Q 54: Precision Measurements and Metrology III

Time: Thursday 14:00–16:15 Location: S SR 111 Maschb.

Group Report Q 54.1 Thu 14:00 S SR 111 Maschb.
Matter wave interferometry for inertial sensing and tests of fundamental physics — •Dennis Schlippert[1], Henning Albers[1], Claus Braxmaier[2], Felipe Guzmán[2,3], Lee Kumanchik[2], Christian Meiners[1], Ashwin Rajagopalan[1], Robert Rengelink[1], Logan L. Richardson[1,3], Christian Schubert[1], Dorothee Tell[1], Étienne Wodey[1], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]DLR Institut für Raumfahrtsysteme, Bremen, Germany — [3]College of Optical Sciences, University of Arizona, Tucson, USA

We report on recent developments concerning the commissioning of the Very Long Baseline Atom Interferometry test stand. Stretching over 15 m, the facility with its high-performance magnetic shield, Rb-Yb atom sources, and a low-frequency seismic attenuation system, will allow us to take on the competition with the stability of superconducting gravimeters with absolute measurements. By operating in a differential mode, we anticipate tests of the Universality of Free Fall at levels of parts in 10^{13} and below. We will furthermore report on matter wave sensors enhanced with opto-mechanical resonators as well as fully guided interferometry and discuss the potential of such systems in inertial sensing and fundamental physics.

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Q 54.2 Thu 14:30 S SR 111 Maschb.
Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Ernst M. Rasel[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Institute for Quantum Optics, Hanover — [2]Institute for Theoretical Physics, Hanover

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 present an efficient numerical solver of the timedependent dynamics of atom-light interactions in position space. It is designed to allow for a flexible simulation of a wide range of nonideal effects. This approach is also aimed to be cross-regime, valid for different types of beam splitters (Bragg, Raman and Bloch) and free from approximations incompatible with a metrological use.

Q 54.3 Thu 14:45 S SR 111 Maschb.
Optimal mixed states for quantum metrology — •Lukas Fiderer[1], Julien Mathieu Elias Fraïsse[2], and Daniel Braun[1] — [1]Eberhard Karls University Tübingen, Germany — [2]Seoul National University, South Korea

The optimal initial state for estimating a parameter encoded to the state through unitary dynamics has been known since long: an equal superposition of eigenstates corresponding to the largest and smallest eigenvalue of the generator of the unitary dynamics. In principle, such an optimal initial state can be prepared by applying an appropriate unitary transformation to an available pure state. However, access to pure states is not always granted in realistic measurement setups, for instance, due to noise or interactions with an environment. In the present work, we answer the following question: Given a mixed state, what is the optimal initial state that can be prepared with the help of a unitary transformation? We give the quantum Fisher information for this optimal initial state and extend results for optimal quantum metrology with pure states to the regime of mixed states.

Q 54.4 Thu 15:00 S SR 111 Maschb.
Frequency spectrum of an optical resonator in a curved spacetime — •Dennis Rätzel[1], Fabienne Schneiter[2], Daniel Braun[2], Tupac Bravo[3], Richard Howl[4], Maximilian P E Lock[3], and Ivette Fuentes[4] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Institut für Theoretische Physik, Eberhard-Karls-Universität Tübingen, D-72076 Tübingen, Germany — [3]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [4]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

There is an ever growing number of proposals for high precision experiments to measure gravitational effects. In particular, more and more researchers from the fields of quantum optics and quantum optomechanics are becoming interested in GR and propose metrological experiments. Usually, such proposals rely heavily on a notion of length. However, in GR, as coordinates have no physical meaning, there is no unique concept for the length of a matter system.

In this talk, the conceptual problem of length is addressed for a subset of experimental proposals. In particular, the effect of gravitational fields and acceleration on the frequency spectrum of an optical resonator is discussed in the framework of GR. The optical resonator is modeled as a deformable rod of matter connecting two mirrors. Explicit expressions for the frequency spectrum are given for the case of a small perturbation. As example situations, uniform acceleration and geodesic motion in the gravitational field of the earth are discussed.

Q 54.5 Thu 15:15 S SR 111 Maschb.
Gravitational properties of light — •Dennis Rätzel[1], Ralf Menzel[2], and Martin Wilkens[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]University of Potsdam, Institute for Physics and Astronomy Karl-Liebknecht-Str. 24/25, 14476 Potsdam

As Einstein's equations tell us that all energy is a source of gravity, light must gravitate. However, because changes of the gravitational field propagate with the speed of light, the gravitational effect of light differs significantly from that of massive objects. In particular, the gravitational force induced by a light pulse is due only to its creation and annihilation and decays with the inverse of the distance to the pulse.

