.*** *Left: Sketch of a biological neuron (black dot). Different signals from nearby neurons (colored) are collected by the neuronal dendrites through interconnecting synapses. The neuronal body integrates the signals and, if above a threshold, produces a voltage spike which is sent via the neuronal axons (black arrow) to the post-synaptic neurons*

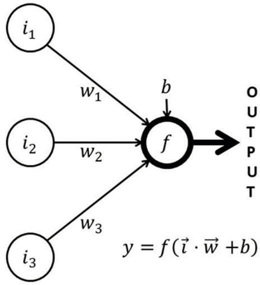


***Figure 1.*** *Right: Sketch of an artificial neuron where the output y is produced by the formula given in the inset from the different inputs i (image courtesy of Gianmarco Zanardi)*

optical or electrical and its choice again depends on the topology of the network and the specific requirements of the task [23].

In ANNs, the nonlinear activation function is implemented within the node. This aspect of the neuron plays a fundamental role in the learning process since it determines the output of the node. Here, PNNs provide many possible choices [24, 25]. For example, a suitable activation function is the square modulus $|\cdot|^2$: this is easily implemented by a direct detection process of the optical signal (e.g., with a photodiode) [26, 27]. The intensity (and thus the power) I(t) associated with an optical signal is indeed directly proportional to the square modulus of the electric field E(t), i.e. $I(t) \propto |E(t)|^2$ [28]. Another activation function can be provided by a Semiconductor Optical Amplifier (SOA) integrated within the neuron [29]. An SOA behaves linearly for low input optical power but reaches saturation for higher power values [30]. Its power-gain curve thus is strongly nonlinear, making SOAs suitable for acting as a nonlinear node in a PNN. Here, we are mostly interested to discuss nonlinear nodes based on microring resonators [31, 32]. Since the microring's optical transfer function depends on the stored optical power [33], they can be used to implement different kinds of nonlinear transfer functions [34].

The optical domain offers an optimal testing ground for ANNs that process information using complex-valued parameters and variables [35]. The light propagation in waveguides and its nonlinear interaction with various media are naturally described in the complex domain where both the phase and the amplitude of the electric field associated with the optical signal have to be taken into consideration. Complex numbers are thus intrinsically involved in optical systems which turns out to be ideal for the implementation of complex-valued neural networks [35–37]. Even though each complex number can be represented by means of two real numbers, a complex-valued ANN must not be considered equivalent to a real ANN with a doubled number of parameters [36, 37]. Indeed, when it comes to complex multiplication, the rotatory dynamics of complex numbers enter into play, leading to a reduction of the degrees of freedom as compared to the case of completely independent parameters. Therefore, this opens further opportunities for PNNs, which easily manipulate complex numbers. This possibility, associated with properly chosen nonlinear nodes and an effective readout strategy, yields that even a simple hardware implementation of a PNN manages to perform demanding tasks, which would require a much higher cost if faced with traditional ANNs [38].

In our talk, we have discussed a few simple PNNs implemented on a silicon photonics platform [32] that demonstrate the basic mechanism of silicon-based PNNs. Silicon photonics is particularly interesting since its easy integration with electronics allows for on-chip training of the network and for volume fabrication of the PNNs [16]. First, a simple optical neuron is discussed where different delayed versions of the input optical signal are made to interfere before the output port [38, 39]. Then, the simple microring resonator is used to demonstrate complex nonlinear dynamics [33]. Based on these results, a Reservoir Computing network implemented by a single microring resonator within a time delay scheme is used for complex classification tasks [40]. Moreover, linear and nonlinear memory tasks are used to evaluate the memory capacity of a microring resonator [41]. Finally, we show the possibility to extend the microring resonator fading memory by using an external optical feedback loop [42].

## Acknowledgments

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### References

[1] Genty, G., *et al.* (2020). Machine learning and applications in ultrafast photonics. *Nature Photonics* 15, 1.
[2] Sze, V., *et al.* (2017). Efficient processing of deep neural networks: A tutorial and survey. *Proceedings of the IEEE* 105, 2295.
[3] Bhattacharya, G. (2021). From dnns to gans: Review of efficient hardware architectures for deep learning. arXiv preprint arXiv:2107.00092.
[4] Dhilleswararao, P. *et al.* (2022). Efficient hardware architectures for accelerating deep neural networks: Survey, IEEE Access.
[5] M. F. A. R. D. T. (FAIR)†, Bakhtin A., *et al.* (2022). Human-level play in the game of diplomacy by combining language models with strategic reasoning. *Science* 378, 1067.
[6] Li, Y. *et al.* (2022). Competition-level code generation with alphacode. *Science* 378, 1092.
[7] Strubell, E., Ganesh, A., McCallum, A. (2019). Energy and policy considerations for deep learning in NLP. arXiv preprint arXiv:1906.02243.
[8] Wu, C.-J. *et al.* (2022). Sustainable ai: Environmental implications, challenges and opportunities. *Proceedings of Machine Learning and Systems* 4, 795.
[9] Boahen, K. (2022). Dendrocentric learning for synthetic intelligence. *Nature* 612, 43.
[10] Sui, X., *et al.* (2020). A review of optical neural networks. *IEEE Access* 8, 70773.
[11] Liu, J., *et al.* (2021). Research progress in optical neural networks: theory, applications and developments, PhotoniX 2, 10.1186/s43074-021-00026-0.
[12] Porte, X., *et al.* (2021). A complete, parallel and autonomous photonic neural network in a semiconductor multimode laser. *Journal of Physics: Photonics* 3, 024017.
[13] Cheng, J., Zhou, H., Dong, J. (2021). Photonic matrix computing: from fundamentals to application. *Nanomaterials* 11, 1683.

[14] Zhou, H., *et al.* (2022). Photonic matrix multiplication lights up photonic accelerator and beyond, Light. *Science & Applications* 11, 1.
[15] Testa, F., *et al.* (2019). Integrated reconfigurable silicon photonics switch matrix in iris project: Technological achievements and experimental results. *J. Lightwave Technol*. 37, 345.
[16] Vivien, L., Pavesi, L. (2016). Handbook of silicon photonics (Taylor & Francis).
[17] Rosenblatt, F. (1958). The perceptron: a probabilistic model for information storage and organization in the brain. *Psychological review* 65(6), 386.
[18] Sharkawy, A.-N. (2020). Principle of neural network and its main types: Review. *Journal of Advances in Applied & Computational Mathematics* 7, 8.
[19] Brunner, D., Psaltis, D. (2021). Competitive photonic neural networks. *Nature Photonics* 15, 323.
[20] Pai, S. *et al.* (2020). Parallel programming of an arbitrary feedforward photonic network. *IEEE Journal of Selected Topics in Quantum Electronics* 26, 1.
[21] Medsker, L., Jain, L. C. (1999). Recurrent neural networks: design and applications (CRC press).
[22] Antonik, P., Marsal, N., Rontani, D. (2020). Large-scale spatiotemporal photonic reservoir computer for image classification. *IEEE Journal of Selected Topics in Quantum Electronics* 26, 1.
[23] Ma, C., *et al.* (2021). Comparing different nonlinearities in readout systems for optical neuromorphic computing networks. Scientific Reports 11.
[24] Dabos, G., *et al.* (2022). Neuromorphic photonic technologies and architectures: scaling opportunities and performance frontiers. *Optical Materials Express* 12, 2343.
[25] El Srouji, L., *et al.* (2022). Photonic and optoelectronic neuromorphic computing. *APL Photonics* 7, 051101.
[26] Hamerly, R., *et al.* (2019). Large-scale optical neural networks based on photoelectric multiplication. *Physical Review X* 9, 021032.
[27] Shen, Y., *et al*., Deep learning with coherent nanophotonic circuits. *Nature photonics* 11, 441 (2017).
[28] Optical receivers, in Fiber-Optic Communication Systems (2002). John Wiley & Sons, Ltd. Chap. 4, pp. 133– 182.
[29] Shi, B., Calabretta, N., Stabile, R. (2019). Deep neural network through an inp soa-based photonic integrated crossconnect. *IEEE Journal of Selected Topics in Quantum Electronics* 26, 1.
[30] Optical receivers, in Fiber-Optic Communication Systems (2002). John Wiley & Sons, Ltd. Chap. 6, pp. 226– 278.
[31] Bogaerts, W. *et al.* (2012). Silicon microring resonators. *Laser & Photonics Reviews* 6, 47.
[32] Pavesi, L. (2021). Thirty years in silicon photonics: a personal view. *Frontiers in Physics*, 709.
[33] Borghi, M., *et al.* (2021). On the modeling of thermal and free carrier nonlinearities in silicon-on-insulator microring resonators. *Opt. Express* 29, 4363.
[34] Biasi, S., *et al.* (2023). Photonic computing using integrated microring resonators, arXiv preprint.
[35] Lee, C., Hasegawa, H., Gao, S. (2022). Complex-valued neural networks: A comprehensive survey. *IEEE/CAA Journal of Automatica Sinica* 9, 1406.
[36] Hirose, A. (1994). Applications of complex-valued neural networks to coherent optical computing using phase sensitive detection scheme. *Information Sciences – Applications* 2, 103.
[37] Hirose, A., Yoshida, S. (2012). Generalization characteristics of complex-valued feedforward neural networks in relation to signal coherence. *IEEE Transactions on Neural Networks and Learning Systems* 23, 541.
[38] Mancinelli, M., *et al.* (2022). A photonic complex perceptron for ultrafast data processing. *Scientific Reports* 12, 4216.
[39] Staffoli, E., *et al.* (2023). Equalization of a 10 gbps imdd signal by a small silicon photonics time delayed neural network.
[40] Borghi, M., Biasi, S., Pavesi, L. (2021). Reservoir computing based on a silicon microring and time multiplexing for binary and analog operations. *Scientific Reports* 11, 15642.
[41] Bazzanella, D., *et al.* (2022). A microring as a reservoir computing node: Memory/ nonlinear tasks and effect of input non-ideality. *Journal of Lightwave Technology* 40, 5917.
[42] Donati, G., *et al.* (2022). Microring resonators with external optical feedback for time delay reservoir computing. *Opt. Express* 30, 522.

# Laser Spectroscopy Applied to Environmental Monitoring

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Laser spectroscopy, developed since the early 70's, has had a very strong impact on basic science, as well as on practical applications. The many aspects of laser spectroscopy have been covered in monographs, e.g., in [1]. The present account deals with applications of laser spectroscopy to the remote sensing of the environment (see, e.g., [2]). Laser radar (lidar) systems are frequently employed – traditionally based on the time-of-flight approach and employing pulsed lasers, but more recently also utilising CW lasers in a triangulation scheme (Scheimpflug arrangement).

Air pollutants have been much studied by lidar techniques, but water bodies and vegetation are also targets of such methods. More recently, the techniques have been extended to both atmospheric and aquatic fauna [3].

Remote sensing by lidar utilises backscattering from distant targets. Detecting and analysing scattering from close range features many similarities to lidar. The Gas in Scattering Media Absorption Spectroscopy (GASMAS) technique can be considered as short-range lidar and has many applications [4].

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### References

[1] Svanberg, S. (2022). *Atomic and Molecular Spectroscopy – Basic Aspects and Practical Applications*. 5th Edition, Chapters 9 and 10 (Springer, Heidelberg).
[2] Chi, J. B., *et al.* (2022). Ten years of interdisciplinary lidar applications at SCNU, Guangzhou. Proc. ILRC-30 (Springer).
[3] Brydegaard, M., Svanberg, S. (2018). Photonic monitoring of atmospheric and aquatic fauna. *Lasers and Photonics Reviews* 12, 1800135.
[4] Svanberg, S. (2013). Gas in Scattering Media Absorption Spectroscopy – from basic studies to biomedical applications. *Lasers and Photonics Reviews* 7, 779.

# Some Challenges in Medicine Addressable by Laser Spectroscopy

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## Introduction

Although the tremendous development within the medical field there are still numerous challenges. One such example is from the field of neonatology where there is a lack of continuous lung monitoring of the preterm babies. These small babies constitute an extremely vulnerable group of patients and should need a continuous cod-side monitoring of the lung function, as sudden events, such as pneumothorax, can be very dangerous and difficult to discover immediately.

According to statistics 10–15% of deliveries are preterm (born before gestation week 37) and are associated with an increased risk of morbidity and future unwanted side effects due to insufficient action from immature organs, especially the lungs negatively affecting the very vulnerable brain [1].

Another demand comes from a completely different field, namely oncology, dealing with the wish to deliver less invasive therapies to reduce hospital time and patient complications. It is a well-known fact that the incidence of malignant tumour diseases increases and according to WHO statistics, there will be a doubling of cancer cases within 40 years [2]. Already now malignant tumours cunt for more than 30% of the deaths in the population. Of particular interest is prostate cancer, which is the largest cancer type for men now over numbering lung cancer. Prostate cancer counts for approximately 20% of all male cancers. About 15–20% of the prostate patients recur after therapy and the conventional therapy for this group is Androgen deprivation therapy (ADT) to lower the levels of androgens and thus reduce the tumour growth [3, 4]. ADT has shown to be more toxic than anticipated when introduced with a variety of quite serious side effects, including an increased incidence of cardio-vascular events. The patients with recurrent prostate cancer usually have an expected life span of 10–15 years after recurrence diagnosis and therefore it is of great importance to develop better strategies.

## Laser Spectroscopy Techniques

Gas in Scattering Media Absorption Spectroscopy (GASMAS) is a technique for gas monitoring [5] and has been developed for many applications in medicine and biology, including e.g., for fruit ripening studies to correlate optimal consumption status and in the long run help to reduce the spoilage rate, which for fruit is reported up to 40% [6, 7]. In medicine, the GASMAS technique has been used for e.g., sinus cavity ventilation post a common cold [8] in order to get an objective measure of a probable sinusitis, a disease where antibiotic drugs are overprescribed and thus contributing to the serious development of antibiotic resistance, a global threat to mankind, equally alarming as the global warming.

Clinical studies have been performed and results have been presented showing the capacity of GASMAS to monitor free oxygen gas in the lungs of small children [9].

A spin-off company, Neola Medical, [10] has further developed the equipment for lung monitoring in preterm babies and the product is under final regulatory development for clinical study use in the near future. A research project has been initiated towards the expansion of lung spectroscopy monitoring to adults [11].

Photodynamic Therapy (PDT) is a non/minimal invasive cancer therapy modality utilising light, a sensitising agent and the endogenous tissue oxygen. These three components together produce singlet oxygen or free radicals, which are toxic to cancer cells. The physics behind the technique relies on light induced excitation of the delivered sensitising agent, which is "lifted" to a higher energy level. The excess energy reacts on the triplet oxygen, which is transferred to cell toxic singlet oxygen. As many of the sensitising agents show a selective retention, the modality is specific to cancer tissue and non-active in normal tissue. The light can be delivered perpendicularly to the skin surface for treating skin cancer. Clinical Phase III studies have shown 90–95% cure rate [12] and has been clinically adopted as one of the modalities for non-pigmented skin cancer. The light penetration through the skin varies from 3–6 mm depending of the absorption wavelength of the sensitizer (630–750 nm). To reach deeper tumours interstitial PDT is used with the optical fibres inserted into the tumour mass [13–15]. A fibre-based therapy system with a laser unit is developed with a unique capacity. The optical fibres have a dual function of both delivering the therapy light and also monitor the diagnostic parameters. Due to this dual function an interactive dosimetry (IDOSE) is calculated adjusting for the individual optical status of each patient. The placement of the fibres takes into account also the organs at risk, such as the rectal wall, the urethra and the sphincters, in order to minimize side effects on normal tissue and still deliver full lethal light dose to the tumour volume. The system development is managed by the company SpectraCure AB [16] and the same company is running an international clinical trial on recurrent prostate cancer in the US, Canada and England and soon starting up at the home university hospital.

## Summary

These two examples show the potential of laser spectroscopy to actively contribute to obvious challenges in medicine and how academical research is translated out into the clinical health care sector to the benefit of patients in various fields.

## Acknowledgments

The author gratefully acknowledges a most stimulating collaboration with many colleagues and students.

### References

[1] Goldenberg, R. L. *et al*. (2008). Epidemiology and causes of preterm birth, *Lancet* 371(9606), 75–84.
[2] https://www.who.int/news-room/fact-sheets/detail/cancer
[3] https://www.cancer.org/cancer/types/prostate-cancer/about/key-statistics.html
[4] https://www.cancer.org/cancer/types/prostate-cancer/treating/hormone-therapy.html
[5] Svanberg, S. (2013). Gas in Scattering Media Absorption Spectroscopy – from basic studies to biomedical applications, *Lasers and Photonics Reviews* 7, 779.
[6] Huang, J., *et al.* (2016). Gas Exchange in Fruits Related to Skin Condition and Fruit Ripening, *J. Biomed. Opt.* 21 (12), 127007. https://doi.org/10.1117/1.JBO.21.12.127007.
[7] Lin, X. B., *et al.* (2020). Ripening of Avocado Fruits Studied by Spectroscopic Techniques. *J. Biophotonics*. https://doi.org/10.102.jbio.202000076.
[8] Zhang, H., *et al.* (2021). Gas Monitoring in Human Frontal Sinuses Stability Considerations and Gas Exchange Studies. *Sensors* (Basel), Jun 28, 21(13), 4413. https://doi.org.10.3390/s21134413. PMID: 34203142; PMCID: PMC8271500.
[9] Svanberg, E. K., (2016). Non-invasive optical monitoring of free and bound oxygen in humans. In *Lund University Faculty of Medicine Doctoral Dissertation Series* 2016(27).

[10] https://www.neolamedical.se/

[11] Sahlberg, A. L., *et al*. (2021). Gas in scattering media absorption spectroscopy on small and large scales: Towards the extension of lung spectroscopic monitoring to adults. *Translational Biophotonics*. https://doi.org/10.1002/tbio.202100003.

[12] Wang, I., *et al.* (20130. Photodynamic therapy versus cryosurgery of basal cell carcinomas; results of a phase III randomized clinical trial. *Br. J. Dermatol.* 144, 832–840.

[13] Svanberg, K., Bendsoe, N. (2013). Photodynamic Therapy for Human Malignancies with Superficial and Interstitial Illumination, in *Lasers for Medical Applications: Diagnostics, therapy and surgery,* Ed. H. Jelinkova (Woodhead Publishing, Cambridge), pp. 760–778.

[14] Svanberg, K., *et al.* (2013). Clinical and Technical Aspects of Photodynamic Therapy – Superficial and Interstitial Illumination in Skin and Prostate. In *Handbook of Biophotonics, Photonics for Health Care,* Eds. J. Popp, V. Tuchin and A. Chiou, Wiley-VCH, 2:3:18, pp. 259–287.

[15] Komolibus, K., *et al*. (2021). Perspectives on interstitial photodynamic therapy for malignant tumours. *JBO*. 10.1117/1.JBO.26.7.070604.

[16] https://spectracure.com/en.

# DESIREE – a tool for studies of atomic, molecular and cluster ions

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The double electrostatic ion-beam storage ring, DESIREE, at Stockholm University is an instrument consisting of two 8.7 m circumference ion-beam storage rings for keV particles, and with a common section where the beams of the two rings can be merged. The apparatus is mounted inside a doubled-walled vacuum system, the inner chamber of which is maintained at a temperature of 13 K when in operation. This low temperature combined with sophisticated ultra-high vacuum technology allows to maintain an extremely high vacuum with a residual gas consisting exclusively of a few thousand hydrogen molecules per cubic centimetre. These conditions allow for the storage of fragile ions for very long times, up to hours, leaving time for long-lived metastable levels to decay or for the populations to be manipulated by means of laser irradiation. The combination of this detailed control of the quantum levels of the stored ions and the ability to investigate reactions between oppositely charged ions makes DESIREE completely unique.

The instrument will be very briefly described and recent results on mutual neutralisation studies and their impact on the determination of elemental abundances from astronomical observations [1, 2] will be presented along with a few other recent highlights of the science at DESIREE [3–5].

## Acknowledgments

DESIREE is operated as a Swedish National Research Infrastructure with support from the Swedish Science Council under contracts 2017-00621 and 2021-00155. The mutual neutralisation studies of astrophysical significance are part of the project “Probing charge- and mass- transfer reactions on the atomic level” supported by the Knut and Alice Wallenberg Foundation (2018.0028). The individual VR grant (2022-02822) is further acknowledged.

### References

[1] Eklund, G., *et al.* (2020). Cryogenic merged-ion-beam experiments in DESIREE: Final-state-resolved mutual neutralization of $Li^+$ and $D^-$. *Physical Review A* 102, 012823.

[2] Grumer, J., *et al.* (2022). State-Resolved Mutual Neutralization of $Mg^+$ and $D^-$. *Physical Review Letters* 128, 033401.

[3] Gatchell, M., *et al.* (2021). Survival of polycyclic aromatic hydrocarbon knockout fragments in the interstellar medium. *Nature Communications* 12, 6466.

[4] Kristiansson Moa K. *et al.* (2022). High-precision electron affinity of oxygen. *Nature Communications* 13, 5906.

[5] Stockett M. H., *et al.* (2023). Efficient stabilization of cyanonaphthalene by fast radiative cooling and implications for the resilience of small PAHs in interstellar clouds. *Nature Communications* 14, 395.

# Photonics Flagship and Photonics in Finland

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The Academy of Finland launched Finland's Flagship Programme in 2019 [1]. The 8-year program supports high-quality research but also increases the economic and societal impact emerging from the research. The program creates future know-how and sustainable solutions to societal challenges and promotes economic growth by, e.g., developing new business opportunities. Important features are close cooperation with business and society, adaptability, strong commitment from host organisations, and international collaboration.

Among the first six flagships was Photonics Research and Innovation PREIN [2]. Partners are Tampere University (coordinator; Professor Goery Genty, director), the University of Eastern Finland UEF (lead impact activities; Professor Jyrki Saarinen, deputy director), Aalto University, and VTT Technical Research Centre of Finland. Besides many partners, PREIN has extensive geographic coverage: from Oulu to Tampere and Espoo (capital region), and Joensuu in the east. PREIN has over 400 staff members, over 50 collaborating countries, and over 280 collaborating institutions.

PREIN covers the entire value chain in photonics: from novel ways to manipulate light (WP1 Light Field Control) to new materials and structures (WP2 Materials & Structures), advanced components and light sources (WP3 Active Photonic Components), and systems and instrumentation (WP4 Applied Research). Key application areas are life science and health care, ICT, autonomous vehicles and mobile devices, environmental monitoring, AR/VR/XR, and clean energy. At the beginning of this year, a new work package, Quantum Technology, was added. PREIN covers close collaboration with industry, which is operated with a close partnership with Photonics Finland [3]. Education covers teaching for degrees (MSc and Ph.D.) but also lifelong education modules to industry and photonics education in physics lessons at schools (Photonics Explorer Kit campaign [4]). Outreach is important for children and other citizens, besides decision-makers and other stakeholders. For example, this June, photonics and its applications and impact are, for the third time, one of the topics in SuomiAreena, where important themes are openly discussed in expert panels in front of a live audience in Pori [5]. Photonics infrastructure at Tampere University, UEF, and VTT, from design to fabrication, integration, and characterisation (Finnish Infrastructure for Light-based Technologies FinnLight) has a national role in the Academy of Finland's FIRI: Research infrastructures as collaborative platforms.

The history of university-level research and education in photonics in Finland spans over 50 years when a few universities started photonics research as part of their physics and optoelectronics programs. But it took until 1996 before the Finnish Optics Society FOS was founded. In 2014, FOS was restructured and renamed Photonics Finland to cover the photonics industry and its interests. Today, Photonics Finland has over 300 individual members from academy and industry (also including student members), all universities involved in photonics research and education in Finland as organisational members, and over 100 corporate members from Finland, but also abroad. Photonics Finland is the contact point for the whole photonics ecosystem in Finland.

Key competencies in photonics in Finland are optical sensing and imaging, micro- and nanophotonics, lasers and fibre optics, and extended reality. About 300 companies in photonics or enabled by photonics with ca. 4,5000 photonics professionals are responsible for about 1.5-billion-euro revenue. The growth rate in Finland exceeds the growth rate of the global photonics market, which is also larger than average industrial growth.

Photonics Finland, together with PREIN, is an active generator of networking and matchmaking opportunities – last year, more than two events per month. The main annual event is Optics and Photonics Days OPD, which gathers over 300 photonics experts from industry and academy in Finland and abroad for three days. This year OPD 2023 will be organised in Joensuu from the 30th of May to the 1st of June. Photonics Finland also organises the Finnish Pavilion at Photonics West in San Francisco, CA, USA, and Laser World of Photonics in Munich, Germany.

Photonics is typically offered as a specialisation in degree programs in physics, materials science, or electrical engineering. But there are also master's degree programs specialising in photonics, including two international MSc degree programs in Photonics. UEF and Tampere University are also participating in four Erasmus Mundus programs in Photonics.

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### References

[1] www.aka.fi/en/research-funding/programmes-and-other-funding-schemes/flagship-programme/
[2] www.prein.fi
[3] www.photonics.fi
[4] www.photonics.fi/photonics-explorer-kit-for-schools/
[5] www.suomiareena.fi/en
[6] www.photonics.fi/opd2023/

# Semiconductor Materials and Technologies for Nuclear Radiation Detectors

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Of all the nuclear radiation detectors, semiconductor material detectors provide the best spectrometric characteristics needed for the precision analysis of these radiations. Semiconductor detectors are used in nuclear industry and environmental monitoring, mining industry and medicine, scientific research, and many other applications. Doubtlessly, varying applications where different types of radiation are registered, require the use of different types of detectors optimised for the conditions of the tasks.

This paper presents the results of the development of semiconductor technologies for nuclear radiation detectors based on such semiconductor materials as HPGe, Si, CdZnTe, TlBr, perspective Perovskite type crystals as well as advanced scintillation crystals $LaBr_3$, $CeBr_3$, $SrI_2$ [1–7]. The technological process of manufacturing any even the simplest semiconductor detector includes the growth of semiconductor crystals, mechanical crystal processing (slicing, dicing, lapping, polishing), chemical etching, creation of p-n junctions and contacts (diffusion, drift, ion implantation), vacuum deposition of different metal and dielectric layers, photolithography, surface passivation, detectors assembling or wire-bonding, and other technological operations. The technological equipment that provides the listed technologies, is being analysed.

Serious attention is paid to the metrological support of the detectors under development, which is carried out using certified radionuclide sources. Analysis of the features and performance of the developed detectors demonstrates the uniqueness of each of them for solving certain scientific problems.

HPGe is the undisputed leader in precision gamma ray spectrometry in the range of 3 keV – 10 MeV. Providing excellent energy resolution (0.80 keV on 122 keV; 1.75 keV on 1332 keV) and high registration efficiency of gamma radiation (up to 160%), these detectors are not only manufactured in standard configurations, but also developed in the form of unique designs of detectors for various international scientific projects (Fig. 1a) [1, 2]. Of particular interest is the manufacture of ultra-low-background HPGe detectors for the search for dark matter, the registration of neutrino-antineutrinos, the search for double beta decay and other international scientific projects [3].

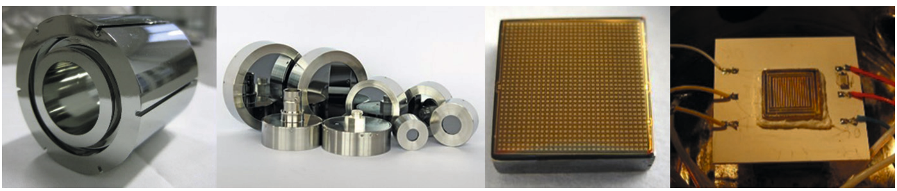

***Figure 1.*** *Semiconductor detector crystals: a) segmented HPGe for investigation of nuclear reactions; b) ion implanted Si for alpha particles; c) pixelated CdZnTe for gamma imagine systems; d) strip TlBr detector prototype*

Ion-implanted Si detectors are certainly superior to other types of detectors in detecting low-energy X-rays (1–30 keV) as well as alpha particles (4–9 MeV) (Fig. 1b).

CdZnTe is a unique material for detection highly active gamma radiation fluxes in the range of 20–3000 keV and is used in nuclear industry to control spent nuclear fuel and radioactive waste, as well as in imaging systems for space research, medicine and technical tasks (Fig. 1, c) [4, 5].

