83rd International Scientific Conference of the University of Latvia 2025

Atomic, molecular, and optical physics section (UL FST Laser Centre section)

Book of Abstracts

Wednesday, 29th of January 2025, 11:00 AM
University of Latvia, Jelgavas iela 3, room 801/802

Laser Centre

UNIVERSITY OF LATVIA

Atomu, molekulu un optiskas fizikas sekcija (LU EZTF Lāzeru Centra sekcija)

Atomic, molecular, and optical physics section (UL FST Laser Centre section)

Wednesday, **29th of January 2025, 11:00 AM**,
Jelgavas iela 3, room 801/802

Programma/Programme

Chairpersons: Prof. Ruvins Ferbers, Prof. Marcis Auzinsh		
11:00–11:20	***K. Puķītis***	Exploration of near-infrared and short-term variability in spectra of post-AGB stars
11:20–11:40	***Ā. Lapiņš**, M. Tamanis, I. Klincāre, D. Jermacāne, I. Brakmane, R. Ferbers*	Reanalysis of K_2 molecule ground electronic state
11:40–12:00	***S. Filatov**, M. Auzinsh*	Exploring symmetries of two-qubit entanglement: Stabilizer group structure and Bloch sphere geometry
12:00-12:20	***V. Krūmiņš**, AEgIS collaboration*	Developments for Rydberg positronium spectroscopy
12:20-12:40	***O. Rudzītis**, R. Lazda, A. Asare, F. Gahbauer, M. Auzinsh*	Quantum Random Number Generation Using Nitrogen-Vacancy Centres in Diamond
12:40–13:10	**Kafijas pauze, diskusijas/Coffee break, discussions**	
13:10–13:30	***M. Jani**, R. Lazda, F. Gahbauer, A. Asare, M. Mrózek, A. M. Wojciechowski, W. Gawlik, M. Auzinsh*	Multi-parameter study of a diamond magnetometer
13:30–13:50	*A. Mozers, A. Nikolajevs, **J. Birznieks**, L. Miķelsons, F. Gahbauer, M. Auzinsh*	Sensitivity characterization of magneto-optical signals in atomic Cs with linearly polarized excitation
13:50–14:10	*A. Mozers, L. Seržane-Sadovska, J. Birznieks, **L. Miķelsons**, F. Gahbauer, M. Auzinsh*	Radio-frequency induced splitting of non-zero magnetic field magneto-optical double resonances for single- and double-photon magnetic-dipole transitions in the Cs ground state
14:10-14:30	*A. Mozers, **D. Jermacāne**, F. Gahbauer, M. Auzinsh*	Nonlinear-Zeeman-splitting error-free magnetooptical signals using higher order coherences in ^{87}Rb
14:30–15:00	**Noslēgums, diskusijas/Conclusions, discussions**	

Exploration of near-infrared and short-term variability in spectra of post-AGB stars

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Almost nothing is known about the stellar wind in the beginning of post-asymptotic giant branch phase despite it directly and indirectly contributing to shaping of the subsequent planetary nebula. A way to observe physical processes in the extended atmospheres of post-asymptotic giant branch stars, that are related to the formation of the stellar wind, is provided by high-resolution spectroscopy. In particular, molecular lines have been proven to be effective in probing such processes in case of relatively cool post-AGB objects; however, investigation of molecular features in high-resolution has been limited to sub-micron wavelengths. Lower resolution studies in longer near-infrared wavelengths have revealed CO line variability and linked it with episodic mass loss [1,2].

I have observed high-resolution spectra up to 1.7 microns in the near-infrared of early post-asymptotic giant branch stage stars IRAS 22272+5435, IRAS Z02229+6208, and IRAS 20000+3239. Variable CN Red system lines belonging to various vibrational bands and Δv=3 bands of the CO molecule (Figure 1) are visible in spectra of all three stars. Only in the case of IRAS 22272+5435 variability in CN and CO lines is qualitatively similar. Additionally, I have found evidence for possible intraday variability in the spectrum of IRAS Z02229+6208.

