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Quantum sciences, Space sciences and Technologies – PHOTONICS RIGA 2023

20–21 April 2023, Riga

Presentation Abstracts

Thursday, April 20

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Sergey Kravchenko, *Cryogenic and Vacuum Systems*
tbc

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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, *Katholieke Universiteit Leuven* & Arnolds Ūbelis, *University of Latvia*

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

Vladislavs Bezrukovs, *Engineering Research Institute Ventspils International Radio Astronomy* & et al

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

Preface: FOTONIKA-LV since 2010

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Up to now, only bottom-up efforts of recognized individual researchers, a few strong research groups, and industry leaders have been driving RTD&I in Latvia relying on extremely intensive project life, project-related funding, and in practical absences of institutional funding as a result of serious mistakes and wrong priorities of the national RTD and innovation policy and R&I culture, see: "S*trongly insufficient institutional funding is the major weakness of R&I policy in Latvia, - was strongly and convincingly stated in evaluations performed by the Technopolis group in 2014*[1] *and repeatedly again in 2021*[2]*"*.

The current *National Science Platform FOTONIKA-LV* in quantum sciences, space sciences and technologies at the University of Latvia is also the result of bottom-up action and emerged as an association, *FOTONIKA-LV,* of three research institutes *(strong in quantum sciences, space sciences and technologies)* at the university, based on an agreement signed by directors on April 24, 2010. The institutes joined forces to boost photonics sciences and technology in Latvia, to be in line with EC defining photonics among the leading six key enabling technologies in Europe in October 2009[3]. Re-identified in 2020 in the document considering a new industrial strategy of Europe[4]. Specific emphasis on quantum sciences was made in 2018, when the European Commission decided to finance the Quantum Flagship - the third largest-scale research and innovation initiative for the next 10 years[5].

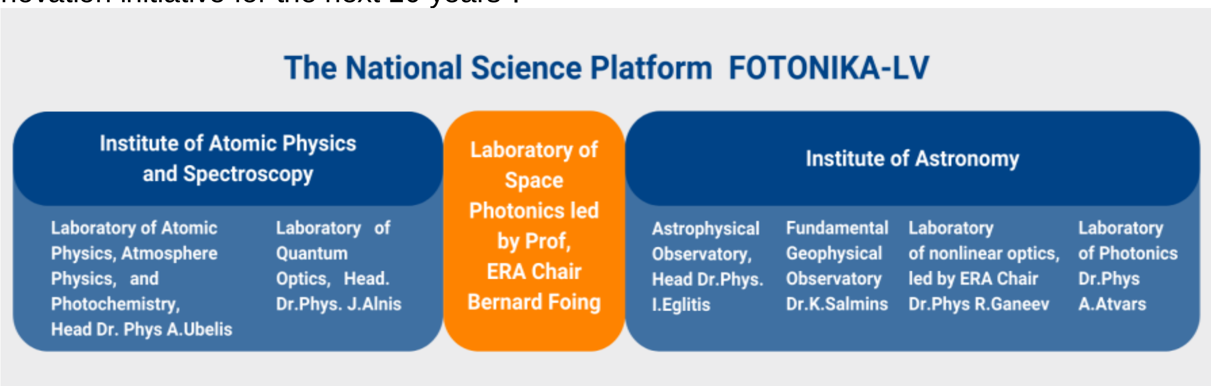

Fig.1. *Current structure of NSP FOTONIKA-LV.*
The structure will face optimizations and structural changes in the process of building the National Centre of Excellence FOTONIKA-LV

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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: DOI: 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 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] Willner et al.: Optics and Photonics: Key Enabling Technologies. Vol. 100, May 13th, 2012 | Proceedings of the IEEE
[4] Brussels, 10.3.2020. COM(2020) 102 final. .A New Industrial Strategy for Europe see also: https://www.photonics21.org/
[5] https://qt.eu/about-quantum-flagship/ : The Quantum Flagship is driving this **quantum revolution in Europe**.

Currently the National Science Platform *(NSP) FOTONIKA-LV*[6] at the University of Latvia *(composed of 5 laboratories dedicated to Quantum Sciences and Photonics, the Astrophysical observatory and the Fundamental Geodynamic observatory having an advanced SLR station: ILRS code RIGL1884*[7]*).*

The foundation of *FOTONIKA-LV* was a decisive step forward starting remarkable structural changes at the University. Since 2010, research teams associated with *FOTONIKA-LV* experienced the implementation of 15 large-scale projects including, 6 ERDF projects and 16 projects financed from FP7 and H2020 budgets. Crucial for the growth and structural changes were five FP7 projects; *see*[8,9,10,11,12].

The first largest success was the *3.8 MEUR* FP7-REGPOT-2011-1 project #285912 *(Coordinator Dr. A. Ubelis; see ref.*[8]*)* that allowed to recruit/repatriate researchers *(18)*, particularly Dr. Phys. Jānis Alnis[13], who started his post doc career as a Marie Curie fellow of Nobel prize winner Theodor Hänsch[14] was repatriated from photonics in Latvia. Dr. Phys. Roman Viter[15], currently positioned among more productive physicists in Latvia, was recruited from Ukraine. Professional NGO *"Riga Photonics Centre"* was co-founded, and membership in the *European Photonics Industry Consortium*[21] was established. Active contacts with Latvian SMEs in the photonics domain were established. (*12 cooperation projects, 11 SMEs were supported in designing proposals for commercialization of their disruptive innovation prototypes (TLR around 6) to be financed by Horizon 2020 SME Instrument or currently from EIC "challenger" calls budget).* Many FP7 and Horizon 2020 project proposals were prepared *(FP7: 16 applications; 10 financed projects. H2020: 23 applications; 6 financed projects.)* by recruited and repatriated researchers under the leadership of the scientific secretary A. Ubelis.

The transformation of the association into the National Science Platform *FOTONIKA-LV (see Fig.2)* was the next step in quality and quantity regarding structural changes, because, besides academic activities, cooperation with an excellent group of *"high-tech"* SMEs in the domain of photonics had been intensified. Currently *NSP FOTONIKA-LV* is implementing 12 projects. Among them are 4 ERDF projects, 3 ESA projects, one space project from the European Institute of Innovation & Technology *(EIT)*[16], 3 National Science Council projects, and two strategically very important *WIDERA ERA chair* projects – *QUANTUM-LV* and *SPACE-LV (see ref.*[5,6] *above),* ensuring strategic leadership from two excellent, worldwide known, researchers and science managers – Dr. R. Ganeev[17] and Prof. B. Foing[18].

The TEAMING project will establish the National Centre of Excellence in Quantum Sciences and Photonics in Latvia to be in service for academia and industry nation-wide, *see Fig.2.*

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

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

[8] FP7-REGPOT-2011-1. FOTONIKA-LV, reg. Nr. 285912 (2012-2015), Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area (scored 15 from 15; size 3,8MEUR)

[9] See final report of FOTONIKA-LV, reg. Nr. 285912 (2012-2015) on https://cordis.europa.eu/project/id/285912/reporting/de

[10] Dr.Arnolds Ubelis. Coordinator. NOCTURNAL ATMOSPHERE - FP7-PEOPLES-2011-IRSES project, contract Nr294949. "Secondary photochemical reactions and technologies for active remote sensing of nocturnal atmosphere" (01.05.2012-30.04.2016).

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[12] Dr.Arnolds Ubelis. PI. FP7-PEOPLES-IRSES-2013. Grant. 612691. REFINED STEP. An international network on new strategies for processing calcium phosphates (03.11.2013-02.11.2017).

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

[14] https://www.nobelprize.org/prizes/physics/2005/hansch/facts/ DOI: 10.13140/RG.2.2.21960.52489.

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

[16] EIT "EuroSpaceHub" (No 220812, 2022-2024) Title: " Increasing space innovation and technology transfer by connecting space academia, industry, and startups" - https://eit-hei.eu/projects/eurospacehub/

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

[18] [18] Bernard Foing: https://scholar.google.com/citations?user=_fTVp0kAAAAJ&hl=lv&oi=sra

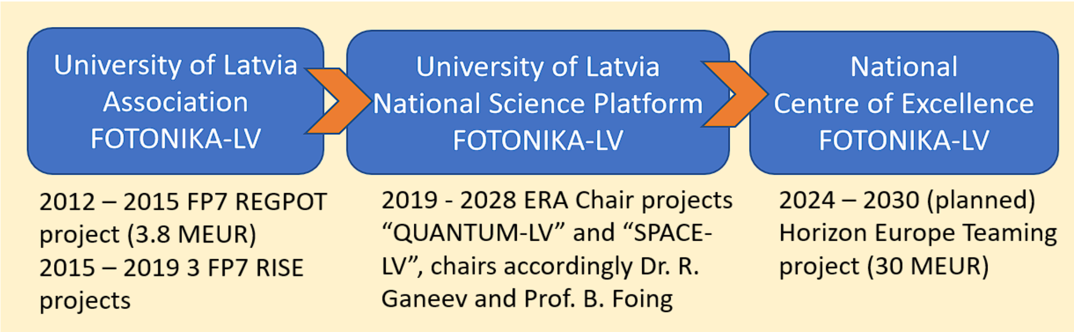

Figure 2: History and forecast for the evolution of FOTONIKA-LV*. It originated as an Association, currently being the National Science Platform, and would be upgraded to the scale of an independent NCoE FOTONIKA-LV recognized in the ERA in quantum sciences and photonics, providing nation-wide services to academia and industry.*

Recent Developments of Nonlinear Optics in Latvia

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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. The basics for carrying out the NLO experiments require the application of short laser pulses possessing sufficient intensity. Though some NLO studies have been carried out in Latvia in earlier years, most advanced reports appeared during the last few years. The application of picosecond and femtosecond pulses allowed analysing various NLO properties of materials. Additionally, the newly synthesized small-sized multi-atomic ensembles have demonstrated a strong NLO response, which allows their application for optical limiting, optical switching, formation of coherent short-wavelength sources, manipulations of the spatial and polarization properties of laser beams, etc.

