Q 31: Precision Measurements: Atom Interferometry I (joint session Q/A)

Time: Wednesday 11:00–13:00 Location: F102

Q 31.1 Wed 11:00 F102

Ultracold matter trapped by light singularities and quantum noise. — •Alexey Okulov — Moscow, Russia

Superfluids within helical boundaries are interesting from the point of view of low dimensional physics, phase transitions and inertial sensors. The sensitivity to the ultraslow motions of reference frame is limited by an unavoidable zero-point fluctuations. The basic uncertainty relations induce the phase uncertainty by corresponding fluctuations of the particles amount in ultracold ensemble. Hopefully there exists an opportunity to reduce the phase uncertainty by means of the proper structuring of the boundaries geometry. Our aim is to present the convincing arguments in favour of usage the helical laser traps formed by the counterpropagating Laguerre-Gaussian optical vortices to reduce the restrictions on phase deviations. The evaluation of the phase uncertainty with multimode coherent states approach leads to the optimistic result that phase measurement accuracy may be improved by a factor containing 2ℓ, where ℓ is the topological charge of LG vortices, compared to the conventional nontwisted trap geometries. Recent advances in development of highly charged optical vortices with $\ell = 10^3-10^4$ open the opportunity to improve the sensitivity to reference frame slow motions by several orders of magnitude.

Q 31.2 Wed 11:15 F102

Simulating space-borne atom interferometers for Earth Observation and tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional performance to test the postulates of General Relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented sensitivity beyond current limits.

In this contribution, we present a simulator for satellite-based atom interferometry and demonstrate its functionality in designing the STE-QUEST mission scenario, a satellite test of the UFF with ultra-cold atoms to 10^-17 as proposed to the ESA Medium mission frame [https://arxiv.org/abs/2211.15412]. Moreover, we will highlight the possibility of this simulator to design Earth Observation missions going beyond state of the art such as the CARIOQA concept [https://arxiv.org/abs/2211.01215].

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Q 31.3 Wed 11:30 F102

Multi-Axis sensing utilising guided atom interferometry — •Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Wei Liu, Henning Albers, Ernst Rasel, and Dennis Schlippert — Leibniz Universität Hannover, Institut für Quantenoptik

Inertial sensors based on atom interferometry are a superior alternative to classical sensors regarding accuracy and long-term stability. Particularly in the field of autonomous navigation quantum sensors can become a viable addition to GNSS and classical IMUs. Yet the simultaneous measurement of accelerations and rotations is challenging to present experiments.

In our setup a 1064 nm crossed optical dipole trap (ODT) is used for the evaporation to quantum degeneracy. By using acousto-optical deflectors in both ODT beam paths, we add versatile control over the trapping potentials with respect to position and trap depth. This allows for the creation of one or more BECs amounting to a total number of up to 250×10^3 ultracold ^{87}Rb atoms prepared in the magnetic insensitive state $|F = 1, m_F = 0\rangle$. After preparation the ensembles are loaded into 1D-optical waveguides to counteract gravity and ensure radial confinement. Subsequently we span Mach-Zehnder atom interferometers utilising double-Bragg diffraction. In addition to measuring accelerations, we discuss future perspectives enabling sensitivity to gradients and rotation rates.

Q 31.4 Wed 11:45 F102

Principal Component Analysis for Image processing in Atom Interferometry — •Stefan Seckmeyer[1], Holger Ahlers[1,2], Sven Abend[1], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR) Institut für Satellitengeodäsie und Inertialsensorik,, Hannover, Germany

Image analysis plays an important role in several current state-of-the-art atom interferometry experiments. We investigate the extraction of physical quantities from absorption images of atom interferometers using principal component analysis (PCA).

As a starting point we take a simple mathematical model for the images of the output ports of a two-port atom interferometer which is using a Bose-Einstein condensate as an atom source.

We show an analytic prediction of the PCA results for a subset of parameters which allows us to ascribe physical quantities to the output of a PCA analysis. Using this method we are not only able to extract the interferometer phase for each image but also a spatial phase aberration map shared by all images, here introduced at the final beam splitter.

