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Application Note

iQLOC: Ion Quantum Logic Optical Clock

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Techniques developed for quantum computing with trapped ions can be used to perform precision spectroscopy of ion species such as aluminum which has an ideal transition for an optical clock but cannot be laser cooled directly. In our project at Piet Schmidt's Experimental Quantum Metrology group we set up an optical clock experiment with aluminum as the clock ion and a Ca^+ the logic ion. The latter provides sympathetic cooling, state preparation, and internal state detection after interrogation of the clock transition.

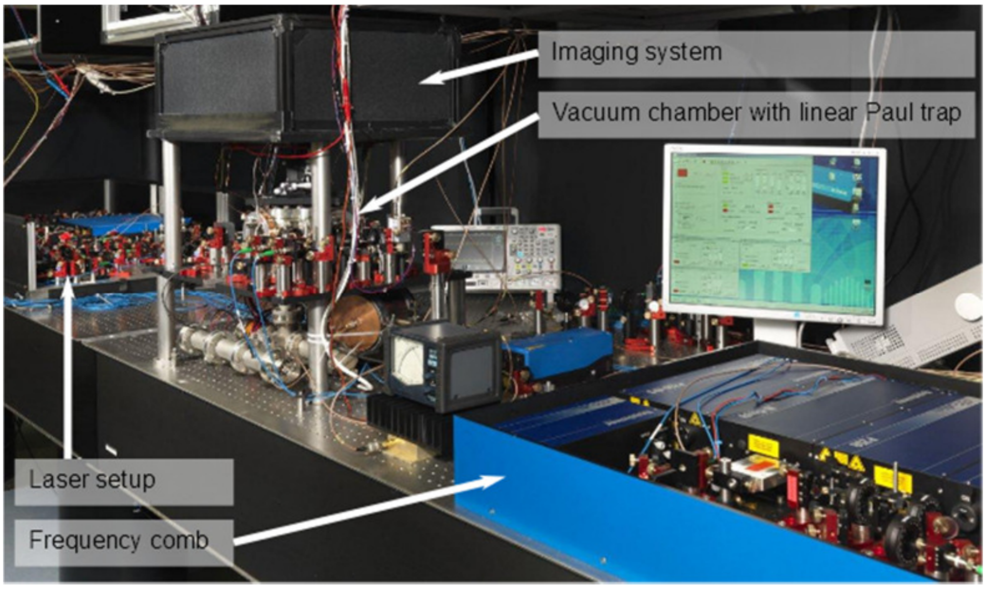

Figure: View of the experimental setup of the aluminum clock.

The current cesium frequency standards are using the microwave transition between the two hyperfine levels of the ground state of ^{133}Cs. The frequency of this transition is approximately 9.1 GHz. Optical clocks (like the aluminum clock) are using optical transitions with frequencies on the order of 1×10^{15} Hz. Due to these higher frequencies optical clocks offer a much higher stability, which is important for many applications, such as the investigation of a possible time variation of fundamental constants and relativistic geodesy.

$^{27}Al^{+}$ has been chosen as the clock ion since it has a narrow 8 mHz clock transition at 267 nm which is very insensitive to shifts due to external fields. Hence, aluminum clocks promise a very high accuracy and stability. Currently, the most accurate optical atomic clock is an aluminum clock at NIST which achieves a fractional frequency uncertainty of below 9×10^{-18} [1].

One of the requirements for precision spectroscopy is laser cooling. However, aluminum has no suitable transition for cooling. The idea is to trap a second ion of a different species, called the logic ion, together with the clock ion in the same trap. This logic ion has a better accessible cooling and detection transition than the clock ion. It cools the clock ion sympathetically via the Coulomb interaction, and through a series of laser pulses it allows transferring the internal state of the clock ion after probing the clock transition onto the internal state of the logic ion where it can be read out using standard techniques. This state projection and read out scheme is called quantum logic spectroscopy [2]. We are currently implementing this scheme with $^{40}Ca^{+}$ as the logic ion [3].

Within this experiment we demonstrated a high-bandwidth transfer-lock scheme which is capable of transferring short-term stability from a stable master laser to an otherwise free-running diode laser at 729 nm via a frequency comb [4]. Limited by the intrinsic noise of the comb at high Fourier-frequencies and the available feedback bandwidth, we synthesize a virtual beat signal for the 729 nm laser in which the effect of the comb noise is suppressed by microwave feed-forward electronics, a so-called transfer oscillator lock [5], circumventing a tight comb lock. By eliminating the need for auxiliary reference cavities for laser prestabilization at each wavelength, this capability allows a substantial simplification of experimental setups requiring multiple stable lasers, such as high-accuracy frequency standards based on quantum logic spectroscopy, experiments in Rydberg spectroscopy, or coherent photoassociation and control of molecules with Raman pulses.

References:

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