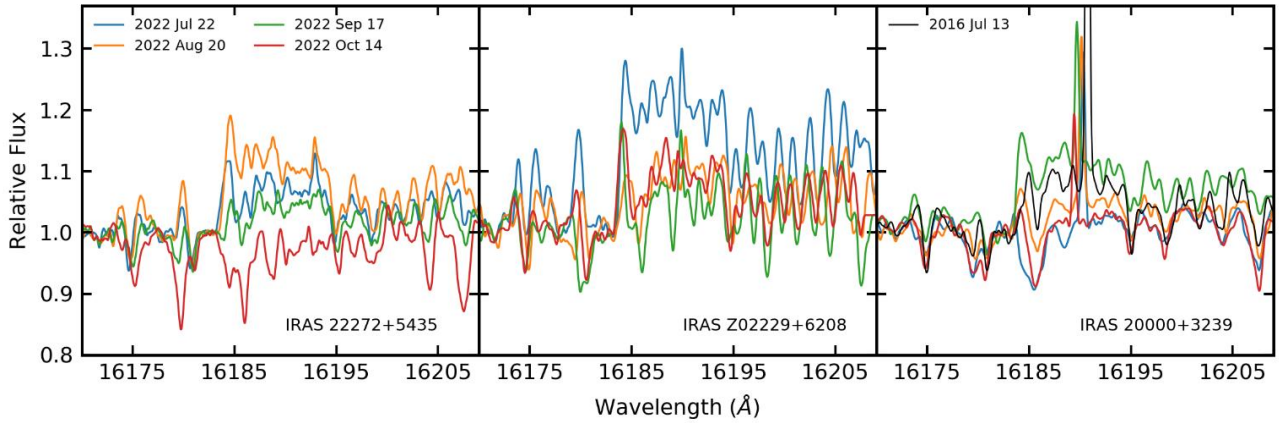

Figure 1: Variability in the CO (6,3) bandhead. Variable features shortward of 16182 Å are CN Red lines. Intense telluric emission at around 16190 Å is visible in the case of IRAS 20000+3239.

Acknowledgement:

This research is financed by the Recovery and Resilience Facility project "Internal and External Consolidation of the University of Latvia" (No.5.2.1.1.i.0/2/24/I/CFLA/007) by implementing grant project “Exploration of near-infrared and short-term variability in spectra of planetary nebulae precursors” (LU-BA-PG-2024/1-0020).

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Reanalysis of K_2 molecule ground electronic state

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The state-of-art determination of exact potential energy curves (PECs) of excited electronic states for any diatomic molecule requires very accurate description of the ground electronic state. Under the current investigation, we examine the models [1,2] of the description of K_2 ground electronic state. The accuracy problem of the description of K_2 ground state emerged during our recent study of $A^1\Sigma_u^+ \sim b^3\Pi$ excited states complex in K_2 [3]. Initial tests of reproducing the line positions in K_2 laser induced fluorescence (LIF) spectra to the vibrational-rotational v'', J'' levels of the ground $X^1\Sigma_g^+$ state by Dunham matrix [1] and PEC [2] have shown that experimental line positions ν_{expt} differ from calculated counterparts ν_{calc} , and the difference has an oscillating character, see Fig1a. A preliminary analysis of this behaviour was done in the BS thesis of D. Jermacane [4]. In present work we report the very accurate measurements of line positions and the analysis of dependences $\nu_{expt} - \nu_{calc}$. A software was developed to approximate the spectral line profiles by a Gaussian function which allowed to increase the measurement accuracy.

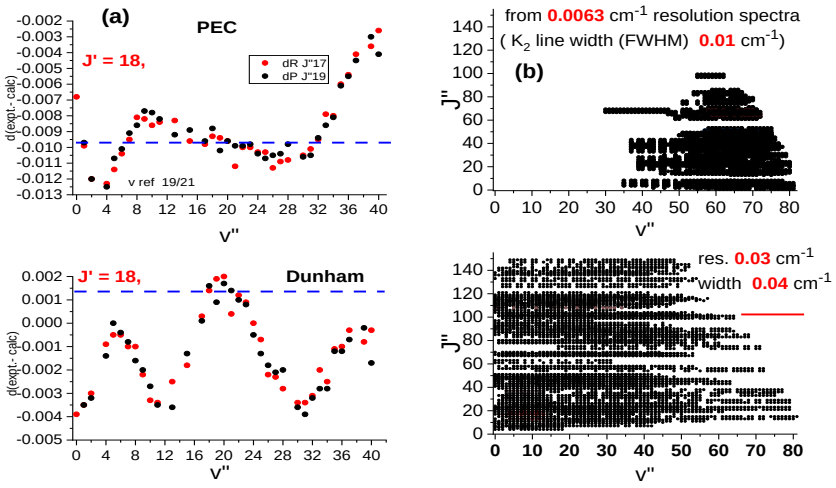

Figure 1. (a) The difference between measured and calculated line positons in LIF doublet progression obtained by PEC [2] and Dunham matrix [1] as dependent on the X-state vibrational levels.; (b) present data field of measured transitions.