The results of the development of detectors based on promising semiconductor materials are presented. The TlBr detectors are still in the prototype stage and demonstrate very promising characteristics (Fig. 1d) [6]. The readiness of the project to develop detectors based on Perovskite type crystals, which are widely used for the production of solar panels, is considered. Such advanced crystals are of interest as a semiconductor material for X- and gamma – ray detectors, especially for pixel detectors for imaging systems.

At the same time, advanced scintillation materials such as $LaBr_3$, $CeBr_3$, $SrI_2$, the energy resolution of which has already reached a level below 3% on 662 keV, are increasingly used by us in the developed equipment, since they already allow to solve many spectrometric tasks.

Serial production of the developed detectors is the basis for the production of nuclear-engineering equipment with their use to register nuclear radiations for many applications. Samples of Waste Assay and Free Release Monitors for monitoring nuclear materials in the nuclear industry, equipment for radionuclide analysis of aerosols in the atmosphere during radiation monitoring of territories, etc., are presented.

**References**


[1] Nurgalejev, R., *et al.* (2021). Spectrometric performance of a HPGe semi-planar detector with large diameter. *NIM A* 985 164712.

[2] Sokolov, A., *et al.* (2021). Segmented Flow-Through HPGe Detector for Nuclear Reactions Research. *IEEE Trans. on NS* 68(1), 54–58.

[3] Sokolov, A., *et al.* (2012). Support of Low-Level Instrument Background for HPGe Detectors. *IEEE Trans on NS* 59(4), 1273–1277.

[4] Bulycheva, A., *et al.* (2009). CdTe linear arrays for registration of gamma-ray hard fluxes. *NIM A* 607, 107–109.

[5] Ramsey, B. *et al.* (2001). Preliminary Performance of CdZnTe Imaging Detector Prototypes. *NIM A* 458(1–2), 55–61.

[6] Gostilo, V., *et al.* (2002). Single Detectors and Pixel Arrays Based on TlBr. *IEEE Trans. on NS* 49(5), 2513–2516.

# Negative Ions – Fragile Quantum Systems

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Negative ions, which are formed when an electron is attached to a neutral system, are unique quantum systems. The lack of a long-range Coulomb force causes the inter-electronic interaction to become relatively more important. As a consequence, the independent particle model, that adequately describes atomic structure under normal conditions, breaks down. Experimental studies of negative ions can therefore serve to probe the electron correlation and hence be used to test theoretical models that go beyond the independent particle approximation [1].

I will in this presentation give an overview of experimental methods to study negative ions and present recent experimental highlights. This will include work using linear accelerators [2], storage rings [3] and the radioactive beam facility ISOLDE facility at CERN [4]. The common denominator in the work is that negative ions are studies using the photodetachment process, where one or more electrons are removed due to the absorption of a photon. The light sources used in the experiments are high resolution tuneable nanosecond laser or high intensity femtosecond lasers. The experimental results will be compared with recent advanced many-body calculations.

### Acknowledgments

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#### References

[1] Pegg, D. J. (2004). Structure and dynamics of negative ions. *Reports on Progress in Physics 67*, 857.

[2] Eklund, M., *et al.* (2020). Tomography of photoelectron distributions produced through strong-field photodetachment of $Ag^-$. *Physical Review A 102*, 023114.

[3] Kristiansson, M., *et al.* (2022). High-precision electron affinity of oxygen. *Nature Communications 13*, 5906.

[4] Leimbach, D., *et al.* (2020). The electron affinity of astatine. *Nature Communications 11*, 3824.

# Highly sensitive negative ion spectroscopy with MIRACLS

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The electron affinity (EA) of a chemical element is defined as the energy released as an electron is attached to a neutral atom. The binding of such an "extra" electron does not arise from the net charge of the atomic system but is a result of complex electron-electron correlations. Hence, precise measurements of EAs are powerful benchmarks of atomic theories reliant on many-body quantum methods, which are typically applied to several atomic spectroscopy studies aiming at answering quantum chemistry, nuclear structure, and fundamental symmetries questions. The EA is also an important parameter for understanding the chemical behaviour of an element since it is strongly related to how much such an element is prone to form chemical bonds by sharing electrons [1]. However, the EAs of several rare and radioactive elements are still unknown and detailed information, such as isotope shifts and hyperfine splittings of EAs, is available only for a handful of stable cases.

The standard technique for the precision determination of EAs is the laser photodetachment threshold (LPT) method, in which a photon with sufficient energy is used to detach an electron from a negative ion. This technique has been restricted to mostly stable, abundant species given the low photodetachment probabilities. At ISOLDE, we are currently exploring the use of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) technique [2] to enhance the sensitivity of LPT to study the EA landscape among rare and radioactive species. The novel method is based on a Multiple-Reflection Time-of-Flight (MR-TOF) device to trap ions in a stable trajectory. This allows us to greatly extend the ions' exposure time to lasers, significantly increasing the sensitivity by orders of magnitude while keeping the high resolution of a collinear geometry.

The technique has been developed offline and employed in the improved determination of the EA of 35Cl. The achieved precision is competitive to that obtained in previous experiments [3], yet employing orders of magnitude fewer ion samples and using high-resolution continuous wave lasers with much reduced laser power, which highlights the gains in sensitivity of this method. In this talk, I will introduce the novel technique, its development, and its first results, as well as discuss its potential implications for rare isotope sciences.

**References**

[1] Leimbach, D., *et al.* (2020). The electron affinity of astatine. *Nat Commun 11*, 3824.

[2] Sels, S., *et al.* (2020). First steps in the development of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy. *Nucl. Instr. Meth. Phys. Res. B 463*, 310.

[3] Berzinsh, U., *et al.* (1995). Isotope Shift in the Electron Affinity of Chlorine. *Phys. Rev. A 51*, 231.

# The Hybrid Photodetector (HPD) as a detector for Satellite Laser Ranging, first results

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Satellite laser ranging (SLR) technology, as the current 'state of the art' technology, has a system capable of 24/7 operation that uses a high repetition rate laser (kHz or more), a very short (~10 ps) and low power (μJ) laser pulse, and a single photon detecting capability for the returning laser pulse with a corrected SLR-Satellite distance RMS of the order of 10 mm [1].

The Single Photon Avalanche Diode (SPAD) is one of the 'state of the art' SLR photodetectors in use, having high quantum efficiency, single photon sensitivity, short recovery time and giving clear signal statistics. [2, 3]

The typical SPAD photosensitive sensor surface has a submillimetre size (800–100 μm).

In order to use a SPAD as a SLR sensor, the SLR Telescope should have a high-quality image focus. The focus position should have an excellent time and spatial stability, in order to keep the object image focused on the SPAD photosensitive area independent of the telescope pointing direction on the sky.

The Riga SLR telescope has Cassegrain-Mangin optics in a Coudè mount and was designed and built in the early 1980's to operate using a PMT detector with a photosensitive surface of 1 cm or bigger. The mechanical and optical tolerance for focus size and positional stability, including dynamic pointing accuracy was optimised for the operating parameters available when it was designed.[1] Currently our Coudè focus spatial stability is at the 1 mm level. This does not allow for operating a SPAD sensor.

To get a detector performance better than that of the Hamamatsu H11901-20 PMT in use, we decided to test a Hybrid Photodetector (HPD) as a cost-efficient alternative to SPAD.

A PicoQuant Hybrid-40 HPD sensor [4] has been installed at the Riga 1884 SLR station as a second receiving channel sensor in order to test its potential to support SLR ranging in particular space debris observations. It offers a high quantum efficiency, single photon sensitivity with low timing jitter, and a narrow pulse height distribution with a lower dead time than either PMT or SPAD.

The PicoQuant Hybrid-40 has a 3 mm photosensitive surface diameter and is a good match for our current Coudé focus positional stability.

We present the initial experimental determinations of HPD parameters, its calibration characteristics as part of the SLR system, and the first experimental SLR ranging.

## Current SLR photodetectors in use

Since the 1964 start of SLR observations, the photosensors used for detecting the laser photons reflected back from the object in orbit, can be divided into two main groups:

- The original detectors, PhotoMultipliers (PMT) and Microchannel Plates (MCP), are mature technologies still in use as the primary photosensor in several SLR stations, including Riga. They are capable of operating with a wide range of signal amplitudes, from a single-photon signal to a multiphoton signal. But has a higher signal jitter than either SPADs of HPDs.

[1] Our Telescope was the pre production example. Later units, in particular from the late 80's and early 90's, had better mechanical quality.

- The single photon avalanche diode (SPAD) which is ideal for SLR stations using high repetition rates of several kHz, with short few ps laser pulses and very low power-per-laser pulse values where a single photon per pulse is detected on each return pulse.

The HPD combines a photocathode as in the PMT with a semiconductor where the signal amplification occurs (as in the SPAD) [5]. In our case, the HPD photocathode has a sensitive area diameter of 3 mm, so the telescope focusing tolerances are relaxed in comparison to a SPAD.

Chinese researchers have reported about the use of superconducting wires for single photon detection at 1064 and 532 nm in SLR observations. In this case, the focusing tolerances are similar to those of SPAD, and the use of cryogenics complicates its operation [6, 7].

## HPD time-walk against signal amplitude characteristics

In our SLR calibration chain, we have the possibility to change the laser pulse intensity by using a polaroid attenuator, keeping fixed the laser pulse linear polarisation falling into the photodetector. We can generate calibration laser pulses from single-photon to very strong multiphoton ones.

The HPD signal amplitude/timewalk characteristics can be studied by generating a set of calibration time-of-flight (ToF) measurements with variable amplitude pulses, where the number of photons on the pulse can be represented by the signal amplitude values generated by the measurement chain. These amplitudes are not a set of discrete values but a continuum.

A ~12000 data set <12,000 was generated to study the HPD characteristics and to create a compensation curve for our processing software, used for both calibrations and the satellite range data sets [8].

By applying the compensation curve, all the measurements can be corrected to a fixed reference amplitude value, typically close to the centre of the linear part of the few-photon range.

The SLR system is tuned in a way that laser strong pulses beyond the operational amplitude range mode (Fig. 1) are not generated during the measurement process.

For the SLR calibration this is done by standard fixed polaroid settings, for the observations by optimising the laser beam divergence and the field of View (FOV) size. During the data processing, any measurement with amplitude values outside the predefined amplitude range is discarded.

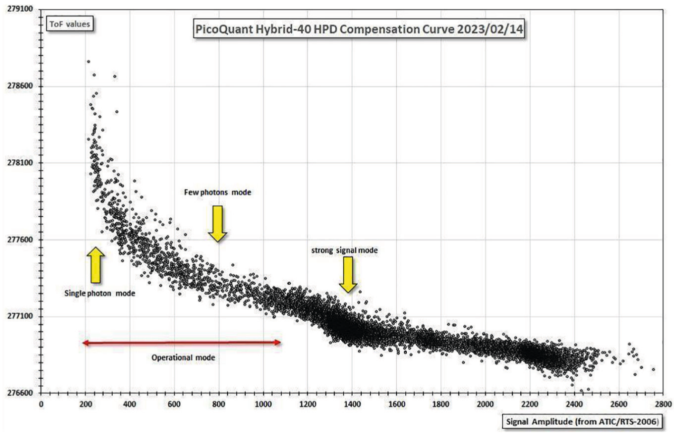


***Figure 1.*** *The PicoQuant Hybrid-40 HPD ToF/Amp plot, and the HPD compensation curve is generated from this set*

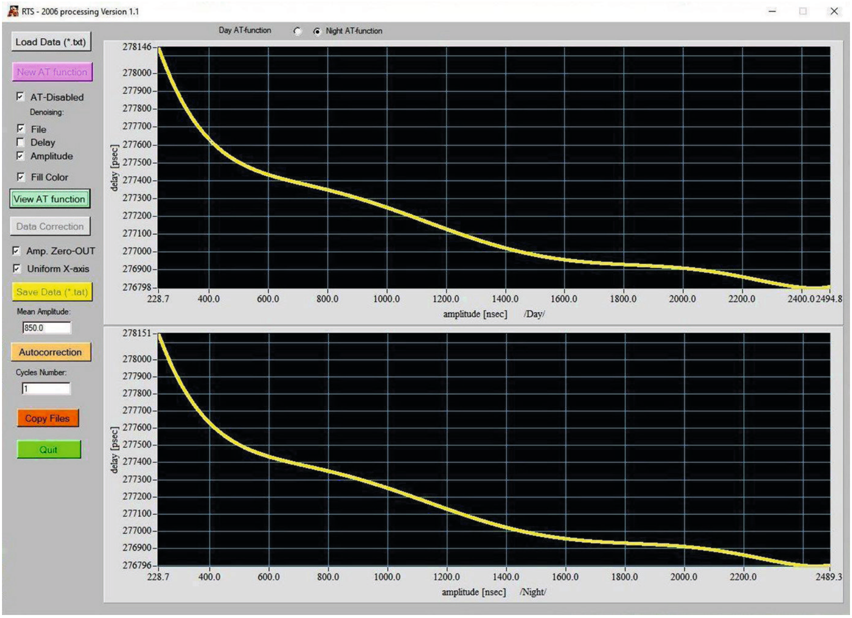


***Figure 2.*** *PicoQuant Hybrid-40 HPD compensation curve*

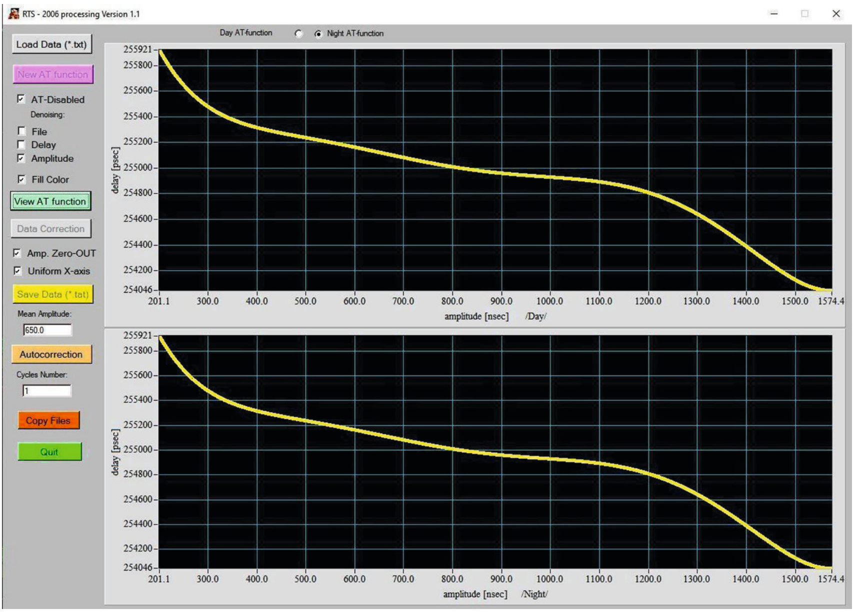


***Figure 3.*** *Hamamatsu H11901-20 PMT compensation curve*

In Figs. 2 and 3 we present the compensation curves in use for our standard Hamamatsu H11901-20 PMT + C5594 amplifier and for the PicoQuant Hybrid-40 HPD. Note that the compensation curve shape, amplitude, and ToF ranges are different for each sensor.

## Preliminary test results

Comparing similar calibration test runs and SLR observations to the Lares2 (COSPAR 2208001) satellite, we have found that when using the PicoQuant Hybrid-40 HPD as detector, the data RMS both for calibrations and satellite range distances is about 60% of the values when using the Hamamatsu H11901-20 PMT.

## Conclusions

The preliminary tests on the use of a Hybrid Photodetector (HPD) as a detector for Satellite Laser Ranging as an alternative for a SPAD detector are promising and we plan to run more tests during the spring-summer 2023 and use the PicoQuant HPD sensor for the incoming multi-static space debris observation tests. If successful, we are considering putting it into regular use for SLR observations during the year 2023–2024.

## Acknowledgments

This research is supported by the ESA project 4000131217/20/NL/SC '*Developing multistatic space debris laser range capability development for SLR station Riga*'.

### References

[1] Wilkinson, M. (2019). The next generation of Satellite Laser Ranging Systems. https://cddis.nasa.gov/2019_Technical_Workshop/docs/2019/presentations/Session1/session1_Wilkinson_presentation.pdf.

[2] Blazej, J., Prochazka, I. (2009). Single and few photon avalanche Photodetector detection process study. *Proc SPIE 7384*. https://doi.org/10.1117/12.835564.

[3] Kirchner, G., *et al.* (1997). Time-walk-compensated SPAD: multiple-photon versus single-photon operation, Proc.SPIE 3218, Laser RadarRanging and Atmospheric Lidar Techniques (22 December 1997). https://doi.org/10.1117/12.295659.

[4] PicoQuant Hybrid-40: https://www.picoquant.com/images/uploads/downloads/13-pma_hybrid.pdf.

[5] Joram, C. (1999). Large Area Hybrid Photodetectors. https://ssd-rd.web.cern.ch/pad_hpd/Literature/como.pdf.

[6] Hao, L., *et al*. (2016). Superconducting nanowire single photon detector at 532 nm and demonstration in satellite laser ranging. https://arxiv.org/ftp/arxiv/papers/1602/1602.03816.pdf.

[7] Xue, Li, *et al.* (2016). Satellite laser ranging using superconducting nanowire single-photon detectors at 1064 nm wavelength. *Optics Letters 41*, 3848–3851. https://doi.org/10.1364/OL.41.003848.

[8] Artyukh, Yu., *et al*. (2020). Digital Range-bias Correction at SLR Station Riga-1884, 12$^{th}$ International Workshop on Laser Ranging, Matera, Italy 2000. https://cddis.nasa.gov/lw12/docs/Artyukh_et_al_DRCEV.pdf.

# EuroSpaceHub, how to digitise the space and aviation ecosystem to leverage funding, talent, innovation and entrepreneurship

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The European Innovation Ecosystem to digitally connect the Space Academic, Research, Industry and Startups to leverage Innovation Together. EuroSpaceHub aims to digitally connect the space ecosystem in Europe, from tech transfer offices to industry, space accelerator networks, research centres, and other universities. The project will allow these actors to easily connect with financial opportunities from the Horizon Europe framework, the venture capital programme, and the InnovFin initiative. EuroSpaceHub will bridge the gap between academic institutions and industry using a collaborative mindset and entrepreneurship programmes inside the universities connected through tech transfer offices.

The EuroSpaceHub consortium has five full partners: Vilnius Gediminas Technical University in (Lithuania), International Space University (France), Complutense University of Madrid (Spain), Lunar Explorers Society (the Netherlands) and Collabwith Group (the Netherlands). These full partners are supported by 12 associate partners from the space ecosystem, including one ESA business incubation centre, two venture capital networks, three higher education institutions, two photonics and aerospace research centres, one technology park, one space foundation, and the Ministry of Economics in Lithuania.

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# Projects in Baldone Astrophysical Observatory

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At the Baldone Astrophysical Observatory (IAU Code 069), astronomers operate with a Schmidt-type 1.2-meter telescope installed with two STX-16803 CCDs. 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 are quantum effectivity of about 80 percent, 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.

## Studies of small bodies of the Solar system

Monitoring of asteroids in the Baldone observatory took place starting in 2008, mainly without a filter. 149 new asteroids were discovered from 2008–2022. Names are given for 16 asteroids.

***Table 1.*** *Asteroid names were discovered and awarded at Baldone Observatory*

| Asteroid number | Name | Year of award of name | Asteroid number | Name | Year of award of name |
|---|---|---|---|---|---|
| 274084 | Baldone | 2011 | 352646 | Blumbahs | 2015 |
| 284984 | Ikaunieks | 2012 | 428694 | Saule | 2016 |
| 294664 | Trakai | 2012 | 320153 | Eglītis | 2016 |
| 321324 | Vytautas | 2012 | 457743 | Balklavs | 2017 |
| 330836 | Orius | 2013 | 545619 | Lapuska | 2021 |
| 392142 | Solheim | 2014 | 604750 | Marisabele | 2022 |
| 332530 | Canders | 2015 | 567580 | Latuni | 2022 |

Some of the clear nights in the three last years were devoted to studying the dynamics of NEO-type asteroids in the G(RP) passband. Observations were also managed to be during nights with a small phase of the Moon. The list of observable asteroids was compiled using the links of the Minor Planet Center NEO checker [5] and the MPC light curve database (ALCDEF, 2022). The list included those NEO and main belt asteroids with a brightness greater than 18 magnitudes without period data. Observations of selected asteroids in Baldone Observatory are usually made on three to five following nights. Three to five hours long series of observations are dedicated to each asteroid at night. On average, it gives more than one hundred observations for each object. The particular asteroid observations were made in the period 2020–2023, mainly with exposures of 120 or 240 seconds in order to achieve a signal-to-noise ratio greater than 20.

Scientific assessments of the risk of, as well as the hazards posed by, future asteroid impact with Earth is one of the important reasons to investigate asteroids, especially NEO-type. On the other side, the investigation of asteroid properties is important for the development of the evolution theory of the Solar system and the classification of small

Solar system objects. Without the above, from the photometric study of light curves, we can obtain additional information about the size, the rotation period, the structure of objects, and the existence of craters and ice fields on the surface, which is very important data for space missions. In connection with the involvement of private companies in the manufacture and launch of spacecraft, the research of the properties of asteroids, which can be used in the sense of mineral mining in the near future, is becoming more and more important. Measurements of CCD images of asteroids were made after the application of standard procedures of master flat and master dark images. For further processing, we selected only that series where the reference star's brightness errors on average are smaller than 0.03 magnitudes. It helps to discard observations with poor sky instant transparency. Each measurement of an asteroid consists of a time and apparent magnitude couple. Both values must be corrected for each measurement series because the distance of an asteroid relative to Earth and to the Sun changes. Time and apparent magnitudes are reduced to the first observation moment data by following equations:

$$t = (JD - JD_0) - \frac{D}{c}$$

$$\Delta m_1 = -2.5\log\left(\left(\frac{D_i^2}{D_0^2}\right)\left(\frac{R_i^2}{R_0^2}\right)\right),$$

where $R$ is the distance to the Sun and $D$ to the Earth. Index zero indicates the first observation datum. These two corrections lead to the solar phase apparent magnitude diagram, which gives not only an idea of which type the asteroid is, but also provides the possibility to reduce all observations to the solar phase of the first observation:

$$\Delta m_2 = (F_i - F_0)k,$$

where $F$ is the solar phase and $k$ is the slope coefficient in the phase diagram. After, a corrections analysis of the obtained light curves were made by three different methods: Fourier series (F) (more detail in [6], Lomb-Scargle periodogram (L-S) [9], and Phase dispersion minimisation (PDM) [8] methods. F method gives usable results from analysing long series of observations in multiple following nights when the rotation period isn't longer than 7–10 hours. In cases of small series of observations scattered over a large period of time, the L-S and PDM methods work more reliably. All three methods can be safely used if the number of observations greatly exceeds one hundred. The PDM method is particularly sensitive to a small number of observations. If the number of observations is less than one hundred, the PDM method mostly does not give good results. In cases where the results of F analysis indicated a period exceeding 7 hours, published Minor Planet Center brightness data were analysed additionally. From the beginning period diapason from 0.5 hours until 100 hours are analysed. An analysis by all three methods gives a power spectrum with many peaks (see Fig. 1) and give the most phase curve for the taken method. In some cases, this is not yet the desired rotation period and needs additional analysis in shorter ranges around peaks with a probability higher than 50%. The separation of such possible periods is based on two more features. The first phase curve should have two complete peaks and two minimums (see example in Fig. 2). The second characteristic is that the shape of the power peak should resemble a Gaussian distribution (see example in Fig. 3). At that real period, these features will be formed by analysing the observations obtained by different observatories. Small differences in period values can be combined using a weighted average. Thus, it would be possible to observe both the different number of observations in the data set and observe the probability/significance values of the power spectrum peaks obtained in the analysis. The true rotation period of the asteroid is considered to be the mean weighted period obtained using all calculated periods from

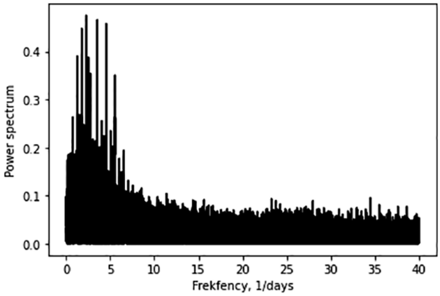


***Figure 1.*** *The L-S periodogram for asteroid Nr 4747 in range 0.01–40*

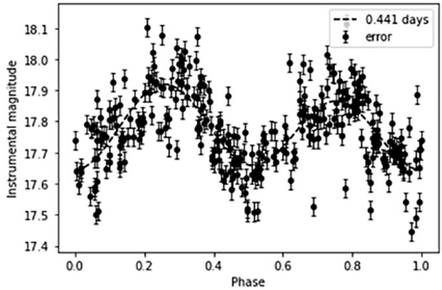


***Figure 2.*** *The calculated the light curve for asteroid Nr 4747 with L-S method*

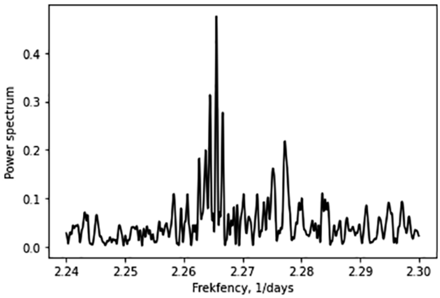


***Figure 3.*** *The L-S periodogram for asteroid Nr 4747 in range 2.24–2.30*

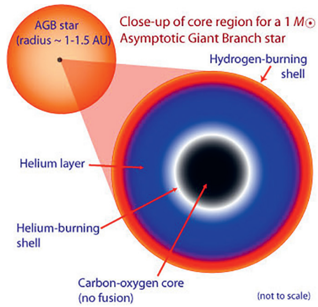


***Figure 4.*** *Model of a carbon star*

data of different observatory measurements. When obtaining the rotation period in this way, the scatter around the mean light curve and the number of observations can be taken into account.

## Investigation of Carbon stars

Carbon stars are post main-sequence stars. A carbon star is a class of stars with a high carbon-to-hydrogen ratio, and a relatively low temperature (2000–3000 K). They are a rare and beautiful class of red giant stars unusually rich in carbon. As a star ages, and it depletes its' store of hydrogen, it can begin to burn helium into carbon and become a giant star. They are enriched in carbon. Therefore, molecules such as $C_2H_2$ (acetylene) or $C_2$, CN, CH, HCN, etc. are observed, which produce characteristic absorption bands in the optical and infrared range of the stellar spectra. The star brightens and cools similar to a red giant, but with greater luminosity, usually at the Asymptotic Giant Branch stage. The atmospheres of these luminous low-temperature stars are often unstable, and they pulsate with a timescale of typically one year. Under the action of this pulsation, the atmosphere is extended, and, in the upper layers, the matter may reach a temperature low enough for some elements to condense into dust. These stars expel much of their carbon-rich envelopes as a wind. These envelopes will eventually mix with the surrounding environment; so that much of the carbon throughout the Milky Way comes from mass-losing carbon stars. Carbon-rich regions are very interesting from the point of view of the formation of carbon life forms.

In the previous years, 316 C stars were discovered in Baldone Observatory and included in the General Catalogue of Galaxy carbon stars, which the Observatory published in 2001 [2]. The next step was to create a list of potential C-stars. The list of stars was selected from the 2 μ All Sky survey 2MASS and contains more than 20000 objects. Therefore, the program of observation in Baldone Observatory was planned to cover five-degree delta slices, in each season of observation, beginning from the pole and gradually declining to the celestial equator. At the exposures from 120 to 480 seconds, the captured photons from red objects cover the region from 5500 Å to 10000 Å. Bands seen in the spectra of carbon stars mainly belong to the strong CN molecule of red system bands, the redder Swan system C2 band, sodium doublet, and the Earth atmospheric $O_2$ A- band (approximately at 7650 Å). In the last ten years in Baldone observatory, 53 new carbon stars were discovered from more than 2000 checked potential C stars. Continuing investigation of newly discovered C stars, the distances (r) in kpc was calculated from the equation Mk – K + 5 lgr + Ak + 10 = 0, where Ak is interstellar absorption, Mk absolute magnitude in K passband, and mk observed K magnitude. Mauron [4] investigation of C stars in LMC showed that the absolute K magnitude of late carbon stars varies in a small range of magnitude from –8.1 to –7.4 depending on $(J – K)_0$ colour indices. Assuming that the properties of carbon stars are similar to the LMC and the Milky Way, we can obtain the value of the absolute magnitude of individual carbon stars from its $(J – K)_0$.

