FRI 8: Quantum Detectors in Optics and Particle Physics

Time: Friday 10:45–12:15 Location: ZHG009

FRI 8.1 Fri 10:45 ZHG009

Laser-Doppler-Vibrometer mit quetschlichtverbesserter Auflösung — •Mengwei Yu[1], Pascal Gewecke[2], Roman Schnabel[2] und Christian Rembe[1] — [1]Institut für Elektrische Informationstechnik, TU Clausthal, 38678 Clausthal-Zellerfeld — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg

Das heterodyne Laser-Doppler-Vibrometer (LDV) detektiert kleinste Schwingungsamplituden bei mechanischen Strukturen mit einer Auflösung im Sub-Picometerbereich und ist typischerweise durch Photonenschrotrauschen beschränkt. Kennzeichnend für das heterodyne LDV ist, dass das Fotodetektorsignal einen Träger bei der Differenzfrequenz zwischen Mess- und Referenzlicht hat. Korrelierte Photonen überwinden als sogenanntes Quetschlicht die Schrotrauschgrenze von optischem Messverfahren. Durch das Einkoppeln von vakuumquetschtem Licht in den Messstrahl eines LDVs kann entweder das Amplituden- oder das Phasenrauschen des Lichts effektiv unterdrückt werden. Die Reduzierung des Phasenrauschens führt zu einer Verbesserung des Träger-Rausch-Verhältnisses und folglich zu einer verbesserten Amplitudenauflösung bei der Schwingungsmessung. In dieser Studie wird ein heterodynes LDV vorgestellt, das die Einspeisung von Quetschlicht mit synchroner Abtastung und Demodulation kombiniert. Die digitale Vibrationsamplitudenauflösung wird in diesem Beitrag von einem durch Schrotrauschen limitierten Wert von 6 $\mathrm{fm}/\sqrt{\mathrm{Hz}}$ auf ein sub-Schrotrauschen-Niveau von 4 $\mathrm{fm}/\sqrt{\mathrm{Hz}}$ verbessert, was das Potenzial quantenbasierter Technologien in hochpräzisen optischen Messsystemen aufzeigt.

FRI 8.2 Fri 11:00 ZHG009

Dynamics of quantum mixtures in microgravity — •Lakshmi Priyanka Guggilam, Jonas Böhm, and Dorthe Leopoldt — Institut für Quantenoptik, Leibniz Universität Hannover

The MAIUS (Matter wave interferometry under microgravity) project aims to demonstrate atom interferometry in weightlessness as a promising tool for precision measurements, e.g., of Einstein*s equivalence principle (EEP), with accuracies that couldn*t be achieved with classical tests. With the launch of MAIUS-1, it was possible to create the first BECs in space using Rb-87 atoms and performing interference experiments with these macroscopic quantum objects. In MAIUS-2, we focus on understanding the dynamics of K-41 and Rb-87 quantum mixtures in microgravity to pave the wave for long-time dual species atom interferometry. This talk is focused on the preparation of K-41 and Rb-87 quantum mixtures in the Einstein Elevator, an active drop tower providing 4 s of microgravity time every 4 minutes. In addition, the simultaneous transport of both species to weaker traps using Short-cut To Adiabaticity (STA) protocols and their resulting dynamics will be discussed. These techniques are important prerequisites to perform EEP tests with BECs created on an atom chip under microgravity. The MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

FRI 8.3 Fri 11:15 ZHG009

Gravitational wave-induced photon superradiance in atoms — •Navdeep Arya and Magdalena Zych — Stockholm University, Stockholm, Sweden

The effects of spacetime curvature on atoms are typically very small. However, we argue that spontaneous buildup of quantum coherence enables atoms in an array to cooperate and amplify their response to gravitational waves. This cooperation manifests as gravitational wave-induced photon superradiance—delayed, intense, and directional emission of photons at frequencies shifted by the gravitational wave frequency. This effect arises in a regime distinct from flat-spacetime superradiance, which allows gravitational effects to dominate the collective atomic response. The effect persists despite common experimental challenges like position disorder and partial filling, highlighting coherent atom arrays as potential candidates for broadband gravitational wave detection. Our findings demonstrate a coupling interface between general relativistic gravity and quantum matter under laboratory settings in a many-body system, with implications for both fundamental science and practical applications.

