Q 68: Poster – Precision Measurement (joint session Q/A)

Matter Wave Optics and Interferometry; Atom and Ion Clocks; Nuclear Clocks; Metrology; Others

Time: Thursday 17:00–19:00 Location: Philo 2. OG

Q 68.1 Thu 17:00 Philo 2. OG

Optical simulations for noise analyses in space-based interferometers — •Rodrigo Garcia Alvarez — Max Planck institute for Gravitational Physics (Albert Einstein Institute), Hannover, Germany

A major contributor of noise in the Laser Interferometer Space Antenna (LISA) is the so-called tilt-to-length coupling (TTL). This is the path length signal noise induced by angular and lateral jitters in an interferometric setup. Various TTL noise simulations conducted using IfoCAD, an in-house interferometry c++ library are presented. These simulations include TTL noise in the test mass interferometers and the inter-satellite interferometers, caused by the jitter of the transmitting and receiving spacecraft. The status of IfoCAD simulations using LISA's latest optical design is included.

Q 68.2 Thu 17:00 Philo 2. OG

Unifying Sequential Bragg and Bloch Large-Momentum-Transfer Atom Interferometry — •Ashkan Alibabaei[1], Patrik Mönkeberg[2], Klemens Hammerer[2,3,4], and Naceur Gaaloul[1] — [1]Institut of Quantum Optics, Leibniz University Hannover, Germany — [2]Institute für Theoretical physics, Leibniz University Hannover, Germany — [3]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck, Austria — [4]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria

Large-momentum-transfer (LMT) techniques significantly enhance the sensitivity of atom interferometers. Although Bloch oscillations and sequential Bragg diffraction are widely used, they are typically treated as separate methods. We introduce a unified Floquet framework that encompasses both processes within a single theoretical description, enabling direct and systematic comparison. Using this approach, we analyse losses and dephasing and establish criteria for achieving their fundamental performance limits. The framework is validated through agreement with exact numerical simulations and recent state-of-the-art experimental results [Rodzinka et al., Nat Commun 15, 10281 (2024)], providing a robust foundation for optimizing future LMT implementations.

Q 68.3 Thu 17:00 Philo 2. OG

Development of a Compact Electronic System for the Absolute Aero Quanten-Gravimetry (AeroQGrav) Project — •Patrick Rössler, Knut Stolzenberg, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover - Institut für Quantenoptik

To map the Earth's gravitational field within a restricted area we utilize an airplane as a platform for combining inertial and positional sensors at lower altitudes. Within a measuring duration of 5 s we are aiming for a spatial resolution of 0.3 to 0.5 km, by the implementation of a cold atom quantum gravimeter with the sensitivity of 1 μm/s^2 and combine it with the data stream of the GNSS position system, a terrestrial laser scanner and a laser velocity meter. The presented work shows the requirements to build a robust, fast and precise electronic system to operate the quantum gravimeter and merge the aforementioned sensors data streams using sensor fusion in the noisy environment of an airplane.

Q 68.4 Thu 17:00 Philo 2. OG

Double Bragg atom interferometry with Bose-Einstein condensates in microgravity — •Anurag Bhadane[1], Dorthe Leopoldt[2], Priyanka Barik[2], Govindarajan Prakash[3], Julia Pahl[4], Sven Herrmann[3], Andre Wenzlawski[1], Sven Abend[2], Markus Krutzik[4,5], Patrick Windpassinger[1], Ernst Rasel[2], and The Quantus Team[1,2,3,4,6,7] — [1]JGU Mainz — [2]LU Hannover — [3]ZARM, U Bremen — [4]HU Berlin — [5]FBH Berlin — [6]U Ulm — [7]TU Darmstadt

The Quantus-2 device is a mobile, high flux ^{87}Rb Bose-Einstein condensate(BEC) interferometer optimized for microgravity platforms such as the Bremen Drop Tower and the GraviTower Bremen Pro, and serves as a pathfinder for future space based quantum sensors. A magnetic quadrupole lens combined with collective mode excitation of the BEC enables interferometry times beyond one second using double Bragg diffraction. At these durations, systematic effects like parasitic wavefront distortions, which imprint spatial phase variations across the atomic cloud, together with shot to shot pulse amplitude fluctuations reduce the achievable contrast. We present the dominant contrast loss mechanisms, supported by quantitative performance characterization, and outline mitigation strategies for long duration interferometry in microgravity.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant numbers DLR 50WM1952-1957 and DLR 50 WM2450A-F.