The interstellar absorption $A_k$ and $(J – K)_0$ were calculated from the interstellar reddening. $A_k = 0.302E(B – V)$ and $(J – K)_0 = (J – K) – 0.405E(B – V)$, where E(B – V) is taken from infrared full-sky dust maps obtained by Schlafly and Finkbeiner (2011). As a result, the distribution of newly discovered carbon stars in our Galaxy was obtained.

## The digitisation of Baldone Schmidt archive astronomical photo plates

From 1966 Baldone Schmidt operate in the Astrophysical Observatory of University of Latvia. For 39 years, continuing observations on photographic plates were made, and more than 24500 plates are saved in the observatory archive [3]. The archive contains positions and brightnesses of about 2 billion stars in U, B, V, and R passbands and the observatory has electron scan copies. The archive contains regular observations in the selected region of sky during a 30–40-year period. Now, Baldone astronomers made scans with LINUX/MIDAS/ROMAFOT 64-bit software complex to obtain equatorial coordinates in GAIA DR2 system, U, B, V magnitudes in Jonson and R magnitude in Becker photometric systems.

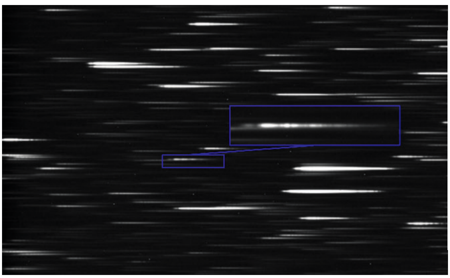

***Figure 5.*** *Four-degree objective prism CCD image obtained with Baldone Schmidt. C star spectrum and multiplied the same star spectrum is seen in the central part of the image*

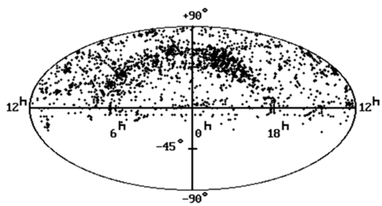


***Figure 6.*** *All-sky distribution of the 22000 direct observations, made with the Baldone Schmidt telescope, in 1966–2005 in equatorial coordinates in equal-area projection*

## Acknowledgments

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### References


[1] ALCDEF (2022). https://alcdef.org
[2] Alksnis, A., *et al.* (2001). General Catalog of Galactic Carbon Stars by C. B. Stephenson. Third Edition. *Baltic Astronomy 10*, 1–318.
[3] Alksnis, A., *et al.* (1998). Baldone Schmidt telescope plate archive and catalogue. *Baltic Astronomy 7*, 653–668.
[4] Mauron, N. (2008). New observations of cool carbon stars in the halo. *Aaph. J. 482*, 151–163.
[5] MPC (2022). Minor Planet Center. https://www.minorplanetcenter.net/data.
[6] Pravec, P., Harris, A.W. (2000). Fast and Slow Rotation of Asteroids. *Icarus 148*, 12–20.
[7] Schlafly, E. F., Finkbeiner, D. P. (2011). Measuring Reddening with Sloan Digital Sky Survey Stellar Spectra and Recalibrating SFD. *Aph. J. 737*, 103, 13 pp.
[8] Stellingwerf, R. F. (1978). Period determination using phase dispersion minimization. *Aph. J. 224*, 953–960.
[9] VanderPlas, J. T. (2018). Understanding the Lomb–Scargle Periodogram. *Aph. J. S. 236*, 28.

# Space compacts as a means to implement UN Space2030 Agenda linking activities in space to UN Sustainable Development Goals

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Space2030 Agenda is the UN initiative with the theme "Space drives sustainable development" [1]. It was launched in 2018 with high expectations [2]:

> *The Space2030 agenda promises a step change in how space is considered in the UN system, with Member States laying out a vision to enhance the use of space science and technology for the attainment of the 2030 Sustainable Development Agenda.*

By 2021 when Space2030 Agenda was approved by UN General Assembly (UNGA) the outlook for space development had changed radically. The U.S.A. was advancing the Artemis Moon mission with the possibility of a lunar landing by 2021 and the vision of linking peaceful uses of outer space in a simple manner was not achieved, although it remained clear that advances in the peaceful uses of outer space were drivers of sustainable development, which is the theme of Space 2030 Agenda.

The organisation of the session "Prospects for Latvian space science and technology to fulfil UN Space2030 Agenda" at the Science Summit at the UN General Assembly in September 2022 [3] called for close review of the UN space initiative. I had envisioned the session as an opportunity for the key elements of the space community in Latvia to present what they do and attempt to show how their activities advance sustainable development. The goal I set for my presentation was to make a statement how Latvia's space activities fulfil the expectations of Space2030 Agenda. I discovered that the document offered little guidance for implementation by nation states. The implementation plan in paragraph 20 consists of one line: "Each Member State will implement the "Space2030" Agenda on a voluntary basis". However, the document also called for progress reporting in paragraph 30 to UNGA in 2030 and a general progress review at the midpoint in 2025. I concluded that with little guidance that states would likely be unable to implement Space2030 Agenda and there would be little to report to UNGA in 2030.

I saw similarities between the role of space in sustainable development and the highly complex problem of sustainable energy development. In Africa about 600 million people do not have access to electricity. The access deficit has been close to 600 million for more than a decade. New approaches are needed to accelerate access and development. The UN developed an instrument called Energy Compact [4] which allowed states, regions, cities, universities, NGOs and international organisations to make a commitment to a roadmap that they developed themselves, towards the achievement of universal access to sustainable development. The energy problem is exceedingly complex with many different actions required. I had been instrumental in the development of an Energy Compact for ANSOLE [5] and was convinced that a similar approach could work for Space2030 Agenda and UN Sustainable Development goals. The ANSOLE Energy Compact addresses capacity building in Africa for sustainable energy through a multi-level approach with measures to build capacity in research and innovation where universities in Africa are central to the capacity of rural communities often with high rates of illiteracy to plan, secure financing, deploy and operate decentralised solar, small hydro, and biomass energy systems. Outer space activities can take many forms just as there are numerous approaches to advance sustainable energy. Space drives sustainable development no less than sustainable energy drives the other SDGs [6]. This idea was articulated in my presentation to the Latvia space session at SSUNGA77 [7].

The authors as Board members of ACES Worldwide are developing an approach for member states, international organisations, regions, cities, and other civil organisations to document their commitment to a roadmap to implement Space2030 Agenda showing linkage to specific UN SDGs and a roadmap to 2030 and beyond. Space Compacts hold promise for broader application than initially envisioned in Space2030 Agenda whose implementation plan only refers to implementation by states. By broadening the possibility of implementing Space 2030 Agenda by international organisations, cities, regions, NGOs, and private business the means to really track progress become possible with the registration of space compacts. There are broader implications of the space compact. For one, space compacts can precisely articulate how an entity – state organisation or firm – advances sustainable development. There are calls for an 18$^{th}$ sustainable development goal relating to outer space development. It would be exceedingly difficult for the UN system to adopt the 18$^{th}$ SDG. Another aspect of space compacts is that their implementation potentially addresses the requirement stated in Article I of the Outer Space Treaty that space activities by UN member states shall be "carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development…" [8]. This aspect of space compacts addresses the call by Mariana Mazzucato to direct the global financial system to serve the common good [9]. Affirming a general principle may not result in actions that comply with the principle. Commitment to a compact links the activities of the organisation to the common good. Development of a Space Compact Registry to be administered by the UN Office for Outer Space Affairs (UNOOSA) is part of the initiative led by ACES Worldwide with a consortium of partner organisations.

## Acknowledgments

I am indebted to Dr. Joseph Pelton, Chairman of the Alliance for Collaboration in the Exploration of Space[1], who sees the broader potential of space compacts and has committed ACES Worldwide to the realisation of the initiative. Upsana Dasgupta's work has demonstrated the broader relevance of the Space Compact instrument by the development of model space compacts for NGOs in India. Madhu Thangavelu's broad perspective spanning architecture and aerospace engineering with leading roles in key international space organisations is particularly relevant to address the problem of implementation of Space2030 Agenda.

This research was conducted through donated professional work of the named individuals.

### References

[1] UN Space2030 Agenda approved by the UN General Assembly on 25 October 2021. https://www.unoosa.org/res/oosadoc/data/resolutions/2021/general_assembly_76th_session/ares763_html/A_RES_76_3_E.pdf

[2] https://www.unoosa.org/oosa/en/outreach/events/2018/spacetrust.html

[1] https://acesworldwide.org/aces-worldwide-board-of-directors.html

[3] https://ssunga77.sched.com/event/15tkd/ref-28234-prospects-for-latvian-space-science-and-technology-to-fulfill-un-space-agenda-2030
[4] https://www.un.org/en/energycompacts/
[5] https://www.un.org/en/energycompacts/page/registry#AfricanNetworkforSolarEnergye.V
[6] https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[7] https://static.sched.com/hosted_files/ssunga77/ee/Space%20Compact-%20Latvia.pptx
[8] https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html
[9] Mazzucato, M. (2023). Financing the Common Good. https://www.project-syndicate.org/commentary/new-economic-paradigm-common-good-market-shaping-by-mariana-mazzucato-2023-05/

# ChatGPT and other AI tools to accelerate development at the community level in Sub-Saharan Africa

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ANSOLE (African Network for Solar Energy) is committed to achieving SDG7, universal access to sustainable, reliable and affordable energy in Africa by 2030. This commitment is documented in the Energy Compact ANSOLE registered with the UN in July 2022. This is an extremely urgent problem that is getting worse despite aggressive efforts by African states and institutions as well as international donors including the UN, World Bank, USAID, EU, and other donors of developmental assistance (Fig. 1). The Outlook for 2030 shows a continued deficit of nearly 600 million people without access to electricity by 2030 (Fig. 2).

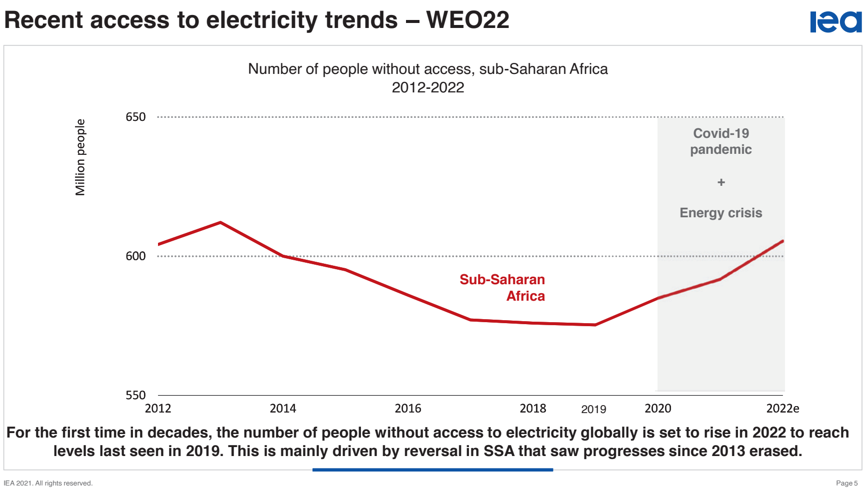


***Figure 1.*** *Source: https://static.sched.com/hosted_files/scienceusafricaleaders/0a/IEA%20-%20US%20Africa%20Science.pdf [1]*

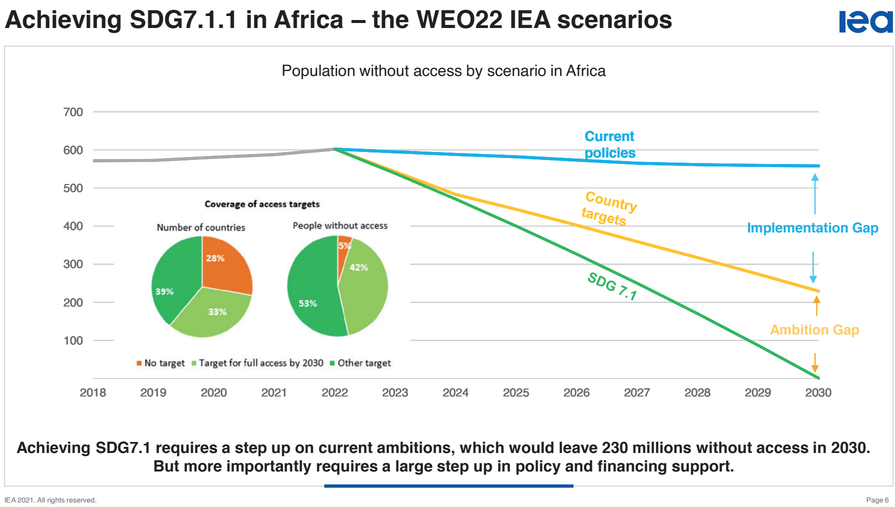


***Figure 2.*** *Source: https://static.sched.com/hosted_files/scienceusafricaleaders/0a/IEA%20-%20US%20 Africa%20Science.pdf*

The IEA talks of a need for greater ambition to reach SDG7. Based on the record of the past decade greater ambition (more investment) cannot be counted on. The concept advanced by ANSOLE is to address the problem as a whole to add intelligence at all levels by building a continental innovation hub to accelerate energy technologies innovation, deployment and developing associated supply chains in Africa and linking Africa with outside suppliers and energy technology providers in a manner that accelerates development in Africa.

Artificial Intelligence (AI) has emerged as a key means to address needs in Africa due to the extraordinary size of the continent, the extremely rapid population growth coupled with rapid brain drain of skilled specialists by out-migration. This example from medicine is indicative of a widespread problem:

> *In 2015, there were only 34,000 doctors serving about 180 million people. This year, the number has gone down to 24,000, according to the Nigerian Medical Association, NMA. Meanwhile, the Worldometer estimates that Nigeria's population has climbed to over 211 million.*

Examples of successful use of AI in Africa are in health care and medicine, agriculture, and environmental management. In fact, Africa is emerging as an important global centre for the development and application of AI [3, 4].

We propose the development of AI tools to empower local communities in rural areas of sub-Saharan Africa, to use tools like ChatGPT even where the community may have low levels of literacy to address access to energy, water and other critical needs to reach relevant decisions about technical matters using vernacular languages not only text but also oral and video media. Low literacy is both a barrier to more rapid development as well as a spur to emigration for talented young people whose development in less developed communities may be hampered and where basic needs are not being adequately met. Digitalisation is made possible even in environments of low levels of literacy through the use of AI tools with audio and video interfaces enabled to communicate in English, French, Portuguese, and indigenous languages. The ANSOLE Energy Compact includes a matchmaking and knowledge exchange platform that will enable AI tools developed in one area of Africa or for one level of the sustainable development ecosystem to be effectively transferred across national borders and institutional barriers thereby enabling acceleration of technology solutions to be adapted to meet needs and accommodate conditions in Africa including possible dysfunctions in governance above the community level.

The ANSOLE Energy Compact [5] with the UN is a commitment to fulfil a roadmap for multi-level capacity-building to achieve SDG7 for Africa through actions in the following domains:

- Training specialists to deploy RE in access-deficit communities,
- Developing research & innovation capacities through fellowships, staff exchanges, scientific events and publications,
- Fostering pan-African cooperation of academic, civil society, religious and cultural groups,
- Creating a match-making platform (MMP) to share knowledge, expertise and research infrastructures in Africa with cooperating institutions elsewhere effectively.

Fully implemented the ANSOLE Energy Compact would enable a pan-African innovation hub to accelerate SDG7 by empowering all levels of the energy innovation ecosystem operating in states in Africa as well as pan-African institutions with highly relevant and timely knowledge to advance development. Insofar as sustainable, reliable and affordable energy enables other SDGs the capacity building enabled as a result of the ANSOLE Energy Compact becomes a driver of sustainable in general. The ANSOLE MMP becomes a hub of a pan-African innovation ecosystem.

**Building the ANSOLE Matchmaking portal using ChatGPT**

A custom chatbot can be built to gather needed datasets and enable analysis of the data and use. A key data set for advancing energy access in deficit communities in the SSA is community needs assessments. A custom chatbot to capture community level data, store for subsequent use and analysis is a critical initial step of building the ANSOLE MMP. The data needs to be stored in standard formats to enable analysis across regions or by types of communities or for multi-location projects potentially implementing different technical solutions due to the varied conditions of specific communities whether terrain, soils, prevailing weather, rainfall, sunlight exposure and other variables built into the needs assessments with information gathered by a custom chatbot [6] in a standard manner that enables data to be used for energy systems planning, financing and deployment as well as analysed across regions and other relevant parameters.

1. Conduct a needs assessment: Start by identifying the key stakeholders and their needs. Conduct a survey or focus groups to gather information on the challenges that communities in sub-Saharan Africa face in accessing affordable and reliable electricity.
2. Determine the data to collect: Based on the needs assessment, determine the data that is required to plan microgrid electrical systems. This could include information on population, energy consumption, existing infrastructure, natural resources, and other factors that could impact the feasibility of microgrid systems.
3. Develop the chatbot: Once you have identified the data to collect, design a chatbot that can conduct surveys or ask questions to gather the necessary information from stakeholders. You can use a platform like Tars or BotStar to build the chatbot.
4. Store the data: As the chatbot collects data, it should store the information in a centralised database that can be accessed by stakeholders. You could use a cloud-based database like Google Cloud Firestore or Amazon Web Services (AWS) to store the data securely.

5. Analyse the data: Once you have collected the data, use analytics tools to analyse the information and identify patterns or trends that could inform the planning of microgrid systems.
6. Make the data available: The chatbot should also provide stakeholders with access to the data collected. You could set up a dashboard that displays the data in an easily understandable format, or allow stakeholders to query the database directly through the chatbot.
7. Add other types of data to the matchmaking platform using chatbots customised for the purpose start with research infrastructure in participating research institution partners, then add research expertise capturing key CV data from participating partners.
8. Continuous improvement: Finally, the chatbot should be continuously improved based on feedback from stakeholders. Use analytics tools to measure the effectiveness of the chatbot and identify areas for improvement.

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**References**

[1] Tonol, G. (2022). Access to Electricity Trends in Africa. IEA presentation to ANSOLE session at Science Event at US-African Leaders Summit December 15, 2022, Washington. https://static.sched.com/hosted_files/scienceusafricaleaders/0a/IEA%20-%20US%20Africa%20Science.pdf
[2] Curbing Health Sector Brain Drain (2022). https://www.vanguardngr.com/2022/11/curbing-health-sector-brain-drain/
[3] Hao, K. (2019). The Future of AI Research is in Africa. *MIT Technology Review*. https://www.technologyreview.com/2019/06/21/134820/ai-africa-machine-learning-ibm-google/
[4] Gadsala, A. (2018). Coming to Life: Artificial Intelligence in Africa, Atlantic Council
[5] ANSOLE Energy Compact with the UN. https://www.un.org/en/energycompacts/page/registry#AfricanNetworkforSolarEnergye.V. The roadmap to 2030 and details of specific provisions of the Compact can be downloaded from here: https://www.un.org/sites/un2.un.org/files/energy_compact_ansole-un.pdf
[6] The African Smart Communities project uses the OpenAi Large Language model to construct chatbots used for needs analysis data capture, data analysis, communications between project partners and stakeholder institutions, and with the public. Below is a list of sources on chatbox design and use.
   a. Tamrakar, R., Wani, N. (2021). Design and Development of CHATBOT: A Review. https://www.researchgate.net/publication/351228837
   b. Chakravarthi, S., Sankar, N. Chatbots: Design, Build, and Deploy Intelligent Bots. This book offers a practical guide to building chatbots using popular, platforms such as Dialogflow, Microsoft Bot Framework, and IBM Watson
   c. Gomathy, C. K. (2022). Artificial Intelligence Chatbot Using Python. https://www.researchgate.net/publication/360620158
   d. Chatbot Magazine: This online magazine features articles, tutorials, and case studies on chatbot design, development, and use.
   e. Botpress Community: https://community.botpress.com/. Botpress is an open-source platform for building chatbots. The Botpress Community offers forums, tutorials, and other resources for developers.
   f. Chatbot News Daily: This website provides daily news and updates on chatbots and related technologies.
   g. Chatbots Life: This online community features articles, tutorials, and case studies on chatbot design, development, and use.

# Diffractive phase elements to form new class of optical fields are driving with versatile spatial distributions

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Diffractive phase elements with suitable phase profiles efficiently shape Gaussian laser beams into versatile spatial patterns of structured laser beams with desirable light-matter interaction properties in a transformative way [1–2]. Specifically, these diffractive optical elements are realised to have a high-damage threshold useful in controlling the spatial dynamics of lasers with high-energy densities. The resultant optical fields with unconventional focusing properties trigger unique observations in mediums and materials. In this context, binary phase elements, diffractive lenses, spiral phase elements, and vortex phase elements are developed and investigated for transforming Gaussian beams to optical fields whose significance is demonstrated in nonlinear optics and higher-order harmonics generations, which will be useful for numerous applications, including material characterisation, optical trapping, optical manipulation, imaging, free-space optical communication, spectroscopy measurements, etc.

### Acknowledgements

This research is supported by European Regional Development Fund (1.1.1.5/19/A/003).

### References

[1] Singh, M., *et al*. (2019). Intense vortex high-order harmonics generated from a laser-ablated plume. *Appl. Phys. Lett.* 115, 231105.

[2] Reddy, A. N. K., *et al*. (2021). Robust demultiplexing of distinct orbital angular momentum infrared vortex beams into different spatial geometry over a broad spectral range. *IEEE Access* 9, 143341–143348.

# Short presentations

# Studying radioactive negative ion production cross sections

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The valence electron of a negative ion is not bound by a long-range Coulomb potential but instead a shallow induced dipole potential which mainly arises from electron-electron correlation. As a result, negative ions have binding energies of about an order of magnitude smaller than neutral atoms. These correlation effects can be probed by measuring the electron affinity (EA) which is the amount of energy released when an electron binds to a neutral system to form a negative ion.

Little is known about the structure of radioactive negative ions. Such studies are of interest for benchmarking atomic theory as well as medical and environmental applications e.g., targeted alpha therapy and uranium mine management. The first EA investigations for radioisotopes were of iodine-128 ($^{128}I$) [1] and astatine (At) [2] made at CERN-ISOLDE. However, the production of radioactive negative ion beams can be significantly more challenging than the production of positive ions of the same element [3]. With the collinear resonance ionisation spectroscopy (CRIS) experiment at ISOLDE, negative ions can be produced via double electron capture reactions in a charge exchange cell. Therefore, we plan to add a permanent spectrometer to the beamline where radioactive negative ions can be studied, specifically in the actinide region.

The EA can be experimentally determined with laser photodetachment. At CRIS, we plan to observe the cross section of photodetachment in two ways. The residual neutral atoms can be detected or, depending on the electron configuration, a multi-step excitation scheme of laser photodetachment followed by resonance ionisation can be used.

Negative ion yield tests at CRIS have been carried out for uranium (U) [4]. After commissioning the spectrometer, EAs for polonium and francium will be among the first to be measured. Francium, the heaviest alkali metal, will require a two-step excitation scheme as mentioned above. This method has been successful for stable caesium (Cs) [5] and rubidium (Rb) [6].

In this contribution, results from the $U^-$ yield test, methods for alkali metal EA measurements, the future spectrometer for negative ion studies at CRIS, and plans for GRIBA experiments will be presented.

## Acknowledgements

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**References**

[1] Rothe, S., *et al.* (2017). Laser photodetachment of radioactive 128I-. *Phys. G Nucl. Part. Phys.* 44(10). https://doi.org/10.1088/1361-6471/aa80aa

[2] Leimbach, D., *et al.* (2020). The electron affinity of astatine. *Nat. Commun.* 11(1), 1–9. https://doi.org/10.1038/s41467-020-17599-2

[3] Menna, M., *et al.* (2017). R&D for the development of negative ion beams of halogens. *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms* 266(19–20), 4391–4393. https://doi.org/10.1016/J.NIMB.2008.05.064

[4] Nichols, M., *et al.* (to be publ. 2023). Investigating radioactive negative ion production via double electron capture. *Nucl. Inst. Methods Phys. Res. B EMIS 2022 Conf. Proc.* (in press)

[5] Navarro-Navarrete, J. E., *et al.* (to be publ. 2023). A high-resolution measurement of the electron affinity of Cs. *Submitted to PRA* (in press)

[6] Ringvall-Moberg, A., *et al.* (to be publ. 2023). *The electron affinity of rubidium: a state selective measurement* (in press).

# High-order harmonics generation in the plasmas containing newly synthesised materials

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Through the phenomenon of high-order harmonics generation (HHG) in the laser-induced plasmas (LIP) nonlinear optical (NLO) properties in a diversity of materials can be studied. These materials include a broad range of samples (from simple metals to complex molecular compounds). Additionally, the combination of different schemes, like probing extended and multi-jet plasmas in the frame of the quasi-phase-matching approach, application of two and multi-colour pump, resonance enhancement of generation harmonics, time-resolved LIP probing, searching for the advanced nanostructured plasmas, search for the advanced molecular plasmas for efficient HHG, analysis of the spatial coherence of harmonics from plasmas, generation of attosecond pulses during HHG in LIP, HHG spectroscopy of materials, application of vortex beams for HHG in plasmas, etc. strongly enriches the range of the phenomena involved in this field of research. As a result, the HHG in LIP serves as an advanced tool for analysing the high-order NLO properties of various materials.

Results showing the possibility of the formation of the optimal conditions for HHG while analysing the dynamics of LIP characteristics using laser induced breakdown spectroscopy (LIBS), such as the decay of plasma emission in the visible range and the velocity of plasma at different energies of the heating pulses are demonstrated in [1, 2]. The electron temperatures and densities of chromium (Cr), indium (In) and tin (Sn) LIPs are determined. The analysis is carried out at different regimes of HHG using the shorter- and longer-wavelength driving pulses. The abovementioned plasma characteristics were determined, and the correlation between the formation of optimal plasma and the highest harmonic yield was defined. The optimisation of plasma parameters made it possible to achieve the enhancement of a single harmonic or group of harmonics in the different spectral regions.

Carbon-containing plasma is proven to be the attractive medium for harmonics generation. Some compounds of carbon with other elements (carbides) can cause the combination of the advanced nonlinear optical properties of two components. The molecules containing metals and carbon (metal carbides) can be used for HHG and analysed by different methods such as the application of two-colour pump, different ablation methods and chirped pulses. Additional option here is the use of the nanoparticles (NPs) containing such molecules since NPs proved to enhance the harmonic yield. In [3] experimentally demonstrated the harmonic generation in the $B_4C$ and $Cr_3C_2$ NPs-containing plasmas and compare them with the SiC NP LIP. Various parameters of HHG in these LIPs were examined, and the simplified two-colour pump model calculations of HHG based on the strong field approximation was presented.

A class of materials brought together under the common term «perovskites» attracted the attention of the research because of their exciting optical and optoelectronic properties. These materials have potential applications in lasers, light-emitting diodes, photodiodes, and photodetectors. Perovskite materials have also proven to be excellent NLO materials in a broad spectral range, thus making them the promising candidates for photonics and optoelectronics applications. NLO properties such as saturable absorption, reverse saturable absorption, two-photon-absorption process, and third order NLO properties have been demonstrated for the metal containing perovskites. However, the high-order NLO properties of perovskite materials are still demanding further research. Meanwhile, an alternative class of lead-free perovskites like $MA_2CuCl_4$, $MA_2CuBr_4$, etc., where $Pb_2$+ ion became substituted by $Cu_2$+, is of primary importance due to lower toxicity. In [4, 5], the high-order NLO properties of the two lead-free perovskite materials and Ni-doped $CsPbBr_3$ perovskite nanocrystals were investigated. The difference between perovskite materials was shown through the HHG under the influence of the strong electromagnetic field.