We can expect the gravitational field of light to be extremely weak. However, the properties of light are premises in the foundations of modern physics: they were used to derive special and general relativity and are the basis of the concept of time and causality in many alternative models. Studying the back-reaction of light on the gravitational field could give new fundamental insights to our understanding of space and time as well as classical and quantum gravity.

In this talk, a brief overview is given of the gravitational field of one-dimensional light pulses and Gaussian beams with finite divergence in the framework of general relativity. A glimpse is caught of the gravitational interaction of two single photons which turns out to depend on the degree of their polarization entanglement.

Q 54.6 Thu 15:30 S SR 111 Maschb.
Probing physics beyond the standard model with ultracold mercury — Thorsten Groh and •Simon Stellmer — Physikalisches Institut, Universität Bonn, Germany

Ultracold samples of atoms, cooled to temperatures of a few μK or even into the quantum-degenerate regime, allow for an exquisite control of all their internal and external degrees of freedom. It is this high degree of control, combined with the small size of these samples, that we want to exploit to search for physics beyond the standard model.

As a first experiment, we aim to measure the atomic EDM of mercury. Improving the sensitivity of current experiments (which operate with thermal samples) might allow us to constrain the parameter range of beyond-standard-model theories.

We are currently setting up the experiment and will report on the progress.

Q 54.7 Thu 15:45 S SR 111 Maschb.
Suppression of the AC-Stark shift by vortex light beams — •Sabrina A.-L. Schulz[1,2] and Andrey Surzhykov[1,2] —

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Since the groundbreaking work of Allen et al. in 1992 [1], the interest in twisted light has grown steadily both in experiment and theory. Twisted light beams carry a non-zero projection of orbital angular momentum (OAM) onto their propagation direction, have a helical phase front and an intensity minimum in the beam center [2].

Atoms located in this minimum experience a reduced AC-Stark shift [3] and, therefore, twisted beams may considered as valuable tool to drive atomic clock transitions. In this contribution, particular emphasis is paid to the electric-octupole (E3) transition $^2S_{1/2} \rightarrow {}^2F_{7/2}$ in the $^{171}\mathrm{Yb}^+$ ion. To investigate the dependence of the AC-Stark shift in this ion on the parameters of the (twisted) light beam, we used the relativistic Dirac quantum theory and the density matrix formalism. Based on this theory, detailed calculations were done for the E3 atomic clock transition and these results may be implemented in the $^{171}\mathrm{Yb}^+$ single-ion clock experiments at PTB [4].

[1] L. Allen, et al. Phys. Rev. A 45, 8185 (1992)
[2] H. M. Scholz-Marggraf, et al. Phys. Rev. A 90, 013425 (2014)
[3] C. T. Schmiegelow, et al. Nature Communications 7 12998 (2016)
[4] N. Huntemann, et al. Phys. Rev. Lett. 116, 063001 (2016)

Q 54.8 Thu 16:00 S SR 111 Maschb.

Interference of clocks: A quantum twin paradox — •Alexander Friedrich[1], Sina Loriani[2], Fabio Di Pumpo[1], Stephan Kleinert[1], Christian Ufrecht[1], Enno Giese[1], Albert Roura[1], Dennis Schlippert[2], Wolfgang P. Schleich[1], and Ernst M. Rasel[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm. — [2]Institut für Quantenoptik, Leibniz Universität Hannover.

Atom interferometry has become a formidable tool for high-precision quantum metrology applications as well as investigations into the fundamental interconnections between relativity and quantum mechanics. On the other hand, quantum systems in the form of atomic clocks are routinely employed in tests of special and general relativity. The combination of atom interferometry and atomic clocks in terms of quantum-clock interferometry [1, 2] is a promising candidate for the investigation of special and general relativistic effects with and on quantum objects. In our contribution we investigate the realization of a quantum twin paradox via matter wave clock interferometry. In particular, we discuss the theoretical framework, realization and specific measurement scheme which allows us to extract the special relativistic twin paradox contribution from the interferometer phase shift.

[1] M. Zych et al., Nat. Commun. **2**, 505 (2011)
[2] A. Roura, arXiv 1810.06744, (2018)

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