Q 56: Poster VII

Time: Thursday 17:00–19:00 Location: KG I Foyer

Q 56.1 Thu 17:00 KG I Foyer

High-order harmonic generation in gases with μJ laser pulses — •Matthias Meier[1], Philip Dienstbier[1], Yuya Morimoto[2], Francesco Tani[3], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]RIKEN Cluster for Pioneering Research (CPR), RIKEN Center for Advanced Photonics (RAP), Japan — [3]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Applying strong few-cycle pulses in the infrared together with attosecond pulses in the ultraviolet regime in a pump-probe scheme provides a mighty tool for spectroscopy of ultrafast electron dynamics. In order to improve statistics as well as signal-to-noise ratio while keeping the measurement time to a minimum, high repetition rates are desirable. Here, we present a laser system operating at 1 MHz which delivers near infrared 8 fs pulses with an energy of 10 μJ. These pulses drive the process of high-order harmonic generation in an adjacent vacuum chamber where the pulses can furthermore be characterized. The infrared pulses are obtained from shortening 210 fs pulses of an Ytterbium laser amplifier with stable carrier-envelope phase by means of a two-stage compressor based on two argon-filled hollow-core photonic crystal fibers.

Q 56.2 Thu 17:00 KG I Foyer

Influence of molecular properties on matter-wave interferometry — •Lukas Martinetz[1], Benjamin A. Stickler[2], Ksenija Simonović[3], Richard Ferstl[3], Markus Arndt[3], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Germany — [2]Ulm University, Germany — [3]University of Vienna, Austria

Matter-wave interferometers served to confirm the wave-particle duality with large molecules [1] and enabled to prepare highly delocalized quantum states with molecules of ever increasing mass [2]. Since the internal molecular dynamics can play a decisive role in the interaction with the diffraction grating, matter-wave interferometers hold out the prospects of being sensitive probes for molecular properties. Here, we quantify the impact of these properties by calculating the interference pattern of molecules that are diffracted at a standing laser wave. The interaction with the laser enters through the Talbot coefficients, which incorporate state-dependent polarizabilities and photon-absorption cross sections, and the depletion of the molecular beam through ionization or cleavage. Furthermore, our calculation accounts for the finite size of the particle source and collimation slits, for a distribution of initial particle velocities, as well as for gravity, the Coriolis force and an asymmetric standing laser wave due to non-ideal retroreflection at the grating mirror. We display and discuss features of the pattern for the different molecular processes and compare our model with recent experiments aiming at measuring molecular parameters.

[1] M. Arndt et al., Nature 401, 680 (1999)
[2] Y. Y. Fein et al., Nat. Phys. 15, 1242 (2019)

Q 56.3 Thu 17:00 KG I Foyer

Tunable Bragg-diffraction beam splitters for molecular matter waves — •Eric van den Bosch[1], Benjamin A. Stickler[2], Lukas Martinetz[1], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Germany — [2]Ulm University, Germany

Matter-wave interferometry offers rich applications ranging from testing fundamental principles of quantum mechanics with large particles to probing material properties and measuring accelerations with high precision. The lack of brilliant sources for heavy particles requires efficient ways to split an incident wave packets into two branches. One way to achieve such large momentum beam splitters is Bragg diffraction at thick optical gratings, as realised experimentally in [1].

We study how further modulations of the laser grating, e.g. adiabatic application of an additional constant force, may extend established means to control populations in the interferometer arms [2], as well as provide a first step towards Bragg diffraction at thin gratings.

[1] Brand, Kiałka, Troyer, Knobloch, Simonović, Stickler, Hornberger, Arndt (2020). Bragg diffraction of large organic molecules. Physical Review Letters, 125(3) [2] Siemß, Fitzek, Abend, Rasel, Gaaloul, Hammerer (2020). Analytic theory for Bragg atom interferometry based on the adiabatic theorem. Physical Review A, 102(3)

Q 56.4 Thu 17:00 KG I Foyer

Atom interferometry with ultra-cold atoms in microgravity — •Anurag Bhadane[1], Julia Pahl[2], Dorthe Leopoldt[3], Sven Abend[3], Ernst M. Rasel[3], Markus Krutzik[2,5], Sven Herrmann[4], Andre Wenzlawski[1], Patrick Windpassinger[1], and The QUANTUS Team[1,2,3,4,6,7] — [1]JGU Mainz — [2]HU Berlin — [3]LU Hannover — [4]U Bremen — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

QUANTUS-2 is a mobile, robust, high flux ^{87}Rb atom interferometry device that can operate in the microgravity environment provided by the drop tower and Gravitower located in Bremen and act as a pathfinder for future space missions. QUANTUS-2 exploits a magnetic lens enhanced by the quadrupole field of the atom chip which enables longer coherence times under microgravity to perform atom interferometery over one second with double Bragg diffraction.

Here, we present the latest results on atom interferometry on extended time scales in the drop tower and initial experiments in the Gravitower.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Climate Action under grant number DLR 50WM1952-1957.

Q 56.5 Thu 17:00 KG I Foyer

Generating auto-ponderomotive potentials using flat, chip-based electrodes for shaping electron beams — •Franz Schmidt-Kaler, Michael Seidling, Robert Zimmermann, Nils Bode, Fabian Bammes, Lars Radtke, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Manipulating free electron beams has been realized with complex electrostatic fields generated with planar electrodes. Within the frame of the moving electron, these static fields transform into an alternating auto-ponderomotive potential, resembling the one of a microwave-driven Paul trap confining the electrons. Prior, we showed that we can split and guide electron beams along curved paths this way, with electron energies ranging from a few electron volts to 1.7 keV (for splitting) and 9.5 keV (for guiding). Here we focus on electron beam resonators. We have demonstrated the first linear version to work for 50 eV electrons and measured its coupling efficiency. All configurations can be integrated into standard SEM*s, offering entirely new options for future coherent electron control. Interaction-free measurement schemes based on repeated electron sample interaction could benefit greatly.