**Acknowledgments**

This research was funded by European Regional Development Fund (1.1.1.5/19/A/003).

**References**

[1] Kim, V. V., *et al.* (2022). Plasma dynamics characterization for improvement of resonantly-enhanced harmonics generation in indium and tin laser-produced plasmas. *Photonics* 9(3), 600.
[2] Kim, V. V., *et al.* (2022). Influence of chromium plasma characteristics on high-order harmonics generation, *Applied Physics B* 128(2), 217.
[3] Kim, V. V., *et al.* (2022). Harmonics Generation in the Laser-Induced Plasmas of Metal and Semiconductor Carbide Nanoparticles. *Nanomaterials* 12, 4228.
[4] Konda, S. R., *et al.* (2023). High-order harmonics generation in nanosecond-pulses-induced plasma containing Ni-doped $CsPbBr_3$ perovskite nanocrystals using chirp-free and chirped femtosecond pulses. *Nanotechnology* 34, 055705.
[5] Kim, V. V., *et al.* (2022). High-order harmonics generation in the laser-induced lead-free perovskites-containing plasmas. *Sci Rep* 12, 9128.

# Impact of Urban Forest on Heat and Photochemical Pollution in Riga, Latvia

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A method known as Contiguous and Logical Enhancement of Atmospheric Resolution (CLEAR) has been developed for atmospheric simulation for weather/climate and air pollution. Currently, input and nesting for refinement of resolution by a regional model are through statistical interpolation/extrapolation. Unlike the current methods for refining the resolution with nested grids having a 3 : 1 ratio, the CLEAR method goes beyond the state-of-the-art. The resolution is logically doubled as the model calculates in the central/forward difference methods. The method is computationally expensive but the results of it will be scientifically valid due to horizontal interpolations in the model being eliminated. The algorithm, shell script and a Python/CDO code to automate these runs on WRF/WRF-Chem have already been developed. Currently, it is being tested and validated in other studies. To demonstrate the improvements of the method, it will be employed to quantify the impact of urban vegetation on both heat and photochemical pollution in Riga, the capital city of Latvia.

Riga is the most populous city in the country with a population of 0.7 M. The development of urban forests in Riga has a long history. The city of Riga covers 304.05 $m^2$, and around 20% of the urban area is covered by forests. The dynamics of land use and management of green space in Riga city are based on the main laws in Latvia which define the management, maintenance, and spatial characteristic of the urban forest – Law on Forest, Protecting Zone Law and Spatial Planning Law, and the numerous documents and regulations of municipality. According to Latvia's legislation, urban forests' timber production and clear-cutting are not allowed.

Riga city forests consist of 15 forest tracts which are connected with rural forests and some small, isolated forests. The main tree species is Scots pine Pinus sylvestris L. (46.9 $km^2$ or 88% of total forest area) and is characterised by landscape attractiveness. In the summer season (JJA), air temperatures go above 32 $^oC$. Several studies showed that the green infrastructure within the city decreases air temperature. However, how much it affects is quantified through careful numerical modelling. This is one of the objectives of the proposal. Also, this huge forest area within the city should modify the ozone levels because of considerable biogenic emissions such as isoprene. In the low $NO_x$ scenario, ozone levels are decreased and in the high $NO_x$ levels, the same is increased. However, with the rapid changes in transportation and industrialisation, it is highly beneficial to study the impacts of green infrastructure on the ozone levels in Riga, Latvia.

This proposed work is designed based on the above atmospheric simulation method, a.k.a. CLEAR. The main goal of the project is to understand and quantify the impact of urban forests on Riga city air temperature and photochemical pollution. To meet the project goals, the following objectives are planned.

1. To measure biogenic emissions in the forested locations in and around Riga during the summer months (June, July, and August).
2. To quantify the impact of urban forest on air temperature in Riga, Latvia.
3. To quantify the impact of urban forest on photo-chemical pollution in Riga, Latvia.

A coupled meteorology-chemistry model (e.g., Weather Research and Forecasting) with online chemistry will be employed to quantify the impacts of the urban and peri-urban vegetation on air temperature and photochemical pollution in Riga, Latvia. The chemistry mechanisms used will be version 2 of the Regional Atmospheric Chemistry Model (RACM2) with Mainz Isoprene Mechanisms (MIM). The RACM2 has been validated with the most updated chamber studies and the advanced scheme now is widely used for ozone studies. Despite being superior, the RACM2 has weaknesses in the chemistry of biogenic emissions like isoprene, mono-terpenes, and sesquiterpenes. Simultaneously isoprene has a significant impact on the atmospheric oxidation and its products such as ozone and peroxyacetyl nitrate (PAN). Therefore, we will employ a combined RACM2 and MIM scheme to simulate the photochemical oxidation (e.g., ozone, PAN, and inorganic and organic acids) well under the emissions of both anthropogenic and biogenic interactions. The coupled WRF-Chem model handles meteorology and chemistry together. This model can be used for both urban heat island and air pollution studies because the transport and chemical processes work in tandem for the local and transport realisation of the pollution in the intended region. Depending on the anthropogenic emission scenarios, the biogenic emissions from the plants do have two distinct impacts on ground-level ozone pollution. At high $NO_x$ presence, the biogenic emissions interact with the $NO_x$ and form more ozone, whereas, at lower $NO_x$ levels, the formed ozone competes with biogenic emissions such as isoprene, and resultant ozone levels go down.

Sensitivity experiments along with a control run will be made for each urban heat island and photo-chemical pollution studies. Along with these modelling experiments, the proposal also is planned to go for a biogenic measurements campaign in Riga's forest tracks for a week during the summer months to validate the biogenic emission model embedded in the WRF-Chem model. These experiments will quantify the impact of different forest tracks on Riga's air temperature and ozone pollution.

# Laser-Induced Plasma Lasers: Polarisation properties

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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. We call this effect Laser-Induced Plasma Lasers (LIPLs). Lasing was found in LIP on atoms from the 13th and 14th periodic table groups and in *Na, Ca, Ti, Zr, Fe, Mg, Cu,* and *V.* The polarisation properties of the lasing light are studied, finding that the Degree of Polarisation (DOP) varies depending on the pumping transition chosen. DOP can be reliably controlled by applying a relatively weak (≤ 0.3 T) external magnetic field $\boldsymbol{B_{ext}}$ [1-5].

LIP on atoms from the 13th group (except Tl) generates according to the 3-level generation scheme [1-3]. A model explaining polarisation and effects of the external magnetic field in LIPLs of the 13th group is based on considering optical transitions between magnetic sublevels involved in the pumping–generation cycle.

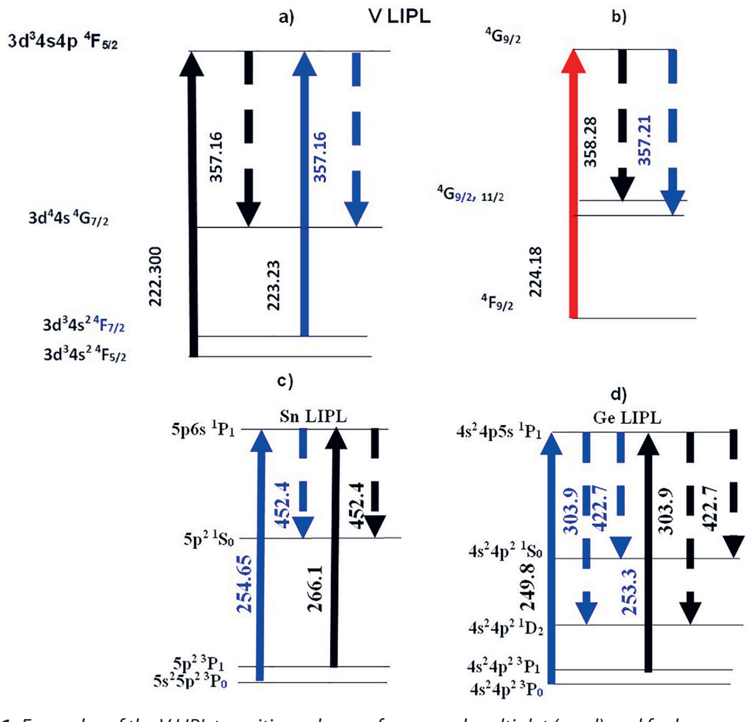


***Figure 1.*** *Examples of the V LIPL transition schemes for ground multiplet (a,c,d) and for lower generation levels multiple (b) differ on one (**Δ J** = ± 1). The numbers along the arrows are pumping and generation wavelength. Black and blue arrows down are generation transitions with negative and positive DOP, respectively. Energy levels are not located accordingly to the true scale for more clarity*

Most LIPLs on the 14th group and other elements generate according to the quasi-tree generation scheme, which we nominate as a Direct Generation (**DG**) scheme because generation occurs directly from the pumped level. A typical example is Ti LIPLs [5]. The modified Hanle effect may explain DG LIPLs polarised generation and $\boldsymbol{B_{ext}}$ effects [5]. We pay attention that pumping the **same generation** line from ground level multiplets with $\boldsymbol{\Delta J = \pm 1}$ of the total angular moment $\boldsymbol{J}$ leads to a change in the sign of the DOP of the generation line (Fig. 1a). The changes in the sign of the DOP also occur for generation lines, with common upper level but lower levels differ on $\boldsymbol{\Delta J = \pm 1}$ (different generation line) (Fig. 1b). These effects need additional theoretical consideration. Still, it may be supposed that density matrix formalism has to be used to explain these effects.

**References**


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

[2] Nagli, L., *et al.* (2016). Stimulated emission and lasing in laser-induced plasma plume. *Opt. Comm*. 378, 41–48.

[3] Gornushkin, I., Glaus, R., Nagli L. (2017). Stimulated emission in aluminium laser-induced plasma: the kinetic model of population inversion. *Appl. Opt*. 56, 695–701.

[4] Nagli L., *et al.* (2021). Polarization. Effects in Laser-Induced Plasma Lasers based on elements from the 13th group. *Appl. Phys*. 129, 013103.

[5] Nagli, L., Gaft, M., Raichlin, Y. (2022). Hanle effect in Ti Laser-Induced Plasma Lasers. *Opt. Comm*. 517, 128292-1-8.

# Network of coupled lasers and its applications

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Lasers are the key components for many branches of science and technology and also serve as fundamental tools for studying other systems. Particularly, lasers with very high power and ideal beam quality have a large potential in scientific research, material processing, optical communication, medicine, industry, and defence, and research in this direction has been in progress ever since the invention of the laser [1]. High-power lasers often have beam quality, stability, and heat dissipation inferior to those of low-power lasers. These problems put an upper limit on generating high powers from a single laser while maintaining good output beam quality. An alternate approach to obtain high-power laser radiation with excellent beam quality is by combining a large number of individual lasers with lower power outputs [1]. In particular, phase locking and coherent addition (coherent beam combination) of lasers are very promising approaches to synthesising high-power lasers with ideal beam quality. The phase locking of lasers requires transferring some energy from one laser to another and strongly depends on the coupling strength between the lasers [2]. The phase locking of laser arrays with various coupling techniques was started with semiconductor diode lasers [3] and gas lasers [4], and quickly extended to solid-state [5] and then fibre lasers [6]. However, the phase locking of many lasers is a challenging task, since it requires, at the very least, a common lasing frequency for all the lasers, a prospect that vanishes exponentially with the number of lasers [7]. More recently, this idea was realised in a degenerate cavity laser with solid-state Nd:YAG gain medium, where large arrays of lasers are generated and phase-locked by coupling them using the Talbot diffraction [8–11].

Further, performing rapid and efficient computation for investigating large-scale computational problems with physical-based platforms has become a very hot and emerging field of research [12]. Particularly, solving computationally hard problems is becoming increasingly important in modern society. Examples of applications include artificial intelligence, drug discovery, optimisation of cognitive wireless networks, analysis of social networks, and management of large data sets [13]. Many of these computationally hard problems are generally mapped on universal spin models, where spins encode the variables, and interactions between the spins determine the coupling between the variables. The problem is then reduced to a ground state search of the spin Hamiltonian [14]. A large network of lasers with nearest-neighbour coupling has been shown to rapidly dissipate into long-range phase ordering, identical to the ground-state of a corresponding XY spin Hamiltonian [8, 9]. The exact mapping between the laser phases and classical XY spins makes them an ideal candidate for simulating spin systems which are sometimes very challenging in condensed matter experiments for practical reasons. Due to the good scalability, arbitrary coupling, and room temperature operation, networks of coupled lasers have attracted considerable interest in using them as physical simulators.

Here, we present the generation and phase locking of large networks of lasers using a degenerate cavity, for generating high-power density at the output of the laser. Further, we show how this large network of coupled lasers can be used to simulate spin systems, investigate topological defects (Kibble-Zurek mechanism), and solve computationally hard problems.

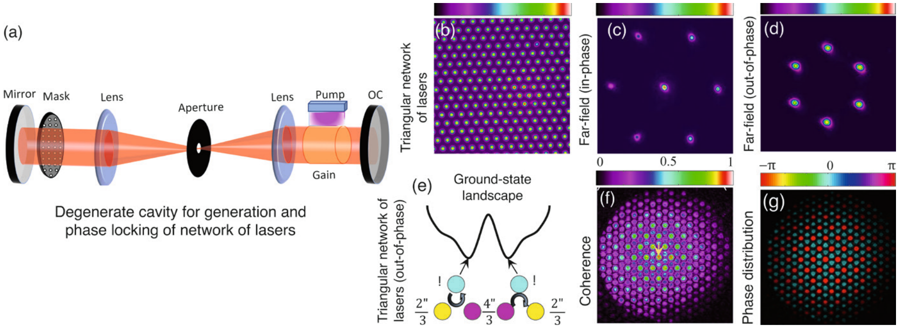


***Figure 1.*** *(a) Experimental setup of degenerate cavity laser. (b) Near-field intensity distribution of lasers in a triangular network. Far-field intensity distribution of triangular network of lasers with (c) in-phase locking, and (d) out-of-phase locking. (e) Energy landscape with doubly degenerate ground state in out-of-phase locked lasers in triangular network. (f) Coherence of lasers. (g) Ensemble averaged phase distribution of lasers in out-of-phase locked lasers*

Fig. 1(a) shows the experimental schematic of a degenerate cavity which includes a solid-state Nd:YAG gain medium, pumped with a flash lamp providing pulses with a 100 µs time duration with a repetition of 1s. It also includes two plano-convex lenses in a telescope configuration, which ensures a perfect imaging inside the cavity. Due to this any point $E(x, y)$ on the mirror re-images onto itself after every round-trip of the cavity. A metal mask containing a network of holes (with hole diameter of 200µm and separation 300 µm (centre-to-centre)) is placed near the mirror, which enables the formation of lasers in a desired network geometry [8-11]. An aperture in the far-field plane (midway between the plano-convex lenses) is used to force each laser in a fundamental $TEM_{00}$ Gaussian mode. The generated network of lasers in a triangular array (near-field intensity distribution) is shown in Fig. 1(b), indicating that each laser consists of a fundamental Gaussian distribution ($TEM_{00}$ mode). Further, to couple and phase lock the lasers, we have used the method of Talbot diffraction, where lasers are coupled with nearest-neighbour positive/negative coupling [8–11]. The positive/negative coupling refers to the phase locking of lasers in the in-phase/out-of-phase configurations.

Fig. 1(c) and 1(d) show the far-field intensity distribution of lasers in a triangular network obtained with the positive and negative coupling between the lasers, respectively. The bright centre in the far-field intensity distribution confirms the in-phase locking of lasers (Fig. 1(c)), whereas the dark centre in the far-field intensity distribution confirms the out-of-phase locking of lasers (Fig. 1(c)). As evident in both cases, the intensity is focused on the diffraction peaks with high-power density. Unlike out-of-phase locking, most of the intensity is tightly focused at the centre in the form of a single spot (only a small fraction lies in the first-order peaks) in the in-phase locking, which is useful for high-power applications in various fields. Using the same process, the lasers can also be generated and phase-locked in different network geometries, such as square, honeycomb, and Kagome [10, 11]. As these lasers are generated from the same cavity, there thus consists a small detuning (due to aberration and thermal lensing effects) among them. This requires a small coupling between the lasers to phase lock them. Therefore, with this approach, large networks of lasers can be generated and phase-locked to obtain the output with high-power density.

In coupled lasers, the dissipative coupling can drive the system to a stable, steady-state, phase-locked solution with minimum losses, which can be directly mapped to the ground-state of the classical XY spin Hamiltonian [8, 9]. This exact mapping of lasers to the classical XY spins, enables to simulations of spin systems [8], topological defects (Kibble-Zurek mechanism) [9], and solutions of large-scale optimisation problems (computationally hard problems) [12–14]. The success of solving optimisation problems relies on efficiently and rapidly finding the ground-state of spin Hamiltonian. However, if the ground state is degenerate or nearly degenerate, the ground-state manifold must be fairly sampled in order to obtain the full knowledge of the minimal-energy state of the system, which requires many repetitive simulations under exactly the same conditions [15, and references therein]. Fair sampling refers to the process of sampling all the populated states of a complex system in accordance with the correct distribution. We have performed a rapid statistical fair sampling of ground-state manifolds with the network of coupled lasers [16]. To do this we directly measure the statistical average of spin ordering of the ground state manifold by measuring the coherence between the lasers in different network geometries with single, double, and many degenerate ground states. For a triangular network of lasers with negative coupling, the results of fair sampling of ground state are shown in Figs. 1(e)-1(g). Fig. 1(e) shows the energy landscape of doubly degenerate ground-states of an XY spin Hamiltonian in a triangular lattice. These two degenerate ground states correspond to vortex and anti-vortex solutions of a triangular network of lasers. To fairly sample these two degenerate ground states, we measured the coherence function of lasers using the Mach-Zehnder interferometer [16], as shown in the Fig. 1(f). The arrow marks the position of a reference laser. As evident, the coherence shows oscillations, where coherence with respect to the reference laser revives every three lasers. This surprising behaviour can be understood by the fact that for the nearest-neighbour (NN) and next-nearest-neighbour (NNN) lasers, the vortex and anti-vortex solutions differ by $\pm 2\pi/3$. As a result of ensemble averaging of measurements, the coherence is reduced to 50%. However, for the next-next-nearest-neighbour (NNNN) laser, these two solutions have the same relative phase which provides a coherence of 100%. The same trend continues for other lasers with large distances from the reference laser. Fig. 1(g) shows the ensemble averaged phases of the lasers indicating a phase difference of $\pi$ between the nearest neighbour (from the reference laser). This again demonstrates the two degenerate ground states of a triangular network of negatively coupled lasers.

## Acknowledgments

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### References

[1] Eckhouse, V., *et al.* (2006). Intracavity coherent addition of 16 laser distributions. *Optics Letters* 31(3), 350–352.

[2] Eckhouse, V., *et al.* (2008). Loss enhanced phase locking in coupled oscillators. *Physical Review Letters* 100(2), 024102.

[3] Philipp-Rutz, E. M. (1975). Spatially coherent radiation from an array of GaAs lasers. *Applied Physics Letters* 26(8), 475–477.

[4] Newman, L. A., *et al.* (1986). High power coupled CO2 waveguide laser array. *Applied Physics Letters* 48(25), 1701–1703.

[5] Fabiny, L., *et al.* (1993). Coherence and phase dynamics of spatially coupled solid-state lasers. *Physical Review A* 47(5), 4287–4296.

[6] Fridman, M., *et al.* (2010). Passive phase locking of 25 fiber lasers. Optics Letters, 35 (9), 1434–1436.
[7] Jeux, F., *et al.* (2004). Efficient passive phasing of an array of 20 ring fiber lasers. *Laser Physics Letters* 11(9), 095003.
[8] Nixon, M., *et al.* (2013). Observing geometric frustration with thousands of coupled lasers. *Physical Review Letters* 110(18), 181402.
[9] Pal, V., *et al.* (2017). Observing dissipative topological defects with coupled lasers. *Physical Review Letters* 119(1), 013902.
[10] Tradonsky, C., *et al.* (2017). Talbot diffraction and Fourier filtering for phase locking an array of lasers. *Applied Optics* 56(1), A126–A132.
[11] Tradonsky, C., *et al.* (2015). Conversion of out-of-phase to in-phase order in coupled laser arrays with second harmonics. *Photonics Research* 3(3), 77–81.
[12] Yamamoto, Y., *et al.* (2017). Coherent Ising machines – optical neural networks operating at the quantum limit. Npj Quantum Information, 3(49), 1–14.
[13] Papadimitriou, C. H., Steiglits, K. (1998). Combinatorial Optimization: Algorithms and Complexity (Dover Publications).
[14] Berloff, N. G., *et al.* (2017). Realizing the classical XY Hamiltonian in polariton simulators. *Nature Materials* 17, 1120–1126.
[15] Takeda, Y., *et al.* (2018). Boltzmann sampling for an XY model using a non-degenerate optical parametric oscillator network. *Quantum Science and Technology* 3(1), 014004.
[16] Pal, V., *et al.* (2020). Rapid fair sampling of the XY spin Hamiltonian with a laser simulator. *Physical Review Research* 2(3), 033008.

# Event Time and Amplitude Meter: High-Precision Measurement Device Based on Enhanced Event Timing Principles

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The Institute of Electronics and Computer Science (EDI) has rich traditions in extremely precise event timing. Event Timers designed at EDI such as A033-ET[1] and A040-ET[2] measure time of events with an extremely high degree of precision, with an error rate of less than 5 and 3 picoseconds respectively. These devices are extensively utilised in satellite laser ranging applications, including in more than 50% of the International Laser Ranging Service (ILRS) network. Nevertheless, they do have certain limitations. One is their vulnerability to environmental parameters like temperature, which significantly increases the timing errors under unstable environmental conditions. Another is their inability to capture information about the amplitude of the event, which introduces relatively large timing errors is the sequence of events has large variance in the amplitude of the event pulses.

The next-generation timing device created at EDI is called Event Time and Amplitude Meter (ETAM). This new device features functionality for adaptively compensating the measurement error based on the temperature readings, as well as includes a peak-detector based amplitude measurement module, which allows to accurately measure both the arrival time and the amplitude of nanosecond-duration pulses.

Fig. 1 shows the architectural overview of the device. It has two event inputs (although only one can be active simultaneously) and 10 MHz reference clock input. The external clock is expected to be extremely stable in order to achieve the specified timing precision; in absence of an external clock, the internal crystal oscillator can also be used, however in this case, precision is not guaranteed. The 10 MHz clock input, if present, is upconverted in the internal PLL to a 100 MHz clock source, which is used to power the FPGA and other digital logic in the device.

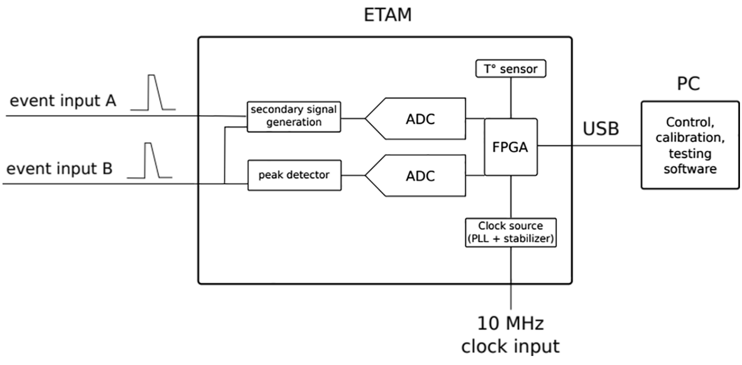


***Figure 1.*** *The architectural overview of the ETAM device*

1 https://www.edi.lv/wp-content/uploads/2019/11/A033ET-Family-2017_Riga.pdf

2 https://www.edi.lv/wp-content/uploads/2019/07/InfSeminar20200227v3.pdf

For event timing, the ETAM uses the Enhanced Event Timing (EET) method described by Artyukh [1]. The event inputs are connected to a secondary signal generator. The secondary signal generator creates a fixed-shape signal (Fig. 2) that is asynchronous to the system's clock, but in phase with the event's signal. By measuring the phase of the secondary signal, fine-grained time resolution is obtained, which is added to the system clock's time notion in order to remove the ambiguity about the relative time of the event. More formally, the time of the j-th input event is measured as [1]:

$$t_j = N_j T_R + \tau(S_{j1}),$$

where $T_R$ is the period of the system's clock pulse (10 ns for a 100 MHz system clock), $N_j$ is the number of the system's clock pulses at the time of the event, $S_{j1}$ is the digitised amplitude measurement of the secondary signal generated after the event (with amplitude threshold greater than or equal to Q), and $\tau(u)$ is a calibration function. The calibration function is obtained in a specific calibration process; the process uses the assumption that the shape of the secondary signal is fixed, therefore its measured amplitude only depends on the phase of the secondary signal, and therefore on the timing of the event itself. We also note that in the ETAM device, only the amplitude measured in the point $S_{j1}$ is used as the argument of the calibration function $\tau(u)$. Previous Event Timers used measurements on both the rising edge (R) and falling edge (F) of the secondary signal, in up to four points: $S_{j1}$, $S_{j2}$, $S_{j3}$, and $S_{j4}$.

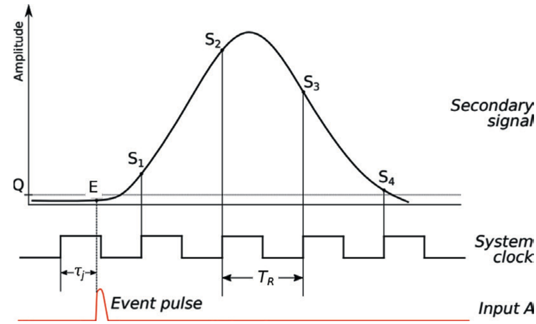


***Figure 2.*** *The principles of the Enhanced Event Timing method [1]. The shape of the secondary signal is shown, in relation to the timing of the input pulse (event) and the system clock*

The event input B is also connected to a peak detector circuit (Fig. 1). The pulse amplitude measurement technology of ETAM operates on the digitisation of the peak-detected signal. The built-in amplitude measurement functionality allows to correct the timing interval measurement results in a post-processing step. This mechanism is similar to the peak-detector utilised in the Time Selector/Amplitude-to-Time Interval Converter (TS/ATIC) system, also developed by EDI and currently employed at the Riga Satellite Laser Ranging (SLR) station. However, ATIC's method of amplitude measurement is hindered by a lengthy (microsecond) dead-time, which the ETAM decreases to around 40 nanoseconds: improvement of more than an order of magnitude. ETAM itself has a slightly reduced dead time compared with the previous-generation event timers; however, the main source of the improvement lies in the new architecture of the measurement setup, compared with the previous system which requires an external signal splitter and amplitude measurement device.

The new ETAM will not only reduce dead time, but also simplify the setup for using Event Timers in SLR applications and has the potential to reduce costs thanks to this integration of amplitude measurements in a single device.

Last but not least, the calibration process of the ETAM has undergone significant improvements. In previous timer models, recalibration was necessary whenever environmental factors shifted in order to maintain precise timing. However, the ETAM production process now includes the creation of numerous calibration tables (i.e., τ(u) functions) for different operating temperatures, with a one-degree Celsius interval. During operation, the ETAM monitors its internal temperature using a built-in temperature sensor (Fig. 1). Whenever it detects a shift greater than 1°C, it switches from the current calibration table to a new one. Although the calibration tables are presently stored in the controlling PC's memory due to their size, we are exploring alternative methods, such as polynomial approximation and other compression techniques, to enable the complete storage of calibration data on the FPGA.

Tab. 1 shows the expected performance of the EDI Event Time and Amplitude Meter (ETAM), based on design and preliminary test results. The initial testing results show improvements both in precision and in temperature stability. Moreover, as expected, the ETAM features reduced dead-time and improved functionality of the gate signal generator.

