Q 75: Matter Wave Optics II

Time: Friday 14:30–16:00 Location: K/HS2

Q 75.1 Fri 14:30 K/HS2

QUANTUS 2 - a matter wave interferometer in extended free fall — •Christoph Grzeschik[1], Achim Peters[1,2], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]IQO, Leibniz Universität Hannover — [4]ZARM, Universität Bremen — [5]ILP, Universität Hamburg — [6]Institut für Physik, Johannes Gutenberg-Universität — [7]Institut für Quantenphysik, Universität Ulm — [8]Institut für angewandte Physik, TU Darmstadt — [9]MPQ, Garching

Inertial sensors based on cold atoms are an outstanding tool for fundamental physics research under microgravity such as testing the Einstein equivalence principle. Here we present the first results of our apparatus after drops and catapult shots in the Bremen drop tower. During a microgravity time of 9s the apparatus is capable of subsequently producing and performing experiments with up to four ^{87}Rb BECs. During the first drop and catapult campaigns we found that the position and dynamics of the atoms closely follow the predictions made by an extensive simulation of our magnetic chip. By implementing magnetic lensing we will be able to demonstrate atom interferometry with unprecedented interrogation times. For future campaigns the setup will be modified to produce mixtures of both Rubidium and Potassium for dual species atom interferometry.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50WM1131-1137.

Q 75.2 Fri 14:45 K/HS2

Atom interferometry with BECs and Double Bragg Diffraction — •Martina Gebbe[1], Sven Abend[2], Matthias Gersemann[2], Hauke Müntinga[1], Holger Ahlers[2], Ernst Maria Rasel[2], Claus Lämmerzahl[1], and The QUANTUS-Team[1,2,3,4,5,6,7,8,9] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universtität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

Current inertial sensitive atom interferometry devices operate mostly with sources of laser cooled atoms. The velocity distribution and finite size of these sources limit the efficiency of employed beam splitters and the analysis of systematic uncertainties. These limits can be overcome by the use of ultra-cold sources such as Bose-Einstein condensates or even delta-kick cooled atomic ensembles. Atomic chip technologies offer the possibility to generate a BEC and perform delta-kick cooling in a fast and reliable away. We show the application of a symmetric Bragg beam splitting technique, called double Bragg diffraction which offers interesting features and enables new geometries for future atom interferometers. Moreover, we have realized an atomic gravimeter using the chip as retroreflector demonstrating the use as compact inertial sensor. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant numbers DLR 50 1131-1137 (QUANTUS-III).

Q 75.3 Fri 15:00 K/HS2

Theoretical description of light-pulse atom interferometry in generic potentials — •Wolfgang Zeller[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS TEAM[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Laser-Physik, Universität Hamburg — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

During the last few decades the excellent capabilities of light-pulse atom interferometers have been demonstrated in high-precision measurements of fundamental constants, inertial sensing and gravimetry. When increasing the interrogation time and the effective momentum transfer to improve the sensitivity, anharmonicities in external fields can give rise to non-negligible effects in high-precision measurements. In addition, if different internal states are involved (e.g. when using Raman scattering) the forces experienced by the atoms can be even state- and branch-dependent. In this talk we present a theoretical description [1,2] of light-pulse atom interferometers that accounts for those effects and highlight the consequences for the density profile and the contrast.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

[1] Zeller, Roura and Schleich, in preparation.
[2] Roura, Zeller and Schleich, New J. Phys., in press, arXiv:1401.7699.

Q 75.4 Fri 15:15 K/HS2

Interference of quantum clocks and universality of free fall — •Albert Roura, Enno Giese, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

By preparing appropriate superpositions of their internal states, particles employed in matter-wave interferometry can also behave as quantum clocks. Differences in the proper time along the branches of the interferometer lead then to a reduction of contrast in the interferometry measurements. It has been argued that when this difference is due to the gravitational redshift, the effect can probe aspects of the interplay between quantum mechanics and general relativity which have not been tested experimentally so far [1]. In this talk we will bring to light the direct relationship between the aforementioned reduction of contrast due to the gravitational redshift in matter-wave interferometry with quantum clocks and the universality of free fall. Furthermore, it will be shown that the parameters characterizing possible deviations from the standard result for the gravitational redshift in this context can be more easily measured in tests of the universality of free fall with quantum systems [2,3].

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1136.

[1] M. Zych *et al.*, Nat. Commun. **2**, 505 (2011)
[2] D. Schlippert *et al.*, Phys. Rev. Lett. **112**, 203002 (2014)
[3] D. N. Aguilera *et al.*, Class. Quant. Grav. **31**, 115010 (2014)

Q 75.5 Fri 15:30 K/HS2

T^3-interferometer for precise measurements — •Matthias Zimmermann[1], Maxim A. Efremov[1], Wolfgang P. Schleich[1], Sara Desavage[2], and Frank Narducci[2] — [1]Institut für Quantenphysik, Universität Ulm, Ulm, Germany — [2]Naval Air Systems Command, EO Sensors Division, Patuxent River, Maryland 20670, USA

We present a novel scheme for an atom interferometer in order to increase the precision in measuring the gravitational acceleration g by a few orders of magnitude. The propagator of a massive particle in a linear gravitation potential is well-known to contain a phase φ_g scaling with the third power of time T, $\varphi_g \propto g^2T^3$. However, since in the conventional schemes [1,2] for atom interferometers both the ground and the excited atomic states are exposed to the same gravitational acceleration g, the phase φ_g cancels out and the interferometer phase scales as T^2. In contrary, by applying an external magnetic field, we effectively prepare two different accelerations g_g and g_e for the ground and excited states of the atom. In this way, depending on its internal state, the atom experiences two different phases $\varphi_g^{(g,e)} \propto g_{g,e}^2 T^3$ and the total interferometer phase scales as T^3.

[1] W.P. Schleich, D.M. Greenberger, E.M. Rasel, *New J. Phys.* **15**, 013007 (2013)
[2] E. Giese *et al.: Proceedings of the International School of Physics «Enrico Fermi» 15-20 July 2013 - Atom Interferometry, Course 188* (IOS Press, 2014); arXiv:1402.0963

Q 75.6 Fri 15:45 K/HS2

Simulating matter-wave interferometers with ray tracing — Mathias Schneider and •Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

The development of quantum limited acceleration and rotation devices is a key research direction. In the context of ultra-cold atoms, whether thermal clouds or Bose-Einstein condensates, this is usually realized by atomic matter-wave interferometers [1].

The numerical solution of the associated three-dimensional equa-

tions of motion, e.g. Schrödinger-, Gross-Pitaevskii, or Liouville equation is cumbersome. However, designing and simulating matter-wave interferometers is, in many ways, analog to the design of high precision optical devices. In case of the latter, one does not rely on Maxwell's equations but rather on efficient semi-classical ray tracing methods. In the same spirit, we approximate the dynamics of thermal clouds or Bose-Einstein condensates with a ray tracing formalism.

To this end, we employ the effective single-particle Wigner function as a phase space representation of the atom cloud, which is well suited for describing partially coherent matter-waves used for interferometry. When classical transport theory is valid, the Wigner function flows along the classical phase space trajectories. On the other hand, when the ensemble interacts with a coherence creating device, like a beam splitter or double slit, one has to use an appropriate map.

We demonstarte the use of 3D matterwave interferometry in gravity for thermal ensemble.

[1] H. Müntinga *et al.*, Phys. Rev. Lett. 110, 093692 (2013)