Q 61: Matter Wave Interferometry and Metrology III

Time: Thursday 14:30–16:30 Location: P 11

Q 61.1 Thu 14:30 P 11

Electron induced Raman interferometry with 'large' mass particles — •Christian Vogt — BIAS - Bremer Institut für angewandte Strahltechnik GmbH

General relativity and quantum mechanics provide two highly successful yet fundamentally incompatible descriptions of nature for different parameter regimes. An important frontier in modern physics is therefore to design experiments that operate in areas where both may simultaneously influence the dynamics. Experiments where one could measure the gravitational attraction from a quantum object are impossible for now but steady progress has been made by preparing increasingly massive objects in quantum states, typically demonstrated through interference.

Matter-wave interferometers have been realized for electrons, atoms, and complex molecules, with the current mass record around 25 kDa. A promising platform for pushing these limits further is levitated optomechanics, where silica nanoparticles are trapped under high-vacuum conditions and their center-of-mass motion can be cooled to the motional ground state. Since the associated wave packets are only on the picometer scale, current efforts focus on wave function expansion, for example in inverted gaussian or other nonlinear potentials.

We propose a different strategy, where the particles are forced into superposition states by entangling them via coulomb interaction with an electron in superposition. In the talk we will present promising theoretical results on the feasibility of such experiments well beyond the current mass record.

Q 61.2 Thu 14:45 P 11

A compact, highly stable dual-laser system for quantum logic spectroscopy of ^{27}Al^{+} — •Gayatri R. Sasidharan[1,2], Sofia Herbers[1], Constantin Nauk[1,2], Joost Hinrichs[1,2], Fabian Dawel[1], Benjamin Kraus[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 clocks using trapped ^{27}Al^{+} reach a fractional frequency uncertainty below 10^{-18} [1]. For coherent manipulation of trapped ions, lasers with long coherence time and narrow linewidth are needed. The best stationary laser systems reach an instability of 4 x10^{-17} [2] and transportable systems 1.6 x 10^{-16} [3]. This is achieved by stabilizing the laser frequency to a optical cavity. A dual wavelength coated optical cavity is a practical solution addressing space limitations in transportable setups. In this talk, we present a compact, highly-stable dual-laser system for quantum logic spectroscopy. The 729 nm and 1068 nm transitions on ^{27}Ca^{+} and ^{27}Al^{+}, respectively, are needed to perform quantum logic spectroscopy on the clock ion ^{27}Al^{+}. We report on photothermal and vibrational noise affecting the instability of the cavity. This work shows that a dual wavelength coating can be used for highly stable laser applications making it viable tool for precision spectroscopy experiments.

[1] Marshall, et al., PRL 135, 033201 (2025)
[2] D. G. Matei, et al., PRL 118, 263202 (2017)
[3] S. Herbers, Opt. Lett., OL 47, 5441-5444 (2022)

Q 61.3 Thu 15:00 P 11

Heterodyne cavity-tracking for enhanced displacement sensing — •Nurmi Sawlanski, Shreevathsa Chalathadka Subrahmanya, and Oliver Gerberding — Institute of Experimental Physics, University of Hamburg, 22761 Hamburg, Germany

Gravitational-wave detectors allow us to observe compact binaries and other extreme astrophysical events by measuring minute changes in the distance between nominally free-falling test masses. To separate these signals from seismic motion and technical disturbances, the detectors rely on ultra-sensitive displacement sensors in their active isolation and control systems. Improving such sensors is therefore essential for future gravitational-wave observatories.

Heterodyne cavity-tracking is a laser interferometric displacement readout scheme that enables sub-femtometer precision with an operating range on the order of a wavelength. A laser is locked to the resonance of a cm-scale cavity containing the proof mass, and the resulting frequency changes are measured via a heterodyne beat with a second, stable laser using a GHz-bandwidth phasemeter. This combines high precision with a dynamic range suitable for tracking test-mass motion.

Our fiber-based setup has achieved a displacement sensitivity of about 20 fm/$\sqrt{\text{Hz}}$ for frequencies above 5 Hz and a dynamic range of six orders of magnitude by tracking motions up to 0.15 μm. To further improve the achievable sensitivity, we plan to implement Pound-Drever-Hall locking for laser stabilization and to move to a free-beam vacuum setup. In this talk, we present the sensing scheme, current performance, and planned experimental steps.

Q 61.4 Thu 15:15 P 11

Ramsey-Bordé Interferometry with a Thermal Strontium Beam for a Compact Optical Clock — •Oliver Fartmann[1], Marc Christ[2], Amir Mahdian[1,2], 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 clocks based on Ramsey-Bordé interferometry (RBI) with a thermal atomic beam offer higher stability than optical vapour cell clocks while being less complex than cold atom clocks.

This talk presents the realization of strontium RBI on the narrow $^1S_0 \rightarrow {}^3P_1$ intercombination line at 689 nm. A structured optimization of major subsystems was carried out, including clock-laser pre-stabilization to a high-finesse cavity, successive improvements to the atomic oven, spectroscopy-based error-signal generation, feedback loop, and a systematic evaluation of clock stability limitations.