***Table 1.*** *Comparison of our previous timer A040-ET and expected performance of the new ETAM*

| | ***A040-ET*** | ***ETAM (preliminary)*** |
|---|---|---|
| Timing precision (RMSD) | 2.5–2.7 ps typically | 2.1–2.4 ps typically |
| Timing precision (RMSD) stability (Single calibration at 22.5 °C) | <4 ps (15–30 °C range) | <2.6 ps (15–30 °C range)<br><3 ps (5–40 °C range) |
| Single-input timing offset drift | <2 ps/°C | <1 ps/°C |
| Input-to-input timing offset drift | <0.2 ps/°C | <0.2 ps/°C |
| Dead time | 50 ns | 30–40 ns |
| Minimum input pulse width | 700 ps | 700 ps |
| Pulse amplitude measurement range (positive or negative) | – | 50 mV – 2 V |
| Pulse amplitude measurement precision (RMSD) | – | <3.5 mV (2V pulse amplitude)<br><2.3 mV (1V pulse amplitude) |
| Pulse amplitude measurement accuracy | – | <50 mV (any shape and width pulse)<br><5 mV (if tuned for particular shape and width pulse) |

## Acknowledgments

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### References

[1] Artyukh, Yu N. (2001). A method for continuous superprecise time-interval measurement. *Automated Controls and Computer Sciences* 35(5).

# Next Generation Relativistic Radio-Physical Gravimeter for Geology, Seismology and Geodesy

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Due to general scientific progress, there is now an actual demand for cost-effective, rapid, and very high-resolution (highly sensitive) measurements of the profile of Earth's gravitational potentials (including remote areas with complicated terrain [1]). Operational and ultraprecise information of characteristics of the Earth's gravitational field is important for solving currently emerging scientific, and technical (as well as social, everyday life) problems in geodesy, geophysics, environmental protection, seismic incidents, volcanism, mining, building industry, life safety, etc. The understanding of the geophysical processes in the lithosphere and near-Earth space [2] mobile ground-based / marine-based / air-based facilities will be needed to record the global spatial-temporal distribution of gravitational fields with the maximum resolution.

We present the prototype of a unique mobile relativistic radio physical gravimeter, RG-α MOBILE (IPR secured by 6 patents [3–8]) based on a sophisticated physical principle**.** RG-α MOBILE operates by measuring the change in frequency of electromagnetic radiation (GPS signal) under the influence of gravity. The "red-shift" effect of EM radiation frequency is used to substantially increase the precision (up to $10^{-14}$) of recording even the tiniest details of the profile of the Earth gravitational field. This is an exclusive game-changing innovation, offering new, never been before seen perspectives on geology, seismology, geodesy, cartography and industry, mining (gas & oil extraction) and building industry especially. Currently on the market there are no, series gravimeters being produced based on such sophisticated physical principles which allows one to measure gravity constant, and the mass of the physical object simultaneously with unmatched resolution.

Ultrasensitive, handy, ultraprecise relativistic radio-physical gravimeter is a timely disruptive innovation for the multipurpose needs of public and private entities, governmental agencies, research institutions, and private companies. The instrument has the following abilities: measures three components of free fall acceleration without the influence of inertial acceleration; measures velocity of movement, and time as well.

The pilot measurement series in the feasibility study indicates the potential to contribute to earthquake early warning systems.

The prototype of RG-α MOBILE gravimeter (Fig. 1, 2) if developed to the market maturity will be beyond the "state-of-the-art" instruments in worldwide family of gravimetric devices, and a timely response to the societal challenges and niche markets in the following areas and related sectors of science, technology and economy:

- Geology and mining – to measure cost-effectively minute gravity anomalies (not currently detectable) precisely pointing to the location of deposits of various minerals and, particularly, of oil & gas;
- Geodesy, geophysics, seismology, the construction industry – to perform ultraprecise gravity mapping of territories, including dynamically changing 3D maps and particularly to monitor minute incidents of tectonic plate interactions. Designers of construction will utilise the data to determine subsoil conditions;

- Metrology – for new opportunities in the production of new etalons for gravity constants and free-fall acceleration (demand sustained by many universities, research institutes and relevant agencies).

The innovation can be used for several purposes. Some of the major possible clients are the exploration and drilling companies "Exploration and drilling companies frequently fail to make drilling directly in the area of the deposit of oil or gas and are suffering extra expenses and losing time as a result." The market is always searching for new and most cost-effective products for geodesy and geomatics, so, in that field, there is a need for this innovation as soon as possible.

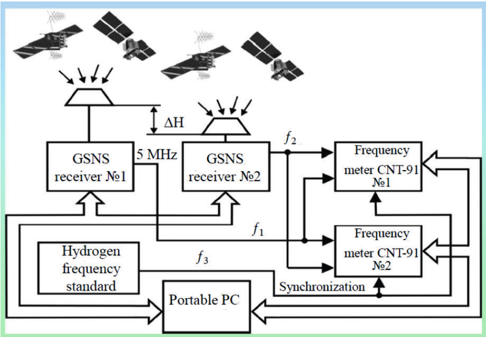


***Figure1.** The principal scheme outlying RG-a MOBILE device*

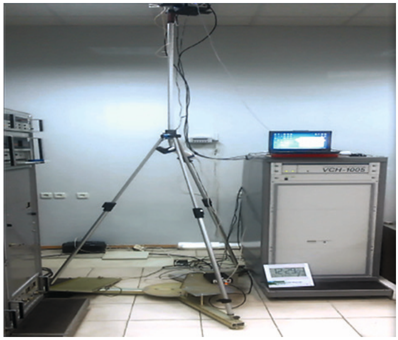

***Figure 2.** Configuration and geometry of RG-a MOBILE prototype, tested in real environment (TRL ≥ 6).*

**References**

[1] Niebauer, T. (2015). Gravimetric Methods – Absolute and Relative Gravity Metter's: Instruments Concept and Implementation, pp. 37–59. *Treatise on Geophysics*, Vol. 3, Geodesy ed. Thomas Herring, Elsevier.

[2] Chambers, D. P. (2015). Gravimetric Methods – Satellite Altimeter Measurements, pp. 117–150. *Treatise on Geophysics*, Vol. 3, Geodesy ed. Thomas Herring, Elsevier.

[3] Patent 83239 Ukraine. IPC G01 V7/00 (2008). Method for determining the parameters of the gravitational field. A. L. Makarov, S. A. Matvienko, O. V. Meleshko, M. A. Androsov (Ukraine). State Enterprise "Design Bureau "Yuzhne" named after M. K. Yangelya" Declared. 20.02.06; publ. 25.06.08; Bul. No.12.

[4] Patent 90960 Ukraine. IPC G 01 V 7/00 (20010). Satellite radio navigation system. S. A. Matvienko (Ukraine) – Declared. 24.12.08; Publ. 10.06.10; Bul. No. 11.

[5] Pat. 90961 Ukraine. IPC G 01 V 7/00 (2010). Radiophysical gravimeter. A. P. Matvienko, S. A. Matvienko, A. V. Meleshko (Ukraine) – Declared. 24.12.08; Publ. 10.06.10; Bul. No. 11.

[6] Patent 98358 Ukraine. IPC G01 V7/14 (2012). Method for measuring geodetic parameters and a device for its implementations. A. Matvienko, V. M. Romanko, O. V. Romanko (Ukraine) – Declared 03.06.10; Publ. 10.05.12; Bul. No. 9.

[7] Patent 115255 Ukraine. IPC G 01 V 7/00 (2017). Method and device for measuring gravitation constant. S. A. Matvienko – Declared. 02.07.15; Publ. 10.10.17; Bul. No. 14.2017. Bull. No. 1.

[8] Patent 115891 Ukraine. IPC G 01 V 7/00 (2018). Method and device for measuring mass. S. A. Matvienko – Declared 02.07.15; Publ. 10.01.18; Bul. No. 1/2018.

[9] Patent 124381 Ukraine. IPC G 01 V 7/00 (2021). Relativistic gravimeter and method of measuring the value of free fall acceleration. S. A. Matvienko (Ukraine) – Declared 05.06.18; Publ. 08.09.21; Bull. No 36.

# The Progress of the EU supported Project "EuropeanSpaceHub" at the University of Latvia

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The University of Latvia (UL) as an associated partner is implementing the European Union supported Project "EuropeanSpaceHub". The implementation period will span almost two years, and the budget is fully covered by the UL. The project involves the National Science platform (NSP), FOTONIKA-LV, the Institute of Astronomy of Latvia, and the University of Latvia. It will create a wider collaborative cluster from local space active research institutions, HEIs, firms and intermediators.

The EuropeanSpaceHub is an innovation platform whose aim is to digitally connect and facilitate the European space ecosystem, connecting different stakeholders such as scientists, academics, research centres and institutes, entrepreneurs, startups, venture capitals and many others.

The space industry has grown in importance over the last decade, not just from a scientific perspective, but also from a business and geopolitical perspective. In this context, connecting various players in the European space industry and related fields is critical for the innovation, economy, and security of the continent.

Our approach is to assess the concept of innovation as an open system, providing an essential impact to the growth of both the local and global economy. We see societal and business culture to be a critical growth factor in small post-soviet transition economies [1]. The "innovation ecosystem as a network of institutions in public and private sectors whose activities and interactions initiate, develop, modify, and commercialise new technologies" has such valuable growth potential [2]. Such an innovation system is usually driven by an entrepreneurial and technologically vibrant university with its research centres of excellence including an interactive collaboration between all actors, and available innovation culture in institutions, and new technology adoption readiness [2].

The main goals of the EuropeanSpaceHub in Latvia are:

- to create vibrant space cluster involving radioastronomy and space geodesy utilising local facilities and photonics research competence from other University of Latvia and Riga Technical University structural units, Daugavpils University, Ventspils University of Applied Sciences and Rezekne Academy of Technologies;
- use the NSP FOTONIKA-LV as a solid base to collaborate with the main European Photonics research centres and local industry thus creating interactive local space ecosystem as a node for networking with other similar ecosystems;
- create a space incubation capacity based on one of the university's business incubators;
- provide local partners with entrepreneurial and innovation training, mentoring, and funding opportunities, including testing of new training modules;
- create a new technology transfer strategy and entrepreneurship liaison for universities for strengthening entrepreneurial and innovation ecosystems;
- develop a strategy for local space innovation ecosystems;
- connect the space ecosystems of universities and industry via the EuroSpaceHub digital platform to increase collaboration and valorisation of technology transfer, and to leverage start-up projects with access to networks;

- organise events connecting students and non-academic staff to attract multi-disciplinary space professionals for innovation workshops, analogue missions, astronaut training, and space instrumentation and ecosystem networking events.

The EuroSpaceHub consortium has five full partners: Vilnius Gediminas Technical University (Lithuania), International Space University (France), Complutense University of Madrid (Spain), Lunar Explorers Society (the Netherlands) and Collabwith Group (the Netherlands). In addition, the project has 12 associate partners, one of which is the University of Latvia.

The research performed so far has outlined several key conclusions. The space ecosystem performance depends on:

1. Conducive culture and transformation of neo post-soviet mindset.
2. Strong leadership. Enabling space policies and political will to reach strategic goals and get sufficient national level resources.
3. Availability of appropriate funding.
4. Qualitative human capital and sustainable and sufficiently financed space related research.
5. Venture friendly markets for novel and innovative space products.
6. Infrastructure support including large scale research facility operation, maintenance, and renovation.

Actual information is on the Project web page – https://www.eurospacehub.com/.

**References**

[1] Cooke, R. A., Clayton J. (2016). Whitepaper. Building a culture for innovation. Human Synergistic International, Australia, 24p. https://www.human-synergistics.com.au/docs/default-source/default-document-library/building_a_culture_for_innovation_wp.pdf?sfvrsn=2

[2] Ozols, A., Avotins V. (2023). Modern economic policy. Practical considerations: case of Latvia. In: *Conf. Proceed. Challenges, trends and inspirations within the Labour Market*, November 10–11, 2022, Publ. House A. Dubček University in Trenčin, pp. 192–199. https://fsev.tnuni.sk/konferencia2022/Zbornik.pdf?v1.

# Shock metamorphism, a cause for spectral changes in meteorites: from Tartu to Riga, a cooperation

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Asteroids tell about the history of the solar system, the accretion of planets, the shaping of planetary surfaces, and the source ingredients for life on Earth. The meteorites associated to asteroids treasure limitless information on the processes occurring on these planetary bodies. In most cases scientists use reflectance spectra properties of the asteroids to map out their distribution in the solar system and especially in the Main Asteroid Belt [1, 2]. Among these asteroids reside two major groups: the S-type asteroids, host to ordinary chondrites, and the C-type asteroids, host to carbonaceous chondrites; both chondritic meteorites are primitive rocks of the solar system. To distinguish S-type asteroids from C-type asteroids, one can observe the dips in absorbances at 1 and 2 microns of wavelength in the near infrared; in S-type asteroids the absorption bands are clearly visible (silicate minerals) while in C-type asteroids these bands are absent, which also is cause to the darker appearance of these asteroids. In parallel to spectral studies, shock processes can alter the surface of asteroids and, to some extent, their reflectance spectra [3].

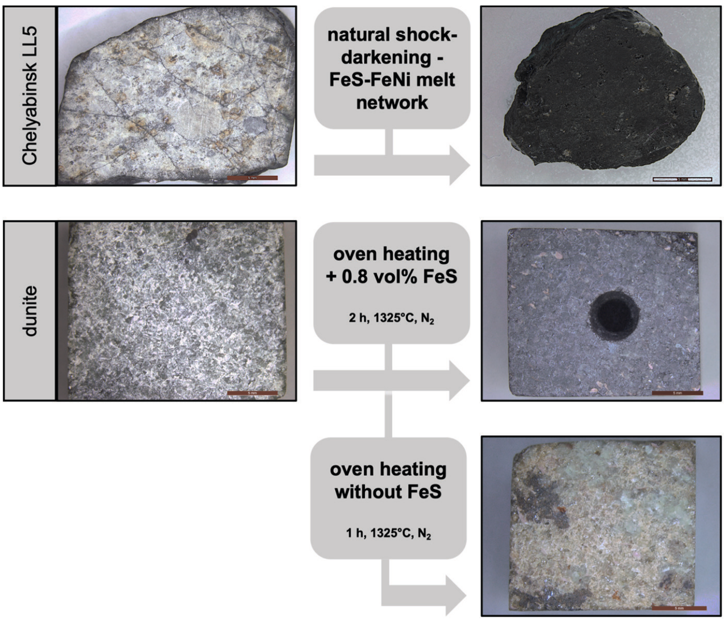


***Figure 1.*** *Natural darkening from shock in the ordinary chondrite LL5 and darkening in an Earth rock from high temperature treatment inducing the melting of a foreign source of FeS. In both occurrences the FeS melt mobilises and spreads within the rock and darkens it*

## Research on shock-darkening

The research is based on a Marie Skłodowska-Curie proposal aimed to be financed locally by the European Regional Development Fund of Latvia. It is also a collaborative work between the University of Latvia and the University of Tartu, Estonia. Its focus is on the shock-darkening of ordinary chondrites [3]. This process involves the melting of iron sulphides (troilite, FeS) and their remobilisation within silicate cracks produced by the shock wave (Fig. 1). The occurring darkening strips the reflectance spectra from their S-type characteristic absorption bands at 1 and 2 microns to give them an appearance close to C-type asteroid spectra (Fig. 2). The research centres on the following themes:

1) in situ observations of shock-darkening in meteorites with a timely review of the entire process,
2) in depth review of numerical modelling for shock experiments, an expensive and precious tool used to study shock processes in meteorites and other materials [4, 5],
3) systematic study of the chemical and physical markers of the melting and mobilisation of iron sulphides within rocks to better characterize shock-darkening spectral changes [3, 6] (Fig. 2).

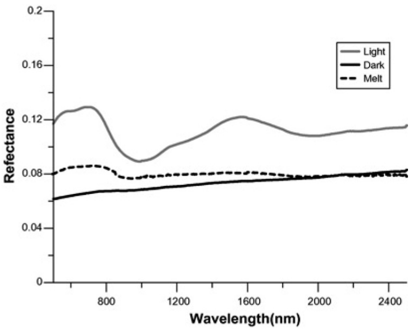


***Figure 2.*** *Near-infrared reflectance spectra profiles for the Chelyabinsk LL5 meteorite. The dark meteorite spectra profile appears flat from the absence of silicate absorption bands that are present in the light meteorite spectra. This is a consequence of silicate crack filled with molten and opaque FeNi-FeS. Red dashed lines are positions of silicate absorption bands. [3, modified]*

### Reviewing shock-darkening

The first aspect of the research aims at gathering samples that show characteristics of shock-darkened meteorites, especially ordinary chondrites. Meteoritic candidates must resemble meteorites such as the Tsarev L5 [7] and the dark Chelyabinsk LL5 [3] ordinary chondrites. Treating the samples to analyse them under microscope and scanning electron microscope (SEM), energy-dispersive spectroscopy (EDS), is paramount to morphologically document on the process further. With enough documentation, a review of the process is possible. In fact, shock-darkening is only considered as a shock feature and has never been reviewed in its entirety; literature as old as 30 years is the main source for understanding shock-darkening [7–10] as well as more recent special case studies [e.g., 3, 6, 11, 12]. Shock-darkening is not a part of the shock classification of chondrite whereas shock-darkening happens in very specific conditions that sit between the fifth and sixth stages of the classification [13]; the proposed review aims at giving shock-darkening its rights as an intermediate shock stage.

### Prepping for shock-recovery experiments

Truth be told, shock-recovery experiments are expensive, yet they yield important information involving shock processes [4, 5], including shock-darkening [e.g., 12]. The set-up is rather simple [4, 5] (Fig. 3a), yet the outcome of the propagating shock wave strongly depends on the sample size, its properties, and heterogeneities (Fig. 3b-d). This can lead to unexpected results if the sample preparation is inadequate or if the understanding of shock wave propagation is biased. This research proposes to review shock experiments through the lens of shock physics numerical modelling [14]. Such numerical method is often used along experimental studies [e.g., 12] to describe the interactions and heating/melting behaviour of mineral phases [15 and references therein]. A numerical example is given in Fig. 3d, where the shock wave is depicted by mapping shock pressures at different numerical time steps. This numerical approach can help configure specific samples (case scenario shown in Fig. 3c) that can be studied once recovered (Fig. 3e).

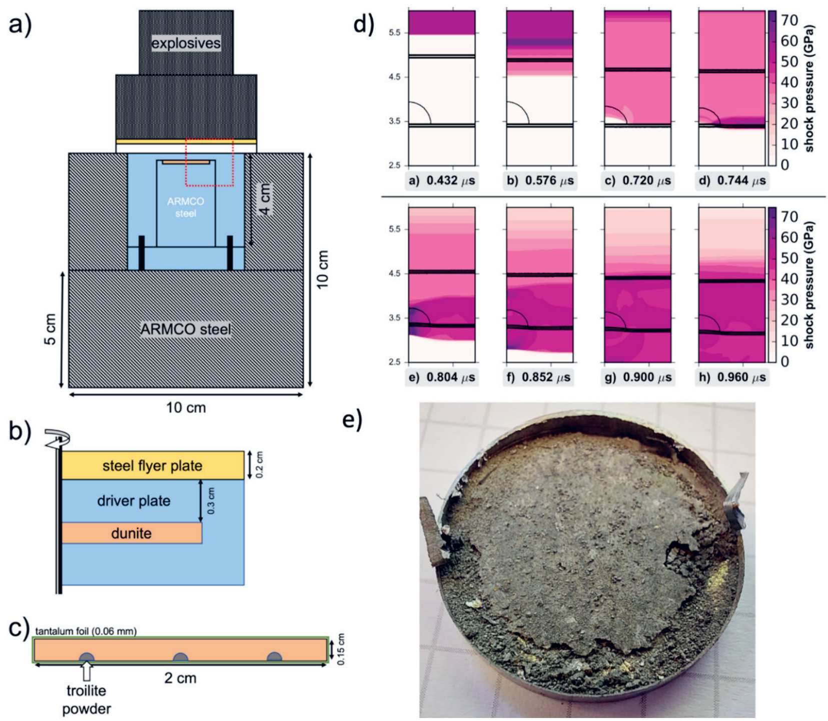


***Figure 3. Case scenario**: drillholes in a dunite disk c) are filled with powdered troilite (FeS) and placed within the system to study shock melting of troilite between 40 and 60 GPa. A tantalum foil wraps the sample. **a-c)** Setup of the shock-recovery experiment. The cylindrical ARMCO steel container in a) encloses the sample disk. The explosives on top of the setup propel a flyer plate toward the steel container which generates a shock wave. The flyer plate is larger than the sample so the shock wave reaching the sample is planar. Axis in b) is a cylindrical axis of symmetry used in 2-D numerical models. **d)** Recordings of the shock wave propagation (pressures) in numerical models (flyer plate velocity: 2430 m/s) at one FeS-filled drillhole position within dunite. Pressures are shown at different time intervals t. **e)** The shocked sample, depicted also in c), is recovered from the steel cylinder in which it was placed and is ready for analyses*

**Proceeding with the spectral studies**

As observed in the study from [6], FeS migrates and darkens the whole rock in 1 hour time and with very small initial amounts of FeS (0.8 vol%, Fig. 1). However, the methodology and technology used by [6] didn't allow the use of shorter heating durations and the samples where constantly flushed by nitrogen which could affect the migration of FeS and the documented chemical changes. Applying methods and analyses used by [6], we aim at employing technology allowing for melting of FeS within rocks in vacuum with shorter time treatments (technology available at the University of Latvia). With the new series of test in controlled environment, we will expend the knowledge on shock-darkening and the spectral changes it causes.

## Bridging the gap: geology and astrophysics

To bring the project to success and to expand the field of shock physics, shock metamorphism, and spectral observations to a larger astrophysical audience, the project will be implemented at the Institute of Astronomy of the University of Latvia. The above-mentioned melting experiments are held at the institute within a high-vacuum and high-temperature furnace with controlled melting of the iron sulphides into suitable samples. Analyses of the rock samples filled and darkened with iron sulphides are done at the University of Latvia, University of Tartu, and possibly, the Institute of Planetology of the University of Münster. The project is an extension between institutions and aims to strengthen the relationship between geology and astrophysics within the University of Latvia and create a new thread of cooperative work between the Department of Geology of the University of Tartu and the Institute of Astronomy of the University of Latvia. With this successful cooperation between institutes and universities, the outcome will open the doors to more innovative projects that will ultimately form a new cluster of science within the Baltic region, especially in the field of shock metamorphism and asteroid studies.

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**References**

[1] DeMeo, F. E., Carry, B. (2014). Solar System evolution from compositional mapping of the asteroid belt. *Nature* 505, 629–634. https://doi.org/10.1038/nature12908

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

[3] 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.

[4] Langenhorst, F., Deutsch, A. (1994). Shock experiments on pre-heated alpha-quartz and beta-quartz: I. Optical and density data. *Earth and Planetary Science Letters* 125, 407–420.

[5] Langenhorst, F., Hornemann, U. (2005). Shock experiments on minerals: Basic physics and techniques. *EMU Notes Mineral.* 7, 357–387.

[6] Moreau, J., *et al.* (2022). Documenting the morphological and chemical effects of melt impregnation of iron sulfides into dunite: a tool for meteoritics and shock metamorphism. *85$^{th}$ Annual Meeting of the Meteoritical Society*, Glasgow, UK,

[7] Heymann, D. (1967). On the origin of hypersthene chondrites: Ages and shock effects of black chondrites. *Icarus* 6, 189–221

[8] Britt, D. T., Pieters, C. M. (1989). Bidirectional reflectance characteristics of black chondrite meteorites (abstract). In: 20$^{th}$ Lunar and Planetary Science Conference. Houston, Texas, pp. 109–110.

[9] Stöffler, D., Keil, K., Scott, E. R. D. (1991). Shock metamorphism of ordinary chondrites. *Geochimica Cosmochimica Acta* 55, 3845–3867.

[10] Rubin, A. E. (1992). A shock-metamorphic model for silicate darkening and compositionally variable plagioclase in CK and ordinary chondrites. *Geochimica Cosmochimica Acta* 56, 1705–1714.

[11] Grokhovsky, V. I., *et al.* (2020). Post-impact metamorphism of the Chelyabinsk meteorite in shock experiment. *Planetary and Space Science* 192, 105050.

[12] Kohout, T., *et al.* (2020). Experimental constraints on the ordinary chondrite shock darkening caused by asteroid collisions. *Astronomy & Astrophysics* 639, A146.

[13] Stöffler, D., Hamann, C., Metzler, K. (2018). Shock metamorphism of planetary silicate rocks and sediments: Proposal for an updated classification system. *Meteoritics & Planetary Science* 53, 5–49

[14] Wünnemann, K., Collins, G., Melosh, H. (2006). A strain-based porosity model for use in hydrocode simulations of impacts and implications for transient crater growth in porous targets. *Icarus* 180, 514–527.

[15] Moreau, J., Schwinger, S. (2020). Heat diffusion in numerically shocked ordinary chondrites and its contribution to shock melting. Physics of the Earth and Planetary *Interiors* 310, 106630.

# Properties of the variability of active galactic nuclei Perseus A, MRK 421, MRK 501 according to joint radio-optical observations in Latvia, Ukraine and Slovakia

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Since 2017 in the framework of joint Latvian-Ukrainian study observations of fast radio and optical variability of the selected AGN, are conducted using the radio telescopes RT-32 and RT-16 in Latvia (VIRAC) and the radio telescope RT-32, which is located near Zolochiv city in Ukraine. Optical observations are provided by: Baldone (Latvia) – the Schmidt telescope with a mirror 1.2 m in diameter, Vihorlat (Slovakia) – the VNT telescope with a mirror 1 m in diameter, Mayaki (Ukraine) – the AZT-3 telescope with a mirror 48 cm in diameter.

Massive radio galaxies associated with clusters or groups of galaxies often exhibit unusual properties, both in variability and in angular VLBI structure, and in activity of relativistic jets. This is explained by presence of gravitational interaction of such galaxies with cluster neighbours, possible absorption of other galaxies in the past, as well as presence of extensive gas envelopes-halos in clusters.

Previously unexplored fast variability of the Seyfert radio galaxy Perseus A in the radio range, with predominant characteristic times 3–5–8 hours (on the radio telescopes of Latvia and Ukraine), has been discovered. In some observation sessions, these flux density variations were close to quasi-periodic ones. Weak flux variations with characteristic times about 1 hour or less (previously not mentioned for this object) were studied and their properties were investigated, which made it possible to conclude that these variations may be related to mid-latitude acoustic-gravity waves in the Earth's ionosphere. Using the possibility of simultaneous observation at frequencies 5 and 6 GHz on the RT-32 Zolochiv, no significant cross-correlation lags (time delays between both frequencies) were recorded for time series 2–3 days in length. This shows that the radio emission at these frequencies comes from one region of space and is well correlated (correlation coefficient 0.7–0.8). Manifestations of an 8-hour quasi-period were found on the VIRAC antennas. This quasi-period was registered simultaneously at frequencies 5, 6.1, 6.7, and 8.7 GHz. This is an interesting result, which suggests that this is not a harmonic of the daily period, but an oscillation of a different nature, but possibly interstellar scintillations or the internal variability of 3C 84. Simultaneous manifestations of 3C 84 variability with a characteristic time of about 6 hours were also recorded on RT-32 Zolochiv and RT-32 VIRAC. This is an argument in favour of detecting manifestations of the internal variability of 3C 84.

In the optical range, the source 3C 84 has a cyclic change in brightness (with a characteristic time about 15–16 days), recorded from light curves obtained at the Mayaki (Ukraine) and Vihorlat (Slovakia) observatories with an amplitude of 0.05 mag, against background of a long-term trend change in brightness, with an amplitude 0.2–0.3 mag. According to AAVSO optical monitoring data, a long-term cycle of about 18 years was found in 3C 84, similar to the harmonic of precession period (40 years). No significant cross-correlation lags between B, V, R, and I bands were found. Perhaps, this is due to the fact that 3C 84 is at minimum of its activity. According to Baldone observatory, 3C 84 has been shown to have intra-night variability with characteristic times around 1 hour and 10 hours.

Quasi-periodic optical variability of the core of the active galaxy MRK 421 (with a quasi-period 9–13 days, depending on optical band) has been detected, confirmed by joint observations of the Mayaki (Ukraine) and Vihorlat (Slovakia) observatories, as well as by analysis of the AAVSO light curves. AAVSO also found a cycle of about 28 days. These are new results obtained in this Project. In V, R, I band, according to the AAVSO data, a quasi-period of 1.6–1.7 years was appeared, which, according to the results of wavelet analysis (for non-uniform time series), was stable from April 26, 1996, to November 23, 2015 (19 years), after which a quasi-period of about 4.4 years was shown.

