Q 15: Matter-wave optics

Time: Monday 16:30–18:45 Location: F 142

Group Report Q 15.1 Mon 16:30 F 142

Atom chip based matter wave interferometry at the Bremen drop tower — •Hauke Müntinga[1], 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, Universität 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

The growing interest in microgravity platforms for AI is motivated by the prospect of performing high precision tests of fundamental gravitational effects, e.g. the WEP. The QUANTUS-I experiment has demonstrated the feasibility of operating delicate quantum optical experiments in a demanding environment and constitutes the first step towards space. In over 400 free fall experiments, the preparation, the free evolution [1] and the coherence of the condensate on macroscopic time scales have been studied. To this end, a matter wave interferometer using Bragg diffraction was implemented in our atom chip based setup and combined with a δ kick cooling scheme to slow the expansion of the clouds. With an asymmetrical Mach Zehnder scheme, contrast in the output ports was observed up to a total time in the interferometer of 677 ms. 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 DLR 50WM1131-1137.

[1] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.2 Mon 17:00 F 142

Charged matter-waves: Towards quantum interference applications with ions and charged molecules — •Alexander Rembold, Georg Schütz, Andreas Pooch, and Alexander Stibor — Physikalisches Institut, Tübingen, Germany

Realizing an ion interferometer opens up possibilities for new experiments in connection with Aharonov-Bohm physics. The large experience for guiding and detecting charged particles can be adopted from electron interferometry. We present the design and the current status in the construction of the first reliable, stable and intensive ion-interferometer for helium ions, based on [1]. In our setup a new technique allows for a coherent ion emission from a pyramidal shaped single-atom tip. The beam is separated and recombined by a fine charged biprism wire. The longitudinal coherence is adjusted by a Wien-filter and the interference pattern is detected after a quadrupole magnification by a delayline detector. Such a novel interferometer combines the advantages of electron, atom and molecule interferometry: efficient emission and detection, good beam guiding and the study of structure dependent effects, especially connected to the magnetic Aharonov-Bohm effect. As it will be proposed, the lower velocity of the ions compared to electrons allows the first direct proof of the electrostatic Aharonov-Bohm effect. The described interferometer can potentially be used to interfere particles with significantly higher masses, such as organic molecules.

[1] F. Hasselbach and U. Maier, 1999 Quantum Coherence and Decoherence, ISQM, Tokyo, p. 299

Q 15.3 Mon 17:15 F 142

Towards a test of Einstein's equivalence principle using a Rb-K atom interferometer — •Dennis Schlippert, Jonas Hartwig, Ulrich Velte, Henning Albers, Jonas Matthias, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on our work directed towards a dual species matter-wave interferometer for performing a differential measurement of the acceleration of free falling ^{87}Rb and ^{39}K atoms to test Einstein's equivalence principle (universality of free fall). According to the minimal Standard Model Extension such a test is very sensitive to composition based equivalence principle violating effects and complementary to classical tests. We will show the enviromental noise limited performance of the single species Rb gravimeter ($7.84 \cdot 10^{-6}\mathrm{m/s^2}/\sqrt{\mathrm{Hz}}$ and $3.86 \cdot 10^{-8}\mathrm{m/s^2}$ @ 49152 s) and the progress of the implementation of the K gravimeter. Moreover, we discuss possibilities to either match the interferometers' sensitivities or to match their free evolution times resulting in high common noise rejection.

Q 15.4 Mon 17:30 F 142

Gravity gradient corrections in μ-gravity. — •Luis Fernando Barragan Gil, Oliver Gabel, and Reinhold Walser — Institut für Angewandte Physik, TU-Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

The realization of Bose-Einstein condensates in μ-gravity conditions, at the ZARM drop tower in Bremen by the QUANTUS collaboration [1,2], has opened the possibility to measure corrections to local gravitational field of the Earth beyond the linear Earth's acceleration (g) [3,4]. This is known as the gravity gradient correction and it is the next dominan contribution found in classical newtonian Physics as well as in general relativistic view of gravity.

We analyse a matter-wave interferometer for coherent states and thermal ensambles in the presence of the harmonic corrections to the gravitational potential. In this work, we use the formalism of generalized squeezed states and compare the results for various experimental observables as interference fringe spacing.

