Q 40: Precision Measurements and Metrology (Atom Interferometry)

Time: Thursday 11:00–13:00 Location: a310

Group Report Q 40.1 Thu 11:00 a310

Very Long Baseline Atom Interferometry: vision and challenges — •Etienne Wodey[1], Christian Meiners[1], Dorothee Tell[1], Robert J. Rengelink[1], Manuel Schilling[2], Klaus Zipfel[1], Wolfgang Ertmer[1], Christian Schubert[1], Ludger Timmen[2], Jürgen Müller[2], Dennis Schlippert[1], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Leibniz Universität Hannover, Institut für Erdmessung

Atom interferometers are powerful tools to perform precision measurements and search for new physics. New applications, including the detection of gravitational waves and exotic matter searches, nevertheless require significant upgrades to the sources of ultracold atoms with enhanced atom numbers and repetition rates on long baselines to achieve low instabilities. In addition, improved control over wavepacket dynamics and the homogeneity of the interferometer's environment are key to reduce instrumental biases.

We report on the development of the Very Long Baseline Atom Interferometry (VLBAI) facility, a 10 m-baseline device located at the newly founded Hannover Institute of Technology (HITec). Based on our work on large scale magnetic shielding and gravitational environment mapping as well as on vibration isolation and high-flux atomic sources, we review recent advances towards effective long baseline matterwave inertial sensors, and discuss methods and challenges for the next generation ultra long baseline atom interferometers.

We acknowledge support by the DFG (Großgeräte), the CRCs 1128 “geo-Q” and 1227 “DQ-mat”, and the EXC 2123 “QuantumFrontiers”.

Q 40.2 Thu 11:30 a310

International Space Station-based Cold Atom Lab: status of first flight investigations — •Naceur Gaaloul[1,5], Annie Pichery[1,5], Waldemar Herr[1,5], Holger Ahlers[1,5], Christian Schubert[1,5], Wolfgang Ertmer[1,5], Ernst. M. Rasel[1,5], Matthias Meister[2,5], Patrick Boegel[2,5], Wolfgang P. Schleich[2,5], Robert Thompson[3], Jason Williams[3], Nicholas P. Bigelow[4,5], and the CUAS Consortium[5] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Quantenphysik, Universität Ulm — [3]Jet Propulsion Laboratory, California Institute of Technology — [4]the University of Rochester — [5]The Consortium for Ultracold Atoms in Space

Space offers a unique low-noise, low-gravity environment necessary for deploying competitive quantum sensors covering a wide spectrum of applications ranging from time and frequency transfer to Earth observation and the exploration of fundamental laws of physics. In this contribution, we report about the CUAS consortium activities within the NASA Cold Atom Lab stationed aboard the International Space Station. It consists of a multi-user Bose-Einstein Condensate facility continuously operating in-orbit. The outcome of a year of operations is presented and their significance for follow-up missions testing general relativity, quantum mechanics or cosmology predictions is highlighted.

We acknowledge financial support from DLR (Grant No. 50WM1861/2), the ”Niedersächsisches Vorab” (QUANOMET, new DLR-SI Institute) and NASA (CUAS RSAs including 1585910).

Q 40.3 Thu 11:45 a310

Atom interferometry in the transportable Quantum Gravimeter QG-1 — •Nina Heine[1], Jannik Wesche[1], Sven Abend[1], Waldemar Herr[1], Jürgen Müller[2], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover, Germany — [2]Leibniz Universität Hannover, Institut für Erdmessung, Hannover, Germany

The transportable Quantum Gravimeter QG-1 will perform absolute measurements of the local gravitaional accelaration with an unrivalled uncertainty below $3\,\mathrm{nm/s^2}$ by utilising collimated atomic ensembles for atom interferometry in a compact setup. To achieve this performance, leading order error sources, predominantly stemming from the horizontal velocity of the interrogated atoms, need to be minimised. This talk elaborates on the design and implementation of the interferometry setup into the atom chip based experimental system. The center of mass motion and the velocity spread of the atomic cloud, as well as their impact on the beam splitting process are evaluated to develop a comprehensive understanding of their contribution to the uncertainty.