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. I also discuss the results of the collaboration of Latvian scientists with researchers from different countries in the fields of nanomaterials, nonlinear refraction, nonlinear absorption, and modulation of the NLO properties of materials by changing the characteristics of laser beams, etc. [1-8]. Among the topics of my talk are the variation of the nonlinear refraction and absorption of spectrally tenable femtosecond pulses in carbon disulphide, 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 characterization 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.

The perspectives of further development in the NLO studies will be discussed. Among them the synthesis and NLO characterization of the nanoparticles produced during laser ablation of various materials, as well as recently performed Latvian-German studies of the high-order harmonics generation in gases using the vortex beams.

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

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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[19], 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 (GOx) 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 localized 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).

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 og glucose droplets where refractive index increases in time.

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

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 optimizing 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 optimization of HgTe QD films for ultrafast optical applications, paving the way for the development of novel photonic devices and systems.

Acknowledgments

Special thanks to Kristians Draguns for summarising publications with ChatGPT.

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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 specialized 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].

In my talk, I will discuss a few simple PNNs implemented on a silicon photonics platform [12] 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 [13]. First, a simple optical neuron is discussed where different delayed versions of the input optical signal are made to interfere before the output port [14, 15]. Then, the simple microring resonator is used to demonstrate complex nonlinear dynamics [16]. 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 [17]. Moreover, linear and nonlinear memory tasks are used to evaluate the memory capacity of a microring resonator [18]. Finally, we show the possibility to extend the microring resonator fading memory by using an external optical feedback loop [19].

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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 utilizing 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 utilizes 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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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 neutralization 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, 4, 5].

Acknowledgments

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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 organizations, 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 characterization (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 organizational 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 fiber 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 organized in Joensuu from the

30th of May to the 1st of June. Photonics Finland also organizes 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 specialization 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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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 optimized 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. 1, a) [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].

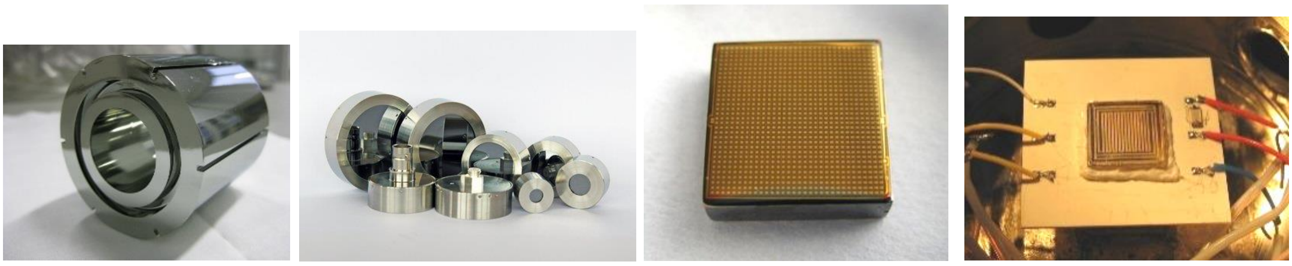

Figure 1. *Semiconductor detector crystals: a) segmented HPGe for investigation of nuclear reactions; b) ion implanted Si for alpha particles; c) pixelated CdZnTe for gamma imagine systems; d) strip TlBr detector prototype*

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. 1, b).

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. 1, d) [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.

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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 tunable nanosecond laser or high intensity femtosecond lasers. The experimental results will be compared with recent advanced many-body calculations.

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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.

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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 ionization 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 ionization 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.

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

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Through 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 result, the HHG in LIP serves as the 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 optimization of plasma parameters allowed achieving 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 united under the common term ‘perovskites’ attracted intensive research attention due to 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
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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 0.7M. The development of urban forests in Riga has a long history. The city of Riga covers 304.05 m^2, and it is 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 km2 or 88% of total forest area) and is characterized by landscape attractiveness. In the summer season (JJA), air temperatures go above 32C. 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 NOx scenario, ozone levels are decreased and in the high NOx levels, the same is increased. However, with the rapid changes in transportation and industrialization, 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 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 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 realization 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 NOx presence, the biogenic emissions interact with the NOx and form more ozone, whereas, at lower NOx 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: Polarization properties

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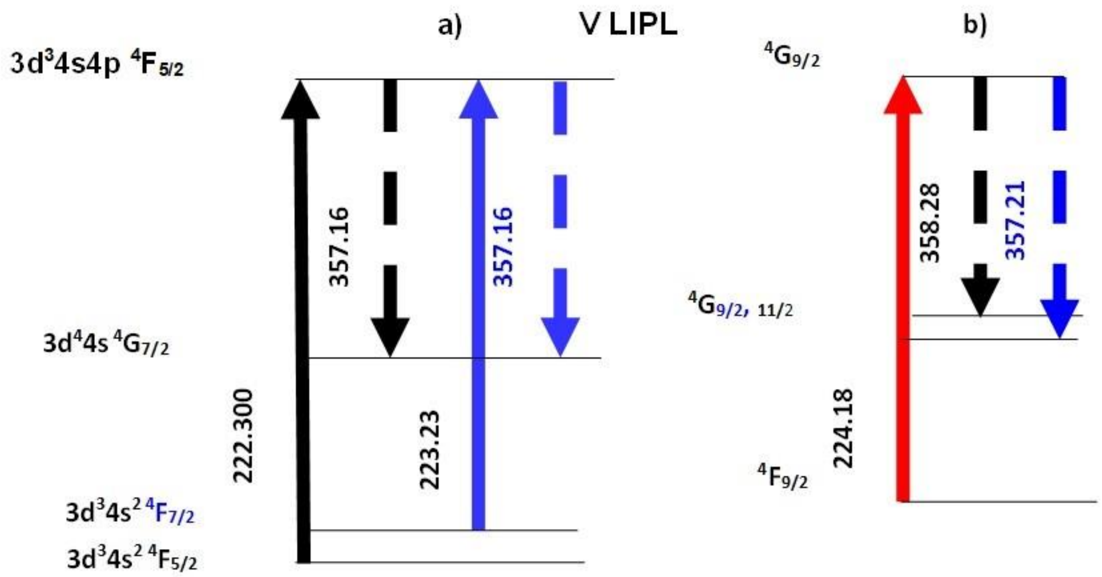
We demonstrate that stimulated emission and lasing occur under appropriate resonant and **linearly polarised** optical pumping of a pre-formed laser-induced plasma (LIP) plume. It manifests as the emission of intense, collimated, and **polarised** beams. We call this effect Laser-Induced Plasma Lasers (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 polarization properties of the lasing light are studied, finding that the Degree Of Polarization (DOP) varies depending on the pumping transition chosen. DOP can be reliably controlled by applying a relatively weak ($\lesssim$ 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 polarization 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.

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 polarized generation and $\boldsymbol{B_{ext}}$ effects.[5]. We pay attention that pumping the **same generation** line from ground level multiplets with $\Delta \boldsymbol{J} = \pm 1$ 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.



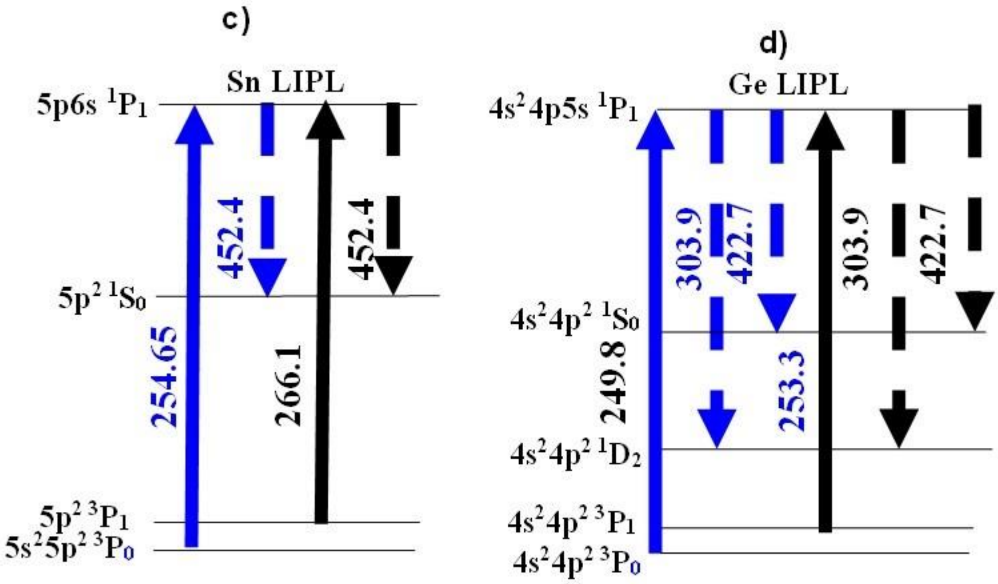


Fig.*1* *Examples of the V LIPL transition schemes for ground multiplet (a,c,d) and for lower generation levels multiple (b) differ on one (Δ **J =** ±1). The numbers along the arrows are pumping and generation wavelength. Black and blue arrows down are generation transitions with negative and positive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

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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, medical, industrial and defence applications, and research in this direction has been in progress ever since the invention of the lasers [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 a 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 synthesize high-power lasers with ideal beam quality. The phase locking of lasers requires transferring some energy from one laser to others, and strongly depends on the coupling strength between the lasers [2]. The phase locking of laser arrays with various coupling techniques were started with semiconductor diode lasers [3], gas lasers [4], and quickly extended to solid-state [5] and then to fiber lasers [6]. However, the phase locking of many lasers is a challenging task, since it requires, at the very least, a common lasing frequency to all the lasers, a prospect that vanishes exponentially with the number of lasers [7]. More recently, this idea was realized 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 very hot and emerging field of research [12]. Particularly, solving computationally hard problems is becoming increasingly important in modern society, for example in applications such as artificial intelligence, drug discovery, optimization 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 interaction between the spins determines the coupling between the variables. and then problem reduces to ground state search of the spin Hamiltonian [14]. A large network of lasers with nearest-neighbour coupling has been shown to rapidly dissipates into long-range phase ordering, identical to the ground-state of a corresponding XY spin Hamiltonian [8, 9]. The exact mapping between the lasers 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 good scalability, arbitrary coupling, and room temperature operation, network of coupled lasers have attracted considerable interests for using them as physical simulators.