Q 56.6 Thu 17:00 KG I Foyer

Characterization of auto-ponderomotive electron guides — •Nils Bode, Franz Schmidt-Kaler, Fabian Bammes, Lars Radtke, Michael Seidling, Robert Zimmermann, and Peter Hommelhoff — Physik Department, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

Advanced control over electron beams may enable new coherent electron applications such as a quantum electron microscope. With the help of auto-ponderomotive structures, we have recently demonstrated electron guiding with energies ranging from 20eV to 9,5keV. These electron guides utilize patterned electrostatic electrode assemblies, which, seen from the comoving frame of the electron, generate a pseudopotential similar to conventional Paul traps. We investigate the stability regions of these new 2D traps as well as the coupling efficiencies, both numerically and in experiment, for beam energies between 50eV and 500eV. Additionally, the interim deceleration of electrons inside the guiding potential down to energies of about 0.1eV was simulated. Initial preliminary measurements show a successful deceleration of 40% for an 500eV electron beam.

Q 56.7 Thu 17:00 KG I Foyer

Demonstration of a well-controlled atomic source for Very Long Baseline Atom Interferometry — •Dorothee Tell, Vishu Gupta, Kai Grensemann, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The sensitivity of an atom interferometer measuring the acceleration of a freely falling atomic ensemble can be increased by scaling up the available free fall time. At the Hannover Very Long Baseline Atom Interferometry (VLBAI) facility, we have set up a 10 m long baseline for fountain interferometry with up to 2.4 s of free fall. This promises highly accurate measurements of gravitational accelerations for gravimetry, but also offers several possibilities to test fundamental physics, e. g. at the interface of quantum mechanics and general relativity. However a high level of control over all systematic effects and noise sources is necessary.

This contribution focuses on the source of rubidium Bose-Einstein condensates recently installed in the facility to complete the setup. We demonstrate how the strict constraints necessary for the operation of a highly accurate inertial sensor can be realized. This comprises a fast all-optical evaporation sequence, flexible methods for manipulating the atoms in a time-averaged optical dipole trap e. g. for reducing the expansion speed during free fall, and methods for a well-controlled, efficient launch of the atoms into the baseline based on an accelerated Bloch lattice.

Q 56.8 Thu 17:00 KG I Foyer

Atomic diffraction from single-photon transitions in gravity and Standard-Model extensions — •Alexander Bott[1], Fabio Di Pumpo[1], and Enno Giese[2,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Technische Universität Darmstadt, Fachbereich Physik, Institut für Angewandte Physik, Schlossgartenstr. 7, D-64289 Darmstadt, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

Single-photon transitions are one of the key technologies for designing and operating very-long-baseline atom interferometers tailored for terrestrial gravitational-wave and dark-matter detection. Since such setups aim at the detection of relativistic and beyond-Standard-Model physics, the analysis of interferometric phases as well as of atomic diffraction must be performed to this precision and including these effects. In contrast, most treatments focused on idealized diffraction so far. In this contribution, we study single-photon transitions, both magnetically-induced and direct ones, in gravity and Standard-Model extensions modeling dark matter as well as Einstein-equivalence-principle violations. We take into account relativistic effects like the coupling of internal to center-of-mass degrees of freedom, induced by the mass defect, as well as the gravitational redshift of the diffracting light pulse. To this end, we also include chirping of the light pulse required by terrestrial setups, as well as its associated modified momentum transfer for single-photon transitions.

Q 56.9 Thu 17:00 KG I Foyer

Atom interferometers in weakly curved spacetimes: Case study of the VLBAI — •Michael Werner and Klemens Hammerer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We present a systematic approach to determine all relevant phases in the VLBAI (Very Long Baseline Atom Interferometer) experiment in Hannover, including (general-) relativistic effects and certain noise sources. Through this approach, we automate the derivation of algebraic expressions for all relevant phases and analyze the impact of mitigation strategies, spanning from the Coriolis effect to gravity gradients. Our objective is to enhance the precision of experiments performed in the VLBAI facility and deepen our understanding of the physics inside such a large scale setup for the detection of relativistic effects.

Q 56.10 Thu 17:00 KG I Foyer

Analytical theory of double Bragg atom interferometers — •Rui Li[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Leibniz University Hanover, Institute for quantum optics, Hannover, Germany — [2]Leibniz University Hanover, Institute for theoretical physics, Hannover, Germany

In this talk, we will provide some new physical insights into a commonly used tool in atom interferometry, namely the double Bragg diffraction (DBD). After reviewing the traditional treatment of DBD with rotating wave approximations and its limitations, we derive an effective two-level-system (TLS) Hamiltonian via Magnus expansion for describing the so-called *quasi-Bragg regime* where most light-pulse atom interferometers are operating. With this effective TLS Hamiltonian, we systematically study the effects of polarization error and AC-Stark shift due to second-order process on the efficiency of double-Bragg beam-splitters. Furthermore, we show that effects of Doppler broadening can be easily included by extending our TLS description to a three-level-system description. Finally, we design an optimal beam-splitter based on our effective theory via a time-dependent detuning and show its robustness against polarization error and asymmetric beam-splitting due to Doppler effect.

Q 56.11 Thu 17:00 KG I Foyer

Phase and error estimation of differential atom interferometry experiments on the ISS — •David B. Reinhardt[1], Nicholas P. Bigelow[2], Matthias Meister[1], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [3]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany — [4]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz Research School, Hanover, Germany

Matter-wave interferometers in space are excellent tools for high precision measurements, relativistic geodesy, or Earth observation. In differential interferometric setups common-mode noise can be suppresed and the differential phase enables the determination of magnetic field curvatures or gravity gradients. Precise estimation of the differential phase is therefore key as its error contributes significantly to the uncertainty of the whole measurement. If the ignorance about noise types is high and the number of measurements points is small the error estimation becomes severely more challenging. To tackle these issues, we present an improved ellipse fitting method for the estimation of phase, contrast, and population offset of differential interferometers as well as their errors using a modified least-square algorithm combined with bootstrapping of experimental data. Finally, we apply our new method to recent data from the CAL mission measuring magnetic field curvatures on the International Space Station.