This allowed us to create new and improved data field of experimental line positions for progressions with different rotational quantum numbers. The present data field is shown in Fig.1b. We aim to construct improved PEC which would avoid observed description drawbacks.

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Exploring symmetries of two-qubit entanglement: Stabilizer group structure and Bloch sphere geometry

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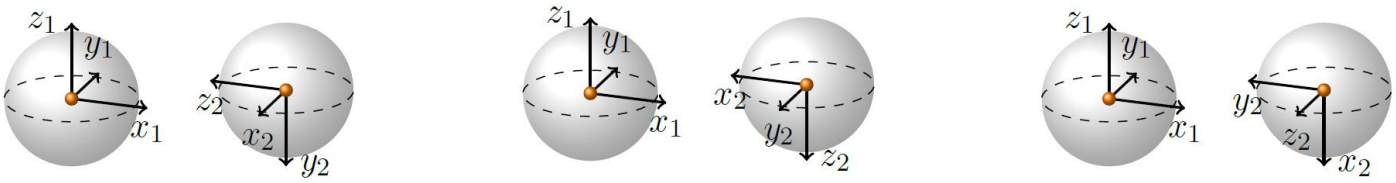
We provide a novel graphical representation of two-qubit quantum states, focusing on entanglement, using two Bloch spheres. Unlike previous methods, this approach assigns a Bloch sphere to each qubit, even when entangled, visualizing local operations as rotations of individual spheres. The key innovation is connecting this graphical representation to the algebraic description through the stabilizer formalism.

This method visualizes entanglement through stabilizer groups, whose elements leave the state invariant, linking algebraic and graphical representations. Entanglement is visualized by the relative orientations of the two Bloch spheres' coordinate axes, derived from the stabilizer group. For example, the Bell state $|\Psi^-\rangle$'s stabilizer group dictates anti-alignment of corresponding axes, visually capturing entanglement's non-local correlations. Local operations, represented by axis rotations, directly alter these relative orientations, visually demonstrating their effect on entanglement. Furthermore, this visualization reveals connections between seemingly disparate entangled states. For instance, states like $\frac{1}{2}(|\uparrow\uparrow\rangle - i|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle - i|\downarrow\downarrow\rangle)$ and $\frac{1}{2}(|\uparrow\uparrow\rangle - |\uparrow\downarrow\rangle - i|\downarrow\uparrow\rangle - i|\downarrow\downarrow\rangle)$, which appear algebraically different from $|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$, are shown to be related by simple rotations of the Bloch spheres and corresponding transformations of their stabilizer groups. This approach facilitates the exploration of symmetries in two-partite Hilbert space.



(a) $\frac{1}{2}(|\uparrow\uparrow\rangle - i|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle - i|\downarrow\downarrow\rangle)$ (b) $|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$ (c) $\frac{1}{2}(|\uparrow\uparrow\rangle - |\uparrow\downarrow\rangle - i|\downarrow\uparrow\rangle - i|\downarrow\downarrow\rangle)$

Figure 1: Two Bloch Sphere representations of the entangled states obtained by cyclic permutation of second BS coordinate axes of the state ($|\Psi^-\rangle$) $\{x_2; y_2; z_2\}$ (b) to $\{z_2; x_2; y_2\}$ (a) and $\{y_2; z_2; x_2\}$ (c).