Here, we present the generation and phase locking of large network of lasers using a degenerate cavity, for generating high-power density at the output of laser. Further, we show that 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) 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 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 network of holes (with hole diameter of 200 μm and separation 300 μm (centre-to-centre)) is placed near to 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 fundamental Gaussian distribution (TEM_{00} mode). Further, to couple and phase the lock the lasers, we have used a 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.

Figures 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 far-field intensity distribution confirms the in-phase locking of lasers (Fig. 1(c)), whereas 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 in 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, thus consists of a small detuning (due to aberration and thermal lensing effects) among them. This requires a small coupling between the lasers to phase lock. Therefore, with this approach large network 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 loss, 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 simulate spin systems [8], topological defects (Kibble-Zurek mechanism) [9], and solving large scale optimization problems (computationally hard problems) [12-14]. The success of solving optimization problems relies on finding efficiently and rapidly the ground-state of spin Hamiltonian. However, if the ground state is degenerate or nearly degenerate, the ground-state manifold must be fairly sampled on 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 rapid statistical fair sampling of ground-state manifold 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). Figure 1(e) shows the energy landscape of doubly degenerate ground-state of a 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 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 $\pm 2\pi/3$, so 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, provides a coherence a coherence of 100%. A same trend continues for other lasers with large distances from the reference laser. Figure 1(g) shows the ensemble averaged phases of the lasers indicating a phase difference of π between the nearest neighbour (from the reference laser). This again demonstrates the two degenerate ground states of a triangular network of negatively coupled lasers.

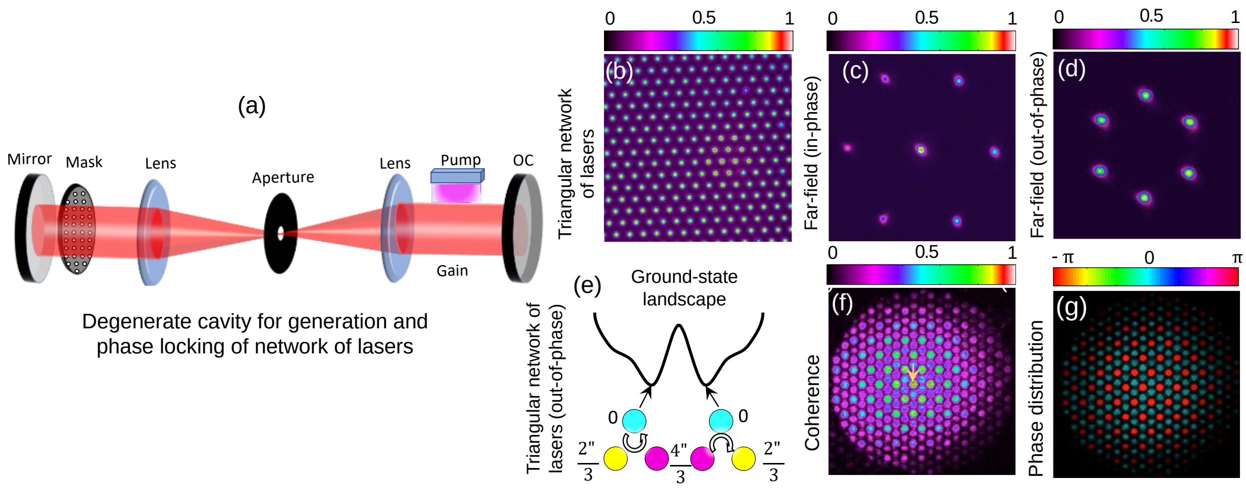

Figure 1. *(a)Experimental setup of degenerate cavity laser. (b) Near-field intensity distribution of lasers in a triangular network. Far-field intensity distribution of triangular network of lasers with (c) in-phase locking, and (d) out-of-phase locking. (e) Energy landscape with doubly degenerate ground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

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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 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) [1,2,3]. The realization 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 National Funding). The Project was initially submitted to the Horizon 2020 call "WIDESPREAD-04-2019: ERA Chairs" and got a score above the threshold. This allowed the Project to be refunded by ERDF and local funds according to funding “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 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 UL. 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 an 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 summarized in Table 1.

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 31.03.2023***	***Achieved by 31.03.2023, %***
ERA Chair holder recruited (agreements)	1	1	100%
ERA Chair scientific group recruited (agreements)	4	5	125%
Publications submitted	24	53	221%
Project proposals submitted	6	35 (2 funded, 1 in reserve list, 1 may be refunded by ERDF)	583%
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	1	50%

The International Advisory Board of the Project, consisting mainly of members of the International Scientific Council of 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 international open 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 characterization of small-sized species.

The core research team of the ERA Chair has been selected in an international competition and is formed by senior researcher Janis 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 Science House. 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 31.03.2023., ERA Chair team published 53 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. Ubelis. Funding was received for 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 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. Ubelis, 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 Center 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 National Science Platform 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 Muenster, 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, 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 selected ERA Chair B. Foing and his team. The score of the project reached a threshold. It is expected that this project could be refunded by European Regional Development Fund when proper 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.), were in active contact with a project team by implementing several projects. Monitoring of Latvia Photonics industry was made – data on turnover, profit and the number of employees were collected. The University of Latvia renewed its membership in European Photonics Industry Consortium (EPIC). R. Ganeev submitted a Latvian patent application. Two other patent applications are in preparation.

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 changed – the Council of the University was introduced in 2022. In Spring 2023, active discussions started at the University of Latvia to reduce the number of faculties to about 4 or 5 and position all research institutes under these faculties. Physics may be positioned under the Faculty of Natural Sciences.

The publicity of the project was made. 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, was organised. Regular photonics-related seminars/colloquia were organised. In total 30 outgoing and 14 incoming travel visits were made that conducted international networking.

On 01.03.2023. the President of the Republic of Latvia Egils Levits visited National Science Platform FOTONIKA-LV (Fig.1.). Progress of the projects implemented by NSP FOTONIKA-LV was reported, as well as future plans and challenges.

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. Ubelis gives presents; (b) ERA Chair R. Ganeev presents his monography to E. Levits.*

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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 1-100s. 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 proping 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.

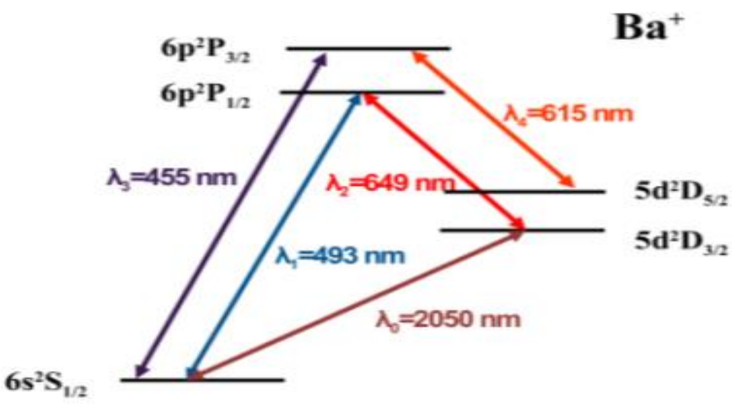

Figure 1. *Level diagram of Ba+ showing the metastable 5d ²D states targeted in the present project. The 6p states are excited by the laser tuned to the 586 and 614 nm, respectively, and the fluorescence detected at 456 nm*

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 lifeitems can still be measured with low uncertainty.

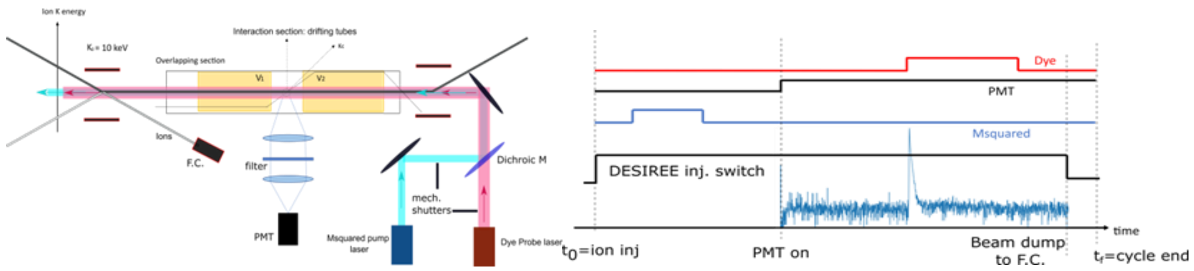

Figure 2. *(left) Experimental setup showing the ion beam, the lasers and the detector. (right) Schematic scheme of the timing of the lasers (blue and red), ion beam injection (black) and photomultiplier detector. The detected signal is shown at the bottom*

Preliminary Result

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.