Quasi-periodic change in the optical brightness of MRK 501 was found in the form of a quasi-sinusoidal wave in optical bands V, R, I, with an average period of 46.7 days. This is a new result obtained in this project. As a result of the project, the second harmonic of 23-day period (previously found in the gamma range) was discovered, which is associated with orbital motion of the second satellite black hole in the binary supermassive black hole system at the core of active galaxy MRK 501. Observations at Baldone showed absence of a significant intra-night variability of MRK 501. Analysis of the long-term radio data of MRK 501 at a frequency 15 GHz (OVRO radio observatory, USA) showed the presence of quasi-periods 1.5 and 5 years, which is very close to the quasi-periods of 1 and 5–6 years found in the optical range using AAVSO data. Thus, good consistency of the manifestation of variability in different bands (radio, optical, gamma) for MRK 501 is confirmed, which may be due to the presence of a supermassive binary black hole in the core of this galaxy, as predicted by other authors.

## Acknowledgements

The main outcome of these studies has been achieved during implementation of the Latvian Council of Sciences grant "Joint Latvian-Ukrainian study of peculiar radio galaxy "Perseus A" in radio and optical bands (lzp-2020/2-0121)".

# Poster presentations

# The progress of the ERA Chair project "The Development of Quantum Optics and Photonics at the University of Latvia"

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The University of Latvia (UL) implements the European Regional Development Fund (ERDF) Project No. 1.1.1.5/19/A/003 "The Development of Quantum Optics and Photonics at the University of Latvia" (Project) [1-3]. The realisation period of the project activities is 01.05.2019–30.11.2023. The budget of the Project is EUR 2.5 million (85% covered ERDF and 15% covered by State Budget funding). The Project was initially submitted to the Horizon 2020 call "WIDESPREAD-04-2019: ERA Chairs" and was scored above the threshold. This allowed the Project to be refunded by ERDF and local funds according to "Regulations Regarding the Implementation of the First, Second, and Third Project Application Selection Round for the Activity 1.1.1.5 "Support for International Cooperation Projects in Research and Innovation" [4]. The Project is implemented by the University of Latvia National Science Platform (NSP) FOTONIKA-LV.

The objective of the Project is to attract a high-level research leader (ERA Chair) who will develop quantum optics and photonics at the University of Latvia and thus will raise the research quality and international recognition of the UL. The project has the following work packages: WP1. Selection and Recruitment of an ERA Chair; WP2. Selection, recruitment, and personnel management of an ERA Chair's research team; WP3. Research activities of the ERA Chair and his/her team; WP4. Preparation of competitive project proposals; WP5. Strategy development and implementation of structural changes; WP6. Communication, Networking, and Dissemination; WP7. Management. The main expected results of the Project and their achievements so far are summarised in Table 1.

The International Advisory Board of the Project, consisting mainly of members of the International Scientific Council of NSP FOTONIKA-LV, twice a year evaluated the progress of the Project. The leader of the Board, S. Svanberg (Lund University, Sweden, h-index 71), and member of the Board, foreign research leader L. Pavesi (University of Trento, Italy, h-index 77), contributed with extra support to the implementation of the Project. The Selection Committee, consisting mainly of Board members and project leaders, in 2019 and 2020, launched open international competitions for the ERA Chair position at the University of Latvia and evaluated candidates. Finally, Dr. Rashid Ganeev was selected and recruited as an ERA Chair in Quantum Optics and Photonics (work agreement started on 08.10.2020.). R. A. Ganeev is a highly productive researcher with a total number of publications (SCOPUS) 539 and h-index 58. The main topics of his scientific interests are nonlinear optics (high-order harmonic generation of laser radiation, investigation of the nonlinear optical properties of various media), investigation and construction of coherent extreme ultraviolet radiation sources, laser – surface interactions, and nanostructuring, nanofabrication, and characterisation of small-sized species.

***Table 1.*** *Main expected results of Project No. 1.1.1.5/19/A/003 and their achievements as of 31.03.2023*

| Expected result | To be achieved during the Project by 30.11.2023 | Achieved by 30.04.2023 | Achieved by 30.04.2023 |
|---|---|---|---|
| ERA Chair holder recruited (agreements) | 1 | 1 | 100% |
| ERA Chair scientific group recruited (agreements) | 4 | 5 | 125% |
| Publications submitted | 24 | 56 | 233% |
| Project proposals submitted | 6 | 36 (2 funded, 1 in reserve list, 1 may be refunded by ERDF) | 600% |
| Patents applied | 2 | 1 | 50% |
| Human Resources Strategy for Researchers prepared | 1 | 0.3 | 30% |
| Strategy for the Development of Quantum Optics and Photonics at the University of Latvia prepared | 1 | 0.7 | 70% |
| International conferences organised | 2 | 2 | 100% |

The core research team of the ERA Chair has been selected in an international competition and is formed by senior researcher Jānis Alnis (Latvia; whispering gallery mode resonator sensors), senior researcher Uldis Berzins (Latvia; atomic spectroscopy), visiting senior researcher Javed Iqbal (Canada, Pakistan; laser-induced breakdown spectroscopy, worked in the Project up to January 2022), researcher Vyacheslav Kim (United Arab Emirates, Uzbekistan; high-order harmonic generation; became a PhD student at the University of Latvia in 2021) and visiting senior researcher Naresh Kumar Reddy Andra (India; photonics). R. Ganeev leads this research group and supports the career development of its members. Additional members and students were recruited to support the core research team. They included PhD students L. Milgrave and K. Draguns, and Bachelor students K. Kalnins and A. Z. Bunkas.

Strong collaboration was established by the team of R. Ganeev and the Institute of Solid State Physics (ISSP), namely, researchers A. Bundulis, A. Sarakovskis, J. Butikova, and J. Grube, already in 2021. ISSP has advanced research equipment, e.g., femtosecond and picosecond lasers, that was used to investigate nonlinear optical effects. Laboratory of Nonlinear Optics (leader – R. Ganeev) was established at the University of Latvia, House of Science. Research equipment, including a picosecond laser, and consumables were purchased, and Lab started to operate in Sept 2022 generating new results that were published in journals. By 31.04.2023, the ERA Chair team published 56 publications in Q1 and Q2 journals that are indexed in SCOPUS. R. Ganeev published two books [5, 6].

During the Project, various new project proposals were prepared. By 31.03.2023, there were 16 pan-European and 19 local project proposals submitted. The majority of pan-European (Horizon Europe) projects were prepared by A. Ūbelis. Funding was received for the European Space Agency project No. 4000135730/21/NL/SC "Satellite and space debris photometry capability development for SLR station Riga" (63 kEUR, leader – K. Salmins, October 2021 – July 2022). Funding was received for the European Regional Development Fund project No 1.1.1.1/20/A070 "Next Generational Technology for High Purity Crystal Growth Using MHD Pseudo Levitation" (540 kEUR, industry partners – "AGL TECHNOLOGIES", Ltd., "CRYOGENIC AND VACUUM SYSTEMS", Ltd., leader – A. Ūbelis, 1 April 2021 – 30 November 2023).

The Project team submitted the project proposal for the Horizon Europe 'Teaming for Excellence' call. The project aims to create the Centre of Excellence FOTONIKA-LV at the University of Latvia for the development of photonics, quantum optics, and space photonics. Scientific leaders for three pillars are J. Alnis, R. Ganeev, and B. Foing. Teaming project is seen as the next step for the development of the University of Latvia NSP FOTONIKA-LV and will exploit the achievements of the current ERA Chair project (No 1.1.1.5/19/A/003). Project data: 15 million EUR from European Commission and 15 million EUR from local funds, 6 years, external partners – Lund University, Sweden, and University of Münster, Germany, internal partners – Daugavpils University and Rezekne Academy of Technologies. At first, the project was submitted to the call HORIZON-WIDERA-2022-ACCESS-01-two-stage. It passed Stage 1 competition (submission deadline 05 October 2021) and was included in the reserve list of Stage 2 proposals (submission deadline 8 September 2022). According to our knowledge, it can take up to about 1.5 years to receive the final decision on the funding for projects in a reserve list. Thus, it is expected that the final decision for the Horizon Europe Teaming proposal may be received by the end of 2023. In parallel, an updated Teaming Stage 1 proposal was prepared and submitted for the call HORIZON-WIDERA-2023-ACCESS-01 (call deadline: 12 April 2023). Evaluation results of the proposal are pending.

A project proposal was submitted to Horizon Europe call HORIZON-WIDERA-2022-TALENTS-01 (ERA Chairs) (call deadline: 15.03.2022). The project aims to develop the Space Photonics capacity at the University of Latvia with the help of pre-selected ERA Chair B. Foing and his team (selected in open competition). It was scored above the threshold and is expected that this project could be refunded by European Regional Development Fund when respective Regulations of the Cabinet of Ministers will be issued for the funding period of Structural Funds 2021–2027, similar to Regulations that allowed to refund of the current ERA Chair Project [4].

R. Ganeev as a principal scientist submitted a proposal No 101054219 "Laser ablation spectroscopy with high-order harmonics offers new potential in materials science" for an ERC Advanced Grant (3.5 million EUR, 5 years, submission deadline: 31 August 2021). The project did not receive funding. ERA Chair team member Naresh Kumar Reddy Andra submitted a proposal No 101124394 "Towards frontiers in developing optical fiber tips integrated with multifunctional metasurfaces and photonic structures for generating high-quality structured light fields" for an ERC Consolidator Grant (2.4 million EUR, 5 years, submission deadline: 2 February 2023). The result of this proposal is pending.

Collaboration was made with the industry. Several photonics companies (Baltic Scientific Instruments, Ltd., AGL Technologies, Ltd., Cryogenic and Vacuum Systems, Ltd., AFFOC Solutions, Ltd.), are in active contact with the project team by implementing several projects. Monitoring of the Latvian Photonics industry was made – data on turnover, profit and the number of employees were collected. The University of Latvia renewed its membership in the European Photonics Industry Consortium (EPIC). R. Ganeev submitted a Latvian patent application. Two other patent applications are in preparation.


***Figure 1.*** *President of the Republic of Latvia Egils Levits visits the University of Latvia National Science Platform FOTONIKA-LV (at Skunu 4, Riga) (a) A. Ūbelis gives presents; (b) ERA Chair R. Ganeev presents his monography to E. Levits*

During this project, several structural changes at the University of Latvia were made. Laboratory of Nonlinear Optics was founded (leader – ERA Chair R. Ganeev) and nonlinear optics was introduced at the University of Latvia. The Management Structure of the University of Latvia has changed – the Council of the University was introduced in 2022. In Spring 2023, active discussions started to reduce the number of University of Latvia faculties to about 4 or 5 and position all research institutes under these faculties. Physics could be positioned under the Faculty of Natural Sciences.

The project was made public, and the project web page was launched [1]. The Facebook page and Youtube channel of NSP FOTONIKA-LV were updated. The 4th International Conference "Quantum Optics and Photonics 2021", Riga, Latvia, 22–23 April 2021, and the 5$^{th}$ Anniversary International Conference "PHOTONICS RIGA 2023", Riga, Latvia, 20–21 April 2023 were organised. Regular photonics-related seminars/colloquia were organised. In total, 30 outgoing and 14 incoming travel visits were made that conducted international networking.

On 1 March 2023 the President of the Republic of Latvia Egils Levits visited the NSP FOTONIKA-LV (Fig. 1.). Progress of the projects implemented by NSP FOTONIKA-LV was reported, as well as future plans and challenges were discussed.

**References**

[1] The web page of ERDF project No. 1.1.1.5/19/A/003 "The Development of Quantum Optics and Photonics at the University of Latvia". https://www.erachair.lu.lv/

[2] Atvars, A. (2019). ERA Chair in Quantum Optics and Photonics. Project proposal to H2020-WIDESPREAD-2019-4 call. In: *Abstract book, The 3$^{rd}$ International Conference FOTONIKA-LV "Achievements and Future Prospects"*, Riga, Latvia, 24–25 April 2019, pp. 46–48. https://dspace.lu.lv/dspace/handle/7/56588

[3] Atvars, A., Ganeev, R., Bērziņa, D. (2021). The progress of the ERDF project "The Development of Quantum Optics and Photonics at the University of Latvia" (refinanced Horizon 2020 ERA Chairs project). In: *Abstract book, The 4$^{th}$ International Conference "Quantum Optics and Photonics 2021"*, Riga, Latvia, 22–23 April 2021, pp. 11–13, https://dspace.lu.lv/dspace/handle/7/56613

[4] MK Noteikumi Nr. 315, 6 June 2017, "Darbības programmas "Izaugsme un nodarbinātība" 1.1.1. specifiskā atbalsta mērķa "Palielināt Latvijas zinātnisko institūciju pētniecisko un inovatīvo kapacitāti un spēju piesaistīt ārējo finansējumu, ieguldot cilvēkresursos un infrastruktūrā" 1.1.1.5. pasākuma "Atbalsts starptautiskās sadarbības projektiem pētniecībā un inovācijās" pirmās, otrās un trešās projektu iesniegumu atlases kārtas īstenošanas noteikumi". https://likumi.lv/ta/id/291823-darbibas-programmas-izaugsme-un-nodarbinatiba-1-1-1-specifiska-atbalsta-merka-palielinat-latvijas-zinatnisko-instituciju

[5] Ganeev, R. A. (2022). *Nanostructured Nonlinear Optical Materials: Studies of Clusters, Quantum Dots and Nanoparticles*. 377 p., Cambridge Scholars Publishing.
[6] Ganeev, R. A. (2022). *High-Order Harmonics Generation in Plasmas: Resonance Processes, Quasi-Phase-Matching, and Nanostructures*. 270 p., Springer.

# Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications

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The project proposal (No 1.1.1.1/18/A/155)[1] has been developed in response to the European Regional Development Fund in Latvia measure 1.1.1.1. *Industry-Driven Research* of the specific objective 1.1.1. *To increase the research and innovation capacity of scientific institutions of Latvia and their ability to attract external funding by investing in human resources and infrastructure*. The project was ranked as the second best and has been implemented form 16 May 2019 to 15 May 2022 at a total cost of EUR 643 960.14, from which ERDF funding is 57.8%, state budget contribution is 34.7%, other public funding – 1.5%, private costs – 6%.

The project was implemented in collaboration of three organisations: University of Latvia (LU, lead organisation), Riga Technical University (RTU) and AFFOC Solutions, Ltd (AFFOCS). The involved personnel: LU – Jānis Alnis (project coordinator, Assoc. Professor, leading researcher), Aigars Atvars / Rita Veilande (leading researcher), Inga Brice (researcher), Arvīds Sedulis (laboratory assistant) and the project manager Dina Bērziņa; RTU – Jurģis Poriņš (Professor, leading researcher), Tamara Sharashidze (research assistant), Armands Ostrovskis (research assistant); AFFOCS – Ilya Lyashuks / Sandis Spolitis (leading researcher), Artūrs Ciniņš / Toms Salgals (researcher), Kristians Draguns (technical specialist). The budget allocation among the partners was distributed as follows: University of Latvia (40%), Riga Technical University (20%), AFFOC Solutions, Ltd. (40%).

Main activities (work packages) of the project were:

A1. Development, modelling, testing and optimisation of WCOMB,
A2. The development, construction, and testing of portable WCOMB for application in fibre optical communication systems,
A3. The adjustment and validation of the portable WCOMB prototype in commercial fibre optical communication system,
A4. Dissemination of the project results.

## Project results

All the expected project results and the project monitoring indicators have been achieved and some even exceeded. The novelty level of the obtained results can be estimated as high since a prototype of new WGMR-based OFC light source, capable to provide sustainable operation was constructed, and a new approach for data transmission in fibre optical telecommunication networks has been developed and successfully validated. The project developed new smart materials (WGM resonators), technologies and engineering systems (WCOMB system), contributed and after its completion continues contributing to the ICT sector (application of WCOMB in telecommunication solutions).

### The main results of the project

- ***7 scientific publications*** cited in SCOPUS (3 of them in journals with the citation index at least 50% of the average citation index in the sector) [1–7];

[1] https://www.lu.lv/en/wcomb/

- ***3 know-how descriptions*** (WGM resonator fabrication and testing; Computer modelling of WCOMBs; Technology and test results of WCOMB application into telecommunications);
- ***3 prototypes*** with descriptions (WGM microsphere resonator & WGM microrod resonator; Optimised advanced WCOMB system prototype; portable WCOMB prototype adjustment for field tests in commercial fibre optical communication system infrastructure);
- ***1 patent*** [8] related to the telecommunications sector, particularly the multi-wave light sources, which generate optical frequency combs (OFC) used for data transmission in fibre optical wavelength division multiplexed (WDM) telecommunications systems.

**Other significant achievements**

- ***Microsphere (400 GHz)*** and ***microrod (90-100 GHz) WGM resonator prototypes with excellent performance***. Research visit to Max Plank Institute of Light in Erlangen, Germany contributed to the further collaboration with P. Del'Haye research group, which allowed us to fabricate and test microrod and microdisc resonators.
- Multiple ***setups have been constructed for testing the resonators***. The experimental setup is based on tapered fibre coupling that was applicable for WCOMB generation. Research visit to Max Plank Institute of Light in Erlangen and the Swiss Federal Institute of Technology in Lausanne, Switzerland significantly contributed to the optimisation and advancement of the experimental setup.
- Successful ***field tests and validation of the experimentally developed portable WCOMB multi-wavelength laser source prototype*** in an existing fibre optical transmission line infrastructure.
- ***Modelling activities*** resulted in ***determining precise resonance frequencies, the best simulation parameters for creating a soliton regime***. For better understanding of the physical processes related to the light propagation in micro-resonators, a theory of the photon mathematical model has been developed.
- ***Achieved record 50 Gbps per λ transmission of NRZ-OOK modulated signals with a novel silica microsphere WGMR-based Kerr-OFC as a light source*** operating in the optical C-band, surpassing the previously demonstrated data rate record by five times. In terms of data transmission speed for silica microsphere WGMR-based Kerr-OFC light sources is a data transmission rate record of 50 Gbps per λ.
- During the project implementation 1 ***bachelor's thesis***, 2 ***master's theses***, 1 ***PhD thesis*** have been developed and defended. By the end of 2022 another PhD thesis has been defended.

## Future plans

The sustainability of the project results is ensured and further developed in farther projects, thus increasing the competitiveness of involved partners (scientific institutions – LU ASI, RTU TI, and enterprise – AFFOCS). Further research improvement of the prototype will allow to offer it for the production as a more mature technology; a potential innovation-oriented spin-off company may arise from this activity. Some directions for the future studies and applications:

- research staff from scientific institutions (LU ASI and RTU TI) have become a part of the Latvian Quantum Initiative[2] focused on thematic directions based on

[2] https://www.quantumlatvia.lu.lv/en

the perspective of the future development of Latvian quantum technologies and already existing applications in science and industry (quantum algorithms and software, quantum sensors and devices, quantum communication and communication security);

- studies on microresonator frequency combs and its applications are continued at the University of Latvia (e.g., the project *Development of Quantum Optics and Photonics at the University of Latvia*, PhD studies of the project participant Kristians Draguns, etc.);
- applications of WCOMBs into telecommunications is continued at the Riga Technical University Telecommunications Institute and newly established Communication Technologies Research Center (e.g., the project *Development of optical frequency combs for fiber optic communication systems*, PhD studies of the project participant Armands Osrovskis, etc.);
- the enterprise AFFOCS is gaining new market opportunities based on the experience and knowledge acquired on new portable WGMR-OFC generator construction, adjustment, testing, and validation;
- the patent application has been approved and a technology reducing the number of light sources needed in the transmitter part of the multi-channel WDM fibre optical telecommunication systems without reducing the number of channels used for data transmission and, by using multi-level pulse amplitude modulation (M-PAM) where multiple bits are encoded in one signal level, providing spectrally efficient data transmission between the transmitter side of the fibre optical telecommunication system and its optical network terminals (ONT) will soon enter the market;
- developed prototypes is a starting point for further collaboration and new project proposals: e.g., Laboratory of Organic Materials at Institute of Solid State Physics developing polymer photonics is a new collaboration partner for WCOMB development on polymer chips (project proposals for national funding have been already submitted);
- academic research partners (LU and RTU) are investing in the implementation of new study course modules and developing of new research directions on whispering gallery mode microresonators and optical frequency comb generators for master and PhD students in the field of atomic and quantum physics & telecommunications thus creating high-level specialists in Latvia among both students and specialists;
- experience and contacts obtained through the dissemination of the results at the scientific conferences and workshops have encouraged international mobility and resulted in project proposals with new partners and institutions worldwide: e.g., Center for Soft Nanoscience, Münster University; Quantum Science and Technology Laboratory, University of Trento (project proposals for Horizon Europe funding have been already submitted).

**Project evaluation by independent experts**

Overall evaluation of the level of achievement of the project aims and the planned results was appraised at 95% (Quality of the research – 90%, Economic and social impact of the research – 90%, Implementation quality and efficiency – 100%).

Regarding the scientific quality the experts highlighted: the project since the very beginning has clearly stated its objectives and goals and during its implementation it has followed a clear route to achieve the goals as stated – research activities have included both theoretical and experimental efforts that the research team has developed with a rigorous scientific method working also in collaboration with eminent foreign research institutes. The activities performed includes testing of commercial devices, as well as modelling, design fabrication and testing of novel prototypes of the microresonator. However, regarding the development of the prototype for portable WGMR COMB, even though it is quite compact, it's still far from being portable. The project has obtained clear and evident results whose scientific value is clearly assessed also by the number of scientific papers published after peer review; dissemination has been performed very well with a high number of publications (in highly ranked journals); outreach activities done witness a high commitment of the whole team.

As for economic and social impact, the project was assessed as addressing a problem of strong public need: the demand for high quality, reliable, and secure telecommunication, involving the transmission of spoken words, video signals and data. The project has positively contributed to the economic impact: the prototype realised has significant potential for a future development to a market level maturity. Regardless global epidemiologic situation distribution and dissemination of the project results has been performed in accordance (in some cases outperforming) with the initial plans – the project team has developed significant collaborations both within Latvia and abroad; future more intense collaborations are foreseeable. However, regarding the prototype and the new product to be patented, optical-frequency combs in monolithic WGM microresonators have already been demonstrated and the technology level is high, which may diminish the potential impact of the designed prototype, it could even hinder the outcome of the patent.

Implementation quality was the most highly rated: a wise and accurate planning, distribution and management of both financial and human resources has been done throughout the whole project. The inclusion of a small enterprise increases the impact of the results and ensures future development after the project completion. The personnel is quite balanced regarding gender equal opportunities. The Emergency Health situation was not helping in certain activities such as exchange of researchers or scientific dissemination, but from the midterm, there has been an increment of both, in a way that the team overreached the proposed research products.

## Acknowledgments

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### References

[1] [1] Braunfelds, J., *et al.* (2020). Frequency comb generation in WGM microsphere based generators for telecommunication applications. *Quantum Electronics* 50(11), 1043–1049.

[2] [2] Anashkina, E. A., *et al.* (2020). Microsphere-Based Optical Frequency Comb Generator for 200 GHz Spaced WDM Data Transmission System. *Photonics* 7(3), 72.

[3] [3] Salgals T. *et al.* (2021). Demonstration of a fiber optical communication system employing a silica microsphere-based OFC source. *Optics Express* 29(7), 10903–10913.

[4] [4] Spolitis, S., *et al.* (2021). IM/DD WDM-PON Communication System Based on Optical Frequency Comb Generated in Silica Whispering Gallery Mode Resonator. *IEEE Access* 9, 66335–66345.

[5] Brice, I., *et al.* (2021). Frequency comb generation in whispering gallery mode silica microsphere resonators. *Proc. SPIE,* 11672, Laser Resonators, Microresonators, and Beam Control XXIII, 1167213.

[6] Salgals, T., *et al.* (2022). Silica Microsphere WGMR-Based Kerr-OFC Light Source and Its Application for High-Speed IM/DD Short-Reach Optical Interconnects. *Applied Sciences* 12(9), 12094722.

[7] Bersons, I., *et al.* (2022). Reflection and refraction of photons. *Physica Scripta* 97, 035504.

[8] Republic of Latvia Patent No. 15717. Awarded on 20.04.2023 (https://databases.lrpv.gov.lv/patents/LVP2022000041).

# Proof of the concept pilot studies to build a laboratory prototype of next generation small size boron ion implantation device

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The plans of the project, financed by the EU Regional Development funding in Latvia, studies and proposes research towards miniaturisation of boron ion implanters utilising modern methods [1, 2]. Current commercial devices are large size, costly and not user friendly for the high-tech SME's community [3]. The approach is based on usage of the elementary Boron where the hollow cathode plasma is combined within RF inductively coupled plasma (RF-ICP) to produce Boron ions from pure metallic Boron. The progress of the project has been already reported in conferences, e.g. [4, 5].

The essence of the new approach is based on the following beyond the "state-of-the-art" innovations resulting from intensive studies of publications, technical reports and IPR assets:

1. The use of hybrid system hollow cathode & RF-ICP for generation of boron ions;
2. Incorporation of hybrid plasma producing technology in small-size silica glass & glass & metal & ceramics & metals in the process of assembling boron ion implantation device;
3. Performing ion beam filtration by small size high transmission QMS filter to increase selectivity, to simplify operation, and to decrease weight and costs. That is crucial technological novelty granting purity of Boron ion beam from various trace ions;
4. Relevant efforts were made to elaborate on installation technology, ion optics, beam control system, chamber geometry and tolerances required to utilise the QMS filter.

**Building boron ion accelerator**

We have designed an ion beam optics based on the previous "know-how" and preliminary mathematical calculations. Parameters of each block of the ion beam track were then tested. We used the simplest DC-type LINAC modelling. Several versions and sets of parameters were calculated with formulas using a scientific calculator. Electronics circuitry computer models were then made using LT-Spice, and PCB models were made using Free-CAD.

Mechanically accelerated electrodes are a series of thin short pipes made from aisi-316 material, with an enormous accurately laser to cut the ends with an accuracy of ca 10 microns, positioned between thin plates with centre-cut large holes, two plates before the ends of the pipe for cantering, with and an additional two with smaller ends at the ends of the pipe for positioning. A gap between the ends of short pipes causes acceleration as well as voltage difference and pipe length and are thus critical. The plates positioning the short pipes are fixed on four thin insulator rods using many spring-washers. Silica glass rods are used for mounting in place and used to keep the stainless-steel electrodes in the quartz-glass pipe. Each electrode must have a different voltage.

After alternatives were analysed, the best high voltage circuitry was found by defocusing and ion-beam scanning between the accelerator and implantable sample chamber. Scanning electrodes are placed after the accelerator instead of before. This results in the scanning system needing a relatively high voltage (2 kV). This means that high beam energies conditions are bound by rather narrow declining angle values that may demand longer pipe between the accelerator and implantation chamber. It is calculated that it ought not be a shortcoming as the length is quite acceptable, but the most probable exploitation regime is about 10 keV, not 100 keV where the problem is not manifesting at all.

### Design of mechanical systems

Mechanical parts of the implanter's laboratory prototype were mounted on fashionable alumina T-slot rails with a relevant system ensuring Ar gas supply for plasma functioning and relevant sectional vacuum pumping to ensure the highest vacuum alongside the boron ion beam track till target crystal.

### Design and tests of electronic systems

All electronic circuits were designed by computer-modelling (LT-Spice, FreeCad, Lisa, LT-Spice, KiCAD etc.). Main efforts in electronic circuits design, fabrication and installation is comprised of the following tasks:

a) work on documentation and creating of PCB of QMS power oscillator, its booster cascade and ion-beam declining (scanning) system;
b) production of the first series of power sources in SMPS circuitry with computer adjustment capability; a universal PCB is assembled, tested, and installed in places in an overall electrical circuit with minor changes of output coil turns count and voltage loop dividing factor;
c) The tests of all components, blocks and systems were performed several times optimising the functionality.

