Scalable tests of fundamental physics with multiple trapped Ytterbium ions

Application Note

H. A. Fürst, C.-H. Yeh, Laura S. Dreissen, T. E. Mehlstäubler, QUEST (Institute for Quantum Metrology), Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany (August 2021)

Introduction

Precision laser spectroscopy of trapped ions has proven to be a precise tool not only to build high-precision optical clocks but also to find applications in quantum computing [1,2]. In addition, the remarkable degree of control makes table-top trapped ion systems competitive with large-scale accelerator facilities for finding new physics [3]. Scaling up these systems from one to tens of ions, forming so called Coulomb crystals, requires fast and reliable imaging of individually resolved emitters that are separated by a few micrometers. We use Ytterbium ions due to their large sensitivity for new physics [4,5]. The ions scatter light near a wavelength of 370 nm, where the detection efficiency of standard camera sensors begins to drop.

Experiment

We trap Ytterbium ions in a precision-machined radio frequency Paul trap [6]. The ions are produced via photoionization of neutral Ytterbium from an effusive oven and imaged onto the EMCCD camera iXon DU897 UCS-BB from Andor with a magnification of 24. The back-illuminated sensor variant BB has proven to have an enhanced quantum efficiency over other models in the near-UV and blue wavelength regime. In our experiment, we excite the ions into the metastable electronic F-State, which is extremely sensitive to a potential Lorentz violation. A complex sequence of radio frequency pulses mixes the different spin states in the F-manifold, such that a potential violation signal can be picked up. A violation signal would manifest in a variation of the state-population in these states over the sidereal day [Figure 1].

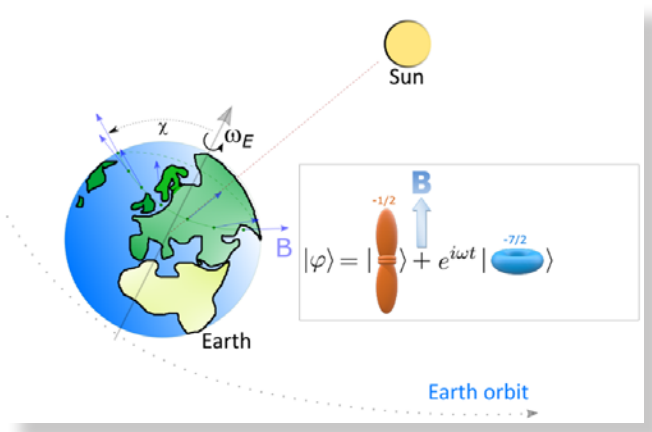

Figure 1: Superposition of electronic spin states in the F-manifold of Yb+. While the earth rotates over the Sidereal day, a potential violation of Lorentz symmetry would manifest in a periodic phase shift between the states that is transferred to a shift in state populations.

After the sequence, we de-excite the ion back to the electronic ground state, where it can scatter photons near 370 nm wavelength. To analyze the success of the de-excitation, we are interested in whether individual ions are fluorescing or not when illuminated with the 370 nm detection laser, referred to as state-detection. The latter case corresponds to the ions still being in the metastable electronic F-state and thus not able to scatter light near a wavelength of 370 nm, which hints to a violation of local Lorentz invariance. Thus, it is of high importance for us that the signal-to-noise ratio of the camera sensors is large to prevent false-positive and false-negative signals. At the same time, fast detection within a few milliseconds is required to keep the detection overhead in our measurements low. A typical image of a linear ten ion crystal is shown in Figure 2, where eight ions are in the bright state and two ions are in the metastable F-state, appearing as gaps in the crystal.

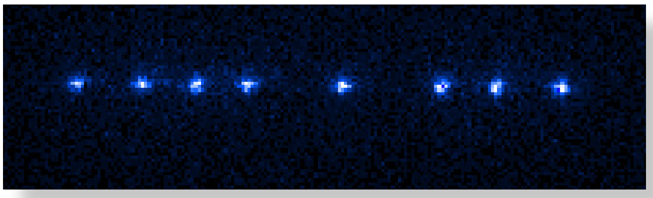

Figure 2: False-color image of a linear coulomb crystal composed of ten Yb+ ions, eight of them fluorescing near 370 nm wavelength.

References:

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Contact:

Prof. Dr. Tanja Mehlstäubler
QuaCCS - Quantum Clocks and Complex Systems
QUEST (Institute for Quantum Metrology)
Physikalisch-Technische Bundesanstalt (PTB)
Bundesallee 100,
38116 Braunschweig, Germany

Phone: +49 (531) 592 4710
Email: tanja.mehlstaeubler@ptb.de
Web: http://www.quantummetrology.de/quaccs/home/