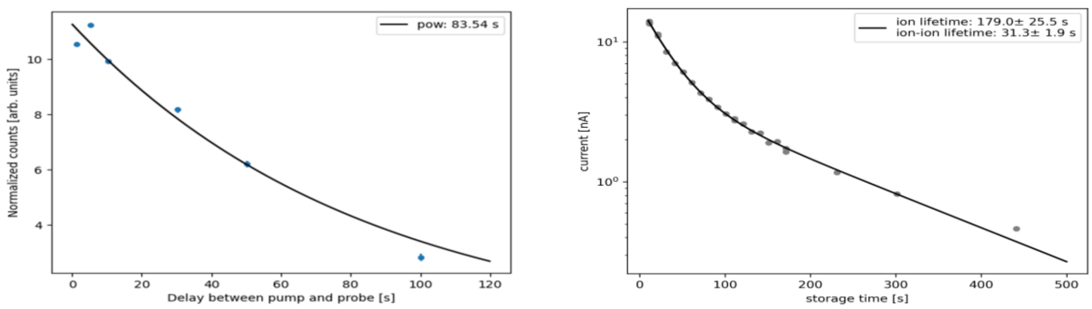

Figure 3. *(left) Lifetime curve as measured in previous experiment (right) Ion beam current showing the initial ion-ion collisions reducing the beam current*

Future work

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

- 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.

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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 (1.1.1.1/18/A/155)[20] 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 second 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 optimization 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 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 completion continues contributing to the ICT sector (application of WCOMB in telecommunication solutions).

The main results of the project are:

- ***6 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) [1-6],
- ***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),

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

- ***1 patent application*** [7] 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 at 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 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 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[21] focused on thematic directions based on 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

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

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 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 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 have been 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 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 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 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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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.

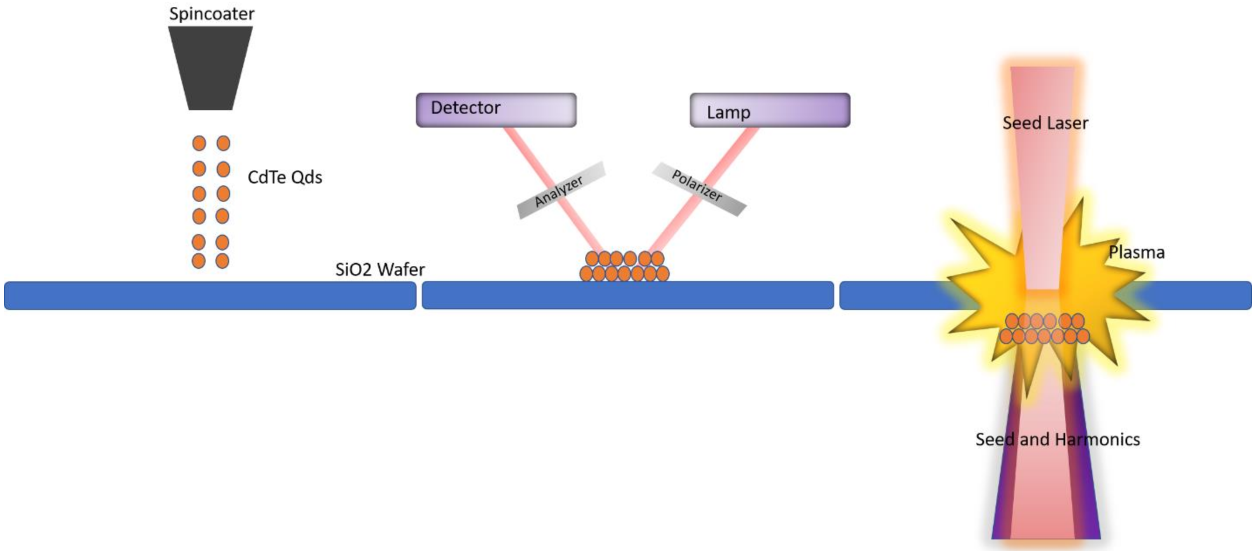

Figure 1. *Schematic depiction of the experimental setup. First, the QDs will be coated by means of a spin coater onto the wafer. Second, the resulting thickness will be measured with an ellipsometer and finally, the harmonics of borosilicate glass are generated in transmission geometry*

Laser intensities above ionization 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 characterized 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 a 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.

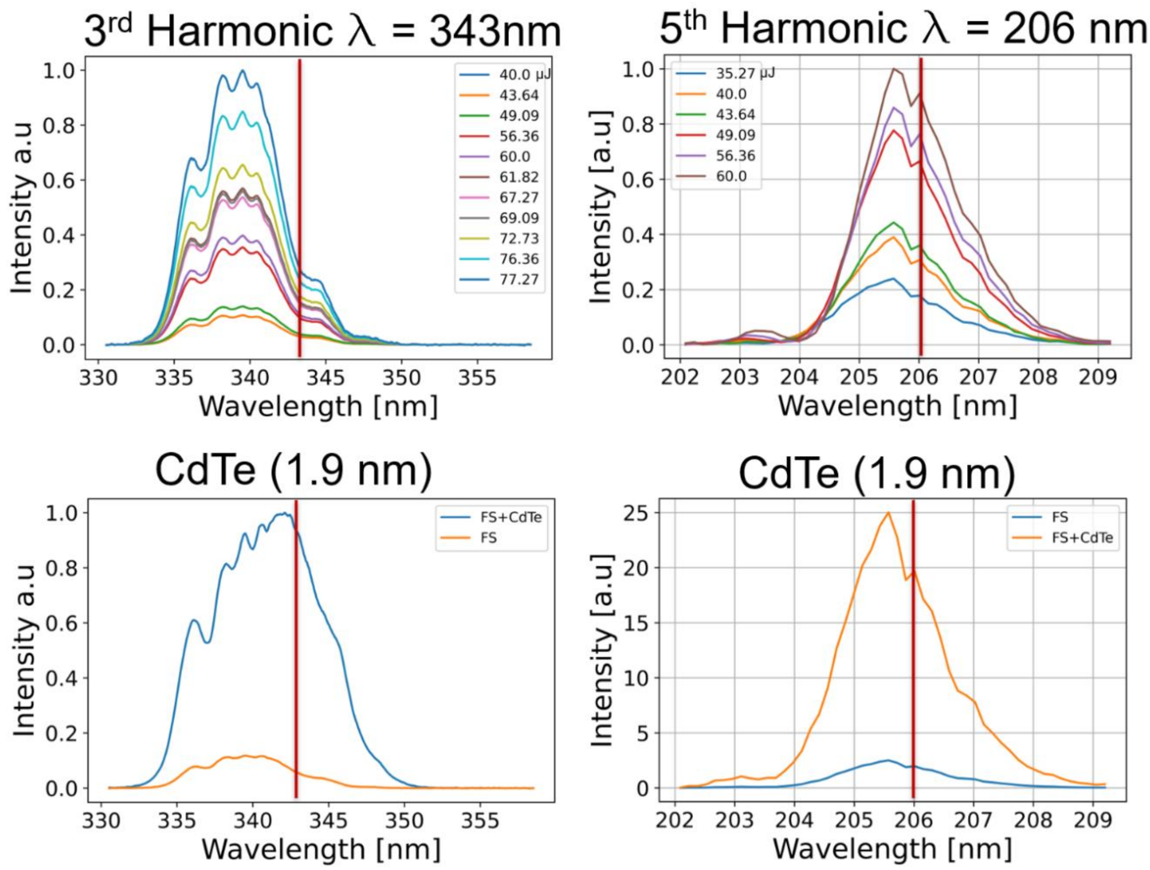

Figure 2. *Spectrum of 3rd and 5th harmonic of Borosilicate glass plasma and CdTe Quantum dot with a size of 1.9nm and a band gap of 2.54 eV*

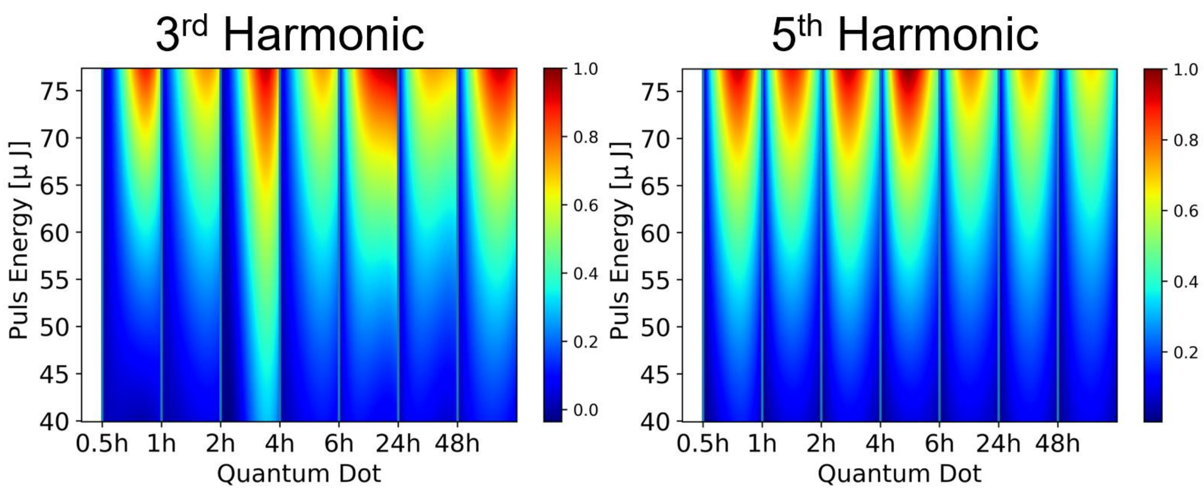

Figure 3. *Recalculated thickness and power dependent yield of 3rd and 5th harmonic of Borosilicate glass plasma and CdTe for all sizes. Reaction times correspond to the quantum dots size by 1.94, 2.01, 2.08, 2.16, 2.30, 2.94, 4.04 nm respectively. Thicknesses are estimated to be 100 nm (3rd) and 60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

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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.

NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020
EIROPAS SAVIENĪBA
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IEGULDĪJUMS TAVĀ NĀKOTNĒ
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Development of next generation technology for ultra purity crystal growth based on MHD semi levitation

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The project proposal (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 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 project implementation, combines multiple zonal purification, Czochralski (cz) and floating zone techniques to grow 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: 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.
- The number of enterprises cooperating with the research organization – 2.

