Contribution ID: **8**

Type: **Invited Oral**

# An Optical Atomic Clock Based on a Highly Charged Ion

*Monday 16 October 2023 14:00 (30 minutes)*

Optical atomic clocks are the most precise and accurate measurement devices ever constructed, reaching fractional systematic uncertainties below one part in $10^{-18}$ [1]. Their exceptional performance opens up a wide range of applications in fundamental science and technology. The extreme properties of highly charged ions (HCI) make them highly sensitive probes for tests of fundamental physical theories [2, 3]. Furthermore, these properties make them significantly less sensitive to some of the leading systematic perturbations that affect state-of-the-art optical clocks, making them exciting candidates for next-generation clocks [4, 2]. The technical challenges that hindered the development of such clocks have now all been overcome, starting with their extraction from a hot plasma and sympathetic cooling in a linear Paul trap [5], readout of their internal state via quantum logic spectroscopy [6], and finally the preparation of the HCI in the ground state of motion of the trap [7], which allows levels of measurement accuracy to be reached that were previously limited to singly-charged and neutral atoms. Here, we present the first operation of an atomic clock based on an HCI ($Ar^{13+}$ in our case) and a full evaluation of systematic frequency shifts [8]. The achieved uncertainty is almost eight orders of magnitude lower than any previous frequency measurements using HCI. Measurements of some key atomic parameters confirm the theoretical predictions of the favorable properties of HCIs for use in clocks. The comparison to the $^{171}Yb^{+}$ E3 optical clock [9] places the frequency of this transition among the most accurately measured of all time. Furthermore, by comparing the isotope shift between $^{36}Ar^{13+}$ and $^{40}Ar^{13+}$ to improved atomic structure calculations, we were able for the first time to resolve the largely unexplored QED nuclear recoil effects. Finally, prospects for 5th force tests based on isotope shift spectroscopy of $Ca^{+}/Ca^{14+}$ isotopes and the high-sensitivity search for a variation of the fine-structure constant using HCI will be presented. This demonstrates the suitability of HCI as references for high-accuracy optical clocks and to probe for physics beyond the standard model.

**References**

[1] Brewer, S. M. *et al.*, Phys. Rev. Lett. **123**, 033201 (2019).
[2] Kozlov, M. G. *et al.*, Rev. Mod. Phys. **90**, 045005 (2018).
[3] Safronova, M. S. *et al.*, Rev. Mod. Phys. **90**, 025008 (2018).
[4] Schiller, S., Phys. Rev. Lett. **98**, 180801 (2007).
[5] Schmöger, L. *et al.*, Science **347**, 1233–1236 (2015).
[6] Micke, P. *et al.*, Nature **578**, 60–65 (2020).
[7] King, S. A. *et al.*, Phys. Rev. X **11**, 041049 (2021).
[8] King, S. A. *et al.*, Nature **611**, 43–47 (2022).
[9] Lange, R. *et al.*, Phys. Rev. Lett. **126**, 011102 (2021).

**Author:** Prof. SCHMIDT, Piet (Physikalisch-Technische Bundesanstalt and Leibniz University Hannover)

**Presenter:** Prof. SCHMIDT, Piet (Physikalisch-Technische Bundesanstalt and Leibniz University Hannover)

**Session Classification:** Optical Ion Clocks I

**Track Classification:** Molecular, Atomic, Ion and Nuclear Clocks