Q 47: Precision Measurements with Optical Clocks (joint session Q/QI)

Time: Thursday 11:00–13:00 Location: E001

Invited Talk Q 47.1 Thu 11:00 E001

Quantum metrology with non-classical states of light — •Michèle Heurs — Institute for Gravitational Physics, Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany

Nowadays, non-classical (fixed-quadrature "squeezed") light is routinely used in second-generation interferometric gravitational wave detectors such as aLIGO and AdVirgo to increase their detection sensitivity, leading to some of the most exciting astrophysical discoveries of the past years. Beyond this well-known application example, squeezing is a quantum technique that can benefit precision metrology in many other areas. It can be useful whenever the signal-to-noise ratio of the measurement is fundamentally limited by the quantum noise of the employed and technically already ultra-stabilised laser light.

This talk will highlight exemplary applications of squeezed light, ranging from interferometric gravitational wave detection to sub-shot-noise limited spectroscopy. The latter example makes use of high-frequency squeezed light sources, so-called *squeezing combs*, which will be introduced in this talk. These squeezing combs exhibit entanglement between the individual upper and lower squeezing sidebands which occur at the free spectral ranges of the squeezing cavity. This feature makes squeezing combs a promising resource for applications in quantum information.

Q 47.2 Thu 11:30 E001

A strontium optical clock based on Ramsey-Bordé spectroscopy — •Amir Mahdian[1], Oliver Fartmann[1], Ingmari C Tietje[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We are developing an optical frequency reference based on Ramsey-Bordé interferometry using a thermal atomic beam. The $5s^2\ ^1S_0 \rightarrow 5s5p\ ^3P_1$ intercombination line in strontium is chosen as our clock transition, which should allow for an Allan deviation as low as 2×10^{-15} between 100 s and 1000 s.

After an overview of the current state of our atom interferometer, the latest developments in our laser systems and frequency stabilization will be presented. Moreover, I outline two methods for reading the population of the associated quantum states in the clock transition, along with the progress on spectroscopy on the $5s5p\ ^3P_1 \rightarrow 5p^2\ ^3P_0$ line at 483 nm.

This work is supported by the German Space Agency (DLR), with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grant number DLR50WM1852, and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 47.3 Thu 11:45 E001

Instability investigation for a dual-wavelength coating frequency stabilization cavity — •Fabian Dawel[1,2], Alexander Wilzewski[1,2], Johannes Kramer[1,2], Lennart Pelzer[1,2], Marek Hild[1,2], Kai Dietze[1,2], Gayatri Sasidharan[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Optical resonators are a key tool for stabilizing lasers. For many experiments space is limited, so it is advantageous to lock multiple lasers to the same resonator. But so far, the correlation in noise contributions for two or more lasers on the same mirror pair has not been investigated. In this talk we present the stabilization of two lasers operating at 729 nm and 1069 nm on one mirror pair. We measure the effect of photo-thermal noise (PTN) and residual-amplitude modulation (RAM) on laser frequency instability. We find correlations between optical power and frequency. The wavelength coating stack next to the substrate shows PTN noise which is suppressed by coherent cancelation to a level of $3 \times 10^{-8}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. The stack on top of this shows a PTN of $7 \times 10^{-7}\ \frac{\mathrm{Hz}}{\mathrm{W}}$. As expected, there is no significant cross-correlation between the lasers for noise induced by RAM. We measured relative frequency instabilities of less than 10^{-14} for both lasers, where the instability of one laser is limited by RAM. This work shows that dual-wavelength coatings can be used for highly stable laser applications, which makes it a viable tool for precision spectroscopy experiments.

Q 47.4 Thu 12:00 E001

The COMPASSO mission and its iodine clock — •Frederik Kuschewski[1], Thilo Schuldt[1], Martin Gohlke[2], Markus Oswald[1], Jonas Bischof[1], Jan Wüst[1,3], Alex Boac[1], Andre Bussmeier[1], Klaus Abich[1], Tasmim Alam[1], Tim Blomberg[1], and Claus Braxmeier[1,3] — [1]DLR Institute of Quantum Technologies — [2]DLR Institute of Space Systems — [3]Ulm University

High-precision clock technologies have a variety of applications both in lab environments and in space, such as research of geodesy, test of relativity theory and also navigation with the GNSS (global navigation satellite system) network. However, the established clock technologies in space (rubidium standards and masers) lack in precision and long-term stability, limiting the accuracy of space research and navigation. Optical clocks have the potential to improve the performance by orders of magnitude, hence offering unprecedented accuracy in numerous fields of research and high-precision navigation [1]. The DLR COMPASSO mission will demonstrate the first optical clock technology in orbit and its payload will be installed on the Bartolomeo platform of the ISS with a scheduled launch in 2025. In this contribution, we will present the mission architecture and highlight the features of the ruggedized clock technology [2], which utilizes modulation transfer spectroscopy in molecular iodine yielding a long-term fractional stability of up to 10^{-15}. [1] Schuldt, T. et al. GPS Solut. **25**, 83 (2021). [2] Schuldt, T. et al. Appl. Opt. **56**, 4, (2017).