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

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Ashes of Michael Danos were scatter in the Baltic Sea near the Riga in autumn 1999, thus giving him access to all the oceans of the world, as befitted a world citizen, and to start his second journey from Riga. He left Riga for the first time in the spring of 1944, to escape the conscription into the German forces and ended in United States as an outstanding worldwide known physicists.

He was Junior Assistant, at University Dresden (1944 – 1945), Assistant, Universities Hannover and Heidelberg (1948 – 1951), Assistant, University Heidelberg (1951 – 1952). He left Germany on 1952 and started his career in USA as an 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 Arizona University /1/. University of Latvia is now proud on its first ERC grant holder Professor Andris Ambainis in the area of quantum computing. There is some good link between past and future in the history of Latvian Quantum Physics. 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/.

He died August 30, 1999 at Georgetown University Hospital after a stroke. He lived in Washington DC.

Michael Danos (January 10, 1922 – August 30, 1999) was born in Riga in the family of Arpad Danos (Musician from Hungary, Arpad was not only an opera singer but also a sportsman: he had competed in the Paris Olympic Games in 1900 in the triple jump) and Olga Vīksna (Latvia opera singer). He had two brothers, older Arpad Danos who suffered and survived Gulag camps and younger Jānis Danos now overcoming age of 99 is a physicist who graduated the Bonch-Bruevich Institute of Radio Engineering named after Bonch-Bruevich (Leningrad, currently St. Petersburg).

Seems, both brothers acquire their interests to electricity from their grandfather Jānis Vīksna having water wheel on the dam of Juglar river powering an electric generator, supplying electric lights to the Vīksna family. Michael started his working days on 1940 (when Soviet Union Occupied Latvia) being employed by VEF, Riga's famous electrotechnical factory. Before escaping to Germany he studied at the University of Latvia Electrical Engineering 1941-1944.

By the way, his son Arpad M. Danos, born in ??? currently is postdoc at Washington University in St. Louis /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/ on 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, especially the Stalin era and the Great Purges, of which she proposes a "history from below". She is famous historian and the best for Michael and Danos family is her book "Mischkas War"/6/ - "history from below" about life of well-situated intellectuals' family life in Latvia during the first 20 years of independence between two world war, two occupations during the WWII and escape of Michael Danos via war damaged Germany to United states. On other side, the story of life of Michael Danos on average is similar to scientific careers of many young and talented Latvians, deported from refugee camps in Germany worldwide evidencing tremendous loses of human capital the nation suffered during and after the WWII.

The contribution of Michael Danos in physics needs the writing of another book. He is co-author of several books /7-11/. He worked for 40 years before his federal retirement in 1994, a physicist at the National Institute of Standards and Technology and its predecessor agency, the National Bureau of Standards.

In the 1970s and 1980s, Michael Danos's studies relativistic heavy ions knowledge base in need for the development of the billion-dollar heavy-ion collider of Brookhaven National Laboratory on Long Island, N.Y.

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

<u>Symposium on Fundamental Issues in Elementary Matter</u> In Honor and Memory of MICHAEL DANOS was held in Physikzentrum Bad Honnef, Germany, 25 - 29 September 2000

The list of his publications collected by Rafalskii counts more than 160. http://www.physics.arizona.edu/~rafelski/MDvitae.txt. Only few are referred below illustrating the diversity of interests /12- 23 /.

RESUME FOR MICHAEL DANOS Date and place of birth data: 10 January 1922, Riga, Latvia Citizenship: USA, Naturalized 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 Riga, Latvia Electrical Engineering 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, U. 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,	**Michael Danos** <u>Evans Hayward</u> and <u>Joseph W. Motz</u> *National Institute of Standards and Technology, Gaithersburg, Maryland*  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)

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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 exclusively 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/. Up to now 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 succeeded in using such comprehensive approach for other elements, but the need is present. Results were found useful in Astrophysics research by research team led by Massachusetts Institute of Technology (USA) in processing the data recorded by 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/, /14/, /15/. Including recently published studies of Arsenic resonance spectra /16/.

ICP-RF atomic spectra sources emits rich with spectral lines spectra of atoms of listed above elements with wavelengths shorter than 500 nm. Besides scientific interests such sources are also useful for wavelength calibrations of other light sources, e.g., various types of lasers. It is well known that wavelengths of atomics spectra lines in major of cases are measured with accuracy up to 0.001 nm /17/. But frequently there are also needs for calibration atomic spectra source for wavelengths longer, than 500 nm.

We are in the process to produce such ICP-RF source based on atomic spectra of noble gases Ar, Kr, Xe having rich line spectrum /17/ where several lines are measured with accuracy up to 0.00001. Our novelty – 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 need to perform search for optimal proportion of concentrations of gases in the bulb of source with mixture of gases.

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Current status of 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 foresee to transform the head quarter's building (Šķūņu street 4, Riga) of National Science Platform FOTONIKA-LV at the university of Latvia, and two observatories (Astrophysical Observatory, Baldone and the observatory in the Botanic Garden of the University where Satellite laser raging station of International Laser Raging Service with code RIGL 1884 /1/ is located) of NSP FOTONIKA-LV into energy autonomous, via application of hybrid, green energy system based on 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, already historically confirmed /2/ loyalty to the EU Green Deal on climate neutrality /3/.

The architect of headquarter building at Skunu street 4 (Fashionable, 5 story 1000 m^2 building with underground area and a courtyard, located on a vivid street of old Riga, Large windows with non-reflecting glass produced by an innovative Latvian photonics SMEs (GroGlass SIA-https://www.groglass.com/) are suitable for outreach campaigning) is famous author of many "Art Noveau" buildings in Riga Paul Mandelstam /4/. The building on Šķūņu 4 was built on 1912 as first building using steel and concreate in Riga, advanced technologies for that time, with large areas on each floor supposed to be used for exhibitions or shops. Only portal of the building holds elements of "art noveau".

The renovation project QUANTUM&SPACE supposed to transfer the headquarter building and premises of two observatories into attractive and suitable space for research and innovation in quantum sciences, space sciences, space photonics and photonics technologies including clean room, glass/quartz/vacuum technology laboratory and well-equipped workshop for optics and fine mechanics.

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

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Slicker3D SIA 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 has 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 upgrade 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 you 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 nanocoatings for camouflaging targets in the microwave and infrared ranges.

Figure 1. *Adaptive camouflage implementation of Slicker3D technology*

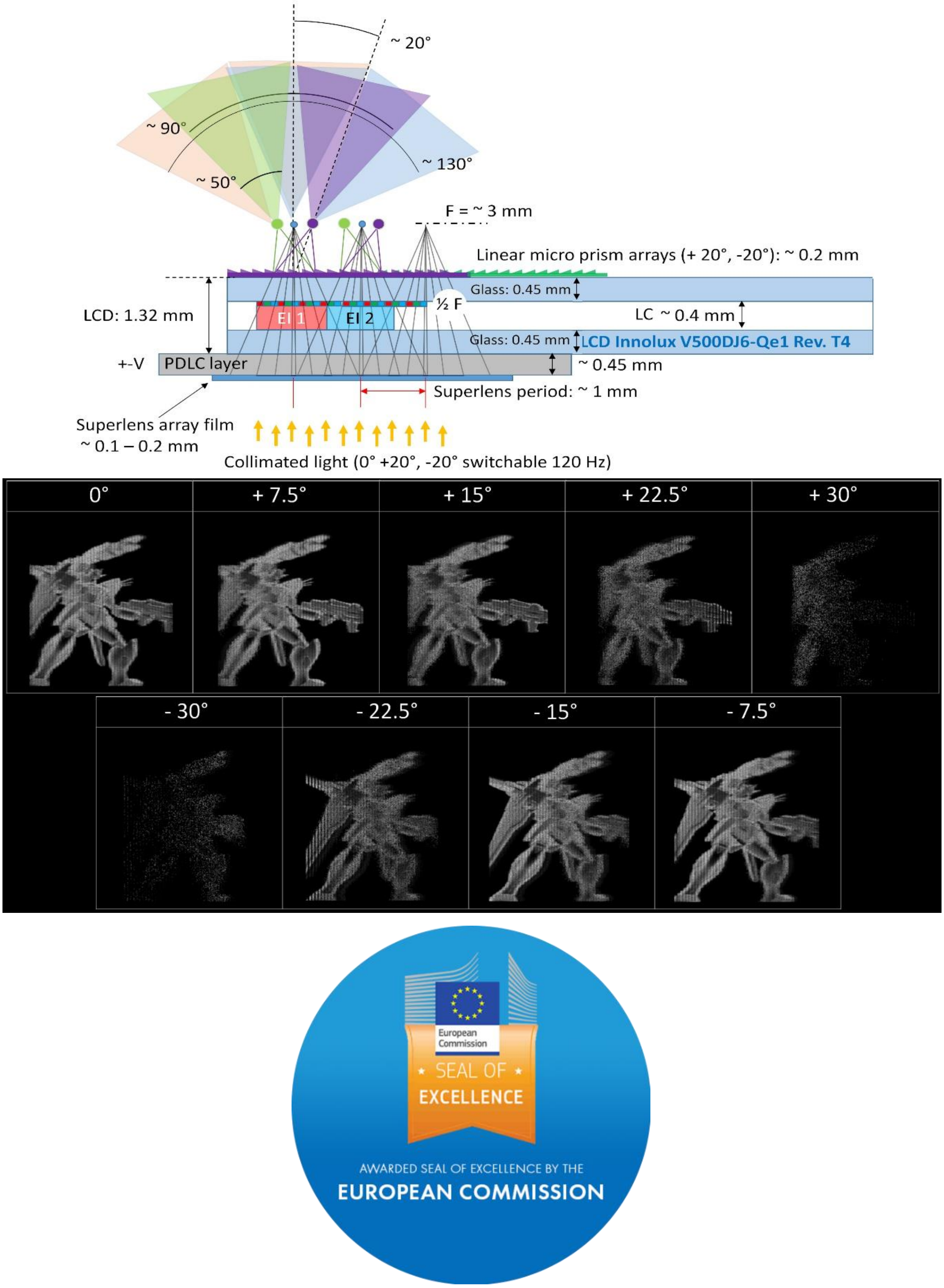

Figure 2. *Slicker3D display basic design and the 3D image simulation (ZEMAX).*

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

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In our recent works, we considered the processes of photoionization of polarized 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.

