Q 33: Matter Wave Interferometry I

Time: Wednesday 11:00–13:00 Location: HS I

Q 33.1 Wed 11:00 HS I

Atom interferometry based quantum inertial navigation sensor — •Mouine Abidi, Philipp Barbey, Xingrun Chen, Ann Sabu, Matthias Gersemann, Dennis Schlippert, Ernst. M. Rasel, and Sven Abend — Leibniz Universität Hannover - Institut für Quantenoptik, Hannover, Germany

Current GNSS-based navigation systems and MEMS sensors provide convenient capabilities but are constrained by GNSS signal unavailability, vulnerability to jamming, and the long-term drift of MEMS sensors. In contrast, atom interferometry-based inertial sensors offer exceptional sensitivity and drift-free performance, making them ideal for applications in navigation, geodesy, and fundamental physics.

In this talk, the latest advancements from the QGyro project will be presented, focusing on the development of a quantum accelerometer that integrates state-of-the-art technologies, including a fiber-based laser system, flat-top beam shaping, ARTIQ electronics, and compact vacuum technology.

We also demonstrate the integration of this compact and robust quantum accelerometer onto a gimbal platform, facilitating its hybridization with classical MEMS sensors and quantum inertial navigation devices, such as accelerometers and gyroscopes. This hybrid system provides continuous, stable, and highly sensitive measurements of accelerations and rotations.

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 33.2 Wed 11:15 HS I

Space-deployed differential atom interferometers for magnetometry — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUESTLeibniz 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 IQST, Ulm University, Ulm, Germany

Matter-wave interferometers deployed in space are excellent tools for high precision measurements, relativistic geodesy, or Earth observation. In particular, differential interferometric setups feature common-mode noise suppression and enable reliable measurements in presence of ambient platform noise. Here we report on orbital magnetometry campaigns performed with differential Mach-Zehnder and differential butterfly interferometers on NASA's Cold Atom Lab aboard the International Space Station. By comparing measurements with atoms in magnetically sensitive and insensitive states, we have measured tiny magnetic-field force gradients and set bounds on force curvatures. Our results pave the way towards precision quantum sensing missions in space.

This work is supported by NASA/JPL through RSA No. 1616833 and the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant numbers 50WM2245-A/B.

Q 33.3 Wed 11:30 HS I

Simulation of 3D inhomogeneous Raman excitation rates under arbitrary rotations — •Ali Mouttaki[1,2], Christian Struckmann[1], Cyrille des Cognets[2], Vincent Jarlaud[2,3], Jan-Niclas Kirsten-Siemss[1], Vincent Ménoret[3], Baptiste Battelier[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institute of Quantum Optics, Germany — [2]Laboratoire Photonique, Numérique et Nanosciencces (LP2N), Univ. Bordeaux, CNRS, Institut d'Optique d'Aquitaine, France — [3]Exail, Institut d'Optique d'Aquitaine, France

Atom interferometers offer several advantages over classical sensors for inertial measurements due to their high sensitivity, great precision and long-term stability. Building on these strengths, the joint laboratory iXAtom - established by LP2N and Exail - aims to develop the next generation of inertial sensors based on cold atoms for geophysics and navigation [Science Advances, vol. 8, no. 45, 2022]. However, onboard applications still face persistent challenges such as low excitation rates and contrast loss caused by rotation and vibrations.

In this work, we present a simulator of 3D inhomogeneous Raman excitation rates of thermal atomic clouds operating under arbitrary orientations and rotation rates of the laser beam. The numerical simulations are validated through comparisons with experimental data. Moreover, we highlight how this simulator allows to better quantify and understand the impact of rotation on atom interferometers.

Q 33.4 Wed 11:45 HS I

Transverse recoil of diffraction wavelets within a matter-wave beam splitter — •Abhay Mishra[1], Adam Abdalla[2], Oleksandr Marchukov[3], and Reinhold Walser[4] — [1]Technical university Darmstadt, Darmstadt, Germany — [2]Technical university Darmstadt, Darmstadt, Germany — [3]Technical university Darmstadt, Darmstadt, Germany — [4]Technical university Darmstadt, Darmstadt, Germany

Atomic Bragg beam-splitters are integral devices for matter-wave interferometers. Interferometric measurements can be used for geodesy, inertial sensing or fundamental physics in space [1]. To achieve the ultimate measurement precision, one has to understand and rectify all sources of aberrations [2], eventually. In this contribution, we consider the transversal recoil of an axially decentered Bose-Einstein condensate in counter-propagating Gaussian beams. Due to the non-separability of the optical dipole potential, one obtains an entanglement between the longitudinal and transversal motion [3]. We study position displacement and momentum transfers using a (3+1D) numerical simulation of the Gross-Pitaevskii equation. These findings are explained by a dynamical model for the coupled motion of the center-of-mass coordinates of the diffraction wavelets, as well as their Schrödinger-amplitudes.

[1] D. Becker, et al., Nature 562, 391 (2018). [2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021). [3] S. Blatt, et al., Rabi Spectroscopy and Excitation Inhomogeneity in a One-Dimensional Optical Lattice Clock, Phys. Rev. A 80, 052703 (2009).