Q 56.12 Thu 17:00 KG I Foyer

Quantum-clock interferometry — •Mario Montero[1], Ali Lezeik[1], Klaus Zipfel[1], Ernst M. Rasel[1], Christian Schubert[1,2], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik

The Equivalence Principle assumes the Universality of Gravitational Redshift (UGR), which asserts that the ticking rate of two idealized clocks in a gravitational field is independent of their internal composition. High-precision UGR tests confirm General Relativity's validity but hold the potential to reveal new physics if deviations are found. Quantum-Clock Interferometry (QCI) offers a UGR test based on specific interferometer geometries with delocalised optical clock states to measure differences in proper time affecting the interferometer's phase [1]. We propose an interferometer geometry sensitive to gravitational redshift that benefits from a common-mode rejection of noise effects.

The feasibility of QCI experiments measuring gravitational redshift depends on the availability of long-lived internal states with large energy difference, making the Yb optical clock transition an ideal candidate. We report on the status of our high-flux source of cooled Yb atoms [2]. The optical transition will be driven by a two-photon E1-M1 Doppler-free excitation, requiring a narrow linewidth and high power light source [3]. Here we present our ultra narrow clock laser at 1156 nm with high powers in excess of 20 W.

[1] PRX QUANTUM 2, 040333 (2023). [2] J. Phys. B: At. Mol. Opt. Phys. 54, 035301 (2021). [3] Phys. Rev. A 90, 012523 (2014).

Q 56.13 Thu 17:00 KG I Foyer

Multi-axis quantum gyroscope with multi loop atomic Sagnac interferometry — •Polina Shelingovskaia[1], Ann Sabu[1], Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[2], Matthias Gersemann[1], Dennis Schlippert[1], Ernst M. Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt,

Twin-lattice atom interferometers promise high-sensitivity rotation measurements. Our objective is to create a transportable multi-axis gyroscope.

This poster will present the technique of a multi-loop atom interferometer scheme that combines large momentum transfer with the possibility to increase the available free fall time.The focus is on the ongoing progress in the construction of the sensor head using BECs of ^{87}Rb atoms. The associated schematic and the realisation of the necessary laser system for cooling and manipulation are also highlighted.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's

Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and from DLR with funds provided by the BMWi under grant no. DLR 50NA2106 (QGyro+).

Q 56.14 Thu 17:00 KG I Foyer

Operating an atom interferometer in a vibrationally noisy environment — •Ashwin Rajagopalan, Ernst M. Rasel, Sven Abend, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik,
Welfengarten 1, 30167 Hannover, Germany

Quantum inertial sensing with atom interferometry is a promising tool for reliable and long term stable measurements of inertial effects. Due to its limited dynamic range and reciprocal response the challenge lies in being able to operate an atom interferometer (AI) in a high vibrational noise environment. We have demonstrated operating a T = 10 ms AI without any vibration isolation with the help of a compact opto-mechanical accelerometer. The accelerometer signal was used to suppress the effects of ambient ground vibrational noise coupling into our AI. The coupled noise with a Gaussian full width half maximum of 3.2 mm/s^2 obscures the AI fringes. With our approach, we were not only able to resolve AI fringes and remove measurement ambiguity, but could also measure at a level which is 8 times more sensitive than the ambient vibrational noise that the AI experiences. The new improved version of the opto-mechanical accelerometer has the potential for high precision AI and accelerometer correlation as they share the same inertial reference. We report on the preliminary results and discuss prospects for AI hybridization suitable for dynamic environments.

Funded by the DFG EXC2123 QuantumFrontiers - 390837967 supported by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+) and DFG SFB 1464 TerraQ.

Q 56.15 Thu 17:00 KG I Foyer

Artificial Intelligence for Quantum Sensing — •Victor Jose Martinez Lahuerta, Jan-Niclas Kirsten-Siemss, and Naceur Gaaloul — Leibniz University Hannover, Institut of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Algorithms from the field of artificial intelligence (AI) and machine learning have been employed in recent years for a variety of applications to efficiently solve multidimensional problems. In physics, these algorithms are applied with increasing success, for example, to solve the Schrödinger equation for many-body problems, or used experimentally to generate ultracold atoms and control lasers. In this project we aim to work on three fundamental pillars of AI in atom interferometry: theory modeling, measurement data extraction, and operation of experiments. Within this context, I will show our results modeling a diffraction phase-free Bragg atom interferometry.

Acknowledgements: This project is funded by the German Space Agency (DLR) with funds provided by the German Federal Ministry of Economic Affairs and Energy (German Federal Ministry of Education and Research (BMBF)) due to an enactment of the German Bundestag under Grant No. DLR 50WM2253A

Q 56.16 Thu 17:00 KG I Foyer

Dark Energy search using atom interferometry in microgravity — •Sukhjovan Singh Gill[1], Magdalena Misslisch[1], Charles Garcion[1], Ioannis Papadakis[2], Baptist Piest[1], Vladimir Schkolnik[2], Sheng-Wey Chiow[3], Nan Yu[3], and Ernst Maria Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany 30167 — [2]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany 12489 — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA 91109

The nature of Dark energy is one of the biggest quests of modern physics. It is needed to explain the accelerated expansion of the universe. In the chameleon theory, a hypothetical scalar field is proposed, which might affect small test masses like dilute atomic gases. In the vicinity of bulk masses, the chameleon field is hidden due to a screening effect making the model in concordance with observations. Dark Energy Search using Interferometry in the Einstein-Elevator(DESIRE) studies the chameleon field model for dark energy using Bose-Einstein Condensate of ^{87}Rb atoms as a source in a microgravity environment. The Einstein-Elevator provides 4 seconds of microgravity time for multi-loop atom interferometry to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity. This method suppresses the influence of vibrations, gravity gradients and rotations via common mode rejection. The specially designed test mass suppresses gravitational effects from self-mass and its environment. This work will further constrain thin-shell models for dark energy by several orders of magnitude.

Q 56.17 Thu 17:00 KG I Foyer

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice atom interferometry (AI) is a method for forming symmetric interferometers with matter waves of large relative momentum spitting by using two counter-propagating optical lattices. It has a prospect of enabling highly sensitive inertial measurements.
A limiting factor for large momentum transfer is the loss of contrast, associated with the differential absolute light shift of far detuned light fields, linked to light fields imperfections. Thanks to a flat-top shaped beam and addition of an oppositely detuned light field, this limitation can be mitigated, and new records in momentum separation can be achieved. This contribution presents the realization of a high power laser system for absolute light shift compensated twin-lattice AI with a monolithically mounted flat-top beam shaper.
We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and from DLR with funds provided by the BMWi under grant no. DLR 50WM2250 (QUANTUS+).