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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 in 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"* to the *call: HORIZON-WIDERA-2022-TALENTS-01* is to contribute substantially to further structural changes which 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)* to found the association *FOTONIKA-LV* to raise 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 6 key technologies in the EU[22].

The growth of *FOTONIKA-LV* in quality and quantity and structural changes started already in 2011 when efforts of joint "task force" resulted in financed FP7 REGPOT project *"Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area" (3,8M€, 2012-2015)[23].* This was the highly competitive *(success rate 7%),* but valuable FP7 financial instrument supporting excellence in countries of convergence regions. On June 18, 2018, by the decree of the Rector *(Nor 1/215)* the status of *FOTONIKA-LV* was increased to the level of National Science Platform *(NSP, fig.1)* referring to the efforts to support national industry in the photonics domain.

Prof. Bernard Foing recognised researcher (**h-**index 50), very experienced in space research, technology development, and science management, agreed to become 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 Space Photonics Laboratory support to be the engine of the development beyond the "state of the arts" research activities basing on 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 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 sciences 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 sciences 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.

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[23] *FP7-REGPOT-2011-1. FOTONIKA-LV, reg. Nr. 285912 (2012-2015), Unlocking and Boosting Research Potential for Photonics in Latvia – Towards Effective Integration in the European Research Area*

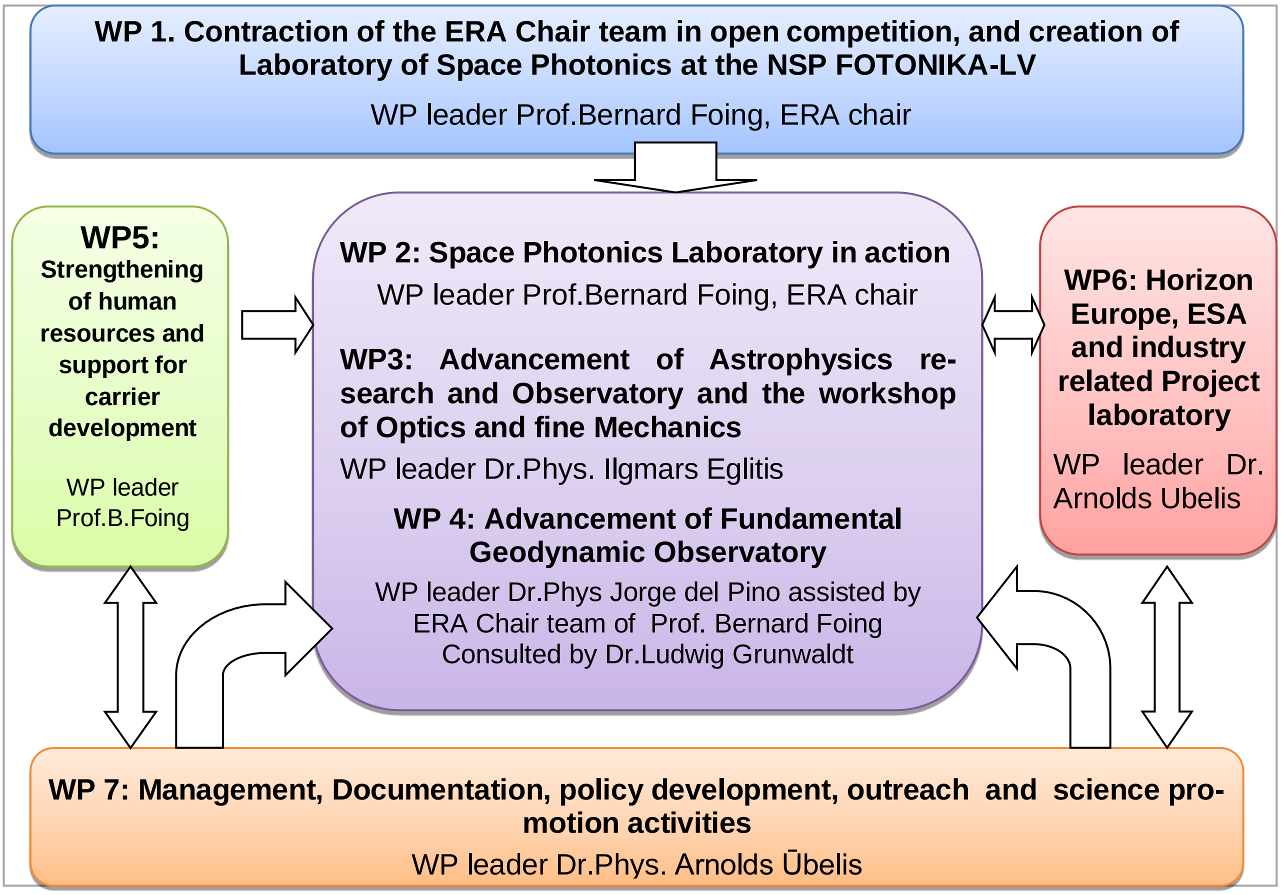
The *SPACE-LV ERA Chair WIDERA* project will make multifold impact, and boost RTD and innovation capacity in space sciences and technologies of *NSP FOTONIKA-LV* in synergetic interplay with ERA Chair project quantum sciences led by worldwide recognised Dr. Rashid Ganeev *(www.erachair.lu.lv)*. The Project will improve remarkably 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 opportunity to communicate and receive qualified advice from Prof. Bernard Foing and his talented ERA Chair team;
- ✓ 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 *NSP FOTONIKA-LV* units will work together with Prof. Bernard Foing, E*RA-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 Space Photonics Laboratory, and specific planning activities. The WP 1 starts with about 2 month's pre-project phase immediately when results of evaluation will be available, to ensure smooth start of 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, new unit of *NSP FOTONIKA* created for the implementation of scientific ambitions of ERA Chair and his team and to provoke synergies from partnership with the labs and 2 observatories, representing both areas space sciences and technologies and quantum sciences. WP 3 and WP4 lead experienced researchers foresee relevant advancement of two observatories having targeted support from ERA Chair project. WP 5 is dedicated to human resources and career development planning and will be led by ERA Chair to benefit as much as possible of his experience as well as to ensure implementation of his innovative approaches and visions. WP6 will ensure widening participation, developing and activating roadmaps of project proposals to Horizon Europa calls, European Space Agency and industry related projects and contracts, particularly specific national scale disruptive innovation projects and eventually large scale RTD projects for the transnational companies in EU and worldwide. The implementation of the work package WP 6 will be led by experienced researcher who was Coordinator of many EU Framework projects including mentioned FP7 REG POT project - Dr. Phys Arnolds Ubelis, who is also scientific secretary and the Leader of NSP FOTONIKA-LV. He will also take leadership of the management work of package WP7 and will serve as a projects Coordinator. WP 7 will start already in pre-project phase; will deal with kick-of 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 specialization strategies.

The project will be supported and advised by internationally visible Scientific Council *(including recognised researchers and entrepreneurs from Latvia and USA)* of NSP FOTONIKA-LV ERA Chair Prof. B.Foing, at least twice in 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.


WP 1. Contraction of the ERA Chair team in open competition, and creation of Laboratory of Space Photonics at the NSP FOTONIKA-LV
WP leader Prof.Bernard Foing, ERA chair
WP5:
Strengthening of human resources and support for carrier development
WP leader Prof.B.Foing
WP 2: Space Photonics Laboratory in action
WP leader Prof.Bernard Foing, ERA chair
WP3: Advancement of Astrophysics research and Observatory and the workshop of Optics and fine Mechanics
WP leader Dr.Phys. Ilgmars Eglitis
WP 4: Advancement of Fundamental Geodynamic Observatory
WP leader Dr.Phys Jorge del Pino assisted by ERA Chair team of Prof. Bernard Foing
Consulted by Dr.Ludwig Grunwaldt
WP6: Horizon Europe, ESA and industry related Project laboratory
WP leader Dr. Arnolds Ubelis
WP 7: Management, Documentation, policy development, outreach and science promotion activities
WP leader Dr.Phys. Arnolds Ūbelis

NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020
EIROPAS SAVIENĪBA
Eiropas Reģionālās attīstības fonds
IEGULDĪJUMS TAVĀ NĀKOTNĒ
ERDF project No. 1.1.1.5/19/A/003
LATVIJAS UNIVERSITĀTE
FOTONIKA-LV

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

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Satellite laser ranging (SLR) technology has as the current "state of art" a system capable of 24/7 operation using a high repetition rate laser (kHz or more), very short (~10pS) and low power (μJ) laser pulses, with a single photon detecting capability for the returning laser pulse, with an expected 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 surface of the SPAD photosensitive sensor surface has a submillimeter size (800-100 μm).

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

In order to get a better performance for our SLR system and, in particular better than from the current PMT Hamamatsu H11901-20 in use, we decided to test a hybrid photodetector (HPD) as a cost-effective alternative to a SPAD.

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

The PicoQuant Hybrid-40 3 mm photosensitive surface area is a good match for our current SLR Telescope Coudé focus optical parameters and positional stability.

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

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 polarization 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 was generated to study the HPD characteristics and to create a compensation curve for our processing software, used for both the calibrations and the satellite ranging 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 photons range.