FRI 8.4 Fri 11:30 ZHG009

Label-free mid-IR imaging with undetected photons — •Marlon Placke[1], Chiara Lindner[2], Felix Mann[1], Inna Kviatkovsky[1], Helen Chrzanowski[1], Frank Kühnemann[2], and Sven Ramelow[1] — [1]Institute for Physics, Humboldt-Universität zu Berlin, Germany — [2]Fraunhofer Institute for Physical Measurement Techniques IPM, Freiburg, Germany

Sensing with undetected photons has become a distinct research field with numerous demonstrated applications, often dedicated to mid-infrared wavelength regions. Since these spectral bands entail molecule specific absorbance signatures also referred to as their fingerprints, sample compositions may be probed spectroscopically. To sidestep the challenges associated with camera sensors and low noise and broadband illumination sources for low-energy mid-infrared photons, we utilise a nonlinear interferometer in a widefield imaging arrangement with around 3500 resolved spatial modes and broadband signal and idler emission around 800 and 3800 nm, respectively. To importantly combine this with high-resolution spectral information, we employ Fourier transform infrared spectroscopy by scanning the interferometric delay and analysing the resulting interferogram for each illuminated camera pixel. Finally, we demonstrate the practicality of our novel hyperspectral technique for applications such as microplastics detection and bio-imaging tasks. Accordingly, this quantum imaging method holds good potential for applications relying on compact, cost-effective, and label-free analysis near the intrinsic performance limit of the probe light itself.

FRI 8.5 Fri 11:45 ZHG009

Optimisation of TES design for the CRESST experiment — •Colin Moore — Max-Planck-Institut für Physik

The Cryogenic Rare Event Search with Superconducting Thermometers (CRESST) experiment aims at the direct detection of sub-GeV dark matter particles via elastic scattering off nuclei in a variety of target crystals at cryogenic temperatures. Located at the underground Laboratori Nazionali del Gran Sasso (LNGS) in Italy, CRESST operates cryogenic calorimeters consisting of an absorber crystal equipped with a tungsten Transition Edge Sensor (W-TES).

The W-TES developed in CRESST are composed of a tungsten thin film serving as the sensitive part of the thermometer, a gold thermal link connecting the sensor to the heat bath, and aluminum phonon collectors which increase the collection area of the sensors. Additionally, each W-TES is equipped with a heater which stabilises the sensors within their superconducting transition.

The technology utilised by CRESST allows for a leading energy threshold. Nevertheless, continuous R&D efforts are underway to further improve signal to noise ratio and overall sensitivity. Optimising the TES design is a non-trivial task, owing to the complex interdependence of the properties of the absorber and sensor. To address these challenges, we have conducted detailed studies targeting specific aspects of the TES design and carried out comparative evaluations of various sensors configurations.

In this contribution, we present the outcomes of these optimisation studies and their impact on the performance of CRESST detectors.

FRI 8.6 Fri 12:00 ZHG009

COMPASSO mission and its quantum optical clock — •Johanna Popp[1], Frederik Kuschweski[1], Jan Wüst[1], Markus Oswald[1], Tim Blomberg[1], Jonas Pollex[2], André Bussmeier[1], Niklas Röder[1], Issaree Khattiwiriyapinyo[1], Thilo Schuldt[1], and Claus Braxmaier[1,3] — [1]DLR Institute of Quantum Technologies — [2]DLR Institute of Space Systems — [3]Institute of Microelectronics, University of Ulm

Quantum optical clocks are high-performance devices in terms of frequency stability and accuracy and are therefore important instruments in research of fundamental and applied physics, such as in geodesy and navigation with the Global Navigation Satellite System (GNSS). The established microwave clock technologies on GNSS satellites are one limititation for geolocation with cm precision. Hence national and international space agencies are aiming to replace these systems with next-generation technologies. In the DLR COMPASSO mission, a quantum optical clock based on modulation transfer spectroscopy of iodine will be deployed to the ISS as a technology demonstrator [1]. In this contribution, we present the mission architecture and highlight the key part of the optical clock: the iodine-based optical frequency reference reaching a fractional instability down to 10^{-15}.

[1] Kuschewski, F. et al. GPS Solut 28, 10 (2024).