We acknowledge financial support from "Niedersächsisches Vorab" through "Förderung von Wissenschaft und Technik in Forschung und Lehre" for the initial funding of research in the new DLR-SI Institute and by the Deutsche Forschungsgemeinschaft (DFG) in the project A01 of the SFB 1128 geo-Q and under Germany's Excellence Strategy - EXC 2123 QuantumFrontiers, Project-ID 390837967.

Q 40.4 Thu 12:00 a310

MAIUS-B: Development and test of the scientific payload — •Baptist Piest, Jonas Böhm, Maike Lachmann, Ernst Rasel, and The QUANTUS team — Institut für Quantenoptik, LU Hannover

Quantum tests of the Einstein equivalence principle (EEP) promise to outreach the accuracy of classical tests based on macroscopic test masses in the course of the next decade. Additionally, they offer to probe quantum aspects of the EEP which are inherently inaccessible for classical tests. Current limitations of ground-based tests using light-pulse matter-wave interferometry are mainly given by the maximum pulse separation time T and the terrestrial environment. A promising approach to overcome this limitation is to perform the experiments in extended free fall, e.g. on a satellite. In 2017, the sounding rocket experiment MAIUS-1 succeeded in generating the first BECs in space using Rb-87 atoms and demonstrated further key methods needed for an EEP test in space. The missions MAIUS-2 and -3 aim to demonstrate BEC-borne dual-species matter wave interferometry with K-41 and Rb-87. This talk shows the current experimental status with a focus on the creation of ultracold mixtures and the interferometry setup. The MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

Q 40.5 Thu 12:15 a310

Simulations of Integrated Laser-Guided Atom Interferometers — •Matthew Glaysher, Florian Fitzek, Sina Loriani, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz Universität Hannover, Institute of Quantum Optics, Germany

Atom interferometry provides a highly accurate measurement tool, its applications ranging from inertial sensing and navigation to tests of fundamental physics. High precision interferometry is achieved either by Large Momentum Transfer or long interrogation times. Whereas the more common light pulse interferometer schemes can produce the necessary momentum transfer, guided interferometers can achieve long interrogation times. For guided ensembles it is essential to understand the internal interactions, as well as the inherent systematics they cause, to realize a phase-sensitive interferometer. For this purpose we compute the dynamics of Bose-Einstein Condensates (BECs) by numerically solving the Gross-Pitaevskii-Equation. We specifically investigate beam-splitting mechanisms and the phase evolution of BECs in a guided system, realized by dynamically shaped cavity modes or painted potentials.

The presented work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL)

Q 40.6 Thu 12:30 a310

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Holger Ahlers[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we contribute to the precise formulation and simulation of the aforementioned effects by employing a position space solver of the Gross-Pitaevskii equation. We specifically target problems connected to gravity sensing as well as the dephasing in trapped atom interferometers. The work is supported by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 40.7 Thu 12:45 a310

Beamsplitters and sensitivity to relativistic effects in atom-interferometry — •Alexander Friedrich[1], Butrint Pacolli[1], Fabio Di Pumpo[1], Enno Giese[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, D-89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Recently, quantum-clock interferometry [1] has been suggested to investigate relativistic effects on the center-of-mass motion in superpositions of internal states. These proposals combine high-precision quantum metrological techniques with studies of the fundamental interconnections between relativity and quantum mechanics. Complementary to tests of relativity with atomic clocks, quantum-clock interferometry allows one to test these effects with a single but delocalized quantum object. However, the sensitivity with respect to relativistic effects [1,2] depends crucially on the geometry and the specific details of the involved beamsplitting processes. In our contribution we investigate, elaborate and clarify the link between typical beamsplitters used in the proposed schemes and the sensitivity to relativistic effects.

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[1] A. Roura, arXiv 1810.06744, (2018)

[2] S. Loriani, A. Friedrich et al., Sci. Adv. **5** (10), eaax8966 (2019)