Q 68.5 Thu 17:00 Philo 2. OG

Towards a quantum inertial measurement unit for navigation utilizing BEC based atom interferometry — •Tobias Bullwinkel, Mouine Abidi, Philipp Barbey, Ashwin Rajagopalan, Ann Sabu, Dennis Schlippert, Ernst M. Rasel, and Sven Abend — Leibniz Universität Hannover, Institut für Quantenoptik

Future enhanced inertial measurement units require more long-term stable and accurate sensors. Utilizing atom interferometry, sensors can be realized that offer drift-free performance and are not vulnerable to signal jamming, in contrast to current navigation solutions. By hybridizing conventional methods with newly developed quantum-sensors, the best of both worlds is combined. The QGyro project aims to create a sensor that is capable of doing three-axis measurements while hybridizing the measurements to a classical IMU. For this, atom iterferometry with Bose-Einstein condensates generated with the help of an atom chip is used. Since mobility is crucial for the system being used in navigation, development is done with transportability and resilience against external factors in mind. All of the sensor periphery is built for easy assembly and fits into one 19* rack, as the electronics and laser systems are designed to be as compact as possible. Additionally, it can be supplied by an external battery, enabling measurements campaigns without constant external power supply. The ARTIQ control system is utilized to run the experimental sequence with extreme accurate time control.This work is supported by the Federal Ministry of Economics and Climate Protection (BMWK) due to the enactment of the German Bundestag under Grant No. DLR 50NA2106 (QGyro+).

Q 68.6 Thu 17:00 Philo 2. OG

Challenges behind performing atom interferometry in extended free fall — •Priyanka Barik[1], Govindarajan Prakash[2], Dorthe Leopoldt[1], Anurag Bhadane[3], Julia Pahl[4], Sven Abend[1], Sven Herrmann[2], André Wenzlawski[3], Markus Krutzik[4,7], Patrick Windpassinger[3], Ernst M. Rasel[1], and QUANTUS Team[1,2,3,4,5,6,7] — [1]LU Hannover — [2]ZARM, U Bremen — [3]JGU Mainz — [4]HU Berlin — [5]U Ulm — [6]TU Darmstadt — [7]FBH Berlin

The QUANTUS-2 apparatus is a high-flux ^{87}Rb BEC machine, based on a magnetic chip-trap, which generates 1×10^5 atoms at a 1Hz rate. High-precision quantum sensing with atom interferometers requires long interrogation time of several seconds with ultra-low expansion rates of the BECs. Thus, we perform our experiment in the DropTower in Bremen with a novel matter-wave lens system for the collimation of the condensate. The apparatus experiences noticeable tilts and rotations which alter the spatial rotation of the ^{87}Rb atomic cloud and its projection along the imaging axes and the interferometry pulses. These rotations lead to position offsets, which become more pronounced as the TOF is increased, and, hence, are expected to contribute to a loss of contrast of the interferometer. We report on the proposal to mitigate these problems using a retro-reflective mirror mounted on a tip/tilt platform which will pave the way for long interrogation times. 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 numbers DLR 50WM1952-1957 & DLR 50WM2450A-F.

Q 68.7 Thu 17:00 Philo 2. OG

Improving PIXL — •Knut Stolzenberg, Daida Thomas, Christian Struckmann, Ashwin Rajagopalan, Alexander Herbst, Wei Liu, Konstantin Avvacumov, Sebastian Bode, Naceur Gaaloul, Ernst Rasel, and Dennis Schlippert — Institut für

