Q 54: Quantum Optics in Space

Time: Thursday 14:30–16:30 Location: HS 3219

Q 54.1 Thu 14:30 HS 3219

Two-Beam Interference in Rindler Spacetime — •Yatin Kumar Jaiswal[1,2] and Sebastian Ulbricht[1,2] — [1]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

The study of polarized light in curved spacetime has been a promising endeavour in the past with theoretical predictions like the gravitational analogue of the Faraday effect and the Spin Hall effect. Motivated by these successes, we conduct a similar investigation for light propagation in Earth's gravity at laboratory scales. One way to do that is to model Earth's local gravity as spacetime perceived by a homogeneously accelerated observer, i.e., the Rindler Spacetime. This model is justified because the Equivalence Principle posits that experiments done in a constantly accelerated frame or in a homogenous gravitational field are indistinguishable. In this contribution, we study the propagation of light in Rindler Spacetime and investigate the interference of two light waves with arbitrary polarizations in the Geometrical Optics regime. We present the most general expression of the Stress-Energy tensor in this spacetime to linear order in gL/c^2, where L is a typical length scale of table-top experiments. Further, we analyze the Poynting vector, i.e., the intensity and its dependence on polarization, as well as the orientations and wavelengths of the interfering beams.

Q 54.2 Thu 14:45 HS 3219

Space Magnetic Gradiometry using Atom Interferometers — •Gabriel Müller[1], Timothé Estrampes[1,2], Annie Pichery[1,2], Nicholas P. Bigelow[3], Naceur Gaaloul[1], and the CUAS Consortium[3] — [1]Leibniz University Hannover, Germany — [2]Institut des Sciences Moléculaires d'Orsay, Université Paris-Saclay, France — [3]University of Rochester, USA

Quantum Sensing is becoming a valuable tool for several applications such as gravity sensing, inertial navigation or magnetometry. Atom Interferometry (AI), a pillar of quantum sensing, has been successfully demonstrated in the lab and field settings.

Here, we report on pioneering AI experiments operated in NASA's Cold Atom Lab (CAL) onboard the International Space Station [E. Elliott et al., Nature 623, 502 (2023)]. In this unique microgravity environment, we prepare ^{87}Rb condensed clouds and utilise them in various atom interferometric schemes. This allows to measure local magnetic potential curvatures and detect tiny residual differential magnetic forces, thereby outperforming the sensitivity of classical methods.

These results pave the way to future Space missions leveraging AI sensors such as for Space Magnetometry. Moreover, we discuss strategies to overcome current sensitivity-limiting factors by improving the AI laser beam optical quality or the atom number as planned for the recently installed CAL upgrade Science Module SM3B.

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Q 54.3 Thu 15:00 HS 3219

Quantum gas mixtures in an Earth-orbiting research laboratory — •Annie Pichery[1,2], Timothé Estrampes[1,2], Gabriel Müller[1], Nicholas P. Bigelow[3], Eric Charron[2], Naceur Gaaloul[1], and the CUAS Consortium[3] — [1]Leibniz Universität Hannover,Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France — [3]University of Rochester, Rochester, NY, USA

The Cold Atom Laboratory (CAL) is a multi-user Bose-Einstein Condensate (BEC) machine aboard the International Space Station, operated by NASA's Jet Propultion Lab. Since its upgrade in 2020, it enables the production and manipulation of dual-species BEC mixtures of K and Rb. We report here about the first quantum mixture experiments realized in space [E. Elliott et al., Nature 623, 502 (2023)] and study its dynamics in weightlessness to prepare dual-species atom interferometry and future tests of the Universality of Free Fall.

Space provides, indeed, an environment where atom clouds can float for extended times of several seconds, as well as miscibility conditions different from ground. Simulating these quantum phases and the dynamics of interacting dual species presents however computational challenges due to the long expansion times. We present a novel theoretical framework based on re-scaled computation grids that allowed to follow the extended free dynamics of quantum mixtures in space.

We acknowledge financial support from the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under Grant No. CAL-II 50WM2245A/B.

Q 54.4 Thu 15:15 HS 3219

Status of the Laser System for Cold Atom Experiments in BECCAL onboard the ISS — •Hamish Beck[1], Hrudya Thaivalappil Sunilkumar[1], Marc Kitzmann[1], Matthias Schoch[1], Christoph Weise[1], Bastian Leykauf[1], Evgeny Kovalchuk[1], Jakob Pohl[1], Achim Peters[1], and the BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10] — [1]HUB, Berlin — [2]FBH, Berlin — [3]JGU, Mainz — [4]LUH, Hanover — [5]DLR-SI, Hanover — [6]DLR-QT, Ulm — [7]UULM, Ulm — [8]ZARM, Bremen — [9]DLR, Bremen — [10]DLR-SC, Braunschweig

The Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) is designed for operation onboard the International Space Station (ISS). This multi-user facility will enable experiments with K and Rb ultra-cold atoms and BECs in mircogravity. Fundamental physics will be explored at longer time- and lower energy-scales compared to those achieved on earth.

The BECCAL laser system is comprised of micro-integrated diode lasers, miniaturized free-space optics on Zerodur boards, and a system of fibres to bring light to the physics package. The design is subject to strict size, weight, and power (SWaP) constraints, and the operation of the system is supported by extensive ground-based systems.

