Q 3: Precision Measurements and Metrology I

Time: Monday 14:00–16:00 Location: Q-H11

Q 3.1 Mon 14:00 Q-H11

Quantum Hybridized accelerometer for Inertial Navigation — •Mouine Abidi[1], Philipp Barbey[1], Yueyang Zou[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Sven Abend[1], and Ernst.M Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Today, precise inertial navigation and positioning systems are the basis for controlling vehicles such as aircrafts, ships, or satellites. However classical inertial sensors suffer from device-dependent drifts and require GNSS corrections that themselves rely on the availability of the signal broadcasted by the satellites. This leads to the non-usability of classical sensors in some environments like in-between buildings, underground, or space.

Hybrid quantum navigation, based on the combination of classical Inertial Measurement Units with quantum sensors based on atom interferometry, is a serious candidate for a new technology that meets the demand of our time requirements for inertial navigation.

Atom interferometers have proven to measure drift-free at very high sensitivities. The main challenge is to transfer a complex laboratory-based device to a robust and compact measurement unit that can be used regardless of their small bandwidth and dynamic range to subtract the drifts of the classical devices. We present the current status of our teststand for a quantum accelerometer employed on a gyro-stabilized platform.

Q 3.2 Mon 14:15 Q-H11

Gravitational Redshift Tests with Atomic Clocks and Atom Interferometers — •Fabio Di Pumpo[1], Christian Ufrecht[1], Alexander Friedrich[1], Enno Giese[2], Wolfgang P. Schleich[1,3], and William G. Unruh[4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institute of Quantum Technologies, German Aerospace Center (DLR) — [4]Department of Physics and Astronomy, University of British Columbia

Atomic interference experiments test the universality of the coupling between matter-energy and gravity at different spacetime points, thus probing possible violations of the universality of the gravitational redshift (UGR). In this contribution, we introduce a UGR violation model and then discuss UGR tests performed by atomic clocks and atom interferometers on the same footing. Consequently, we present a large class of atom-interferometer geometries which are sensitive to violations of UGR, and identify their underlying mechanisms leading to such tests [see PRX Quantum **2**, 040333 (2021)].

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Q 3.3 Mon 14:30 Q-H11

Atom interferometry aboard an Earth-orbiting research lab — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUEST-Leibniz Research School, Hanover, Germany — [3]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQ$^{\mathrm{ST}}$, Ulm University, Ulm, Germany

Atom interferometers based on Bose-Einstein condensates are exquisite systems for quantum sensing applications such as Earth observation, relativistic geodesy, and tests of fundamental physical concepts. The sensitivity of these devices depends on the free fall time of the quantum gas and, therefore, can be strongly improved by working in a microgravity environment. Here we report on a series of experiments performed with NASA's Cold Atom Lab aboard the ISS demonstrating atom interferometers with different geometries in orbit. By employing Mach-Zehnder-type interferometers we have realized atomic magnetometers and successfully compared their outcome to complementary non-interferometric measurements. Our results pave the way towards future precision measurements with atom interferometers in space.

This project is supported by NASA/JPL through RSA No. 1616833 and the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under the grant numbers 50WP1705 and 50WM1861-1862.

Q 3.4 Mon 14:45 Q-H11

Effective Models for Atom-interferometry with Center-of-mass Motion in Quantized Electromagnetic Fields — •Alexander Friedrich[1], Nikolija Momčilović[1], Sabrina Hartmann[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, 89077 Ulm, Germany

Entanglement enhanced metrology promises to boost the sensitivity of quantum devices beyond the classical limit. Future atom interferometric gravitational wave detectors, tests of the equivalence principle or inertial sensors are already envisioned to employ these techniques to reach their full projected potential. However, proper characterization of the dynamic entanglement transfer between parts of the system due to the atom-light interaction requires a quantized description of the light field as well as the atomic degrees of freedom. Starting with a few-mode model of the light-field, coupled to a few-level atom with second quantized motional degrees of freedom we show: (i) how effective Jaynes-Cummings-Paul like multi-mode Rabi models can be derived for multi-photon interactions, and (ii) our approach and the resulting models are not limited to atom interferometry configurations but have possible applications ranging from cavity optomechanics to ion traps.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