Quantenoptik, Leibniz Universität Hannover

Atom interferometers have become a viable tool for inertial sensing and fundamental research, showing excellent long-term stability and sensitivity. However, they are commonly bound to a single sensitive axis, enabling multi-axis inertial sensing only via post-correction with external classical sensors, or correlation with other simultaneous atom interferometers.
The PIXL (Parallelized atom Interferometers for XLerometry) method, utilizing a 3 x 3 array arrangement of Bose-Einstein condensates as input for Mach-Zehnder type atom interferometers, allows for the measurement of the Euler- and centrifugal acceleration, as well as transversal acting linear accelerations induced by gravity.
PIXL's optical dipole trap setup can furthermore accelerate the ensembles transversal to the atom optics light field, resulting in additional phase shifts in the atom interferometers due to the Sagnac effect. Here, first results of improved rotation sensing and post correction of obstructive vibrations are presented.
Moreover, we envision PIXL as a highly accurate tool to characterize wave front abberations, being the main limitation for e.g. the measurement of the fine structure constant.

Q 68.8 Thu 17:00 Philo 2. OG

Frequency ratio measurements at the 10^{-18} level with an aluminum ion clock — •Fabian Dawel[1,2], Derwell Drapier[1], Mirza Akbar Ali[1,2], Lennart Pelzer[1], Kai Dietze[1,2], Bennet Benny[1,2], Johannes Kramer[1,2], and Piet O. Schmidt[1,2] — [1]PTB, Braunschweig, Germany — [2]LUH, Hannover, Germany

The latest generation of optical atomic clocks claims two orders of magnitude improved statistical and systematic frequency uncertainty compared to microwave Cs-clocks. For the redefinition of the second confirmation of the estimated error budgets of optical clocks by frequency ratio measurements is required. Here, we present frequency ratio measurements of our Al^+ ion clock, which is co-trapped with Ca^+ for readout and cooling. The co-trapped ion allows sympathetic electromagnetically-induced transparency cooling during the clock interrogation, which reduces the second-order Doppler effect to a small and probe-time independent value. The introduced electric field of the cooling lasers can be characterized by Ca^+ allowing to bound the ac-Stark shift on Al^+ on a low 10^{-18} uncertainty level, which is the largest contribution to the total systematic frequency uncertainty of 1.7×10^{-18}. We show frequency ratio measurements against a Sr lattice clock with a stability of $5.9 \times 10^{-16}\sqrt{1\,s/\tau}$, limited by the Al^+ ion clock stability. The resulting frequency ratio of $^{27}Al^+/^{87}Sr$ shows a $14\,\sigma$ difference to published results. This shows the importance of inter-institutional frequency ratio measurement for the redefinition of the second.

Q 68.9 Thu 17:00 Philo 2. OG

Advancements of a transportable quantum logic optical clock. — •Sofia Herbers[1], M. Mazin Amir[1,2], Alexander Bernet[1,2], Pascal Engelhardt[1,2], Joost Hinrichs[1,2], Constantin Nauk[1,2], Gayatri Sasidharan[1,2], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

Research in the field of geodesy [1,2], fundamental physics [3], and large scale networks can be performed and complemented with optical clocks. Besides stationary systems, this research also requires transportable systems, which can be operated at different points of interest. We set up a transportable quantum logic optical clock based on $^{27}Al^+$ and $^{40}Ca^+$ and present our latest advancements. We optimized the loading process of a two-ion crystal by an automated two-step splitting protocol. Additionally, we set up a compact, single-pass, and frequency-stable fourth harmonic generation (FHG) to generate 267 nm light for driving the clock transition of $^{27}Al^+$, for which we demonstrated a fractional frequency instability below 5×10^{-17} for the phase-stable light transfer through the FHG at one second averaging time. Furthermore, we optimized our cooling protocol, and investigated magnetic field attenuation using a mu-metal shield. [1] T. E. Mehlstäubleret al. (2018), Rep. Prog. Phys. **81**, 064401 [2] Safronova et al. (2018), Rev. Mod. Phys., **90**, 025008 [3] Vincent et al. (2024), arXiv preprint arXiv:2411.07888

Q 68.10 Thu 17:00 Philo 2. OG

Miniaturized Rubidium Two-Photon Frequency Reference Utilizing MEMS Cells — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Moritz Eisebitt[1,2], Janice Wollenberg[1], Klaus Döringshoff[1,2], Sten Wenzel[1], Andreas Wicht[1], and Markus Krutzik[1,2] — [1]Ferdinand-Braun-Institut (FBH) — [2]Institut für Physik - Humboldt-Universität zu Berlin