Q 47.5 Thu 12:15 E001

Vibration isolation and frequency feedforward techniques in ultra-stable laser systems. — •Sofia Herbers[1], Jialiang Yu[1], Jan Kawohl[1], Mattias Misera[1], Thomas Legero[1], Uwe Sterr[1], Anders Wallin[2], Kalle Hanhijärvi[2], Thomas Lindvall[2], and Thomas Fordell[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Germany — [2]VTT Technical Research Center of Finland Ldt., Finland

To improve the performance of metrology and precision measurements with optical clocks, ultra-stable lasers with extremely low frequency instability are required. Amongst others, accelerations acting on the laser systems' ultra-stable resonators limit the frequency stability even though the resonators' acceleration sensitivity is reduced by novel mounting designs and the best commercially available vibration isolation systems are used to reduce vibrations.

To overcome this limitation, we investigate adding additional feedback corrections to a commercial vibration isolation platform as well as applying feedforward corrections to the laser frequency. Additional seismometers and a tiltmeter are placed on the vibration isolation platform to detect its movement. The sensor outputs are used to generate correction signals that are either sent back to the actuators of the vibration isolation platform or sent forward to the laser frequency.

We acknowledge support by the Project 20FUN08 NEXTLASERS, which has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union*s Horizon 2020 Research and Innovation Programme.

Q 47.6 Thu 12:30 E001

E2-M1 polarisability of the strontium clock transition at the 813 nm lattice magic wavelength — •Joshua Klose, Sören Dörscher, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

To accurately determine the frequency shift of the clock transition caused by the optical lattice with fractional uncertainty of 10^{-17} or below, one must account for electric-quadrupole (E2) and magnetic-dipole (M1) interactions in a strontium lattice clock. However, the values of the E2-M1 polarisability difference of the clock states, $(5s^2)\,^1S_0$ and $(5s5p)\,^3P_0$, found in recent publications [1, 2] exhibit large discrepancies. We report on an independent experimental determination of the differential E2-M1 polarisability, $\Delta\alpha_{\mathrm{qm}}$, by measuring the differential light lattice shift between samples with different motional state distributions, leveraging the different dependence of the light shift terms on the atomic motional state. We find a value of $\Delta\alpha_{\mathrm{qm}} = -987^{+174}_{-223}\,\mu\mathrm{Hz}$, which is in agreement with the value reported in Ref. [1] as well as the result of another recent investigation [3].

This project has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – Project-ID 390837967, SFB 1464 TerraQ – Project-ID 434617780 – within project A04, and SFB 1227 DQ-*mat* – Project-ID 274200144 – within project B02.

[1] I. Ushijima *et al.*, Phys. Rev. Lett. **121**, 263202 (2018)
[2] S. G. Porsev *et al.*, Phys. Rev. Lett. **120**, 063204 (2018)
[3] K. Kim *et al.*, arXiv:2210.16374 (2022)

Q 47.7 Thu 12:45 E001

An indium ion clock with a systematic uncertainty on the 10^{-18}-level — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Nishant Bhatt[1], Moritz von Boehn[1], Ingrid Maria Dippel[1], Jonas Keller[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

Frequency is the most accurate physical property that can be measured by man-made machines. Nowadays, the best atomic clocks are based on optical transitions and reach systematic uncertainties around 1×10^{-18} surpassing the clocks that currently define the SI unit of time by a factor of 100 and more. Because of its intrinsically low sensitivities, $^{115}In^+$ is a candidate for a clock with a systematic uncertainty on the 10^{-19}-level, not only for a single but also multiple indium ions. This so-called "multi-ion clock" allows for shorter averaging times to reach a given statistical uncertainty level [1,2].

In this talk, we will demonstrate clock operation with an $^{115}In^+$ ion sympathetically cooled by three $^{172}Yb^+$ ions in a segmented linear Paul trap. The systematic uncertainty is evaluated on the 10^{-18}-level. The setup is optimized for clock operation with multiple $^{115}In^+$ ions allowing for a similar systematic uncertainty as a single-ion clock [1]. First clock operation with multiple indium ions featuring individual state readout on an EMCCD camera is shown and discussed.

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)