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Developments for Rydberg positronium spectroscopy

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The goal of AEgIS is a measurement of the free fall of antihydrogen. The antihydrogen is formed using charge exchange reaction between positronium and antiprotons. As the cross section for this reaction is dependant on the fourth power of n level of positronium, it is crucial to excite it to high Rydberg states. [1]

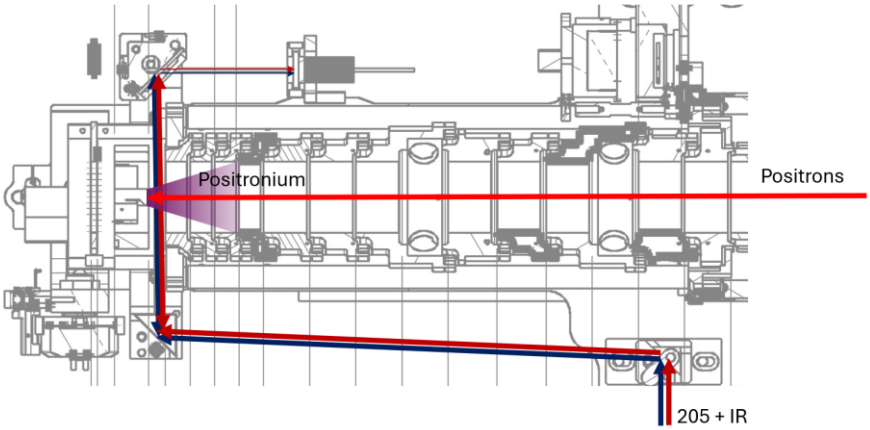

Figure 1: Scheme of AEgIS trap showing positronium formation and laser excitation.

In AEgIS apparatus positronium is first formed in a silica target with nanochannels and then excited using a 2-step process first to 3P state with a 205nm laser and then to Rydberg states using a tuneable 1640nm - 1680nm laser.

We have developed a new tool for the diagnostics of the Rydberg positronium. When applying high voltage to an electrode in the AEgIS trap, we produce a non-uniform electric field which can ionise Rydberg positronium of sufficiently high state. Positrons from the ionised positronium are imaged using an MCP and a phosphor screen. From the images and a map of the electric field it is feasible to estimate the n distribution of the Rydberg positronium.

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Quantum Random Number Generation Using Nitrogen-Vacancy Centres in Diamond

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We propose to explore NV centres in diamond as a single photon sources to generate quantum random numbers (QRNG) using the emitted excited state photon.

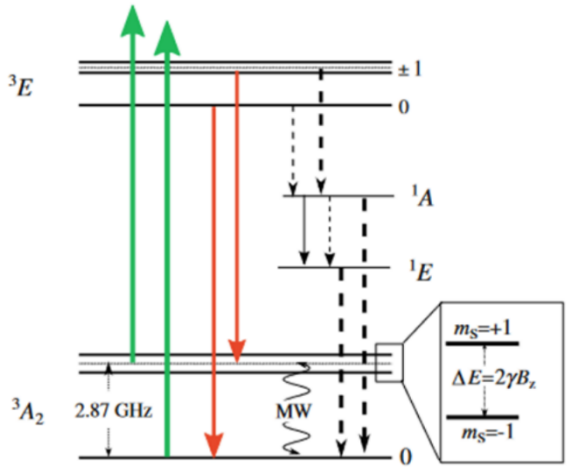

Figure 1: Energy level scheme of an NV centre [1].

The project will consist of a XY translation stage to move the single NV centre to the focused laser. This will solve one of the main obstacles in QRNG of guaranteeing that only a single NV centre is excited by the laser. Furthermore, a 50/50 beam splitter will be used to guarantee that the emitted photon arrives at one of the two single photon detectors and ensures the “quantumness” of the generated number.

The quantum random number will be generated by these detectors. A one will be generated if the detector detects a photon and a zero will be generated if the other detector detects the photon.

Currently the main problems being solved are related to the density of the NV diamond, a lower density diamond is preferred, and the detection of single photons being another main obstacle in QRNG.

Acknowledgment:
Recovery and Resilience Facility project "Internal and External Consolidation of the University of Latvia" (No.5.2.1.1.i.0/2/24/I/CFLA/007), grant project “Single Photon Sources for Quantum Technologies Using Nitrogen-Vacancy Centres in Diamond”, No. LU-BA-PA-2024/1-0071, ESS2024/465-PA-05.