Q 56.18 Thu 17:00 KG I Foyer

Squeezing-enhanced Bragg guided BEC interferometry — •Matthew Glaysher[1], Robin Corgier[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Atom interferometers test fundamental theories and have practical applications such as gravimeters, gradiometers and gyroscopes. Using uncorrelated or classically correlated atomic probes state-of-the-art devices already operate at the standard quantum limit (SQL) set by their finite baseline and/or atom number resources.

To push the boundaries of compact devices, we study the realisation of a a Bose-Einstein condensate (BEC) guided interferometer based on Bragg diffraction [R. Corgier et al., PRA, 103 (2021)]. Taking advantage of the BEC oscillations in the waveguide and the possibility to tune atom-atom interactions we investigate the generation of spin-squeezing dynamics between the two modes in well-defined and well-controlled momentum states. The entangled input state feeds a second interferometer sequence with quantum-enhanced sensitivity capabilities. Realistic aspects of the state-preparation parameters, including diffraction efficiencies and BEC collisions and deformations, are addressed in our scheme.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 56.19 Thu 17:00 KG I Foyer

Three-dimensional absorption detection system in the transportable Quantum Gravimeter QG-1 — •Najwa Sophie Al-Zaki[1], Pablo Nuñez von Voigt[1], Nina Heine[1], Waldemar Herr[2], Christian Schubert[2], Ludger Timmen[3], Jürgen Müller[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Deutsches Zentrum für Luft und Raumfahrt, Institut für Satellitengeodäsie und Inertialsensorik, Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 is designed to determine local gravity to the low nm/s^2 level of uncertainty. The installation of two additional absorption detection systems allows the extension of the interferometer separation time 2T. The consecutive detection of the atomic ensemble in two directions enables reconstruction of their three-dimensional position and size, offering new tools for investigating limiting sources of error. This work focuses on estimating the uncertainty of the bias acceleration due to the Coriolis effect by analyzing the reconstructed three-dimensional trajectory.

We acknowledge financial funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID

434617780 - SFB 1464 and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 56.20 Thu 17:00 KG I Foyer

Noise Description in Bragg Atom Interferometer Using Squeezed States — •Julian Günther[1,2], Jan-Niclas Kirsten-Siemss[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Hannover, Germany — [2]Institut für Quantenoptik, Hannover, Germany

Using entanglement for N-particle states in matter wave interferometers allows one to outperform the standard quantum limit of $\frac{1}{\sqrt{N}}$ for the uncertainty in the phase measurement. We consider the use of one-axis twisted, spin squeezed atomic states in a Bragg Mach-Zehnder interferometer. We evaluate the phase uncertainty in the phase measurement taking into account the fundamental multi-port and multi-path nature of the Bragg processes, and determine optimally squeezed states for a given geometry.

This project was funded within the QuantERA II Programme that has received funding form the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017733 with funding organisation DFG (project number 499225223).

Q 56.21 Thu 17:00 KG I Foyer

Towards a three axes hybrid quantum inertial sensor for navigation — •David Latorre Bastidas[1], Dennis Knoop[2], André Wenzlawski[1], Jens Grosse[2], Sven Herrmann[2], and Patrick Windpassinger[1] — [1]Institute of Physics, JGU Mainz — [2]ZARM, University of Bremen

Hybrid quantum inertial sensors based on cold atom interferometry have been proposed as a more accurate alternative for tracking acceleration, e.g. for inertial navigation, compared to current classical accelerometers. In such hybrid sensors, the atom interferometer is used to correct the drift of the classical sensor. Furthermore, the hybridization of both sensors allows for a higher repetition rate and dynamic range compared to pure quantum atom interferometers. In this project, we plan to build a combination of an atom interferometer based on stimulated Raman transitions in a Mach-Zehnder configuration using Rubidium-87 with opto-mechanical sensors, where the acceleration is measured sequentially for each axis. In the framework of this project a simulation tool was developed to find the optimal operating parameters.

This poster will give an overview of the current design and of the simulations that were used to optimize the measurement sequence. Further, an outlook is given on future on-site measurements and intermediate goals of the project.

Q 56.22 Thu 17:00 KG I Foyer

Laser stabilization for a compact multi-axis inertial navigation system — •Philipp Barbey[1], Matthias Gersemann[1], Mouine Abidi[1], Ashwin Rajagopalan[1], Ann Sabu[1], Polina Shelingovskaia[1], Yueyang Zou[1], Christian Schubert[2], Dennis Schlippert[1], Ernst M. Rasel[1], and Sven Abend[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt

The application of cold and ultracold atoms in light-pulse atom interferometry enables the development of new technologies, including inertial measurement systems for navigation. Quantum sensors utilizing atom interferometry offer precise measurements of inertial forces with a focus on long-term stability, yet developing sensors for field applications requires advancements in the development of compact and scalable technology.

One of our goals is the development of new electronics that control the sensor's operation. In the past, these have often been built using analog components only. Especially in the feedback loops controlling the laser frequency, digital components offer more flexibility in adjusting operational parameters. This poster presents an overview of our proposed quantum sensor, highlighting new developments for laser stabilization, partially based on the ARTIQ experiment control framework.

We acknowledge financial support by the DFG EXC2123 QuantumFrontiers - 390837967 and by the DLR with funds provided by BMWK under Grant No. DLR 50NA2106 (QGyro+)

Q 56.23 Thu 17:00 KG I Foyer

State-of-the art suppression of seismic noise for Very Long Baseline Atom Interferometry — •Kai C. Grensemann, Jonas Klussmeyer, Klaus Zipfel, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

The Hannover Very Long Baseline Atom Interferometer (VLBAI) facility offers exciting capabilities for absolute precision gravimetry with applications in geodesy and tests of fundamental physics. Its 10 m baseline enables free fall times of up to $2T = 2.4$ s and therefore large measurement sensitivity scale factors $k_{\text{eff}}T^2$. However, the sensitivity to vibrational noise of the inertial reference mirror increases similarly. To attenuate seismic vibrations coupling to the mirror, the VLBAI facility is equipped with a state-of-the-art in-vacuum seismic attenuation system (SAS).