Q 3.5 Mon 15:00 Q-H11

Mitigation of spurious effects in double Bragg diffraction — •Jens Jenewein[1], Sabrina Hartmann[1], Albert Roura[2], and Enno Giese[1,3,4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Institut für Quantentechnologien, DLR — [3]Institut für Angewandte Physik, TU Darmstadt — [4]Institut für Quantenoptik, Leibniz Universität Hannover

The Mach-Zehnder interference signal of single and double Bragg diffraction is influenced by the multiport nature of the diffraction process [1]. Under appropriate conditions, higher-order path contributions can be neglected and just two or three paths are respectively relevant for single and double diffraction. Although the central path can contribute significantly to the exit-port population for double diffraction, the coherent overlap with the resonant paths is only small due to velocity selectivity effects. Even when the two resonant paths are dominant for double Bragg diffraction, the interference signal due to a phase shift exhibits that the outer ports are shifted to each other. For three paths, we additionally observe a beating. By summing over the two outer exit ports, one can define an effective port that is insensitive to these effects. We analyze how this feature changes under gravity which cannot be completely compensated by frequency chirping in this case. The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] Phys. Rev. A **101**, 053610 (2020)

Q 3.6 Mon 15:15 Q-H11

Modelling the Impact of Wavefront Aberrations on the Phase of a Precision Mach-Zehnder Light-Pulse Atom Interferometer — •Stefan Seckmeyer[1], Florian Fitzek[1], Tim Kovachy[2], Yiping Wang[2], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Hannover, Germany — [2]Northwestern University, Chicago, United States

Wavefront aberrations are one of the leading systematics in current state-of-the-art atom interferometry experiments. We compare the impact of wavefront aberrations on the final phase of a $2\hbar k$ Mach-

Zehnder geometry between two models. One is derived in the limit of infinitely short atom light interactions where the atoms follow classical paths based on Feynman's path integral method. The other recently developed one models the wavefunction as a complex function in position and momentum space to include among others effects from finite atom-light interaction and coherent diffraction.

Q 3.7 Mon 15:30 Q-H11

Space-borne Atom Interferometry for Tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional access to test the postulates of general relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented performance beyond current limits set by classical experiments.

In this contribution, we present a dedicated satellite mission to test the UFF with ultra-cold atoms to 10-17 as proposed to the ESA Voyage 2050 initiative [Battelier et al., Exploring the foundations of the physical universe with space tests of the equivalence principle, Experimental Astronomy (2021)]. To this end, we highlight our model for suppressing spurious error terms [Loriani et al., PRD 102, 124043 (2020)] and outline our work on a dedicated simulator for satellite-based atom interferometry, which will be an indispensable tool for the detailed analysis of future space mission scenarios.

Q 3.8 Mon 15:45 Q-H11

Dynamic Time-Averaged Optical Potentials for Atom Interferometry — •Henning Albers[1], Alexander Herbst[1], Vera Vollenkemper[1], Ernst M. Rasel[1], Dennis Schlippert[1], and The PRIMUS-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

Optical dipole traps are a commonly used tool for trapping and cooling neutral atoms. However, typical dipole traps are disadvantaged compared to magnetic traps for example implemented on atom chip traps, due to their small trapping volume and lower evaporation speed. The modulation of the center-position of dipole trap beams helps to overcome these limitations by creating large-volume time-averaged potentials with nearly arbitrary shape. The properties of these kind of atom traps can be changed dynamically and allow for faster evaporative cooling as well as atom-optical elements like matter-wave lenses. We use time-averaged optical potentials to generate Bose-Einstein condensates with up to 2×10^5 condensed ^{87}Rb atoms after 3s of evaporative cooling. Subsequently we apply an all-optical matter-wave lens by rapid decompression of the trap. This change in trap confinement induces oscillations of the ensemble, that we stop by turning off the trap, when the size is at a maximum, which reduces the further expansion of the free falling cloud. By means of this matter-wave lens we reduce the expansion temperature to 3nK in the horizontal directions. We present the results of the matter-wave lens and discuss the impact of this technique when used as the source an inertial sensitive free fall atom interferometer.