Optical frequency references based on frequency modulation spectroscopy of atomic vapor are promising candidates for the realization of compact optical clocks with applications including optical calibration, synchronization and navigation. We present the development of a miniaturized rubidium two-photon frequency reference using FM spectroscopy of the $5S_{1/2} \rightarrow 5D_{5/2}$ transition at 778.1 nm. The reference features a 72 ml ($67\times32.5\times33\,mm^3$) spectroscopy unit utilizing microfabricated wafer-bonded rubidium vapor cells.

The spectroscopy unit is driven by a chip-scale ECDL laser as a 778.1 nm light source. We present a first demonstrator achieving short-term fractional frequency instability of $2.8\cdot10^{-12}/\sqrt{\tau}$ up to 200 s, with a flicker floor at $2 \cdot 10^{-13}$. These results show the potential of chip-scale rubidium two-photon frequency references. We aim to further miniaturize and integrate the laser system with a microfabricated-cell spectroscopy module to realize a scalable rubidium optical clock.

This work is supported by German Federal Ministry of Research, Technology and Space, under grant number 50WM2164 and within the Research Program Quantum Systems under contract number 13N17491.

Q 68.11 Thu 17:00 Philo 2. OG

Portable implementation of a Ramsey Bordé atom interferometer with a thermal strontium beam for compact optical clocks — •Amir Mahdian[1,2], Oliver Fartmann[1], Marc Christ[2], Levi Wihan[1], and Markus Krutzik[1,2] — [1]Humboldt-Universität, Inst. f. Physik, Newtonstr. 15, 12489 Berlin — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin

Compact optical atomic clocks based on Ramsey Bordé interferometry (RBI) with thermal atomic beams promise higher stability than optical vapor-cell clocks at substantially reduced complexity compared to cold-atom systems. Building on our previous demonstration[1] on the narrow $^1S_0 \rightarrow {}^3P_1$ line of strontium at 689 nm, and using the $^3P_1 \rightarrow {}^3P_0$ at 483 nm as an alternative for electron shelving detection, we now report our progress towards a portable RBI clock package. The portable apparatus features an integrated thermal atomic source and vacuum system with an in-vacuum micro-integrated retroreflector, as well as a compact spectroscopy setup. We have performed spectroscopy on the 461 nm transition and implemented frequency-modulation spectroscopy with the portable hardware. We will present the latest status of our setup, including initial stability characterization, and the roadmap to full RBI operation and field deployment. These results outline a path to robust, mobile, and ultimately space-qualified optical frequency references based on thermal-beam interferometry.

[1] O. Fartmann et al., EPJ Quantum Technol. 12, 31 (2025).

Q 68.12 Thu 17:00 Philo 2. OG

Entanglement-enhanced multi 40Ca+ ion clock — •Bennet Benny[1,2], Kai Dietze[1,2], Lennart Pelzer[1,2], Vincent Barbé[1], Ludwig Krinner[1,2], Fabian Dawel[1,2], Derwell Drapier[1], Mirza A. Ali[1,2], and Piet O. Schmidt[1,2] — [1]QUEST, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

State-of-the-art optical atomic clocks based on trapped ions require long interrogation times and ion numbers to achieve low statistical uncertainty, but both methods are limited by various noise sources. Therefore, a small number of entangled ions with Quantum Projection Noise (QPN) below Standard Quantum Limit (SQL) might be beneficial. We demonstrated entanglement gain leading to faster averaging and suppression of magnetic-field noise in 40Ca+ ions in Decoherence-Free Subspace (DFS)[1]. Entanglement also provides an improvement in the measurement uncertainty through a reduction in QPN. The DFS method demonstrated near-lifetime-limited interrogation, but any further gain is suppressed by spontaneous-emission events during interrogation. To address this, we propose an experimental implementation of an entanglement-assisted readout method that employs a 4-tone Mølmer-Sørensen gate based DFS to detect and veto spontaneous-emission events from the clock feedback loop. This approach is designed to demonstrate an enhancement beyond SQL and its scaling of the achievable lock performance with ion numbers[2].