Here we present the recently installed SAS with its range of featured sensors and actuators, as well as a first benchmark of the passive vibration attenuation performance. Passive attenuation in all degrees of freedom is achieved by three sets of inverted pendula suspended from geometric antispring filters with a low vertical resonance frequency of 320 mHz. Residual motion at the resonance can be damped actively using three seismometers spread over the suspended platform and six voice coil actuators in a feedback loop. Furthermore, a central out-of-loop low-noise seismometer provides data to post-correct the interferometer measurements. We estimate that the SAS in combination with post-correction will allow instabilities of $\approx 4 \cdot 10^{-10}\,\frac{\text{m}}{\text{s}^2}$ at 1 s, close to the shot-noise limit of $\approx 2 \cdot 10^{-10}\,\frac{\text{m}}{\text{s}^2}$ for 10^6 atoms.

Q 56.24 Thu 17:00 KG I Foyer

Theory of multi-axis atom interferometric sensing for inertial navigation — •Christian Struckmann, Knut Stolzenberg, Dennis Schlippert, and Naceur Gaaloul — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 Hannover, Germany

Quantum sensors based on the interference of matter waves provide an exceptional measurement tool for inertial forces, and are considered next generation accelerometers for applications in geodesy, navigation, or fundamental physics due to the absence of drifts. However, conventional atom interferometers are only able to measure inertial forces along one single axis, resulting in one acceleration and one rotation component. To determine the motion of a moving body, an inertial measurement unit needs to measure the acceleration and rotation of the body along three perpendicular directions. Extending this atom interferometeric measurement scheme to multiple components would normally require the subsequent measurement along a differently oriented axis.

In this contribution, we present our theory and simulation efforts based on experimental schemes enabling three dimensional sensing using simultaneously operated single-axis atom interferometers. We detail the sensitivity and dimensionality scaling of the measurement as well as its potential and improvement avenues.

This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 56.25 Thu 17:00 KG I Foyer

Scenario building for Earth Observation Space Missions Featuring Quantum Sensors — •Gina Kleinsteinberg, Christian Struckmann, Naceur Gaaloul, and for the CARIOQA Consortium — Institute of Quantum Optics, Leibniz University Hanover, Welfengarten 1, 30167 Hanover, Germany

Being extremely sensitive to accelerations and rotations with high stability at low frequencies, atom interferometer configurations offer a versatile approach not only for Fundamental Physics research but also for Earth Observation. The latter is currently gaining more and more significance, as consequences of climate change, e.g. sea level rise and changes in water mass distributions are directly reflected in Earth's gravity field. In order to increase the maturity of quantum sensors in space, the European Commission envisages a quantum pathfinder mission, CARIOQA-PMP (Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry - Pathfinder Mission Preparation), to be launched by the end of this decade. In this contribution, we present a simulation tool capable to analyse the mission scenarios for the quantum pathfinder as well as for the follow-on full-fledge quantum gravimetry mission. The mission scenario is developed in close cooperation with the geodesy community within the CARIOQA-PMP project from the classical satellite simulations, the quantum measurement and finally the recovery of the gravity field from the interferometer signal. This work is supported by DLR funds from the BMWi (50WM2263A-CARIOQA-GE and 50WM2253A-(AI)^2).

Q 56.26 Thu 17:00 KG I Foyer

Quantum metrology for levito-dynamics — •Francis Headley

— Tübingen Universität

There has been much interest in testing the quantum nature of Gravity through table-top opto-mechanical experiments. In particular levito-dynamic systems have been proposed as ultrasensitive force and acceleration sensors and could thus also become a strong candidate for testing the possibility of entangling two massive objects via the gravitational field. These levito-dynamic set-ups promise low decoherence environments which should allow us to probe the quantum dynamics of massive mechanical objects. We present recent theoretical developments for interferometric experiments which utilise a system of massive particles levitated in superconducting traps. Coupling these mechanical oscillators via Gravity harbours the promise of new types of high fidelity measurement of Newtons constant, as well as providing a new and promising play ground for testing different quantum models.

Q 56.27 Thu 17:00 KG I Foyer

Towards a Miniaturized Spaceborne Rubidium Two-Photon Frequency Reference — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[1,2], Klaus Döringshoff[1,2], Nicolas Manrique[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik

We present the development of a miniaturized rubidium two-photon frequency reference using the $5S_{1/2} \rightarrow 5D_{5/2}$ transition at 778.1 nm, developed as a part of the CRONOS project. The project's goal is to demonstrate a micro-satellite-based optical clock in low earth orbit. Optical frequency standards based on frequency modulation spectroscopy of atomic vapor are a promising candidate for realization of compact optical clocks for application in next generation global navigation satellite systems. Rubidium offers a 300 kHz linewidth two-photon transition accessable with inherently Doppler free spectroscopy.

We show a prototype of a compact spectroscopy module achieving fractional frequency instabilities in the regime of $10^{-13}/\sqrt{\tau}$. The design comprises a projected volume below 0.5 l, mass below 1 kg and a power consumption below 10 W. Further we present first results of the utilization of MEMS rubidium vapor cells to reduce the size weight and power budget of the spectroscopy module.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 56.28 Thu 17:00 KG I Foyer

Two-Photon Frequency References for Optical Clocks and Hyperfine Spectroscopy — •Moritz Eisebitt[1,2], Julien Kluge[1,2], Daniel Emanuel Kohl[1,2], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Insitut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik, Humboldt-Universität zu Berlin

We present our monochromatic two-photon frequency references at 778 nm, operating on the $5S_{1/2} \rightarrow 5D_{5/2}$ transition in Rubidium. We use inherently Doppler-free frequency modulation spectroscopy of the approximately 500 kHz broad transition, with detection via the fluorescence at 420 nm. The fractional instability, derived from a beat-note between two independent references, is below $1.7 \cdot 10^{-13}/\sqrt{\tau}$, reaching $6 \cdot 10^{-15}$ for an averaging time τ of 1000 s. We present details on the noise analysis including the influence of residual amplitude modulation and fluctuations in the optical power.