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Multi-parameter study of a diamond magnetometer

M. Jani[1]*, R. Lazda[1]*, F. Gahbauer[1], A. Asare[1], M. Mrózek[2], A. M. Wojciechowski[2], W. Gawlik[2], M. Auzinsh[1]

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Negatively charged nitrogen-vacancy (NV) diamond magnetometers are promising candidates for room-temperature magnetic field sensing. However, systematic studies of magnetic field sensors that evaluate the sensitivity of NV-diamond magnetometers as a function of multiple parameters are sparse. By comparing optically detected magnetic resonance (ODMR) dips for four single-crystal diamonds, we explored how the photon shot-noise-limited sensitivity and experimental magnetic noise floor were influenced by the density of the NV centers and methods of their formation. The lowest shot-noise-limited sensitivity was 380 pT/√Hz; it was significantly affected by ODMR fluorescence, contrast, and linewidth. Using dual-resonance modulation in ODMR, the experimental lowest magnetic noise floor based on power spectral density was 1.14 nT/√Hz. These values can be improved with an increase in laser power. This study [1] will facilitate the selection of appropriate NV diamonds when designing magnetometers for various applications.

Acknowledgment:
This work was supported by the “Latvian Quantum Technologies Initiative” project under the European Union Recovery and Resilience Facility, Grant No. 2.3.1.1.i.0/1/22/I/CFLA/001 and from the Latvian Council of Science, project No. lzp-2021/1-0379: titled “A novel solution for high magnetic field and high electric current stabilization using color centers in diamond”

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Sensitivity characterization of magneto-optical signals in atomic Cs with linearly polarized excitation

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In this research we are experimentally studying the interaction of Cs atoms and linearly polarized laser light to very accurately measure the change in magnetic field by analysing the absorption signal. The studied measuring technique of magnetic field is used in optically pumped magnetometers which have broad uses in medicine and in some cases their sensitivity may surpass that of superconducting quantum interference devices.

The geometry in our experiment is based on [1]. More precisely we are trying to determine the sensitivity of the magnetometer by looking at signals which are obtained using this setup for different pump beam intensities (Rabi frequencies), relaxation rates and angles between the B vector and the x-axis (see Figure 1).

In the experiment Cs atoms interact with the linearly polarized pump beam creating an aligned state of the angular momentum probability distribution of the atoms. Applying an external magnetic field starts a precession of the aligned state around the axis of the magnetic field. This change in the distribution is measured by the low intensity probe beam and through it the resulting dispersive absorption signal is obtained. Taking only one probe beam polarization component leads to the absorption signal shape being a mixture of dispersion and Lorentz type curve. We found that this can be overcome by introducing a second component to each of the probe beam components that is symmetric around the plane defined by E_p and B (z-axis). We could then obtain the optimal values of the parameters for the theoretical absorption curves. The relative sensitivities were obtained as the derivatives of these difference signals at zero magnetic field. Our results show that the highest sensitivity can be achieved with lower values of relaxation rates and pump beam intensities around 0.5 MHz. The dependency of sensitivity on the angle of magnetic field can be compensated by measuring the polarization on two axes (E_x and E_y) simultaneously.

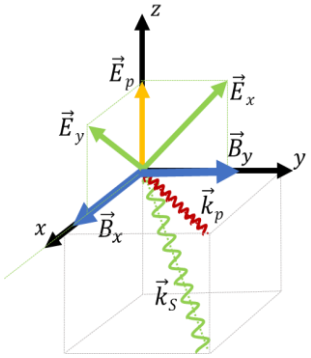

Figure 1: The pump-probe geometry for measuring two orthogonal field components.

Acknowledgment:
We acknowledge the support from the Latvian Council of Science, project No. lzp-2020/1-0180: “Compact 3-D magnetometry in Cs atomic vapor at room temperature”

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Radio-frequency induced splitting of non-zero magnetic field magneto-optical double resonances for single- and double-photon magnetic-dipole transitions in the Cs ground state

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Autler-Townes effect induced ^{133}Cs D_1 magnetic resonance splitting was observed in two different experimental configurations (See Fig.1 (a) and (b)). In both configurations splitting of the peaks associated with single photon transitions were demonstrated to be linearly dependent on the amplitude of the radiofrequency (RF) field as was expected. Furthermore, given that the geometry configuration in figure 1(b) allows for 3 distinct angular moment values q=0, q=±1, we also observed splitting of peaks associated with double photon transitions which were quadratically dependent on the amplitude of RF. We note that while the results are showcased for the ^{133}Cs D_1 F_g=4→F_e=4 transition, similar results were observed for other ^{133}Cs D_1 transitions. Additionally, we observed splitting of peaks, corresponding to three- and half-photon energies, which could be studied further in future, possibly providing insight into novel physical processes.

