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

Time: Thursday 11:00–13:00 Location: N 3

**Invited Talk** A 29.1 Thu 11:00 N 3

**An optical clock with entangled trapped $^{40}Ca^{+}$ ions.** — •Kai Dietze[1,2], Lennart Pelzer[1,2], Bennet Benny[1,2], Fabian Dawel[1,2], Mirza A. Ali[1,2], Derwell Drapier[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30157 Hannover, Germany

Optical atomic clocks based on trapped ions reach fractional systematic uncertainties in the low $10^{-18}$ range. The statistical uncertainty, however, is typically limited by the quantum projection noise due to the small number of ions, requiring long averaging times to reach a comparable level in uncertainty. Entanglement-assisted interrogation schemes can lower this limit by providing a gain in signal-to-noise ratio. We discuss entanglement-based measurement schemes in the presence of spontaneous emission and magnetic-field fluctuations [2] and present our experimental realization of an optical clock employing two entangled $^{40}Ca^{+}$ ions prepared in a decoherence-free subspace. We experimentally compare a classical correlated protocol with an entanglement enhanced protocol based on a magnetically insensitive multi-ion state, demonstrating lifetime-limited coherence times and their applicability within an optical clock comparison [2].

[1] T. Kielinski et al., Sci. Adv. 10, eadr1439 (2024)
[2] K. Dietze et al., arXiv:2506.11810 (2025)

A 29.2 Thu 11:30 N 3

**Precision Angular Profiling of a Thermal Hydrogen Dissociation Source via Recombination Calorimetry** — •Maximilian Balthasar Hüneborn, Sebastian Böser, and Martin Fertl for the Project 8-Collaboration — Johannes Gutenberg-Universität Mainz, Mainz, Germany

Project 8 aims for a 40-meV neutrino mass sensitivity using cyclotron radiation emission spectroscopy (CRES) with atomic tritium to avoid molecular energy uncertainties. At JGU Mainz, the test setup characterizes beam dynamics using a thermal hydrogen dissociation source. Molecular hydrogen flows at up to 20 SCCM through a 1 mm inner diameter tungsten capillary heated to approximately 2200 K, with differential pumping suppressing recombination backgrounds. Precise angular beam profiling is essential to study the beam formation process. We measure the beam profile via a calorimetric wire detector that quantifies recombination heat on a movable tungsten wire, enabling minimally disruptive measurements of beams. A newly built tilt mechanism overcomes the limited angular coverage (-15° to +30°) of the standard translation stage, allowing comprehensive characterization of the beam's full divergence profile. This enables direct comparison between calorimetric and mass spectrometry data, confirming theoretical models of capillary beam output and validating the source geometry's role in atomic beam formation for future tritium operation.

A 29.3 Thu 11:45 N 3

**Spin noise spectroscopy of hot rubidium vapor under two-photon excitation** — •Oskar Sund and Ilja Gerhardt — light and matter group, Institute for Solid State Physics, Leibniz University Hannover, Appelstrasse 2,D-30167 Hannover, Germany

Doppler free realized S-P-D transitions in hot rubidium vapor have emerged as a promising contender as stable, compact and low-cost frequency references, potentially superseding the chip-scale atomic clocks of today. Unlike the conventional approach of the two-photon excitation in rubidium at 778.1 nm, a two-color approach would require significantly lower optical powers and vapor densities while achieving comparable frequency stability [1]. In this work, we present two-color, two-beam spin noise spectroscopy: one laser (780 nm) probes ground-state spin fluctuations, while a second laser (776 nm) completes the 5S-5D ladder-type two-photon transition. By measuring the spin noise on both beams, as well as their noise correlation, we investigate how the two-photon excitation perturbs ground-state spin dynamics and whether additional spin noise features or dynamic back-action from excited states can be observed. Such measurements provide new insights into nonlinear spin-light interactions, potentially relevant for precision metrology, quantum sensing and future frequency standards.

[1] Ahern, E. J., Scholten, S. K., Locke, C. et al. Tailoring the stability of a two-color, two-photon rubidium frequency standard. Phys. Rev. Applied 23, 044025 (2025)

A 29.4 Thu 12:00 N 3

**High-resolution laser spectroscopy on iron** — •Katrin Weidner[1], Thorben Niemeyer[1], Jakob Weiss[1], Sebastian Berndt[1], Pia Breinbauer[1], Christoph E. Düllmann[1,2,3], Raphael Hasse[1], Dennis Renisch[1,2], Jörg Runke[1,2], Matou Stemmler[1], Dominik Studer[2], Sebastian Raeder[2], and Klaus Wendt[1] — [1]Johannes-Gutenber-Universität Mainz — [2]Helmholtz-Institut Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung Darmstadt

High-resolution laser spectroscopy on free atoms provides access to fundamental properties of the atomic and nuclear structure of matter. Iron is among the most abundant metals on Earth and also plays a major role in astronomical observations.