### Conclusions

1. The project succeeded with the design of proof of concept at TLR level up to 4, thus showing the necessity for the investments to proceed to the level of TLR 6 and further feasibility studies and market research concerning eventual commercialisation.
2. Performed work indicates that the project outcome of an industrially tested prototype of small size with user friendly boron implantation sources at the level about TLR 6 is a "disruptive innovation" – able to create a new market of boron implantation devices substituting currently present large and hardly operational devices.
3. The project contributed to knowledge base on the basic characteristics and spectroscopy of elemental boron resulting in studies of atomic and ionised boron in plasma created by hybrid systems of the hollow cathode and RF-ICP plasma.
4. The project contributed to the knowledge base in applied physics and related electronics technologies on manipulation of boron ion beams.

### Acknowledgements

ERDF project No 1.1.1.1/19/A/144 "Technologic research for elaborating the next generation boron ion implementation apparatus with TRL level near to 4".

#### References

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

[2] Blahins, J., Ubelis, A. (2021). Towards Next Generation of Boron Ion Implantation Devices. *Modern Approaches on Material Science* 4(4), 548–550. https://doi.org/10.32474/MAMS.2021.04.000192.

[3] Current, M. I., Rubin, L., Sinclair, F. (2018). Chapter 3: Commercial Ion Implantation Systems. In: *Ion Implantation Science and Technology*. Publisher: Ion Implant Technology Co, 44 p.
[4] Blahins, J., *et al.* (2021). Technological challenges for next generation boron ion implantation device. In the Conference Book: *Quantum Optics and Photonics 2021: Book of Abstracts*: The 4th International Conference, Riga, 22–23 April 2021. Publisher: University of Latvia. https://doi.org/10.22364/qoph.ul.2021.
[5] Blahins, J., Ūbelis, A. (2021). Small size Boron ion implanter concept, p.77. In the Conference Book: Quantum Optics and Photonics 2021: Book of Abstracts: The 4th International Conference, Riga, 22–23 April 2021. Publisher: University of Latvia. https://doi.org/10.22364/qoph.ul.2021.

# Development of next generation technology for ultra purity crystal growth based on MHD semi levitation

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The project proposal (No 1.1.1.1/20/A/070) has been developed in response to the European Regional Development Fund's (ERDF) measure in Latvia 1.1.1.1 "Support for applied research" specific objective 1.1.1 "Improve research and innovation capacity and the ability of Latvian research institutions to attract external funding, by investing in human capital and infrastructure. The project was accepted and is being implemented since April 2021 [1]. The project duration is 32 months: 01.04.2021–30.11.2023. The project's total costs are EUR 540 500, from which the ERDF share is 82.3% of the total budget, state budget contribution is 17.7%.

The studies are aimed at design and construction of unique more efficient equipment for growing crystals (germanium in particular) of high purity. Future needs require a purity of one foreign atom per 1013 germanium atoms in a Ge crystal. The papers on unique computer-modelling and experimental results on aluminium MHD levitation co-authored by Latvian and German scientists and published in 2015 unlock potential for the technological innovation and progress in growing crystals [2]. During the project, high precision measurements were performed for the force, heating and magnetic field acting on a conductive sample placed within an Electromagnetic Levitation (EML) coil and an effect of displacement between levitation and heating regions was observed. Measurement results were compared to some theoretical modelling studies [3] and certain inconsistencies in levitation zone location were observed between theory and practice.

A unique laboratory device, custom made prototype, designed and constructed during the project implementation, combines multiple zonal purification, Czochralski (cz) and floating zone techniques for growing high-purity crystals avoiding contact with parts of the construction in the zone of crystal growth from a large, melted zone by application of magneto-hydrodynamic levitation. Compared with the equipment used in general practice advantages of the novel device consists of three interrelated substantial improvements providing raw material of the highest purity (zonal purification in the equipment used to grow the crystal), absence of contact between the melted zone and casing, computer control of the process ensuring reproduction and precision of the management.

Main activities (work packages) of the project are:

- A1. Model experiments of hydrodynamic stability of melt zones for the MHD pseudo-levitation process.
- A2. Experimental work searching for optimal interrelationships between MHD inductor frequency, temperature profiles and molten zone geometry.
- A3. Creation of a low-temperature (Sn ~300 °C) device to conceptually test pseudo-levitation for the case of easily melting tin, to test the concept and find the best constructive and geometrical solutions for the device.
- A4. Creation of high-temperature (Ge ~1000 °C) equipment based on the experience of working with (Sn ~300 °C) equipment. Adaptation or transformation of individual blocks and development of new blocks. Creation of a high-vacuum system.
- A5. Evaluating the possibilities of MHD pseudo-levitation, high-purity germanium crystal growth experiments in a vacuum, or in a high-purity gas environment in a quartz-metal structure.

All activities are implemented in collaboration among all 3 partners of the project: University of Latvia (lead partner, project manager – Valdis Avotiņš), Cryogenic and Vacuum Systems, Ltd. and AGL Technologies, Ltd.

The budget is distributed among the partners as follows: University of Latvia (64.75%), Cryogenic and Vacuum Systems, Ltd. (25.25%), AGL Technologies, Ltd. (10%).

**Main results planned in the project**

- 6 scientific publications cited in SCOPUS: 2 of them will be in journals with citation rate above 50% of the average,
- 2 prototypes,
- 1 technology right – patent application,
- number of enterprises cooperating with the research organisation – 2.

**References**

[1] Description and quarterly reports of the project from the website of University of Latvia. https://www.lu.lv/en/zinatne/programmas-un-projekti/es-strukturfondi/eraf-projekti/1111-praktiskas-ievirzes-petijumi-4-karta/nakamas-paaudzes-tehnologijas-izstrade-augstas-tiribas-kristalu-audzesana-izmantojot-mhd-pseido-levitaciju/

[2] Spitans, S., Baake, E., Jakovics, A. (2015). New technology for electromagnetic levitation melting of metals. *Applied mechanics and materials* 698, 237–244

[3] Nycz, B., Malinski, L., Przylucki, R. (2021). Influence of Selected Model Parameters on the Electromagnetic Levitation Melting Efficiency. *Applied Sciences* 11, 3827.

# Current status of the NSP FOTONIKA-LV infrastructure project 'QUANTUM & SPACE'

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About 1.5 MEUR renovation project (2023–2024) QUANTUM & SPACE is on the agenda now, and seeks to relocate the headquarters' building (Šķūņu street 4, Riga) to the National Science Platform (NSP) FOTONIKA-LV at the University of Latvia, and two observatories (Astrophysical Observatory in Baldone and the observatory in the Botanic Garden of the University of Latvia where the satellite laser ranging station of International Laser Ranging Service with code RIGL 1884 [1] is located) of NSP FOTONIKA-LV into energetically autonomous, via the application of hybrid, green energy system based utilising heat pumps, photovoltaics and small wind turbines. The NSP FOTONIKA-LV will be the first energy independent research institution in the Baltic States and among the firsts ones across EU to demonstrate loyalty to the, already historically affirmed [2] EU Green Deal on climate neutrality [3].

The architect of the new headquarters at Šķūņu street 4 (a fashionable, 5 story 1000 $m^2$ building with an underground area and a courtyard, located on a vivid street of Old Riga) is the famous architect of many *Art Noveau* buildings in Riga Paul Mandelstam [4]. Large windows with non-reflecting glass produced by an innovative Latvian photonics SME (GroGlass, Ltd.[1]) are suitable for outreach campaigning. The building on Šķūņu street 4 was built in 1912 as the first building in Riga using steel and concreate (which were advanced technologies for that time) and large areas on each floor intended to be used for exhibitions or shops. Only the portal of the building holds elements of *Art Noveau*.

The renovation project QUANTUM & SPACE proposes to transform the headquarters main building and the premises of the two observatories into an attractive and suitable space for research and innovation in quantum sciences, space sciences, space photonics and photonics technologies. The project includes a clean room, glass/quartz/vacuum technology laboratory and well-equipped workshop for optics and fine mechanics.

**References**

[1] https://ilrs.gsfc.nasa.gov/network/stations/active/RIGL_station_info.html
[2] Filho, W. L., Ubelis, A., Berzina, D. (eds.) (2015). Sustainable Development, Knowledge Society and Smart Future Manufacturing Technologies. *Springer World Sustainability Series*. https://doi.org/10.1007/978-3-319-14883-0_5.
[3] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[4] https://replay.lsm.lv/lv/ieraksts/ltv/277231/ielas-garuma-arhitektam-paulam-mandelstamam-150

[1] https://www.groglass.com

# Lifetime measurement of Ba II metastable states: preliminary results

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## Introduction

Most excited levels in neutral and near-neutral atoms and ions have radiative lifetimes in the nanosecond range. However, some low-excitation levels are prevented to decay through normal electric-dipole radiation and instead decay through higher multipole radiation such as E2 and M1. These radiations have 6–8 order of magnitude lower transition rates, resulting in lifetimes in the range of 1–100 s. The light from the metastable levels, so-called forbidden lines, is dominating the spectra from low-density astrophysical plasmas appearing in e. g., gaseous nebulae, planetary nebulae, protostars, stellar chromospheres but also in the outflows from supernovae. These forbidden lines are the key diagnostic tools for astrophysical low-density regions. To be able to use the forbidden lines for important diagnostics of the physical conditions, such as temperature, density, chemical abundance, the lifetime of the metastable level and the transition rates of the forbidden lines must be known. We are therefore developing a laser induced fluorescence technique probing stored ions at DESIREE. One of the most favourable ions to develop the technique of laser probing of a stored ion beam is Ba+. The atomic structure is simple with few levels and the metastable energy levels are located at low excitation energies. This allows for a high population and increased fluorescence signal, making Ba+ an ideal target ion.

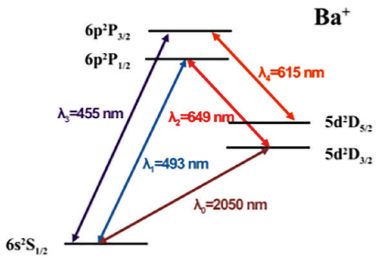


***Figure 1.*** *Level diagram of Ba+ showing the metastable 5d ²D states targeted in the present project. The 6p states are excited by the laser tuned to the 586 and 614 nm, respectively, and the fluorescence detected at 456 nm*

## Experiment

The laser probing technique (LPT) described in the current proposal was derived by Mannervik and his group at the CRYING storage ring [1], and successfully applied to a number of ions of varying complexity [e. g., 2 and references therein]. For several complex ions, the measured lifetimes were combined with astrophysical line ratios to derive experimental transition rates. The LPT utilises a cw laser to probe the number of atoms in the metastable states as a function of time. An ion beam of the element studied is stored, and a fraction of the ions are in metastable states (5d for $Ba^+$).

Monitoring must be made to the collisional processes with the rest gas, the varying ion current between injections and intra-beam losses. The significant repopulation from collisions with the rest gas observed in CRYRING is however not observed in the DESIREE due to the excellent vacuum conditions. The improved conditions to previous and other storage rings require a modified technique, and other corrections, which allows for a more accurate measurement.

One important parameter for an accurate lifetime determination is the ion current which measures the total number of ions. A Schottky spectrum and the measured beam dump current at the end of each cycle are used to monitor the ion beam currents during such measurements. The expected lifetimes for the 5d $^2D_{3/2}$ and $^2D_{5/2}$ states 80 and 32 seconds, respectively.

Thanks to the excellent ion storage conditions in DESIREE these extremely long lifetimes can still be measured with low uncertainty.

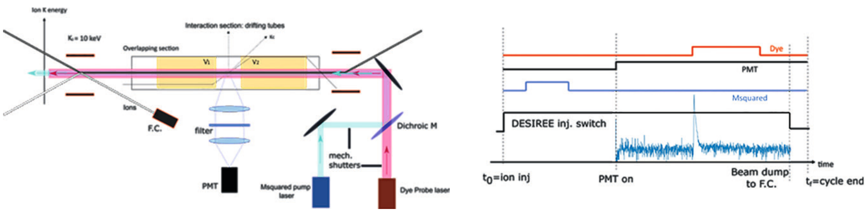


***Figure 2.*** *(left) Experimental setup showing the ion beam, the lasers and the detector. (right) Schematic scheme of the timing of the lasers (blue and red), ion beam injection (black) and photomultiplier detector. The detected signal is shown at the bottom*

## Preliminary Results

In August 2022 on our first beam time the $Ba^+$ ions were stored in the DESIREE ring, and the decay curve of $^2D_{3/2}$ metastable state was successfully recorded through the laser induced fluorescence signal. The lifetime could be determined with a statistical uncertainty of 2% (Fig. 3, left) but systematic effects need to be investigated. The ion beam current is shown in Fig. 3, right. In future experiments we will reduce the ion current to avoid the initial ion-ion collisions contributing to the initial non-exponential decay observed during the first 100 seconds.

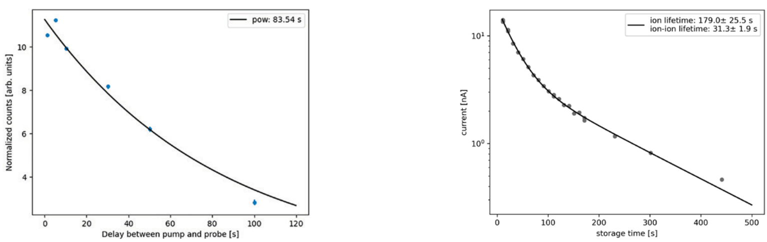


***Figure 3.*** *(left) Lifetime curve as measured in previous experiment (right) Ion beam current showing the initial ion-ion collisions reducing the beam current*

## Future work

We will improve the experimental data during next experimental run which take place in the first week of May 2023. In this run we:

- Measure ion current decay curve for up to 5 minutes.
- Adjust ion current down to level where we can neglect ion-ion collisions.
- Measure fluorescence intensity as function of delay time, with careful measurement of ion current before and after fluorescence measurement at each point.
- Measure ion current decay curve after population of metastable state in order to compare quenching for the metastable state and ground state ions.

## Acknowledgments

This research was supported by ERDF project No 1.1.1.5/19/A/003 “The Development of Quantum Optics and Photonics at the University of Latvia”, and ERDF project No 1.1.1.1/19/A/144 “Technologic research for elaborating the next generation boron ion implantation apparatus with TRL level near to 4” and COST Action CA18212 – Molecular Dynamics in the GAS phase (MD-GAS), supported by COST (European Cooperation in Science and Technology), and the Swedish research council under contract 2020-03505 and 2016-04185.

### References

[1] Mannervik, S, (2002). Studies of Metastable Levels in Singly Charged Ions by Laser Techniques in an Ion Storage Ring. *Physica Scripta* T100, 81–87.

[2] Hartman, H., *et al.* (2008). The FERRUM project: experimental and theoretical transition rates of forbidden [Sc II] lines and radiative lifetimes of metastable Sc II levels. *Astronomy and Astrophysics* 480(2), 575–580.

# Computation and vibrational analysis of lower excited states of $Te_2$ dimer

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Potential energy curves of different electronic states of the $Te_2$ are computed by means of the highly accurate method complete active space self-consistent-field (CASSCF) followed by multireference configuration interaction (MRCI) calculations. An enlarged active space was used by including the 5d orbitals. Extensive use of symmetry is used in order to differentiate the diverse electronic states formed according to rules of Wigner and Witmer. The vibrational analysis of the transitions is planned as part of the study.

# RF ICP plasma atomic spectra source of Ar, Xe and Kr for wavelength calibration of lasers in visible – near IR spectral range ensuring accuracy up to 0.001 nm

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Inductively coupled RF plasma (ICP-RF) (Basic principles and the main design features were comprehensively reviewed by M. I. Boulos in 1985 [1]) is known as the exclusive and ideal source of intensive atomic resonance spectra of various elements [2]. Researchers at the University of Latvia are using ICP-RF since 1970, and have collected valuable experience and IPR assets in designing (see patents [3–4]), manufacturing and application of ICP-RF based resonance atomic spectra sources (Na, Rb, Cs, Zn, Cd, Hg, Sn, Pb, Sb, Bi, S, Se, and Te) for analytical spectroscopy and research on basic properties of atoms, e.g. [5] and their atomic spectra [6]. Iodine resonance line spectra source was used in ozone layer photochemistry research using flash photolysis methods [7–8]. Tellurium is an atom whose atomic properties were persistently studied by our team using RF-ICP plasma source [9–10]. To the best of our knowledge no one has succeeded in using such a comprehensive approach for other elements, but there is still a need at present. Results were found useful in Astrophysics research by a research team led by Massachusetts Institute of Technology (USA) in processing the data recorded by the Hubble Space Telescope [11]. The progress in positioning of telescopes on satellite platforms (like James Webb telescope) [12] revitalised astrophysicists' interest for the research data on basic properties of atoms. There are several articles describing research in response to astrophysics' needs [13–15], including recently published studies of Arsenic resonance spectra [16].

ICP-RF atomic spectra sources emit rich spectral lines and listed are the spectra of atoms for the above elements with wavelengths shorter than 500 nm. Besides their uses in scientific research, such sources are also useful for wavelength calibration of other light sources, e.g., various types of lasers. The specific wavelengths of atomics spectra lines are well known and may be measured with accuracy up to 0.001 nm [17]. But frequently there is also a need to calibrate for an atomic spectra source with wavelengths longer than 500 nm.

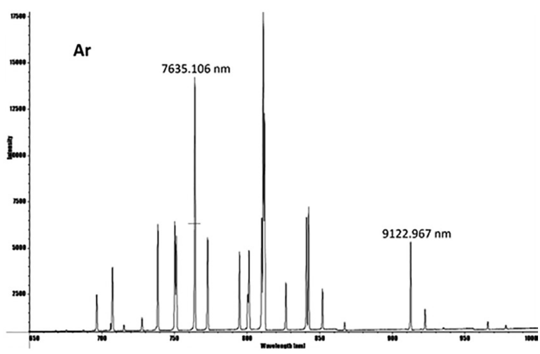


***Figure 1.*** *Spectrum of Argon source excited using RF ICP*

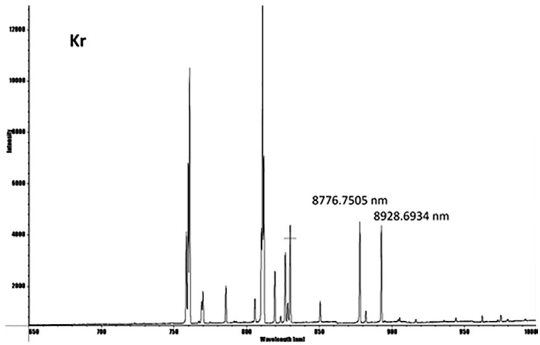


***Figure 2.*** *Spectrum of Krypton source excited using RF ICP*

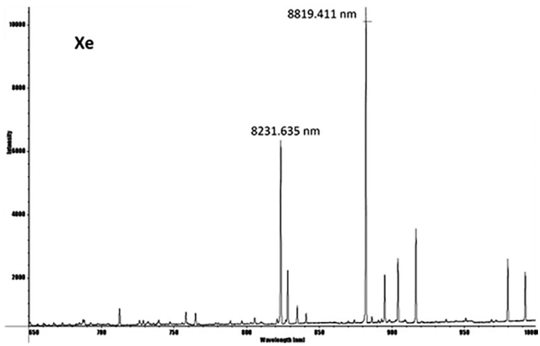


***Figure 3.*** *Spectrum of Xenon source excited using RF ICP*

We are in the process of producing similar ICP-RF sources based on atomic spectra of noble gases Ar, Kr, Xe which have a rich line spectrum [17], where several lines are measured with accuracy up to 0.00001. Our innovation – the manufacturing of combined ICP-RF atomic spectra sources emitting atomic spectra of all three gases. In order to have more or less equal intensities of stronger lines of Ar, Kr, Xe, we must find the optimal proportions and concentrations of the mixture of gases in the source bulb.

**References**

[1] Boulos, M. I. (1985). The inductively coupled R. F. *(radio frequency)* plasma. *Pure & Appl. Chem.* 57(9), 1321–1352

[2] Kazantsev, S. A., *et al.* (2013). Practical Spectroscopy of High-Frequency Discharges. Plenum Press, New York and London.

[3] Khuzmieva B. B., *et al.* (1991). SU patent SU1642537A12: Gaseous-Discharge Electrodeless Lamp. Date: 04/15/1991.

[4] Putninya, S., Skudra, A. J., Ubelis, A. P. (1988). Gaseous discharge source of resonance emission. Soviet patent certificate. CCCP No 1551162. 3 May 1988.

[5] Spietz, P., *et al.* (2001). Estimation of the Emission Temperature of an Electrodeless Discharge Lamp and Determination of the Oscillator Strength for the I($^2P_{3/2}$) 183.038 nm Resonance Transition Spectrochimica Acta Part B 56 2456-2478.

[6] Ubelis, A., *et al.* (1981). The Spectra of High Frequency Electrodeless Lamps in the Vacuum UV Region. *Zhrn. Prikl. Spectr.* 35(2), 216–219 (in Russian).

[7] Spietz P., *et al.* (1998). Study of iodine oxides and iodine chemistry using flash photolysis and time resolved absorption spectroscopy (abstract). *Ann. Geophys.* Supp. II, 16, C p 722. 8.

[8] Gross, U. (2002). The Flash Photolysis Method in the Iodine-Ozon the Iodine Photochemical Research. PhD Thesis.

[9] Ubelis, A., Berzinsh, U. (1991). 5s 5p 6s-5s 5p Transition Probabilities of Te I. *Physica Scripta* 43(2), 162–165.

[10] Ubelis, A., Berzinsh, U. (2006, December). Transition Probability Measurements of Te I Spectral Lines by Methods of Emission and Absorption of Radiation. *Physica Scripta* 28(2), 171. https://doi.org/10.1088/0031-8949/28/2/005.

[11] Roederer, I. U., *et al.* (2012). Detection of the second r-process peak element tellurium in metal-poor stars. *The Astrophysical Journal Letters* 747(1).

[12] https://www.jwst.nasa.gov/resources/JWST_SSR_JPG.pdf; https://webb.nasa.gov

[13] Bengtsson, G. J., *et al.* (1992). Determination of Radiative Lifetimes in Neutral Arsenic Using Time Resolved Laser Spectroscopy in the VUV Region. *Astron. & Astrophýs.* 263, 440–442.

[14] Berzinsh, U., Svanberg, S., Biemont, E. (1997). Radiative Lifetimes for the 4p Excited States of Phosphorous and the Osciliator Strengths of Solar Lines. *Astron. & Astrphys* 326, 412–416.

[15] Li, Z.S., *et al.* (2001). The FERRUM project: radiative lifetimes of the 3d5(6S)4s4p(3P)y6Po states of Fe II measured with time-resolved VUV laser spectroscopy. *J. Phys. B: At. Mol. Opt. Phys.* 34. The FERRUM project aimed to produce reliable oscillator strengths for singly ionized iron group elements of astrophysical interest.

[16] Berzins, U., Ubelis, A., Bziskjans, A. (2021). Branching Fraction Measurements of Arsenic $4p^25s$-$4p^3$ transitions. *Journal of Quantum Spectroscopy and Radiative Transfer* V 276, 107943.

[17] https://www.nist.gov/pml/atomic-spectra-database.

# Lightfield imaging of wide viewing angle for 3D displays and adaptive camouflage using GSL array

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Slicker3D, Ltd. multinational team presents a breakthrough game-changing technology of 3D imaging using advanced light-control films comprising Gabor Superlens microarrays.

The prototypes (TLR ≥ 6) of the optical film and the working 3D SMV display have been tested. European Commission has awarded its Seal of Excellence to SLICKER3D team for Horizon 2020 phase 2 proposal "game-Changing 3D". In the past 2 years of extensive research we sufficiently upgraded our technology, discovering fundamentally new ways to extend the FOV of the system at least twice in comparison to the closest analogues and potentially up to 130°.

The new principle of Slicker3D Lightfield Imaging is secured by patent: US9778471B2, published 2017-10-03.

## Compact 3D display device of extended field of view

Our technology allows a step-forward 3D displays with a FOV of ~130 degree (Fig. 2.), using a combination of GSL film and collimated directive backlights. The new technology is useful for civilian 3D digital signage as well as military applications.

The proposed adaptive camouflage design (Fig. 1.), inspired by the principle of counter-illumination, adapted for camouflage by some marine animals, uses an optical film with a set of Gabor superlenses instead of conventional optics. The superlens was also based on the natural structure of insect eyes. It has a larger field of view than conventional optics and allows to improve the ratio between the viewing angle of the 3D image and the depth of field. In addition, it makes the camouflage surface thin, flat, light, and fully compatible with nano-coatings for camouflaging targets in the microwave and infrared ranges.

***Figure 1.*** *Adaptive camouflage implementation of Slicker3D technology*

## Optical design, simulations and performance

We have had developed several samples of GSL micro structured film and 2 prototypes of 3D display of TRL ~6.

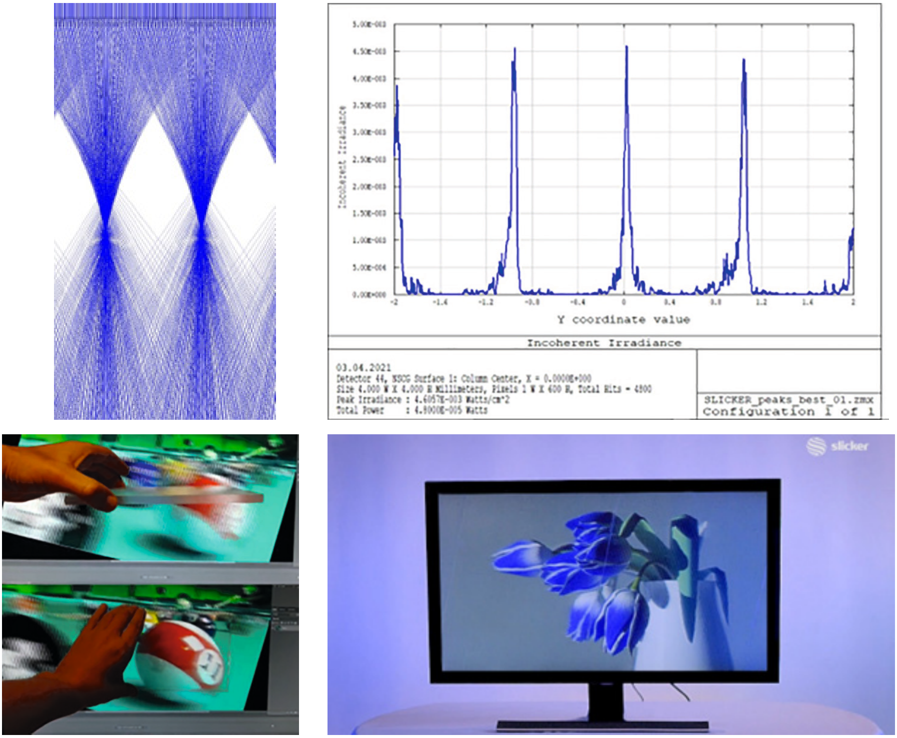


***Figure 2.*** *Optical properties of modelled GSL film (ZEMAX) and the actual 3D image performance*

## Further research and update of the technology

The system shown above has a standard field of view of about 27–30 degrees and extended pixel sampling, eliminating the VAC issue for viewers, making it useful for 3D digital signage solutions. Having achieved these results, we continued our research, discovering a fundamentally new way for further expanding the field of view, to 60–130 degrees, by placing the image source at ½ the focal length of the superlens array. With collimated illumination, one can double the field of view of the system, up to 60 degrees, without spatiotemporal multiplexing of the 3D image, and another 3–5 times using multiplexing plus directional backlight. The basic scheme of the Slicker3D ultra wide-angle display with a viewing angle of 130 degrees is shown in Fig. 3. Compact collimated backlight can be easily achieved with diodes and Fresnel lens arrays, and more advanced with highly collimated micro-LEDs. The proposed method will make 3D displays extremely flat, simple, economical, and free from the problems associated with diffractive optics. The solution can be useful in a wide range of civil, scientific and military 3D devices such as specialised displays and simulators, as well as in adaptive camouflage systems.