[1] Quantus Collaboration *http://www.iqo.uni-hannover.de/quantus.html*
[2] van Zoest, T. et al. *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540-1543 (2010)
[3] Dimopoulos, S. et al. *General Relativistic effects in atom interferometry*, Phys. Rev. D, **78** 042003 (2008)
[4] Kasevich, M. A. and Chu, S.*Atom Interferometry Using Stimulated Raman Transitions*,phys. Rev. D, **67**, 181-184 (1991)

Q 15.5 Mon 17:45 F 142

Theoretical description of QUANTUS experiments on interferometry with BECs in microgravity — •Wolfgang Zeller[1], Enno Giese[1], Endre Kajari[1,2], Stephan Kleinert[1], Vincenzo Tamma[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS Team[1,3,4,5,6,7,8,9,10] — [1]Institut für Quantenphysik, Universität Ulm — [2]Theoretische Physik, Universität des Saarlandes — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, HU Berlin — [6]Institut für Laser-Physik, Universität Hamburg — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin — [10]MPQ, Garching

The pioneering QUANTUS experiments merge microgravity environments with matter-wave interferometry using Bose-Einstein condensates (BECs). Recent experiments have realized a time-asymmetric Mach-Zehnder interferometer that produces in every shot an interference pattern in the density profile. We employ a time-dependent generalization of the Thomas-Fermi approximation [1], which accurately describes the expansion of the BEC in microgravity [2], to provide a simple theoretical explanation of all the relevant features observed in the experiments.

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] Y. Castin and R. Dum, Phys. Rev. Lett. 77, 5315 (1996).
[2] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.6 Mon 18:00 F 142

Physical insights into the time-dependent Thomas-Fermi approximation for Bose-Einstein Condensates — •Vincenzo Tamma, Wolfgang Zeller, Enno Giese, Stephan Kleinert, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

We unravel the physical properties of the time-dependent Thomas-Fermi (TF) regime [1] describing the time evolution of an expanding BEC for an at most quadratic potential. In particular, we study in such a regime the time evolution behavior of the phase and of the modulus of the wave function. We provide physical insight into the validity of the TF approximation depending on the experimental conditions. At the same time we apply perturbation theory in order to obtain corrections to both the phase and modulus that are relevant in different experimental situations. The obtained results have important applications in experiments exploiting long-time BEC evolution leading to interferometry and, in particular, in the experiments performed within the QUANTUS collaboration measuring quantum interference of BEC in microgravity [2].

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] Y. Castin and R. Dum, Phys. Rev. Lett. 77, 5315 (1996).
[2] T. van Zoest et al., Science 328, 1540 (2010).

Q 15.7 Mon 18:15 F 142

Representation-free description of matter wave interferometry — •Stephan Kleinert[1], Wolfgang Zeller[1], Enno Giese[1], Vincenzo Tamma[1], Albert Roura[1], Endre Kajari[2], Wolfgang P. Schleich[1], and the QUANTUS Team[1,3,4,5,6,7,8,9,10] — [1]Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, HU Berlin — [6]Institut für Laser-Physik, Universität Hamburg — [7]Institut für angewandte Physik, TU Darmstadt — [8]MUARC, University of Birmingham, UK — [9]FBH, Berlin — [10]MPQ, Garching

In the late 20th century progress in the coherent manipulation of atoms enabled the use of atom interferometers for high-precision measurements [1,2]. They play a central role in state-of-the-art clocks, inertial sensors and gravimeters.

Our talk provides a compact and versatile description of matter wave interferometry solely based on operator algebra. We present a straightforward method for determining the phase-shift for general multi-loop interferometers taking into account the local gravitational acceleration, gravity gradient and rotation of the device.

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] C. J. Bordé, Physics Letters A 140, 10 (1989).
[2] M. Kasevich and S. Chu, Phys. Rev. Lett. 67, 181 (1991).

Q 15.8 Mon 18:30 F 142

Overcoming loss of contrast in atom interferometry due to gravity gradients — •Albert Roura, Wolfgang Zeller, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Long-time atom interferometry in drop towers, sounding rockets and space missions is required for high-precision measurements of fundamental physical properties, including tests of the equivalence principle. Such measurements rely on the dependence of the phase shift between the two branches of a Mach-Zehnder interferometer as a function of the interrogation time and the corresponding oscillations in the integrated atom density at each exit port. For long times, however, gravity gradients cause the classical trajectories associated with the two branches not to close in phase space, which leads to a spatially dependent phase shift between the two overlapping wave-packets and a fringe-pattern density profile at the exit ports. This in turn implies a loss of contrast in the oscillations of the total number of atoms at each port and a reduction of the interferometer's sensitivity. Here we present a strategy for overcoming such loss of contrast which is very simple to implement.

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.