Further, measurements of the dipole, quadrupole and octupole hyperfine structure constants of Rb $5D_{5/2}$ are presented which surpass the precision of the current state-of-the-art values by one order of magnitude.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50RK1971, 50WM2164.

Q 56.29 Thu 17:00 KG I Foyer

First aluminium ion clock comparisons at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Marek Hild[1,2], Lennart Pelzer[1], Kai Dietze[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

A single trapped $^{27}Al^{+}$ ion is an excellent frequency reference for an optical clock, as it is largely insensitive to external field shifts. Achieved inaccuracies are below the 10^{-18} level and thus make aluminum clocks a promising candidate for the re-definition of the SI second and enable for cm-scale height difference measurements in relativistic geodesy. We estimated the systematic uncertainty budget of PTB's Al^{+} clock using a single $^{40}Ca^{+}$ ion as a sensor. Included in the analysis are shifts by black body radiation, collisions with background gas molecules, residual kinetic energy from uncompensated micromotion and the ac Zeeman shift caused by fast oscillating magnetic fields. The statistical uncertainty is measured by comparing Al^{+} with the strontium lattice clock at PTB. This clock comparisons also allow us to estimate the absolute frequency and compare it to other frequency ratio measurements.

Q 56.30 Thu 17:00 KG I Foyer

Red-Emitting DBR Laser for Strontium-Based Optical Atomic Clocks — •Sandy Szermer, Nora Goossen-Schmidt, Bassem Arar, Ahmad Bawamia, Jörg Fricke, Jonas Hamperl, Karl Häusler, Andre Maassdorf, Christoph Pyrlik, Max Schiemangk, Hans Wenzel, Andrea Knigge, and Andreas Wicht — Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin

Strontium (Sr)-based optical atomic clocks provide promising applications such as improved satellite navigation or fundamental research e.g. redefining the unit of time.

To deliver the repumping wavelengths for a compact, transportable Sr lattice optical clock, we have developed red-emitting distributed Bragg reflector (DBR) ridge waveguide (RW) lasers at 679 nm and 707 nm. A higher-order surface Bragg grating is monolithically incorporated into a section of the RW to achieve frequency selectivity and low frequency noise. We optimised the design of the DBR laser with respect to gain section length and front facet reflectivity. For both wavelengths, the lasers reach FWHM linewidths (β-separation method) of around 1 MHz at optical output powers of more than 70 mW. We present the current status of our work and discuss ongoing life tests for the assessment of the operational reliability.

This work was supported by DLR Space Administration with fund provided by the Federal Ministry for Economic Affairs and Climate Action under grant number 50WM2152 and 50WM2351C.

Q 56.31 Thu 17:00 KG I Foyer

Towards demonstrating a rubidium based optical clock in space — •Nicolas Manrique[1,2], Moritz Eisebitt[1,2], Stephanie Gerken[1], Julien Kluge[1,2], Daniel Emanuel Kohl[1,2], Mathis Müller[1], Norbert Müller[1], Max Schiemangk[1], Dian Zou[1], Klaus Döringshoff[1,2], Andreas Wicht[1], Markus Krutzik[1,2], and the QUEEN/CRONOS Team[1,3,4] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [2]Institut für Physik - Humboldt-Universität zu Berlin — [3]Institut für Luft- und Raumfahrt - Technische Universität Berlin — [4]Menlo Systems GmbH

The QUEEN mission aims to demonstrate an optical atomic clock aboard a micro-satellite in low-earth orbit. The optical clock payload named CRONOS includes a micro-integrated extended cavity diode laser, whose frequency is stabilized to a narrow linewidth Rubidium two-photon transition at 778 nm. A space-borne optical frequency comb transfers the frequency stability of the laser system to the RF regime, providing an electrical clock output at 10 MHz with targeted fractional frequency instabilities better than $3 \times 10^{-13}/\sqrt{\tau}$ over time scales from 1 s to 10^5 s.

Here we present the current design and architecture of the CRONOS payload, targeting a maximum volume of 25 L, mass of 20 kg, and power consumption under 60 W, which shall operate two years in orbit.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) due to an enactment of the German Bundestag under grant numbers 50WM2164.

Q 56.32 Thu 17:00 KG I Foyer

A highly stable laser for quantum logic spectroscopy in an optical $^{27}Al^{+}$ clock — •Gayatri R. Sasidharan[1,2], Benjamin Kraus[1,2], Fabian Dawel[1,2], Lennart Pelzer[1,2], Constantin Nauk[1,2], Joost Hinrichs[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptiik, 30167 Hannover, Germany

Optical clocks using trapped $^{27}Al^{+}$ clock frequency reaches a fractional frequency uncertainty below 10^{-18} [1]. This makes it a viable candidate in a transportable setup for relative geodesy measurements at cm height resolution. The cooling and detection transitions of Al^+ ion is not directly accessible. Therefore, a co-trapped Ca^+ ion is used for sympathetic cooling and state readout through quantum logic spectroscopy. Highly stable lasers are needed to address both logic transitions for $^{40}Ca^+$ and $^{27}Al^+$. We present a laser system operating at 729 nm and 1068 nm locked to a Fabry-Pérot cavity of length 5 cm with dual wavelength coating maintained at a pressure 3 x 10^{-9} mbar [2]. The 729 nm laser is used for the $^{40}Ca^+$ logic transition. The 1068 nm laser is frequency quadrupled and used for $^{27}Al^+$ state preparations and quantum logic operations. The results on stability measurements of two lasers onto the same cavity and correlation measurements in photo-thermal noise are shown.

[1] S. M. Brewer, et al., PRL 123, 033201(2019).
[2] Fabian Dawel, et al., arXiv:2311.11610.