Q 33.5 Wed 12:00 HS I

Atom diffraction through free-standing graphene — •Carina Kanitz[1], Jakob Bühler[1], Vladimir Zobac[2], Joseph James Robinson[1], Toma Susi[2], Maxime Debiossac[1], and Christian Brand[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, Wilhelm-Runge-Strasse 10, 89081 Ulm, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria

Diffraction of particles through materials allows studying their properties in great detail as shown, for instance, in transmission electron microscopy. So far, coherent transmission through materials has only been demonstrated for electrons and neutrons, but not for atoms. This leads to the fundamental question whether this is possible [1]. Here, we report the first results on atomic diffraction through crystalline materials [2]. To achieve this feat, we used H and He atoms with an energy between 400 and 1600 eV normal to the surface. We observe highly-detailed patterns featuring diffraction up to the eighth diffraction order. Our findings are interesting both from a fundamental and applied point of view. They show that atoms can pass through a pristine material and retain their coherence. In this future, this might pave the path for new approaches to study 2D materials in transmission.

[1] Brand et al., New J. Phys. 21, 033004 (2019)
[2] Kanitz et al., in preparation

Q 33.6 Wed 12:15 HS I

Entangled center-of-mass dynamics of diffraction wavelets in a matter-wave beam splitter — •Adam Abdalla[1], Abhay Mishra[2], Oleksandr Marchukov[3], and Reinhold Walser[4] — [1]Institute of Applied Physics, TU Darmstat, Darmstadt, Germany — [2]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany — [3]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany — [4]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany

The resonant momentum exchange between matter-waves and photons from counter-propagating laser beams leads to Bragg diffraction.It is the building block of atom-interferometry used for quantum metrology and inertial sensing [1]. Usually, it is described by a Schrödinger-equation for the matter-wave amplitudes in a static plane-wave basis. However, in typical experiments with Bose-

Einstein condensates, one has a superposition of several wavelets $\psi(\boldsymbol{r},t) = \sum_l c^l(t) u(\boldsymbol{r}, \boldsymbol{R}^{(l)}(t), \boldsymbol{K}^{(l)}(t))$ that extend in the longitudinal x-direction over many optical wavelength $\sigma_x \gg \lambda_L$ and are much smaller than the Gaussian laser waist $w_0 \gg \sigma_{y,z}$ in the transversal direction [2]. In this contribution, we analyze the dynamical center-of-mass evolution of the coupled diffraction wavelets $(c^l(t), \boldsymbol{R}^{(l)}(t), \boldsymbol{K}^{(l)}(t))$ in the non-separable Bragg interference potential [3]. The results are supported by (3+1)D simulations of the Gross-Pitaevskii equation and experiments of QUANTUS Collaboration (DLR, grant number 50WM2450E). [1] S. Abend, et al., AVS Quantum Sci. 6, 024701 (2024) [2] A. Neumann, et al., Phys. Rev. A 103, 043306 (2021) [3] S. Blatt, et al., Phys. Rev. A 80, 052703 (2009)

Q 33.7 Wed 12:30 HS I

Parallelized atom interferometers for inertial sensing — •Knut Stolzenberg, Christian Struckmann, Daida Thomas, Ashwin Rajagopalan, Alexander Herbst, Ernst M. Rasel, Naceur Gaaloul, and Dennis Schlippert — Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167 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.

We show our results on measuring the Euler- and centrifugal acceleration, as well as transversal acting linear acceleration induced by gravity, utilizing a 3×3 array arrangement of Bose-Einstein condensates. The array has a spatial extent of 1.6 mm^2 and serves as input for Mach-Zehnder type atom interferometers, driven by double-Bragg diffraction. We call this method Parallelized Interferometers for XLerometry (PIXL) and discuss its prospects as a future quantum inertial measurement unit and in 3D-reconstruction of electro-magnetic fields.

Q 33.8 Wed 12:45 HS I

Seismic noise suppression for Very Long Baseline Atom Interferometry — •Kai C. Grensemann, Vishu Gupta, Guillermo A. Perez Lobato, 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 gravimetry beyond state-of-the-art precision with applications in geodesy and test of fundamental physics. Its 10 m baseline enables free fall times of up to $2T = 2.4\,\mathrm{s}$ and therefore large sensitivity scale factors $k_{\mathrm{eff}}T^2$. The currently limiting technical noise source for atom interferometers is vibration of the inertial reference mirror. To attenuate seismic vibrations coupling to the mirror, the VLBAI facility is equipped with a unique six degrees of freedom in-vacuum seismic attenuation system (SAS).

Here we present a characterization of the passive seismic isolation performance, as well as our progress towards the six degrees of freedom active stabilization. We utilize three low-noise triaxial seismometers as inertial sensors and six voice-coils for force feedback driven by a digital real-time control system. Furthermore, a central out-of-loop low-noise seismometer can be used to post-correct the interferometer measurements. We estimate that the SAS in combination with ideal post-correction will allow instabilities of below $10^{-9}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ at 1 s, close to the shot-noise limit of $\approx 2 \cdot 10^{-10}\,\frac{\mathrm{m}}{\mathrm{s}^2}$ for 10^6 atoms.