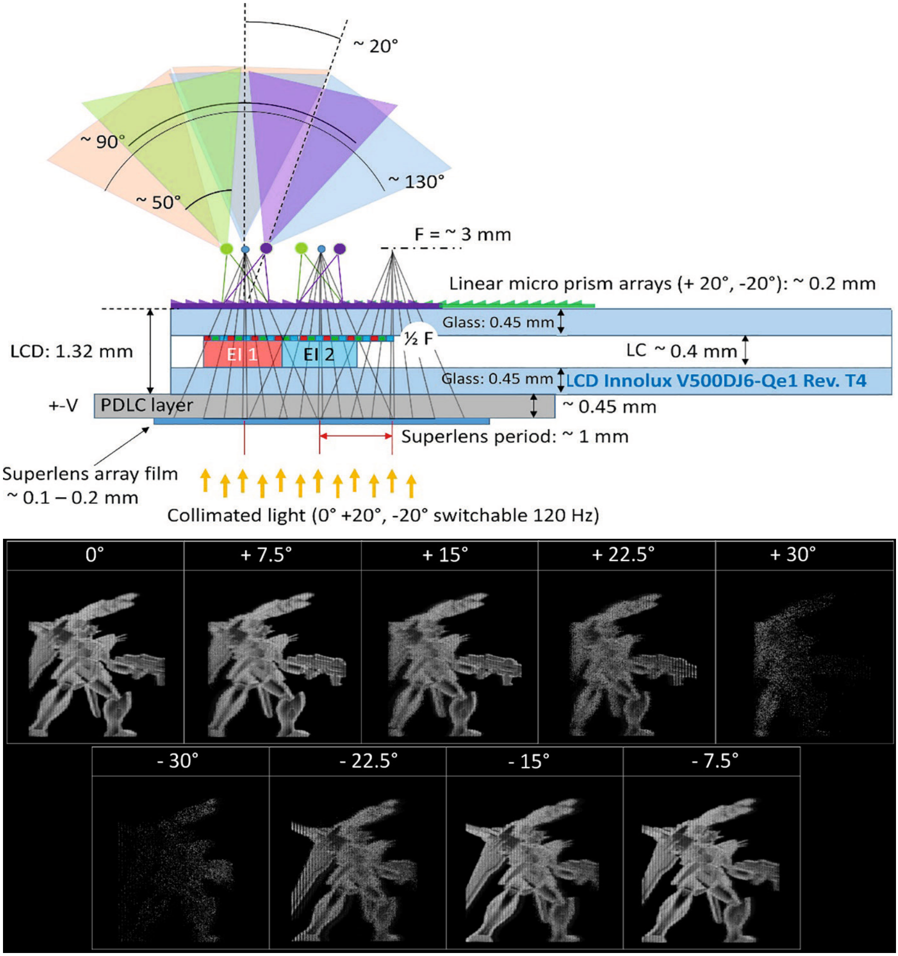


***Figure 3.*** *Super-wide angle Slicker 3D display concept and image simulation of central 3D zone (ZEMAX)*

## References

[1] https://www.slicker3D.com
[2] https://patents.google.com/patent/US9778471B2/en

# Low order harmonic generation in laser induced borosilicate glass plasma and CdTe quantum dots

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An investigation of the size dependent influence of CdTe quantum dots [1, 2, 3] on the generation of low order harmonics up to the fifth order in laser induced plasma (LIP) of borosilicate glass for a fundamental wavelength of l = 1030 nm and a pulse duration of $t$ = 40 fs at a repetition rate of 55 kHz is presented. The aqueous soluble CdTe quantum dots are generated by seed-mediated growth approach with different reaction times. The resulting quantum dots with sizes between 2–4 nm are below the Bohr radius and thus quantum confinement is valid. The CdTe nano particles are spin coated with different thicknesses on the surface of the glass target. The coated thickness is measured by ellipsometry and the topography by atomic force microscopy.

Laser intensities above ionisation threshold (I > 10^14 W/cm^2) are used to generate the plasma by laser induced optical breakdown. Electrons are accelerated in the electric field emitting harmonics after subsequent recombination. The resulting third harmonic is characterised by blue shifts originating from Raman-Anti-Stokes and phonon lines of the borosilicate glass targets giving rise to the emission of non-integer harmonics. Applying spin coated CdTe quantum dots on the targets surface spectral shaping with different sizes and different coating thicknesses is observed. Peak amplification factors between 10 and 17 for small and large particles respectively are reached for the third harmonic while no size dependency of the power density is observed. The influence of Raman lines decreases with increasing size. The fifth harmonic is unaffected by Raman and phonon lines and no spectral shaping is observed as for the third. Amplification factors between 25 and 20 for small and large particle sizes respectively are achieved.

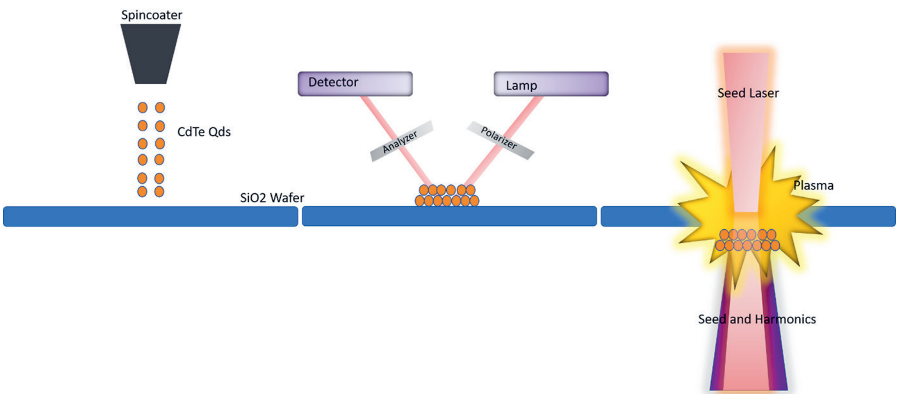


***Figure 1.*** *Schematic depiction of the experimental setup. First, the QDs will be coated by means of a spin coater onto the wafer. Second, the resulting thickness will be measured with an ellipsometer and finally, the harmonics of borosilicate glass are generated in transmission geometry*

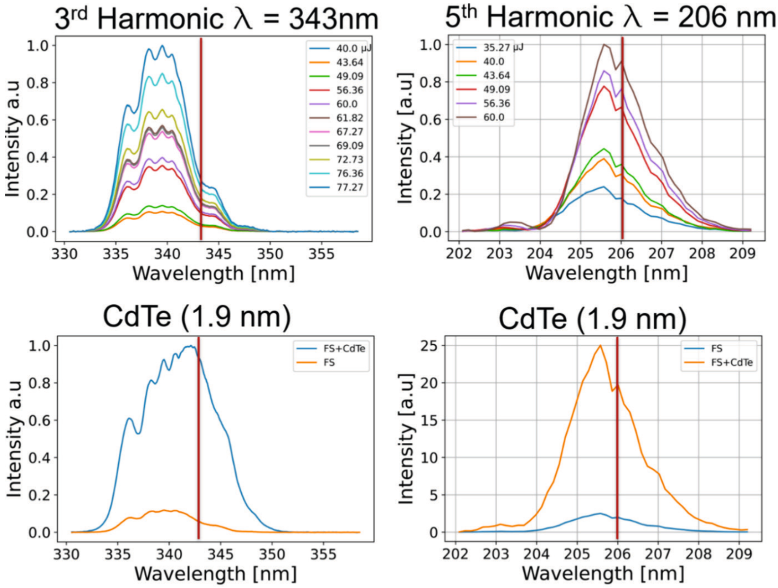


***Figure 2.*** *Spectrum of 3rd and 5th harmonic of Borosilicate glass plasma and CdTe Quantum dot with a size of 1.9nm and a band gap of 2.54 eV*

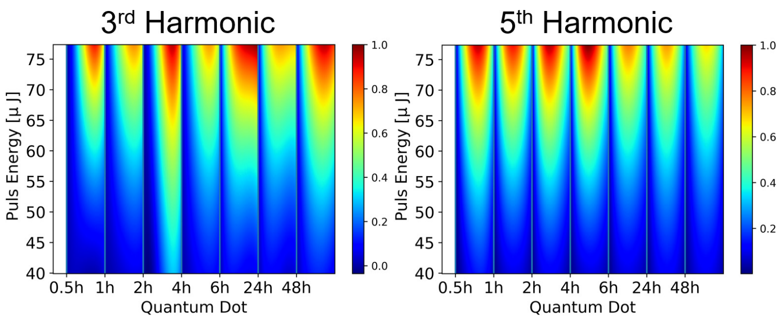


***Figure 3.*** *Recalculated thickness and power dependent yield of 3rd and 5th harmonic of Borosilicate glass plasma and CdTe for all sizes. Reaction times correspond to the quantum dots size by 1.94, 2.01, 2.08, 2.16, 2.30, 2.94, 4.04 nm respectively. Thicknesses are estimated to be 100 nm (3rd) and 60 nm (5th)*

## References


[1] Silva, F. O., *et al*. (2012). Effect of surface ligands on the optical properties of aqueous soluble CdTe quantum, dots. *Nanoscale Research Letters* 7(532).

[2] Xu, Y., *et al.* (2016). Seed-mediated growth approach for rapid synthesis of high performance red-emitting CdTe quantum dots in aqueous phase and their application in detection of highly reactive oxygen species. *Chemical Engineering Journa,* 299, 201–208

[3] Ravaro, L. P., *et al.* (2020). Optical oxygen sensing by MPA-capped CdTe quantum dots immobilized in mesoporous silica. *Microporous Mesoporous Mater* 303(110237).

# Modulation of quantum beats signal upon photoionisation of Xe isotopes in the magnetic field

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In our recent works, we considered the processes of photoionisation of polarised Xe atoms in external magnetic field by femtosecond pulses. It was found that the observed modulation photoelectronic quantum beat signal for Xe cannot be explained by the Paschen-Back effect for fine structure levels. In the present work, the same quantum beats were obtained by registering Xe+ ions. Comparison of the signals of various Xe+ isotopes in the mass spectrum showed that the modulation of quantum beats is due to the hyperfine structure of the Zeeman components of the $^{129}$Xe and $^{131}$Xe isotopes.

**References**

[1] Viktorov, E. A., *et al.* (2021). Observation of Quantum Beats of Two-Photon-Excited States of Xe upon Photoionization. *Opt. Spectrosc.* 129, 1311–1313.

[2] Viktorov, E. A., *et al.* (2021). Photoionization of polarized doublet states of Xenon atom. *J. Phys.: Conf. Ser.* 2086 012174.

# Fabrication of patterned ZnO nanorod arrays

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Zinc oxide (ZnO) is a well-known wide band gap semiconductor material with unique optical, electrical, and piezoelectric properties that makes it widely used in optoelectronics, electronics, and photonics. Nanostructured ZnO films are also extensively used in the development of sensors, proving to be a very effective material in the production of gas sensors, biosensors, and chemical sensors due to their high sensitivity, selectivity, and stability in harsh environments. Surface nanostructuring can substantially enhance sensitivity by expanding the active surface area. However, for certain applications, it may be necessary to achieve selectivity in the coating process to ensure that nanostructures only form in specific areas while leaving interelectrode spaces free of nanostructures. This research examines several methods for creating intricate ZnO nanostructured patterns, including area selective application of Zn acetate seeds followed by hydrothermal growth, selective thermal decomposition of zinc acetate via laser irradiation followed by hydrothermal growth, and the electrochemical deposition method. These methods enable ZnO nanostructures to grow onto designated surface areas with customised, patterned shapes, and they are rapid, cost-effective, and environmentally benign.

**Acknowledgments**

This research was supported by the European Regional Development Fund's programme “Post-doctoral Research Aid” (a project title “Development of nanomaterial-based electrochemical sensor for detection of hydrogen peroxide”; research application No 1.1.1.2/VIAA/4/20/743; research application agreement No 1.1.1.2/16/I/001).

# Grown in Riga worldwide known photonuclear physicist Michael Danos (1922–1999)

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*Source:* Evans Hayward and Joseph W. Motz, *National Institute of Standards and Technology, Gaithersburg, Maryland*

The ashes of Michael Danos were scattered in the Baltic Sea near Riga in autumn 1999 and gave him access to the oceans of the world–befitting his status as a world citizen. This would be his second journey from Riga. The first, would start in the spring of 1944 to escape conscription into the German forces, and end in the United States as an outstanding, world-renowned physicist.

He was junior assistant at the University Dresden (1944–1945), assistant at University Hannover and Heidelberg (1948–1951), and assistant at University of Heidelberg (1951–1952). He left Germany on 1952 and started his career in USA as a research associate (1952–1954), supervised by Prof. C. H. Townes (the Nobel Prize in Physics 1964: Charles H. Townes, Nicolay G. Basov, Aleksandr M. Prokhorov) at Columbia University, New York. His CV is published by the University of Arizona [1].

The University of Latvia is now proud of its first ERC grant holder, Professor Andris Ambainis, in the area of quantum computing. The last publication (1999), from the total of 163 in the CV's list of Michael Danos also concerns quantum physics and applications [2, 3]. This is a good link between past and future in the history of Latvian Quantum Physics.

He died 30 August 1999 at Georgetown University Hospital in Washington D.C. after suffering a stroke.

Michael Danos (January 10, 1922 – August 30, 1999) was born in Riga to parents Arpad Danos and Olga Vīksna. Arpad was a musician from Hungary. He was not only an opera singer but also a sportsman, and even competed for participation in the Paris Olympic Games in 1900 in the triple jump. His mother Olga was also a famous opera singer. He had two brothers: the elder, Arpad Danos, suffered through and survived the Gulag camps, and the younger Jānis Danos – now reaching the age of 99 – is a physicist who graduated from the Bonch-Bruevich Institute of Radio Engineering in Leningrad (modern-day St. Petersburg).

It would seem that both of the younger brothers acquired their interests in electricity from their grandfather Jānis Vīksna, who had a water wheel on the dam of the Juglar river powering an electric generator, which in turn supplied electric lights to the Vīksna family. Michael started working in 1940 (when the Soviet Union occupied Latvia), and was employed by VEF, Riga's famous electrotechnical factory. Before escaping to Germany, he studied electrical engineering at the University of Latvia 1941–1944.

By the way, his son Arpad M Danos currently is postdoc of molecular biology at Washington University in St. Louis (h-index 12, more than 1000 citations) [4]. Influenced by his uncle Jānis, was student in Physics at the University of Latvia, for a year. Currently he is interested in Molecular Biology, Cell Biology and Endocrinology and keeps post doc position at the university.

Michael Danos married Sheila Fitzpatric [5] in 1990. Sheila May Fitzpatrick (born June 4, 1941) is an Australian historian, whose main subjects are history of the Soviet Union and history of modern Russia, with an emphasis on the Stalin era and the Great Purges. She is also known for her book on Michael Danos and Danos family, "Mischkas War" [6] – "history from below". It is about the life of a well-situated intellectual family in Latvia during the first 20 years of independence between the two world wars, the two occupations during WWII, and the escape of Michael Danos via war damaged Germany to the United States.

> "*Two dramas are played out in Sheila Fitzpatrick's Mischka's War: that of Misha, navigating the European catastrophe with an equanimity that often threatens to confound our understanding of it; and the author's own drama, as she tries to preserve the historian's objectivity and "distance" from even the most terrible events, while uncovering the story of one man among the millions caught up in them – the man she met and fell in love with long after the war was over. The result is an absorbing, unsettling, rare and memorable book*."
>
> Don Watson (born 1949, an Australian author, screenwriter, former political adviser, and speechwriter).

Interestingly, Michael's son Arpad M. Danos is currently a postdoc of molecular biology at Washington University in St. Louis (h-index 12, more than 1000 citations) [4]. Influenced by his uncle Jānis, he studied physics at the University of Latvia for a year. Currently his fields of study are Molecular Biology, Cell Biology, and Endocrinology.

The life and story of Michael Danos was in many ways similar to the scientific careers of many young and talented Latvians. They were often deported from refugee camps in Germany to many places worldwide and serve as evidence of the tremendous losses of human capital the nation suffered during, and after WWII.

One could write an additional book on the contributions of Michael Danos to the field of physics but here are a few of his accomplishments: He is the co-author of several books [7–11]. He worked for 40 years as a physicist at the National Institute of Standards and Technology and its predecessor agency, the National Bureau of Standards before his federal retirement in 1994.

In the 1970s and 1980s, Michael Danos studied relativistic heavy ions, and his contributions would later serve as a base for the development of the billion-dollar heavy-ion collider of Brookhaven National Laboratory on Long Island, New York.

In the early 1990s, while on the staff at the National Institute of Standards and Technology, he founded Rayex Co. in Gaithersburg, to develop high-power X-ray tubes for medical imaging and industrial radiology.

Symposium on Fundamental Issues in Elementary Matter[1] in Honour and Memory of Michael Danos was held in Physikzentrum Bad Honnef, Germany, 25–29 September 2000.

The list of his publications collected by Johann Rafalskii counts more than 160[2]. Only few are referred below illustrating the diversity of interests [12–23].

1 http://www.th.physik.uni-frankfurt.de/greiner/index.html
2 http://physics.arizona.edu/~rafelski/MDvitae.txt

**Resume for Michael Danos**

*Date and place of birth data*: 10 January 1922, Riga, Latvia

*Citizenship:* USA, Naturalised in 1957

*Education:*

| | |
|---|---|
| 1948–1950 | University Heidelberg, Germany, Ph.D. (Dr. rer. nat) Physics (with Prof. J. H. D. Jensen) |
| 1946–1948 | University Hannover, Germany, M.S. (Dipl. Ing.) Electrical Engineering (with Prof. Sennheiser) |
| 1944–1945 | University Dresden, Germany, Electrical Engineering (with Prof. Barkhausen) |
| 1941–1944 | University of Latvia, Latvia, Electrical Engineering |

*Employment History:*

| | |
|---|---|
| 1994– | Physicist, Rayex Co, Gaithersburg, MD |
| 1954–1994 | Physicist, National Institute of Standards and Technology (formerly National Bureau of Standards) |
| 1952–1954 | Research Associate, Columbia University, New York (Prof. C. H. Townes) |
| 1951–1952 | Assistant, University Heidelberg, Germany (Prof. O. Haxel) |
| 1948–1951 | Assistant, University Hannover and Heidelberg, Germany (Prof. J. H. D. Jensen) |
| 1944–1945 | Junior Assistant, University Dresden, Germany (Prof. H. Barkhausen) |

*Visiting Professor and Scientist:*

1. University of Maryland, College Park
2. Duke University
3. Purdue University
4. University of Arizona, Tucson
5. CEN Saclay, France
6. Copenhagen University, Denmark
7. CERN, Switzerland
8. Heidelberg University, Germany
9. Freiburg University, Germany
10. Frankfurt University, Germany
11. Erlangen University, Germany
12. Bonn University, Germany
13. University of Melbourne, Australia
14. University of Cape Town, South Africa
15. JINR, Dubna, Russia
16. Kurchatov AEI, Moscow, Russia
17. INI, Academy of Sciences, Moscow, Russia
18. Budker Institute, Novosibirsk, Russia
19. Enrico Fermi Institute, Uni Chicago

*Awards:*

1959 – Guggenheim Fellowship
1966 – Department of Commerce Silver Medal
1970 – Sir Thomas Lyle Fellowship

1972 – Alexander von Humboldt Senior U.S. Scientist Award
1983 – National Bureau of Standards Fellow
1984 – Department of Commerce Gold Medal
1993 – Alexander von Humboldt Senior Fellow

**References**


[1] http://physics.arizona.edu/~rafelski/MDOB.htm

[2] Danos, M., Kieu, T. D. (June 1999). Measurement in quantum physics. *Int. J. of Modern Physics E* 8(3), 257–287. https://doi.org/10.1142/S0218301399000197.

[3] Kieu, T. D., Danos, M. (2001). A no-go theorem for halting a universal quantum computer. *APH N. S., Heavy Ion Physics* 14, 217–225. https://doi.org/10.1556/APH.14.2001.1-4.21.

[4] https://scholar.google.com/citations?user=R0wfpRIAAAAJ&hl=lv&oi=sra

[5] https://www.google.com/search?client=firefox-b-d&q=Sheila+Fithpatric+

[6] Fitzpatrick, S. (2017). *Mischka's war: a European odyssey of the 1940s*. Melbourne University Press.

[7] Danos, M., Gillet, V. (1975). *Relativistic Many-Body Bound Systems*, NBS Monograph 147.

[8] Danos, M., Gillet, V. (1975). *Relativistic Many-Body Bound Systems: Electromagnetic Properties*. Supplement, NBS Monograph 147.

[9] Danos, M., Gillet, V., Cauvin, V. (1984). *Methods in Relativistic Nuclear Physics*. Elsiver-North Holland Publ.

[10] Danos M., Rafelski, J. H. (1984). *Pocketbook of Mathematical Functions*. Deutsch Publ.

[11] Danos, M., Gillet, V. (1990). *Angular Momentum Calculus in Quantum Physics*. World Scientific.

[12] Steinwedel, H., Danos, M. (1950). Proton density variation in nuclei. *Phys. Rev.* 79, 1019.

[13] Danos, M. (1952). Zur Hydrodynamik der Multipolschwingungen des Atomkerns. *Ann. Phys.* (Leipzig) 10, 265–281.

[14] Danos, M., *et al.* (1953). Cerenkov effect at microwave frequencies. *Phys. Rev.* 92, 828.

[15] Danos, M. (1954). Cerenkov radiation from extended electron beams. *Phys. Rev.* 94, 758.

[16] Danos, M. (1957). Analog computer study of electron injection into circular accelerators. *NBS Report* 5425.

[17] Danos, M. (1961). Sum rule for the nuclear photoeffect. *Bull. Am. Phys. Soc.* 6, 432.

[18] Danos, M. (1965). Nuclear physics, a report on the Paris Conference. *Phys. Today* 18(5), 44–50.

[19] Danos, M., Rafelski, J. (1977). Some Consequences of Fermi-Type Theory of Weak Interactions. *Lett. Nuovo Cimento* 19, 339–343.

[20] Rafelski, J., Danos, M. (1980). Importance of the reaction volume in hadronic collisions. *Phys. Letters* 97B, 279–282.

[21] Rafelski J., Danos, M. (1983). Perspectives in High Energy Nuclear Collisions. NBSIR 83-2725.

[22] 22.Danos, M. (1995). Dissipation in quantum physics. *Phys. Rev.* E52, 3637.

[23] Danos, M., Fano, U. (1988). Graphical analysis of angular momentum for collision products. *Physics Reports* 304(4), 155–227.

# Author index

# Industrial Collaboration Partners of the NSP FOTONIKA-LV


## Compiled by Arnolds Ūbelis

*NSP FOTONIKA-LV Scientific Secretary*


**Lightguide, Ltd.**[1] (previously LightGuideOptics) has earned a fresh look. We are ready to show the world our R&D solutions in a new form, to show why we are the leading optical fibre production laboratory[2]. It was 1983, a new branch of manufacturing is being opened under existing and thriving Līvani (Latvia) glass factory that specialised in home decor items.

The company started to produce finest optical fibre bunches alongside widely known vases, light shades and crystals. MSc diploma holder who recently graduated Riga Polytechnical Institute – Daumants Pfafrods was a leader in such drastic changes. One can follow the history of the company from 1983 till 2023[3].

Now Daumants Pfafrods is leading the Company employing about 250 highly skilled professionals including his two sons having MSc degree in physics from the University of Latvia and engineers' degree from the Riga Technical University.

The company plans to continue revolutionising the optical fibre industry with innovative products and solutions, paving the way for a brighter and more connected future.

Currently in the development and construction stage is the companies' latest facility, which will expand their production capacities by an extra 3,000 $m^2$. Lightguide is constantly working to further develop and implement factory automation solutions and bring more unique and innovative solutions to the market.

**Baltic Scientific Instruments, Ltd.**[4] was founded in 1994 on basis of the Riga Research and Development Institute for Radio-Isotope Apparatus (RNIIRP, established in 1966 by the Soviet Union authorities). RNIIRP had Union-wide responsibility for the development of instruments for radiation detection and measurement for the atomic energy industry, environment monitoring, mining, basic and space sciences research and military applications.

Since its founding BSI Ltd is leaded by known researcher, research manager and entrepreneur Dr. Phys. Vladimir Gostilo[5] (h index – 19, more than 100 publications, more than 1000 citations) ensuring very creative efforts of excellent research, technology development and innovation (RTD & I) team of the company.

BSI Ltd is producing devices for spectrometric analysis of radionuclides based on semiconductor and scintillation radiation detectors applicable in multiple industries:

1 https://www.lightguide.com
2 https://www.lightguide.com/news/same-companybetter-brand
3 https://www.lightguide.com/about
4 BSI: https://bsi.lv/en
5 https://scholar.google.com/citations?user=ANuFgD0AAAAJ&hl=lv&oi=sra

nuclear power; environmental monitoring; geophysics and the mining industry; medicine and healthcare; research including space sciences; security systems and customs control etc.[6]

So far, classified as research-oriented Small and Medium-Sized Enterprise (SMS), BSI Ltd is successfully competing with two world-renowned companies in the United States. The. European Space Agency, International Atomic Energy Agency (IAEA), and governments of Singapore and Japan are on the list of BSI Ltd. customers.

BSI Ltd recently voluntarily contributed to the restoration of equipment and safety control systems of the Chernobyl nuclear power station looted and damaged by Russian army[7].


[6] https://bsi.lv/media/uploads/bsi_catalogue.pdf

[7] https://www.voanews.com/a/photos-indicate-russian-looting-of-radioactive-materials-from-ukraine-s-chernoby/6526620.html

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NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020

EIROPAS SAVIENĪBA
Eiropas Reģionālās attīstības fonds

IEGULDĪJUMS TAVĀ NĀKOTNĒ

For the conference book cover, a photograph of the building's Šķūņu St. 4 in Riga (the main building of NSP FOTONIKA-LV) *Jugendstil* (*Art Nouveau*) portal. The building was built in 1911–1912 according to the design of the architect, Paul Mandelstamm. The building's architectural style draws from both neo-classical and vertical *Jugendstil* elements, suited for the narrow streets of historic Old Riga. The portal is adorned with two statues of children, that symbolise intermediaries (www.jugendstils.riga.lv/JugendstilsRiga//Mandelshtams/skunu4) between the spiritual and material worlds. The building has a practical and simple design. It was the first building in the Baltic States to use metal-column-beam structural elements with reinforced concrete panels. Paul Mandelstam designed more than 70 Eclectic, *Art Nouveau*, Neoclassicist buildings that were built in Riga before the first World War, many of which are found in the centre of Riga: Alberta St. 10 (1903), Audēju St. 2 (1910), Dome Sq. 8 (1913), Dzirnavu St. 87 (1903) and 92 (1904), Grēcinieku St. 8 (1911), Kalēju St. 23 (1903), Kaļķu St. 14 (1907) and 22 (1912–1914), Marijas St. 2 (1911), Mārstaļu St. 28 (1906) and 16 (now Peitavas St. 5, 1907), Noliktavas St. 3 (1903), Šķūņu St. 4 (1911), Jewish Club and Theatre on Skolas St. 6 (1913–1914).
In 1915, at the start of the First World War, he fled to Moscow as a refugee, but later returned to Riga in 1918 to work as an architect. He designed buildings mainly in the functionalist style: Kalēju Str. 5 (1926), Elizabetes St. 51 (1928), Stabu St. 47, Smilšu St. 1 (1929), Bruņinieku St. 40 (1929) and 49 (1932), and more.

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**Paul Mandelstamm** (06.09.1872–08.1941) was born in Žagarė (Lithuania, https://replay.lsm.lv/lv/ieraksts/ltv/277231/ielas-garuma-arhitektam-paulam-mandelstamam-150).

His famous father was a poet (https://lechaim.im/academy/uchenyj-evrej/), publicist, and the author of the *Jewish School Project* in Tsarist, Russia. He was the first Jew to graduate from the Department of History and Philosophy at St. Petersburg University in 1844 as a Candidate of Science. Paul studied both architecture and civil engineering at Riga Polytechnic Institute, and graduated in 1892. He participated in the construction of the first electric tram line in Riga in 1900–1901 and supervised the construction of waterworks in the city between 1903 and 1904. He died during the Holocaust, killed in front of his home because he had set foot on a sidewalk where Jews were not allowed to walk.