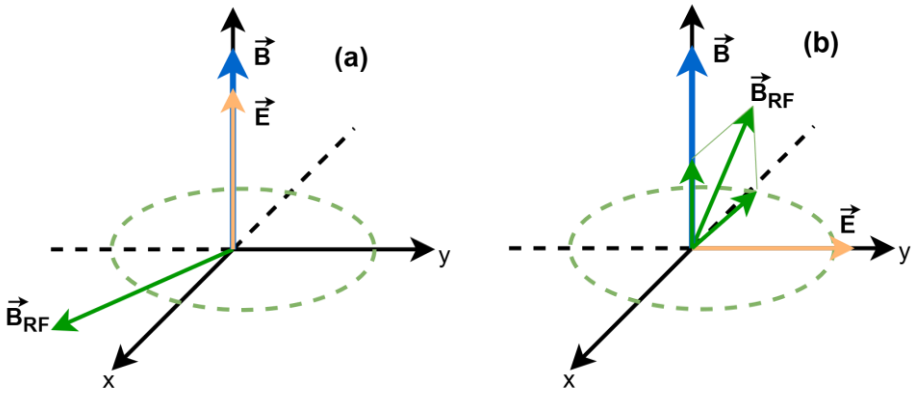

Figure 1: Excitation geometries for observing the magneto-optical double resonances.

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Nonlinear-Zeeman-splitting error-free magnetooptical signals using higher order coherences in ^{87}Rb

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Magnetooptical signals in atomic magnetometers can provide high precision of measurement if no background magnetic field is present. The precision and performance of atomic magnetometers is reduced in external magnetic fields such as the geomagnetic field due to the nonlinear Zeeman (NLZ) effect, causing significant errors. In our project, we explore the possibility to use specific magnetic sublevels of atomic ^{87}Rb in the ground state $5^2S_{1/2}$, specifically, $F_g=2$, $m_{Fg}=2$ and $F_g=2$, $m_{Fg}=-2$ sublevels. The energy of these sublevels changes linearly in respect to magnetic field. To physically excite these specific magnetic sublevels, a laser beam with specific amplitude modulation frequency can be used – first, to excite both $\Delta m_{Fg}=2$ and $\Delta m_{Fg}=4$ coherences, and second, after flipping the phase of the modulation frequency, when the $\Delta m_{Fg}=2$ coherences are eliminated, the fluorescence signal originating only form $\Delta m_{Fg}=4$ coherences could be obtained, as it is visually represented in Figure 1. The external magnetic field value can be determined from the fluorescence signal as a function of modulation frequency.

In the project, it is planned to increase the accuracy of ^{87}Rb atomic magnetometers by completely eliminating errors caused by NLZ effect via the creation of hexadecapole moments ($\Delta m=4$ coherences) with a precise sequence of modulation pulses as well as improve the sensitivity by using fluorescence signals.

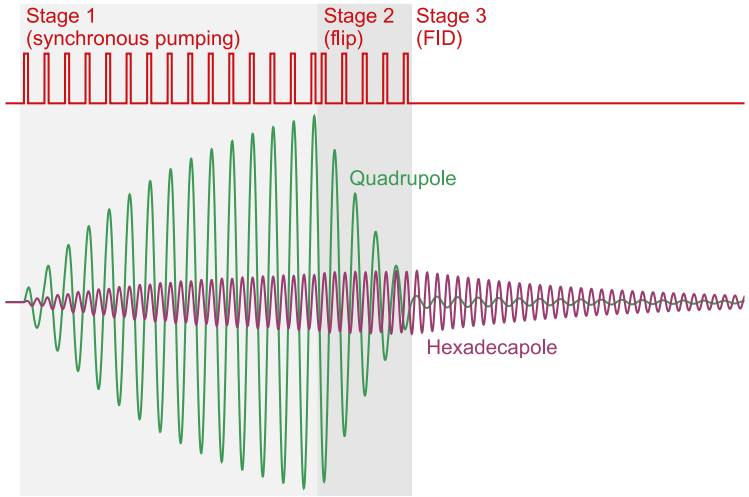

Figure 1: The real part of quadropole (green) and hexadecapole (purple) component moments depending on time and laser modulation frequency (red) [1].

Acknowledgment:
We acknowledge the support from the Latvian Council of Science, project No. lzp-2020/1-0180: “Compact 3-D magnetometry in Cs atomic vapor at room temperature”

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[1] V. M. Acosta, et al., *Optics Express, **16**, 11423*, (2008)

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