Linear ion traps for optical atomic clocks

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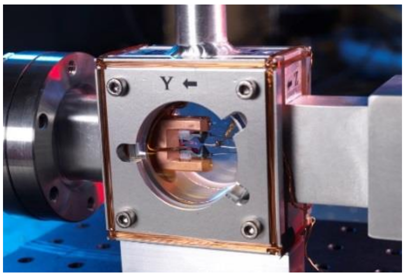
Background and motivation

Recent innovations in the field of frequency metrology [1] have enabled scientists to measure time and frequency with an accuracy approaching a part in 10^{18}, continuing to make frequency the most accurately measured physical quantity. For example, this level of performance will allow us to measure frequency deviations resulting from changes in the gravity potential equivalent to height differences of just 1 cm at the earth's surface, which has applications in surveying for gas and oil, and monitoring ocean currents and sea-level rise. Improved performance will lead to more accurate global navigation satellite systems, enabling autonomous vehicles, revolutionising position sensing in manufacturing, as well as having numerous space applications.

The atomic clocks that enable these measurements are based on interrogating the frequency of an electromagnetic transition between two internal energy levels within an atom. The National Physical Laboratory runs the UK's most accurate clocks, including an ytterbium optical clock, which is based on an optical transition in a single ytterbium ion ($^{171}Yb^{+}$) held in an rf endcap trap (see below). With this experimental apparatus we have created a table-top platform for exploring physics beyond the standard model. [2]

Masters project

The averaging time required to reach statistical uncertainties at the 10^{-18} level in the existing $^{171}Yb^{+}$ clock is currently limited by the Quantum Projection Noise [3] of the single ion. To go beyond this limit, a linear ion trap is needed for probing multiple ions simultaneously and this also opens up the opportunity to use quantum entanglement schemes to reduce this averaging time even further. During the Masters project, a linear ion trap will be prepared. A student will be trained in understanding the requirements of optical clocks such that they can finalise a linear trap design, fabricate the trap, and assemble the ion trap apparatus. This will include building up the vacuum system and associated laser beam steering optics.



Single ion trap in $^{171}Yb^{+}$ clock at NPL

PhD project

Following on directly from the Masters project, the linear trap will be made fully operational as a high stability/high accuracy clock. The homogeneity of laser beam profiles and magnetic field across the ions will need to be evaluated, along with the impact of ion motion and heating on the quantum coherence. To verify the clock's performance, it will be characterised against other optical clocks locally and also compared with clocks across Europe (via optical fibre link) and across the world (via clocks on board the International Space Station). These international comparisons are essential to build confidence in optical clocks prior to a redefinition of the second, and the ability to reach accuracy at the part in 10^{18} in much shorter averaging times is a key step in enabling the uptake of optical clocks across a broad range of applications.

References:

[1] H. Margolis, "Optical frequency standards and clocks," Contemporary Physics, vol. 51, pp. 37-58 , 2010.

[2] R. M. Godun, *et al.*, "Frequency ratio of two optical clock transitions in 171Yb+ and constraints on the time-variation of fundamental constants ," Physical Review Letters, vol. 113, p. 210801, 2014.

[3] W. M. Itano, *et al.*, "Quantum projection noise: Population fluctuations in two-level systems," Physical Review A, vol. 47, pp. 3554-3570, 1993.