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Q 31.5 Wed 12:00 F102

Systematic description of matter wave interferometers using elastic scattering in weakly curved spacetimes — •Michael Werner and Klemens Hammerer — Institut für Theoretische Physik and Institut für Gravitationsphysik (Albert-Einstein-Institut), Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We present a systematic approach to calculate all relativistic phase shift effects in Bragg-type light-pulse matter wave interferometer (MWI) experiments up to (and including) order $\mathcal{O}(c^{-2})$, placed in a weak gravitational field. The whole analysis is derived from first principles and even admits test of General Relativity (GR) apart from the usual Einstein Equivalence Principle (EEP) tests, consisting of universality of free fall (UFF) and local position invariance (LPI) deviations, by using the more general „parameterized post-Newtonian" (PPN) formalism. We collect general phase shift formulas for a variety of well-known MWI schemes and present how modern experimental setups could measure PPN induced deviations from GR without the use of macroscopic test masses. This procedure should be seen as a way to easily calculate certain phase contributions, without having to redo all relativistic calculations in new MWI setups and come up with possibly new measurement strategies.

Q 31.6 Wed 12:15 F102

3D simulations of guided BEC interferometers — •Rui Li, Stefan Seckmeyer, and Naceur Gaaloul — 1Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany

Atom interferometry (AI) has grown into a successful tool for precision measurements, inertial sensing and search for physics beyond standard model. Such high precision measurements are achieved either by large momentum transfer (LMT) or long interrogation times. Recently, the former technique has led to a state-of-the-art separation of more than 400 hbark [1]. In this experiment, Bose-Einstein Condensates (BECs) are used to further enhance precision atom interferometry due to their intrinsically strong coherence and narrow momentum width.*However, simulations of dynamics of BEC interacting with light in a generic 3D setup are limited by computation power and system sizes. In this talk, we present a newly developed numerical toolbox to solve the time-dependent Gross-Pitaevskii equation in 3D. To demonstrate its capability, we study BEC interferometers realized in both free-fall and guided geometry and compare our results with experimental data.*We specifically investigate the double-Bragg diffraction (DBD) of a BEC in a guide by two retro-reflected laser beams in a real-time evolution. Finally, we present a phase scan of a fully guided Mach-Zehnder interferometer based on DBDs combined with Bloch oscillations for LMT.

[1] Gebbe, M., Siemß, JN., Gersemann, M. et al., Nat Comm., 12, (2021) 2544.

Q 31.7 Wed 12:30 F102

A thermal noise interferometer for the characterization of optical coatings — •Janis Wöhler[1,2], Matteo Carlassara[1,2], Firoz Khan[1,2], Philip Koch[1,2], Johannes Lehmann[1,2], Harald Lück[2,1], Juliane von Wrangel[1,2], and David S. Wu[2,1] — [1]Max Planck Institute for Gravitational Physics, Hannover — [2]Institut für Gravitationsphysik, Leibniz Universität Hannover

The peak sensitivity band of ground-based gravitational wave (GW) detectors are currently limited by a combination of quantum noise and coating thermal noise (CTN). The latter is a result of the intrinsic properties, such as the mechanical loss and Young's modulus, of the high reflective mirror coatings used in GW interferometers. We report on a 10 cm hemispherical Fabry-Perot cavity with suspended mirrors capable of directly measuring CTN on a test mirror. All other noise sources were suppressed below CTN by installing it in the 10m Prototype facility in Hannover to leverage the ultra low noise environment and laser source. The calibration of the interferometer readout was achieved with a photon calibrator. This thermal noise interferometer will be an invaluable tool for characterization as part of the current global research efforts to find suitable new coating materials for future GW detectors.

Q 31.8 Wed 12:45 F102

Analysis of polarization states in polarization maintaining optical fibers — •Johannes Bäuerlein[1,2], Jonathan Joseph Carter[1,2], and Sina Maria Koehlenbeck[1,2] — [1]Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstraße 38, 30167 Hannover, Germany — [2]Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Optical fibers proved to be a powerful tool for several applications in the field of laser optics. Here, we contemplate the use of polarization maintaining fibers in interferometric displacement sensors as a tool to minimize the difference of the optical paths of two signals. In an interferometer, a probe and a reference signal is required. Any disturbance that is not common will couple directly into the detected signal of the interferometer. It is therefore advantageous to minimize the difference in the optical path of the signals, we achieve this by sending the signals through the same fiber. To suppress interference between the signals before it is desired, the polarization of the signals must be orthogonal. Therefore, we will study the crosstalk between the two polarization states inside the fiber and its coupling to induced phase noise. We present an optical setup that allows us to measure the strength of the noise due to the crosstalk of polarization states in a fiber. The phase fluctuations will be compared in real time before and after coupling to the fiber, and the differential measurement serves as a monitor of induced noise by the fiber.