A 32: Precision Measurements: Atom Interferometry II (joint session Q/A)

Time: Friday 14:30–16:30 Location: F342

A 32.1 Fri 14:30 F342

INTENTAS - Interferometry with entangled atoms in space — •Jan Simon Haase[1], Janina Hamann[1], Jens Kruse[2], and Carsten Klempt[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstr. 30b, 30167 Hannover

Atom interferometers are high-precision measurement devices for the sensing of inertial moments as accelerations and rotations. A zero-gravity environment enables prolonged interrogation time and consequently a higher resolution. Therefore, space-borne atom interferometers promise unprecedented resolution for a wide range of applications from geodesy to fundamental tests.

A fundamental limit for their precision is the Standard Quantum Limit (SQL), which determines a limit for the interferometric resolution. The SQL can only be surpassed by using entangled ensembles of atoms as a source for the interferometer.

The goal of the INTENTAS project (Interferometry with entangled atoms in space), which will be presented in this talk, is to demonstrate a compact source of entangled atoms in the Einstein-Elevator, a microgravity platform which allows zero-gravity tests for up to 4 s. The planned experiments will pave the way to employ entangled atomic sources for high-precision interferometry in space applications.

A 32.2 Fri 14:45 F342

Generalized Ramsey Protocols — •Maja Scharnagl — Institute for theoretical physics, Leibniz University Hannover, Germany

We consider a variational class of generalized Ramsey protocols with two one-axis-twisting (OAT) operations, one before and one after the phase imprint, for which we optimize the direction of the signal imprint, the direction of the second OAT interaction and the measurement direction via a numerical routine for global optimization of constrained parameters. In doing so, we distinguish between protocols whose signal from spin projection measurements exhibits a symmetric or antisymmetric dependence on the phase to be measured. We find that the Quantum Fisher Information, which bounds the sensitivity achievable with a one-axis-twisted input state, can be saturated in our variational class of protocols for nearly all initial squeezing strengths. Therefore, the generalized Ramsey protocols considered here allow us to reduce quantum projection noise in comparison to the standard Ramsey protocol considerably.

A 32.3 Fri 15:00 F342

Dynamics of quantum gases mixtures in space experiments — •Annie Pichery[1,2], Matthias Meister[3], Eric Charron[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]German Aerospace Center (DLR), Institute of Quantum Technologies, Ulm, Germany

Ultra-cold atomic ensembles are a prime choice for sources in quantum sensing experiments. Space provides an environment where these clouds can float for extended times of several seconds, thus boosting the precision of these sensors. It also enables the operation of Bose-Einstein Condensate (BEC) mixtures for dual interferometers in miscibility conditions not possible on ground.

Simulating such dynamics of interacting dual species BEC mixtures presents however computational challenges due to the long expansion times. In this contribution, scaling techniques to overcome these limits are presented and illustrated in the case of space experiments on the ISS and aboard sounding rockets.

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A 32.4 Fri 15:15 F342

Atom interferometry on the International Space Station — •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 based on Bose-Einstein condensates are exquisite tools for precision measurements, relativistic geodesy, and Earth observation. Employing this quantum technology in space further increases the sensitivity of the measurements due to the extended free fall times enabled by microgravity. 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 comparing measurements with atoms in magnetic sensitive and insensitive states we have realized atomic magnetometers mapping the residual magnetic background in the apparatus. Our results pave the way towards future quantum sensing missions with cold atoms in space.

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A 32.5 Fri 15:30 F342

Large-momentum-transfer atom interferometers with μrad-accuracy using Bragg diffraction — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Christian Schubert[2,3], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Satellitengeodäsie und Inertialsensorik

Large-momentum-transfer atom interferometers that employ elastic Bragg scattering from light waves are among the most precise quantum sensors available. To increase their accuracy from the mrad to the μrad regime, it is necessary to understand the rich phenomenology of Bragg interferometers, which can be quite different from that of a standard two-mode interferometer. We develop an analytic model for the interferometer signal and demonstrate its accuracy using extensive numerical simulations. Our analytic treatment enables the determination of the atomic projection noise limit of an LMT Bragg interferometer and provides the means to saturate this limit. It allows suppression of systematic phase errors by two orders of magnitude down to a few μrad using appropriate pulse parameters.

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A 32.6 Fri 15:45 F342

Applications of tuneable interactions in atom interferometry sources — •Alexander Herbst, Henning Albers, Wei Liu, Knut Stolzenberg, Sebastian Bode, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Atom interferometers are powerful tools for precision measurements in fundamental physics or applications such as inertial sensing. Fundamentally, the sensitivity of these devices is limited by shot noise, thus motivating high-flux atomic sources. Furthermore, control over the ensemble's initial conditions and its expansion dynamics is key for systematic error mitigation.

To address these challenges we demonstrate a high flux source of ultra-cold ^{39}K with nearly Heisenberg limited expansion rates in the horizontal plane. Due to its broad Feshbach resonances at comparably low magnetic fields ^{39}K allows for changing its atomic interactions without the need for complex coil setups. By dynamically tuning its scattering length along the evaporation trajectory we achieve quantum degeneracy in below 200 ms evaporation time, maintaining a constant flux. Subsequently, changing the scattering length to a minimal positive value reduces the mean-field energy, thus offering a simple and robust way to decrease the expansion rate to an effective temperature equivalent of a few nanokelvin. Moreover, our method can also be applied to improve more complex techniques such as matter-wave lensing, allowing for effective temperatures in the sub-nK regime.

A 32.7 Fri 16:00 F342

Optical simulations for highly sensitive atom interferometry

— •Gabriel Müller, Stefan Seckmeyer, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Using atom interferometers as highly sensitive quantum sensors requires both precise understanding and control of their main building block: atom light interactions. To properly describe the atom light interactions we need an accurate description of the laser-driven light fields. Distortions of ideal Gaussian beams on their path to the atoms can cause several disturbing effects. For example, the occurrence of asymmetric optical dipole forces acting on the atoms can cause a loss of contrast. Here, we build an optical simulation tool using Fast-Fourier-transform beam propagation methods to take into account arbitrarily shaped obstacles. We compare these results, on small scales, to solutions of Maxwell's equations finding good agreement. Finally, we apply our optical simulations to guide the design of the next unit of NASA's Earth-orbiting Cold Atom Lab and DESIRE, a microgravity experiment searching for Dark Energy.

This work is supported by DLR funds from the BMWi (50WM2245A-CAL-II and 50WM2253A-(AI)^2).

A 32.8 Fri 16:15 F342

BEC atom interferometry techniques for very long baselines

— •Dorothee Tell[1], Vishu Gupta[1], Henning Albers[1], Klaus H. Zipfel[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

The Very Long Baseline Atom Interferometry (VLBAI) facility at the university of Hannover aims for high precision measurements of inertial quantities. Goals span from absolute gravimetry to fundamental physics at the interface between quantum mechanics and general relativity. To this end, the VLBAI facility will make use of ultracold atoms freely falling in a 10 m long vacuum tube with well-known bias forces. We will utilize Bragg atom optics to realize Mach-Zehnder-like geometries sensitive to acceleration.

Here we present the source of rubidium Bose-Einstein condensates ready to be installed at the bottom of the VLBAI baseline for interferometry on fountain trajectories. We demonstrate the necessary methods and schemes, such as matter-wave lenses, Bragg beam splitters and Bloch oscillations, in proof-of-principle experiments performed in the cm-scale baseline available in the source chamber. We discuss prospects and challenges of extending the free fall distance to 10 m.

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