A 29: Precision Spectroscopy of Atoms and Ions IV (joint session A/Q)

Time: Friday 11:00–12:45 Location: F303

Invited Talk A 29.1 Fri 11:00 F303

An elementary network of entangled optical atomic clocks — •Raghavendra Srinivas, Bethan Nichol, David Nadlinger, Peter Drmota, Dougal Main, Gabriel Araneda, Chris Ballance, and David Lucas — University of Oxford

Optical atomic clocks are our most precise tools to measure time and frequency. Precision frequency comparisons between atoms in separate locations can be used to probe the space-time variation of fundamental constants, the properties of dark matter, and for geodesy. Such frequency comparisons on independent systems are typically limited by the standard quantum limit (SQL). Here, we demonstrate the first quantum network of entangled optical clocks using two $^{88}Sr^+$ ions separated by a macroscopic distance (2 m), that are entangled using a photonic link. We use this network to perform entanglement-enhanced frequency comparisons beyond the SQL[1]. This two-node network could be extended to additional nodes, to other species of trapped particles, or to larger entangled systems via local operations.

[1] Nichol, Srinivas et al., Nature 609, 689-694 (2022)

A 29.2 Fri 11:30 F303

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesalnstalt, Braunschweig, Deutschland — [2]2Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well- suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy, where a well-controllable atomic ion is co-trapped to the molecular ion, both coupled strongly via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Using a Ca ion, we implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion, induced by a far detuned Raman laser setup. We present the latest progress of the experiment, aiming at high precision quantum logic spectroscopy of single molecular ions.

A 29.3 Fri 11:45 F303

An aluminum ion clock with 1.1×10^{-18} estimated systematic uncertainty — •Johannes Kramer[1,2], Fabian Dawel[1,2], Marek Hild[1,2], Lennart Pelzer[1], Kai Dietze[1,2], Steven A. King[3], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Oxford Ionics Limited, Begbroke OX5 1PF, United Kingdom

A single trapped $^{27}Al^+$ ion is an excellent frequency reference for an optical clock, as it is largely insensitive to external field shifts. Achieved inaccuracies are below the 10^{-18} level and thus make aluminum clocks promising candidates for a re-definition of the SI second and enable for cm-scale height measurements in relativistic geodesy. We estimated the systematic uncertainty budget of PTB's Al^+ clock using a single $^{40}Ca^+$ ion as a sensor. Included in the analysis are shifts by black body radiation, collisions with background gas molecules, residual kinetic energy from uncompensated micromotion and the ac Zeeman shift caused by fast oscillating magnetic fields. The latter shift is mainly induced by the applied radio frequency used to trap the ion. Measurements show that these fields are in the range of a few 10 μT in our trap and are therefore a non-negligible contribution to the systematic frequency uncertainty budget.

A 29.4 Fri 12:00 F303

Improved limits for the coupling of ultralight bosonic dark matter to photons from optical atomic clock comparisons — •Melina Filzinger, Martin Steinel, Joshua Klose, Sören Dörscher, Christian Lisdat, Ekkehard Peik, and Nils Huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Ultralight bosonic dark matter is expected to display coherent-wave behaviour. A hypothetical coupling of such dark matter to photons would lead to oscillations in the value of the fine-structure constant [1]. The frequency of the $^2S_{1/2}(F=0) \leftrightarrow {}^2F_{7/2}(F=3)$ electric-octupole transition in $^{171}Yb^+$ is the most sensitive to variations of the fine structure constant among the atomic clocks currently in operation. We compare this frequency to that of the $^2S_{1/2}(F=0) \leftrightarrow {}^2D_{3/2}(F=0)$ electric-quadrupole transition of the same ion, as well as to that of the $^1S_0 \leftrightarrow {}^3P_0$ transition in ^{87}Sr, both of which feature small sensitivities to variations of α. Based on these long-term measurements, we present improved constraints on temporal variations of the fine-structure constant. In particular, constraints on an oscillation with a specific frequency are translated into constraints on the scalar coupling d_e of bosonic dark matter with a specific mass to photons.

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[1] A. Arvanitaki et al., Phys. Rev. D 91, 015015 (2015).

A 29.5 Fri 12:15 F303

An optical atomic clock based on correlation measurements of a two ion $^{40}Ca^+$ crystal — •Kai Dietze[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1], Fabian Dawel[1,2], Johannes Kramer[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

Trapped ion optical clocks reach high relative frequency accuracies but are often limited by quantum projection noise in their statistical uncertainty, thus requiring long averaging times. The statistical uncertainty can be reduced by increasing the number of ions and/or probing the ion(s) for a longer time with the clock laser. By extending the measurement to entangled states the statistical uncertainty can even surpass the quantum projection noise of classical interrogation protocols [1]. In our scheme classically and quantum correlated quantum states of a two-ion $^{40}Ca^+$ crystal are prepared in a so-called decoherence-free substate (DFS), which is insensitive to linear magnetic field fluctuations [2]. We present the results of these correlation measurements within the DFS, showing near lifetime limited coherence times. Furthermore, we demonstrate the stabilization of our clock laser using these classically correlated states. First steps towards the utilization of entangled states prepared with a Cirac-Zoller gate and the integration in the measurement protocol will be shown.

[1] E.M. Kessler et al., PRL 112, 190403 (2014)
[2] C. Roos et al., Nature 443, 316319 (2006)

A 29.6 Fri 12:30 F303

Progress of the $^{171}Yb^+$ single-ion optical clocks at PTB — •Jian Jiang, Martin Steinel, Melina Filzinger, Ekkehard Peik, and Nils Huntemann — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Clocks based on optical reference transitions of single ions confined in radio-frequency traps or neutral atoms trapped in optical lattices are the most accurate measurement devices ever built. The $^2S_{1/2}(F=0) \rightarrow {}^2F_{7/2}(F=3)$ electric octupole transition of a single trapped $^{171}Yb^+$ ion is employed as the reference in our case. In this talk, we report on an improved end-cap ion trap with low-loss insulator material and high thermal conductivity to obtain a homogeneous temperature distribution. A thick gold coating of the electrodes should lead to a low ion heating rate, and a precise evaluation of shifts from residual fields promises a total uncertainty below 1×10^{-18}. For the latter, we make use of the $^2S_{1/2}(F=0) \rightarrow {}^2D_{3/2}(F=2)$ electric quadrupole transition of the same ion. This transition can also be used to efficiently cool the ion to the motional ground state and suppress corresponding Doppler shifts.