Q 56.33 Thu 17:00 KG I Foyer

Artificial clock transitions with multiple trapped $^{40}Ca^+$ ions as frequency references — •Kai Dietze[1,2], Lennart Pelzer[1], Ludwig Krinner[1,2], Fabian Dawel[1], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Bundesallee 100

The statistical uncertainty of trapped ion optical atomic clocks is often limited by the quantum projection noise (QPN) of the underlying quantum system. Low ion numbers, dephasing and transition broadening due to environmental noise or adjacent ions is limiting the transition linewidth and signal-to-noise ratio and therefore the achieavable statistical uncertainty. Here we focus on creating artificial quantum system with the Zeeman states of the $4S_{1/2}$ to $5D_{5/2}$ clock transition of $^{40}Ca^+$, improving the QPN compared to classical interrogation protocols. We will present our results on creating a frequency reference using continuous dynamical decoupling, mitigating noise from magnetic field fluctuations as well as the quadrupole-shift often limiting larger ion numbers [1]. Furthermore we will present results on using GHZ entangled states between two ions as a frequency reference. These state are designed to be in a decoherence free subspace against magnetic field fluctuations, allowing close to lifetime limited coherence times. We demonstrated QPN-limited relative frequency stability for this system, reaching even below the QPN of uncorrelated atoms for intermediate timescales.

[1] Pelzer *et al.*, arXiv:2311.13736

Q 56.34 Thu 17:00 KG I Foyer

Recent progress on PTB's transportable Al^+ ion clock — •Constantin Nauk[1], Benjamin Kraus[1], Joost Hinrichs[1,2], Gayatri Sasidharan[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks demonstrate remarkable fractional systematic and statistical frequency uncertainties on the order of 10^{-18}, opening the door to novel applications. One such application are height measurements in relativistic geodesy at the cm level. However, earth monitoring field campaigns require robust, reliable and transportable hardware.

For this purpose, we are currently setting up a clock based on the $^1S_0 \rightarrow {}^3P_0$ transition in $^{27}Al^+$. A co-trapped $^{40}Ca^+$ ion allows state detection and cooling through quantum logic spectroscopy and sympathetic cooling.

We present the 19" rack design and the current status of the transportable apparatus. The physics package, including the vacuum system designed for pressure ranges below 10^{-10} mbar, and the surrounding optics are discussed. Notably, we present a combining laser setup that combines laser light for ionization, cooling, state read-out and repumping into one fiber. Additionally, we showcase the performance of the cavity-stabilized clock light fundamental laser with a fractional frequency instability of about $2 \cdot 10^{-16}$ at 1 second.

Q 56.35 Thu 17:00 KG I Foyer

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Dark matter searches for physics beyond the standard model (SM) range from cosmological observations to high-energy collision experiments and low-energy table-top experiments. The baryon asymmetry of the universe explained by recent baryogenesis therories requires a degree of CP-violation that might result in a measurable atomic electric dipole moment (EDM). High precision spectroscopy of atomic isotope shifts could probe for a new force carrier that directly couples neutrons and electrons [Delaunay, PRD 96, 093001 (2017); Berengut, PRL 120, 091801 (2018)].

Mercury being one of the heaviest laser-coolable elements makes it an ideal platform for beyond SM physics like baryon asymmetry searches [Graner PRL 116, 161601 (2016)]. Excellent for isotope shift spectroscopy it possesses five naturally occurring bosonic isotopes, all of which we laser cool in our lab.

We report on recent improvements and upgrades on the machine for transferring magneto-optically trapped mercury atoms to a high power optical dipole trap. We present latest results on high resolution deep UV laser isotope shift spectroscopy and multidimensional King plot analysis of the nonlinearities. Furthermore we give outlook to beyond the state-of-the-art measurements of the atomic EDM of mercury.

Q 56.36 Thu 17:00 KG I Foyer

Towards an Autonomous Laser System for Operation in Quantum Technology Applications — •Janpeter Hirsch, Martin Gärtner, Stephanie Gerken, Sriram Hariharan, Nora Goossen-Schmidt, Simon Kubitza, Norbert Müller, Max Schiemangk, Christoph Tyborski, Dian Zou, and Andreas Wicht — Ferdinand-Braun-Institut (FBH), Berlin, Germany

In the domain of quantum sensors, compact laser systems with extremely narrow linewidth and precise control over emission frequency and output power are indispensable components. To alleviate the user's workload, expedite operational processes, and reduce the level of expertise required, an automated adjustment of various actuators becomes essential. As part of an integrated solution, we introduce a high-power, narrow-linewidth laser module, complemented by a frequency-tunable reference module, both operating at a wavelength of 767 nm. While the laser module features an active stabilization of the optical resonator length and enables mode-hop-free tuning of the optical emission frequency, the frequency reference module facilitates an accelerated lock-acquisition. Together, these advancements pave the way for more accessible and efficient quantum technology applications.

Acknowledgement: This work was supported by VDI Technologiezentrum GmbH / Federal Ministry of Education and Research (grant numbers: 13N14906, 13N15724), by DLR Space Administration / Federal Ministry for Economic Affairs and Climate Action (grant numbers: 50WM2053, 50WM2152, 50WM2176, 50WM2164) and by Investitionsbank Berlin / European Union (grant number:10168115).

Q 56.37 Thu 17:00 KG I Foyer

Sideband Thermometry on Ion Crystals — •Ivan Vybornyi[1], Laura Dreissen[2,3], Dominik Kiesenhofer[4,5], Helene Hainzer[4,5], Matthias Bock[4,5], Tuomas Ollikainen[4,5], Daniel Vadlejch[2], Christian Roos[4,5], Tanja Mehlstäubler[2,6], and Klemens Hammerer[1] — [1]Institut für theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany — [3]Department of Physics and Astronomy, LaserLab, Vrije Universiteit, De Boeleaan, 1081 HV Amsterdam, The Netherlands — [4]Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, 6020 Innsbruck, Austria — [5]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria — [6]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Coulomb crystals of cold trapped ions are a leading platform for quantum computing, simulations and metrology. For these applications, it is essential to be able to determine the crystal's temperature with high accuracy, which is a challenging task for large crystals due to complex many-body correlations. Recently [arXiv:2306.07880v3] we presented an ion crystal thermometry method that deals with this problem. With two experiments (4 ions 1D linear chain and 19 ions 2D crystal) we test the new method and cross-check it via other techniques. The results confirm the new method being accurate and efficient. Current work aims to generalize ion thermometry for non-thermal states of motion.