We present high resolution measurements on iron isotopes, addressing the first measurement on the hyperfine structure of the radioisotope $^{55}Fe$ . An efficient three-step ionization scheme is used for excitations with high-power tunable Titan:Sapphire lasers, including second harmonic generation. To investigate the hyperfine structure we explore injection locking with a commercial Optical Parametric Oscillator (OPO).

A 29.5 Thu 12:15 N 3

**DRALS: A new tool to investigate the hyperfine structure in highly charged ions** — •Dimitrios Zisis for the LIBELLE-Collaboration — Institut für Kernphysik, Technische Universität Darmstadt, Germany — Helmholtz Forschungsakademie Hessen für FAIR, Campus Darmstadt, Germany

We report on the first laser excitation of the ground-state hyperfine transition in lithium-like $^{208}Bi^{80+}$. The experiment was performed at the ESR, in May 2025. Detection of the transition was enabled through a new measurement scheme that combines laser excitation with dielectronic recombination (DR). In this approach, the electron cooler is set to a voltage that leads to the DR process predominantly from the upper hyperfine state. Resonant laser driving of the transition to the upper state thus leads to an enhancement of the DR recombination rate detected with particle detectors behind the electron cooler.

This technique has been successfully demonstrated for the first time using the radioactive isotope $^{208}Bi$ in the lithium-like charge state, a species that is inherently difficult to produce, decelerate, and store at the required energies in the ESR. These results establish the feasibility of the method and pave the way for precision measurements during the next beam time, which has already been approved by the GPAC (Proposal G-24-00290). This research was funded by BMFTR, Contract numbers 05P24RD5, 05P21RGFA1 and 5P24RG2.

A 29.6 Thu 12:30 N 3

**The long range validity of the Wigner law - experimental test on negative oxygen** — •Thorben Niemeyer[1], Oliver Forstner[2,3,4], Vadim Gadelshin[1], Raphael Hasse[1], Lothar Schmidt[5], Markus Schöffler[5], Matou Stemmler[1], Dominik Studer[1], and Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz — [2]Friedrich-Schiller-Universität Jena — [3]GSI Darmstadt — [4]Helmholtz Institut Jena — [5]Johann Wolfgang-Goethe Universität Frankfurt am Main

Negative atoms are quantum systems in which an additional electron is bound to the neutral core because of electron correlation effects. Correspondingly, its binding energy is one of the most fundamental properties and its knowledge is important for understanding those fragile quantum systems. The detachment of the additional electron by a photon via laser-ion interaction is a well-established measurement technique. It was recently performed on negative oxygen ions at the Frankfurt Low-energy storage ring FLSR. While the cross section curves near the energy threshold obtained in those kinds of measurements are typically well described by the Wigner law, the description further off from thresholds demands a more elaborate theory.

The measured detachment curve on negative oxygen comprises six photodetachment channels distributed over about 50 meV. We discuss the description of the combined threshold curve, in the Wigner appraoch in comparison to the more refined zero-core contribution theory.

A 29.7 Thu 12:45 N 3

**Assessment of the differential polarizability of** $Yb^+$ **and** $Sr^+$ **clock transitions** — •Martin Steinel[1], Thomas Lindvall[2], Marianna Safronova[3], Melina Filzinger[1], Jian Jiang[1], Saaswath JK[1], Ekkehard Peik[1], and Nils Huntemann[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]VTT Technical Research Centre of Finland, National Metrology Institute VTT MIKES, P.O. Box 1000, 02044 VTT, Finland — [3]University of Delaware, Newark, USA

Optical clocks are leading candidates for a redefinition of the second, with estimated fractional uncertainties at the $6\times10^{-19}$ level [1]. Room-temperature $^{171}Yb^+$ clocks operating on the $S_{1/2} \rightarrow F_{7/2}$ electric-octupole (E3) transition currently reach $3 \times 10^{-18}$ [2], limited by the blackbody-radiation (BBR) shift $\Delta\nu_{\mathrm{BBR}} \propto \Delta\alpha T^4$. The dominant uncertainty arises from the $\sim 2\%$ accuracy of the differential polarizability $\Delta\alpha$, determined from measurements of the light shift induced by an infrared laser with calibrated optical power and in-situ estimate of the beam profile. In contrast, a method balancing the Stark and Doppler shift caused by excess micromotion yields a $\Delta\alpha$ uncertainty of 0.04% for $^{88}Sr^+$ [3]. We present direct comparisons of both techniques using $^{88}Sr^+$ and determine the ratio of $\Delta\alpha$ for $^{171}Yb^+$ and $^{88}Sr^+$, enabling a potential reduction of the E3 BBR-shift uncertainty to $2 \times 10^{-19}$.

[1] M. C. Marshall et al., Phys. Rev. Lett. 135, 033201 (2025) [2] N. Huntemann et al., Phys. Rev. Lett. 116, 063001 (2016) [3] T. Lindvall et al., Phys. Rev. Lett. 135, 043402 (2025)