An update on the progress of the laser system will be given, touching upon the flight model design and the status of ground-based systems built from commercial components.

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Q 54.5 Thu 15:30 HS 3219

Compact and robust design of a crossed optical dipole trap for space application — •Jan Simon Haase[1], Janina Hamann[1], Alexander Fieguth[2], Jens Kruse[2], Carsten Klempt[1,2], and The INTENTAS Team[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]DLR Institut für Satellitengeodäsie und Inertialsensorik, Callinstraße 30b, 30167 Hannover

Towards the implementation of atom interferometry in commercial sensors, improvements of the current systems in compactness and robustness are a next necessary step. Also, for applications in space it is urgent to compactify the sensors and make them robust against accelerations and vibrations.

In the INTENTAS project (Interferometry with entangled atoms in space) evaporative cooling in a novel, optical dipole trap will be used to create Bose-Einstein condensates in a microgravity environment. The project will demonstrate a compact source of entangled atoms in the Einstein-Elevator, a microgravity platform which allows zero-gravity tests for up to 4 s. The planned experiments will pave the way to employ entangled atomic sources for high-precision interferometry in space applications.

In this talk, the novel design of the optical dipole trap is presented. Simulations of the beam deformation and measurements from first flight tests are shown.

Q 54.6 Thu 15:45 HS 3219

QUBE-II: Towards Quantum Key Distribution between a CubeSat and Ground — •Jonas Pudelko for the QUBE-II-Collaboration — Friedrich-Alexander-Universität Erlangen-Nürnberg, Lehrstuhl für optische Quantentechnologien, Staudtstr. 7/B2, D-91058 Erlangen, Germany — Max Planck Institute for the Science of Light, Staudtstr. 2, D-91058 Erlangen, Germany

The limited range of quantum key distribution (QKD) in fiber based systems has led to several projects aiming for the development of a satellite based QKD infrastructure, like the MICIUS mission, which impressively demonstrated QKD on a global scale. However, the high costs of satellite launches for such a system can be reduces dramatically by further reduction in size, weight and power.

The QUBE-II mission is designed to perform the first QKD exchange between a small 8U CubeSat ($10 \times 20 \times 40$ cm^3) and a ground station. Based on the predecessor mission QUBE, two enhanced integrated QKD transmitters implement polarization and phase based versions of the BB84 decoy protocol. Both transmitters are managed by a protocol board, which is using a photonically integrated quantum random number generator as an entropy source. The quantum states are transmitted via an optical telescope with aperture size of 80 mm, which is also used to establish a bi-directional classical data link for post processing.

In this work, we will present the mission concept and discuss the challenges of performing quantum optic experiments on a CubeSat in space.

Q 54.7 Thu 16:00 HS 3219

Time Synchronization in Satellite and Long Distance Quantum Communication — •Pritom Paul[1,2], Christopher Spiess[1,2], and Fabian Steinlechner[1,2] — [1]Fraunhofer Institute for Applied Optics and Precision Engineering, Albert-Einstein-Str. 07, 07745 Jena, Germany. — [2]Friedrich Schiller University, Institute of Applied Physics, Albert-Einstein-Str. 15, 07745 Jena, Germany.

To establish quantum communication, it is crucial to accurately identify and resolve single photon detection events. Issues arise in space-based and long-distance quantum communication systems, where achieving secure communication and picosecond timing accuracy is hindered by low signal-to-noise ratio resulting from propagation loss and atmospheric turbulence. The signal to noise ratio of the synchronization signal improves by the introduction an attenuated pulsed laser from which the timing offset could be determined by its own single photon detection events. Using time multiplexing, the pulsed signal can be isolated from the quantum signal, thereby facilitating the identification of synchronization windows within the detected signal.

In this work we develop a synchronization protocol involving an attenuated pulsed laser combined to the output of an entangled photon source and detected using superconducting nanowire single-photon detectors. Next, we introduce channel losses to emulate a real-world quantum network. This reflects scenarios with substantial node distances, incorporating losses attributed to atmospheric turbulence, particularly in the context of satellite and free space-based networks.

Q 54.8 Thu 16:15 HS 3219

Angular Bloch Oscillations and their applications — •Bernd Konrad and Maxim Efremov — German Aerospace Center (DLR), Institute of Quantum Technologies, 89081 Ulm, Germany

Inspired by the fast-developing field of compact and mobile quantum sensors for space- and ground-based applications, we propose a new concept for measuring the angular acceleration of external rotation. For this, we study the dynamics of ultra-cold atoms in a toroidal trap with additional modulation along the angular direction, realized in labs with the superposition of two Laguerre-Gauss (LG) beams with indices l and $-l$. In the presence of external rotation with small angular acceleration, or by having a well-controllable chirp between the two LG beams, our system is shown to display a new phenomenon we name as the Angular Bloch Oscillations (ABOs). In addition, we show that ABOs can be utilized (i) to precisely transfer certain angular momenta (multiples of $2l\hbar$) from the field to trapped atoms, by using the slowly varying chirp, and (ii) to determine the angular acceleration of the external rotation, by measuring the Bloch period of ABOs.