Q 56.38 Thu 17:00 KG I Foyer

Nigtrogen vacancy center based magnetometer and gradiometer — •JIxing Zhang, Michael Kuebler, Magnus Benke, Yihua Wang, Anjana Karuvayalil, and Joerg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany

Diamond nitrogen vacancy (NV) centers have emerged as a promising platform for quantum sensing with diverse applications spanning multiple disciplines. This research focuses on harnessing the unique capabilities of high-concentration NV centers to achieve unparalleled sensitivity in magnetometry, thereby unlocking significant potential for magnetic measurements. In comparison to established magnetometry technologies like SQUID and OPM, NV-based magnetometry stands out by offering a larger dynamic range, enhanced bandwidth, and superior spatial resolution. This abstract introduces a novel magnetic gradiometer, comprising two NV-based magnetometers strategically designed to resolve weak magnetic signals from a test object amid challenging high environmental magnetic field noise conditions. The study showcases the design principles and presents compelling measurement results for the NV ensemble gradiometer. Our findings highlight its remarkable potential for capturing magnetic signals associated with human muscle and brain activity. This breakthrough not only underscores the versatility of NV-based magnetometry but also positions it as a transformative technology for advancing our understanding of complex biological processes.

Q 56.39 Thu 17:00 KG I Foyer

Optimal Ramsey interferometry with echo protocols based on one-axis twisting — •Maja Scharnagl[1], Timm Kielinski[2], and Klemens Hammerer[2] — [1]Institute for Theoretical Physics, Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Appelstrasse 2, 30167 Hannover, Germany

We study a variational class of generalized Ramsey protocols that include two one-axis twisting (OAT) operations, one performed before the phase imprint and the other after. In this framework, we optimize the axes of the signal imprint, the OAT interactions, and the direction of the final projective measurement. We distinguish between protocols that exhibit symmetric or antisymmetric dependencies of the spin projection signal on the measured phase. Our results show that the quantum Fisher information, which sets the limits on the sensitivity achievable with a given uniaxially twisted input state, can be saturated within our class of variational protocols for almost all initial twisting strengths. By incorporating numerous protocols previously documented in the literature, our approach creates a unified framework for Ramsey echo protocols with OAT states and measurements.

Q 56.40 Thu 17:00 KG I Foyer

Progress towards a continuous wave superradiant Calcium Laser — •David Nak and Andreas Hemmerich — Institut für Quantenphysik, Universität Hamburg, Hamburg, Deutschland

Superradiant Lasers are suitable as light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].

We will present our progress with the advancement of our bichromatic MOT and our incoherent repumping protocol, which will enable us to maintain the superradiant state for an extended period of time.

[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Q 56.41 Thu 17:00 KG I Foyer

spin-dependent exotic interactions — •lei cong[1,2], wei ji[1,2], pavel fadeev[1], filip ficek[1], min jiang[1], victor v. flambaum[1], haosen guan[1], derek f. jackson kimball[1], mikhail g. kozlov[1], yevgeny v. stadnik[1], and dmitry budker[1] — [1]Helmholtz-Institut, Mainz 55128, Germany, and others — [2]Equal contribution

The fifth force may arise due to "new physics" beyond the standard model. We focus on the spin-dependent fifth forces that are mediated by new particles, such as spin-0 particles (axion and axion-like-particles) and spin-1 particles (e.g. light Z' particle or massless paraphoton). These new ultralight particles are also candidates for dark matter and dark energy, and may also break fundamental symmetries. Spin-dependent interactions between fermions have been extensively searched for in experiments, employing methods such as comagnetometers, nitrogen-vacancy spin sensors, and precision measurements of atomic and molecular spectra [1, 2, 3]. Our research involves a theoretical reassessment of exotic spin-dependent forces [4]. It produces a systematic and complete set of interaction potentials expressed in terms of reduced coupling constants. We will conduct an extensive analysis of the existing body of experimental literature on spin-dependent fifth forces, which will produce systematic exclusion plots. This will lead to a comprehensive understanding of the current research landscape and provide insights for further research.

References: [1] Wei Ji, et al. *PRL*, **130**, 133202, 2023. [2] Xing Rong, et al. *NC*, **9**, 739, 2018. [3] Filip Ficek, et al. *PRL*, **120**, 183002, 2018. [4] Pavel Fadeev, et al. *PRA*, **99**, 022113, 2019.

Q 56.42 Thu 17:00 KG I Foyer

Low-noise magnetic sensing with tin-vacancy centers — •Gesa Welker[1], Yufan Li[1], Toeno van der Sar[1], and Richard Norte[2] — [1]Faculty of Applied Sciences, TU Delft, The Netherlands — [2]Faculty of 3mE, TU Delft, The Netherlands

Similar to the well-known nitrogen-vacancies (NV), tin-vacancy (SnV) defects in diamond have optically active spins. One of their most intriguing properties is their resilience to electrical noise, which is four orders of magnitude higher than for NV centers [1]. SnV centers are therefore expected to be formidable magnetic field sensors that outperform NV-based sensors at cryogenic temperatures. To the best of our knowledge, SnV centers have not been used for sensing since their experimental realization in 2017 [2,3]. We develop a fiber-coupled scanning-SnV-magnetometry setup, based on earlier work in our group with fiber-coupled NV centers [4]. We attach a diamond nanobeam with SnV centers to a tapered optical fiber, which we then scan across a sample. Fiber coupling increases sensitivity via a high optical excitation and collection efficiency. It allows using low laser power, thereby bringing millikelvin magnetometry into reach. Furthermore, fiber coupling eliminates the need for realignment of free-space optics when cooling to cryogenic temperatures. Our goal is achieving a sensitivity high enough to study weak magnetic signatures in condensed matter systems, e.g. 2D materials or correlated electron systems. [1] De Santis et al., PRL 127, 147402 (2021) [2] Iwasaki et al., PRL 119, 253601 (2017) [3] Ditalia Tchernij et al., ACS Photonics 4, 2580-2586 (2017) [4] Li et al., ACS Photonics 10, 1859-1865 (2023)