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-40 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

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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.

EuroSpaceHub is co-funded by the EIT HEI Initiative and coordinated by EIT Manufacturing and EIT Raw Materials.

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 magnitude 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 from 2008 mainly without a filter. 149 new asteroids are discovered in the span range.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	Eglitis	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

Part of the clear nights in the three last years is devoted to the studying dynamics of NEO-type asteroids in the G(RP) passband. Observations also managed to use 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 MPC light curve database [1]. 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 a hundred observations for each object. The particular asteroid observations were made in the period 2020-2023 mainly with exposures of 120 or 240 seconds, to achieve a signal-to-noise ratio greater than 20. Measurement of CCD images of asteroids was made after the application of standard procedures of master flat and master dark images. For further processing selected only that series where the reference star's brightness errors at an 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.

After time and brightness corrections analysis of obtained light curves was made by three methods: Fourier series (F) (more detail in [6], Lomb-Scargle periodogram (L-S) [9], and Phase dispersion minimization (PDM) [8] methods. F method gives usable results analysing long series observation 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 a hundred. The PDM method is particularly sensitive to a small number of observations. If the number of observations is less than a 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 Ceter brightness data were analysed additionally. From the beginning period diapason from 0.5 hours till 100 hours are analysed. Analysed by whole three methods give a power spectrum with many peaks and the most on the most appropriate phase curve for the taken method. In some cases, this is not yet the desired rotation period and needs adding analysis in shorter ranges around peaks with a probability high 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. 1).

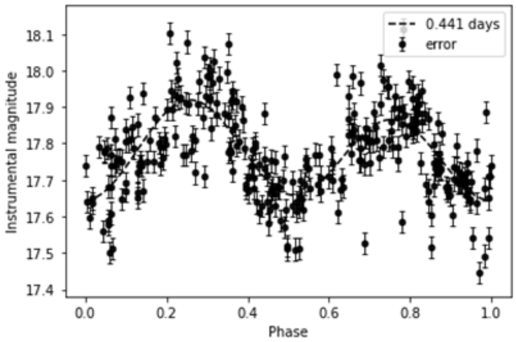

Figure 1. The calculated the light curve for asteroid Nr 4747 with L-S method

The second characteristic is that the shape of the power peak should resemble a Gaussian distribution. These features will be taken into account 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 take into account both the different number of the different number of observations in the data set and observe the probability/significance values of the power spectrum peaks obtained in the analysis.

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 – 3000k). 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 time-scale 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 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 region is very interesting from the point of view of the formation of carbon life forms.

In the previous years, 316 C stars are discovered in Baldone Observatory and their inclosing 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 gradually declining to the celestial equator. At the exposures from 120 to 480 seconds, the captured photons from red objects cover the region from 5500Å to 10000Å. Bands seen in the spectra of carbon stars mainly belong to the strong CN molecule of red system bands, the redder Swan system C_2 band, sodium doublet, and the Earth atmospheric O_2 A- band (approximately at 7650Å). In the last ten years in Baldone observatory 53 new carbon stars are 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 $M_k - K + 5lgr + A_k + 10 = 0$, where A_k is interstellar absorption, M_k absolute magnitude in K passband, 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 digitization of Baldone Schmidt archive astronomical photo plates

From 1966 Baldone Schmidt operate in the Astrophysical Observatory of University of Latvia. During 39 years continuing observations on phtographic plates and more than 24500 are saved in Observatory archive [3]. Archive contains positions ans brightness of about 2 billion stars in U, B, V, R passbands and Observatory has an electron scan copies. Archive contains regular observations in the selected region of sky during 30-40 year period. Now Baldone astronomer made processing of scans with LINUX/MIDAS/ROMAFOT 64-bit software complex to obtain equatorial coordinates.

Acknowledgments

Studies of small Solar bodies is funded by the ERDF project No. 1.1.1.5/19/A/003.

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Space compacts as a means to implement Space2030 Agenda linking space sciences and technologies to UN Sustainable Development Goals

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Space2030 Agenda is the UN initiative with the theme "Space drives sustainable development". The authors are developing an approach for member states, international organizations, regions, cities and other civil organizations 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 are instruments proposed by Riga Photonics Centre are modelled on UN Energy Compacts that were created to advance UN SDG7 – universal access to sustainable, reliable, and affordable energy by 2030 that are registered by UN Energy. Space Compacts hold promise for broader application than Space2030 Agenda implementation with the potential to address 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..." 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 Riga Photonics Centre and other partner organisations.

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

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Riga Photonics Centre's African Smart Communities project with the African Network for Solar Energy (ANSOLE) aims to accelerate development of rural communities in Sub-Saharan Africa (SSA) through use of AI tools. In the pilot phase university partners in Cameroon, Kenya, Nigeria and Rwanda will work with communities to show how ChatGPT and other digital tools can be used by rural communities to make decisions about matters where they have no experience including energy technologies, investments, securing clean water, and producing products that can be sold to generate cash that can be used to pay for products like solar cells and batteries. ChatGPT shows promise in providing useful responses in highly diverse situations including rural environments in the SSA. Plugins from Wolfram can contribute to the accuracy of ChatGPT and African data sets from African partners can make ChatGPT more relevant to African users. In mid-June actual use data is planned to be reported out at a workshop in Nigeria. By the end of November 2023 African data sets should be available to improve the usefulness of the African Smart Communities approach to accelerate community development particularly for access to electricity and clean water. Technical support has been promised from USAID's Center for Digital Development. Working relations are being developed with the African Center for Technology Studies, the RMI African Microgrid Network, and other centres of relevant expertise.

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

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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[24] and A040-ET[25] 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 utilized 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.

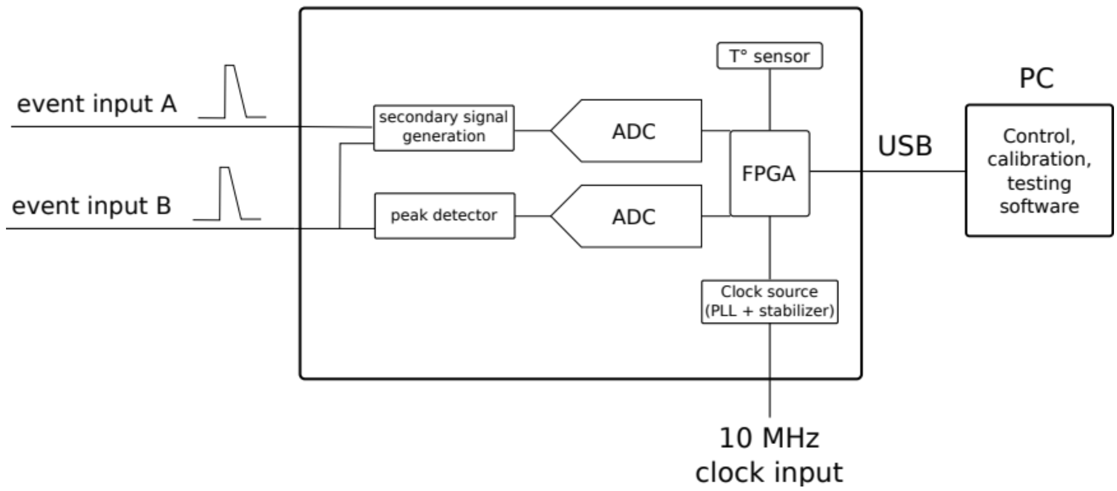

Figure 1. *The architectural overview of the ETAM device*

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.

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

24 https://www.edi.lv/wp-content/uploads/2019/11/A033ET-Family-2017_Riga.pdf
25 https://www.edi.lv/wp-content/uploads/2019/07/InfSeminar20200227v3.pdf

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}.

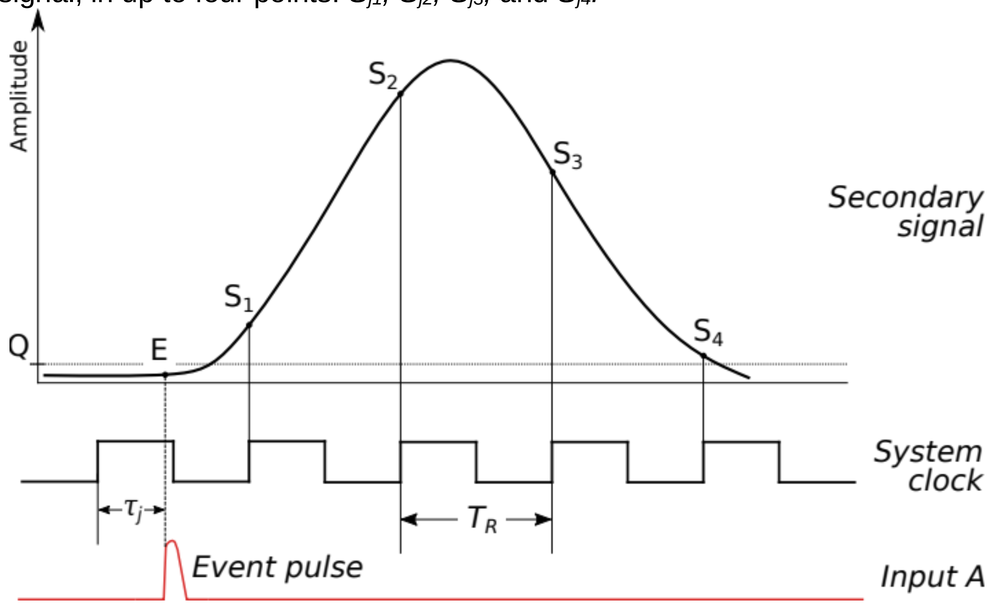

Figure 2. *The principles of the Enhanced Event Timing method [1]. The shape of the secondary signal is shown, in relation to the timing of the input pulse (event) and the system clock*

The event input B is also connected to a peak detector circuit (Fig. 1). The pulse amplitude measurement technology of ETAM operates on the digitization 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) apparatus, 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.