Our first operating RBI-clock demonstrated fractional frequency instabilities below $\sigma_y(\tau) < 10^{-13}$ for averaging times between 1 s and 1000 s, with residual temperature fluctuations identified as the dominant limitation. Building on these results, two additional portable RBI spectroscopy setups were developed, with volumes of only 20 l. Initial instability measurements and the uncertainty budget will be presented.

These systems serve as ground-based demonstrators and testbeds, paving the way for mobile and space-deployable optical clocks.

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

Q 61.5 Thu 15:30 P 11

Exploring few-shot quantum metrology with photonic qubits — •Lukas Rückle[1,2] and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST)

The use of quantum states for metrology tasks has been proven to surpass classical precision limits for the estimation of parameters. Recently, the framework of *probably approximately correct (PAC) metrology* has been introduced. It not only enables the estimation of a parameter in an arbitrarily big parameter space without prior knowledge, but also gives bounds for few- and single-shot metrology settings. It thus bridges the rather theoretical case of performing infinitely many measurements and practical metrology tasks.

Here, we present experimental results in a photonic metrology setting. We show how to use different states and measurements and how for each case to optimize the prediction strategy of the parameter that shall be estimated. Our work shows how to implement the given new framework of PAC metrology and thus helps improving the precision of applications that only allow for a few measurements, e.g. when measuring fast varying systems.

Q 61.6 Thu 15:45 P 11

Phase reconstruction for lattice-confined cold atoms from matter-wave interference measurements — •Niklas Euler[1], Justus Brüggenjürgen[2], Christof Weitenberg[3], and Martin Gärttner[1] — [1]IFTO, FSU Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]IQOQI, Technikerstraße 21a, 6020 Innsbruck, Austria — [3]TU Dortmund, Otto-Hahn-Straße 4a, 44227 Dormund, Germany

In recent years, cold-atom experiments with single-site imaging have become state of the art in matter-wave microscopy, providing unrivaled resolution in position-space measurements. However, achieving similar resolution in different measurement bases has remained challenging for lattice-confined atoms, restricting access to general microscopic state properties. Of special importance to several research avenues is the determination of the phase structure of a quantum state, with previous proposals working only in the regime of weak phase fluctuations. Here, we propose a novel scheme for the reconstruction of quantum phases using only high-precision density measurements after short time evolution, exploiting the sensitivity of the emerging interference pattern with respect to the phases. Our method decomposes the quantum state into local modes that are individually evolved in time, transforming the phase reconstruction into a set of low-dimensional optimization problems with overall linear scaling in the system size. To demonstrate its effectiveness, we applied our method to both synthetic and experimental data and find a generally high reconstruction quality and remarkable robustness to common experimental noise sources.

Q 61.7 Thu 16:00 P 11

Thermal qualification of an atom chip vacuum system — •Markus Trost and Maike Diana Lachmann — Airbus Defence and Space GmbH, Willy-Messerschmitt-Strasse 1, 82024 Taufkirchen, Gernamy

Matter-wave interferometry with ultra-cold atomic ensembles has developed as a promising prospect for acceleration measurements leading to increased long-term stability. Placing such sensors on satellites, offers a variety of application cases such as gravimetry on a global scale, testing fundamental physics or using it to detect drifts of satellites. However, this kind of sensor requires several prerequisites like for example magnetic field creation or an ultra-high vacuum system to generate an ultra-cold ensemble of atoms. While this technology is already well proven on ground-based setups, sounding rockets and the ISS, there has not yet been a dedicated standalone satellite mission for such a system. Particularly the qualification for the unstable thermal conditions on a satellite platform has not been performed yet. Therefore, the Cold Atom Interferometry Vacuum System (CAIVAS) project was initiated by ESA. Within this project, an atom-chip ultra-high vacuum system made for space-based usage is designed and realized. Thermal requirements were defined and subsequently verified. The results of the study will be presented in this talk.

Q 61.8 Thu 16:15 P 11

Concurrent atom interferometry for in situ beam characterization — •Christian Struckmann, Knut Stolzenberg, Daida Thomas, Ernst M. Rasel, 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 a highly sensitive and stable measurement tool for inertial forces with applications in geodesy, navigation, and fundamental physics. One of the leading systematic effects limiting the sensitivity of state-of-the-art atom interferometers is wavefront aberrations. Residual curvature and higher-order distortions of the interrogation beams imprint spatially varying phases across the atomic ensemble, leading to systematic biases. Conventional optical diagnostics only partially capture these effects and do not reflect the in situ, atom-averaged response. This motivates direct, atom-based characterization of the interrogation fields to push the limits of accuracy and robustness.

In this contribution, we present the application of PIXL (Parallelized Interferometers for XLerometry), a novel method to operate a quantum sensor based on a 2D array of Bose-Einstein condensates, to the 3D characterization of the interrogation beam's wave vector and intensity profiles [Stolzenberg et al., Phys. Rev. Lett. 134, 143601 (2025)].