[1] K. Dietze et al., arXiv:2506.11810 (2025)
[2] T. Kielinski et al., Sci. Adv. 10, eadr1439 (2024)

Q 68.13 Thu 17:00 Philo 2. OG

Frequency-Comb Induced Excitation of ^{229}Th in a Crystalline Environment — •Chiara Brüggemann, Tobias Kirschbaum, and

Adriana Pálffy — Julius-Maximilians-Universität Würzburg

Large band gap crystals such as CaF_2 or $LiCaAlF_6$ serve as an ideal host for doping ^{229}Th. This procedure leads to the formation of additional electronic defect states in the band gap. Various works have shown that these states can be used to excite the nuclear ground state population via laser-assisted Electronic Bridge (EB) schemes [1-3]. The EB rate for the ^{229}Th isomeric transition can be calculated using a perturbative approach [3].
In this work, we theoretically investigate EB excitation assisted by optical frequency combs. The latter open new avenues for EB excitation mechanisms using two photon-schemes, as their discrete line spectrum provides ideal conditions for delivering resonant photon pairs. Our approach based on Ref. [3] includes realistic crystal lattice effects, in particular inhomogeneous broadening of the electronic defect states.

[1] B. Nickerson et al., Phys. Rev. Lett. 125, 032501 (2020)
[2] B. Nickerson et al. Phys. Rev. A 103, 053120 (2021)
[3] T. Kirschbaum et al. arXiv:2507.05070 (2025)

Q 68.14 Thu 17:00 Philo 2. OG

Tuning and preparation of a laser system for airborne atom interferometry — •Alisa Ukhanova[1], Julia Pahl[1], Markus Krutzik[1,2], and the AeroQGrav team[1,3,4,5,6,7,8,9] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut (FBH), Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]LUH, Hannover — [4]DLR, Hannover — [5]TUB, Braunschweig — [6]BKG, Leipzig — [7]TUC, Clausthal — [8]Geo++®GmbH, Garbsen — [9]iMAR Navigation GmbH, Ingbert

The "AeroQGrav" project strives to demonstrate an airborne atomic gravimeter, with a higher spatial and temporal resolution and a better long-term stability compared to the existing commercial solutions.

We develop a compact and robust modular flight laser system. Three functional modules provide the light fields for laser cooling of ^{87}Rb atoms in 2D- and 3D-magneto-optical traps, Raman interferometry, and state detection during flight. This poster highlights the design, assembly and verification of the system, with an emphasis on frequency stabilization methods. Our laser system meets the requirements arising from aircraft operation.

Future work will focus on a detailed characterization of the laser system to validate its performance under flight conditions. This project is supported by the VDI Technologiezentrum GmbH with funds provided by the Federal Ministry of Education and Research (BMBF) under grant number 13N16518.

Q 68.15 Thu 17:00 Philo 2. OG

Quantum Systems With Multiple Weak Interactions — •Vinay Tumuluru[1,2,3], Jan Dziewior[1,2,3], Carlotta Versmold[1,2,3], Florian Huber[1,2,3], Lev Vaidman[4], and Harald Weinfurter[1,2,3] — [1]Faculty of Physics, Ludwig-Maximilians-University, Munich, Germany — [2]Max-Planck-Institute of Quantum Optics, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Israel

The ‘quantum weak value’ of a pre- and post-selected quantum system [1] weakly interacting with a ‘pointer’ describes the amplification of effects of the weak interaction [2]. These amplified effects can be observed experimentally in optical interferometers where pre- and post-selection can be finely controlled and performed on different DOFs.

With the path and polarisation DOFs of an optical Mach Zehnder interferometer serving as two systems and the transverse mode of the beam serving as pointer, one can observe weak amplification in individual weak coupling of each system to the pointer as well as the product of amplifications when both systems are coupled simultaneously [3]. Here we analyse and show in the experiment how entanglement between the DOFs changes the resulting amplification significantly.

[1] Y. Aharonov et al, PRL. 60, 1351 (1988) [2] P. B. Dixon et al, Phys. Rev. Lett. 102 (2009) [3] X. Xu et al, PRL. 122, 100405 (2019)