The new ETAM will not only reduce the dead time, but also simplify the setup for using Event Timers in SLR applications, and potentially 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. $\tau(u)$ 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.

Table 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

	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) <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) <2.3 mV (1V pulse amplitude)
Pulse amplitude measurement accuracy	-	<50 mV (any shape and width pulse) <5 mV (if tuned for particular shape and width pulse)

Acknowledgments
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Next Generation's Relativistic Radio-Physical Gravimeter for Geology, Seismology and Geodesy

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Due to general scientific progress, now is 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[26])*. Operational and ultraprecise information of characteristics of the Earth's gravitation 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 geophysical processes in the lithosphere and near-Earth space[27] mobile ground-based / marine-based / air-based facilities will be needed to record the global spatial-temporal distribution of gravitational fields with the maximum of resolution.

We present the prototype of the unique mobile relativistic radio physical gravimeter *RG-α MOBILE (IPR secured by 6 patents[28])* based on 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 increase substantially the precision *(up to 10^{-14})* of recording the tiniest details of the profile of Earth gravitational field. This is an exclusive game-changing novelty, offering new, never been before acknowledged perspectives in geology, seismology, geodesy, cartography and industry, mining *(gas&oil extraction)* and building industry especially. There are no on the market, produced in series gravimeters based on such sophisticated physical principle which allows to measure gravity constant, and the mass of the physical object simultaneously with never reached resolution.

The prototype of *RG-α MOBILE* gravimeter *(fig 2,3 below)* 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 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 utilize the data to determine subsoil conditions;

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- 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).*

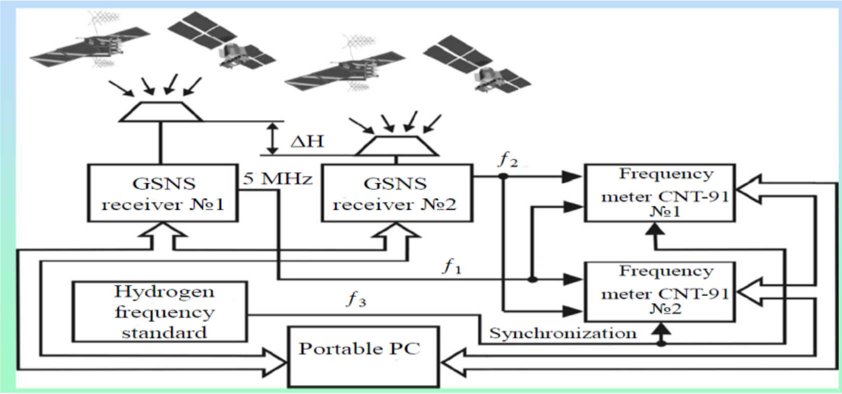

Figure1. *The principal scheme outlying RG-α MOBILE device*

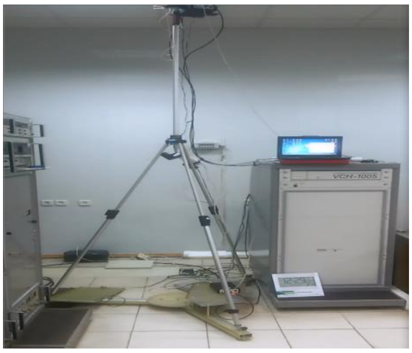

Figure 2. *Configuration and geometry of RG-α MOBILE prototype, tested in real environment (TRL ≥ 6).*

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 European Project ĒuropeanSpaceHub". The implementation period is almost two years and budget are covered fully by UL. The project involves research platform Photonics-LV, Institute of Astronomy of Latvia, UL and will create 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.

The main goals of the EuropeanSpaceHub in Latvia are:

- to create vibrant space cluster involving radioastronomy and space geodesy local facilities and photonics research competence from other UL and Riga Technical University structural units, Daugavpils University, Ventspils Applied Science University and Rezekne Academy of Technologies;
- Use the Photonics Platform as a solid base to collaborate with main European Photonics research centres and local industry thus creating interactive local space ecosystem as a node to network with other such ecosystems;
- Create space incubation capacity based on one of university's business incubators';
- Provide to local partners with entrepreneurial and innovation training, mentoring, and funding opportunities, including testing of new training modules;
- Create a new tech transfer strategy and entrepreneurship liaison for universities to strengthen entrepreneurial and innovation ecosystems;
- Develop a strategy for local space innovation ecosystems;
- Connect the space ecosystems of universities and industry via a EuroSpaceHub digital platform to increase collaboration and valorisation of tech transfer, and to leverage start-up projects with access to networks;
- Connect events with 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 in (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 (UL).

The research performed so far 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. Quality human capital and sustainable and sufficiently financed space related research.
5. Venture friendly markets for novel and innovative space products and
6. Infrastructure support including large scale research facility operation, maintenance, and renovation.

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

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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 and the associated meteorites treasure limitless information on processes occurring on these planetary bodies. Nowadays 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 materials are primitive rocks of the solar system. To distinguish them, 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].

Darkening from shock

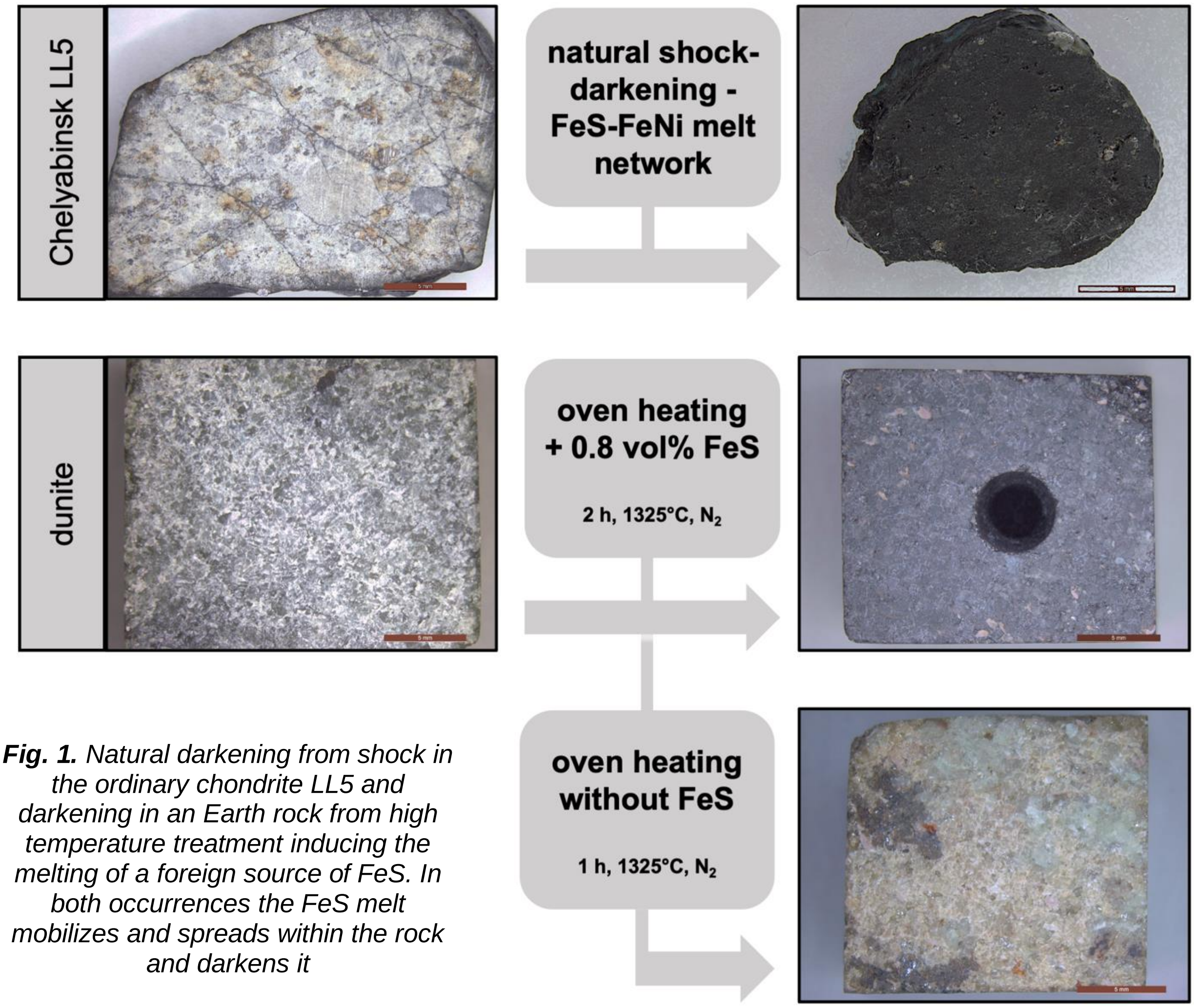

Fig. 1. *Natural darkening from shock in the ordinary chondrite LL5 and darkening in an Earth rock from high temperature treatment inducing the melting of a foreign source of FeS. In both occurrences the FeS melt mobilizes and spreads within the rock and darkens it*

The research that will be held at the University of Latvia and in partnership with the University of Tartu, Estonia, centres on one specific process: the shock darkening of ordinary chondrites [3]. This process involves the melting of iron sulphides and their remobilization within 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. The research is a combination of 3 aspects: 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 to study shock processes in meteorites [4,5], 3) systematic study of the chemical and physical markers of the melting and mobilization of iron sulphides within rocky materials to better characterize shock-darkening [6] (Fig. 1). 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 held 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 well-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.

Bridging the gap: geology and astrophysics

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.

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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 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.

The main outcome of these studies has been achieved during the 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)”.

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BOOK OF ABSTRACTS

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