^{171}Yb^{+} optical clock at NPL for frequency metrology and tests of fundamental physics

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The accuracy and stability of atom-based optical frequency standards make them an ideal metrological tool, with numerous applications in areas requiring precise position, navigation and timing. In isolation, the accuracy of an optical clock is difficult to fully assess. Performing measurements of optical frequency ratios via optical frequency comb systems - whether locally or utilising clocks in different laboratories or countries via interconnected fibre networks - can enable a direct exploration of clock performance at the part-in-10^{17} level and below. Repeatability of the results year on year gives added confidence in how well the clock system and its long-term behaviour are understood - an essential step for redefining the SI second in terms of an optical frequency. The culture of sharing increasingly long-term measurement data has also enabled analysis of clock frequency data on a variety of different timescales, which has great potential for testing fundamental physics theories [1,2].

The electronic structure of the ^{171}Yb^{+} ion provides two clock transitions that are used for optical frequency metrology at NPL: the ultra-narrow electric octupole transition (E3), and the broader electric quadrupole transition (E2), which is additionally utilised as a more sensitive probe of several systematic effects. During clock operation a single ^{171}Yb^{+} ion is held in an endcap trap designed for minimised ion heating rate and symmetric rf delivery to the endcap electrodes [3]. To improve the overall performance of our clock system we have implemented an ARTIQ [4] infrastructure for experimental control of the clock operation and systematics evaluation. Within this new control framework, ion loading, minimisation of ion micromotion in the trap, and magnetic field calibration routines are completely automated and can be scheduled at appropriate intervals during a frequency measurement campaign. Additionally, improved monitoring of experimental parameters such as ion fluorescence and laser wavelengths enables more robust operation (e.g., enabling automatic steering of laser frequencies and the implementation of an ion-recovery algorithm). This helps to maximise the uptime of the frequency measurement process, which exceeded 90% over a 2-week period in a recent measurement campaign. Recent advances in on-the-fly assessment of systematics have enabled near real-time correction of the E3 optical clock output frequency, and this has been used to explore and test future methods for steering the UTC(NPL) time scale.

We will report on absolute E3 frequency measurements and E3/E2 optical frequency ratio measurements in ^{171}Yb^{+}, local ^{171}Yb^{+}/^{87}Sr clock frequency ratios, related uncertainty budgets, and improvements in automation and robust operation of the ^{171}Yb^{+} clock system at NPL. We will also show how these measurement results have been used to constrain temporal variation of the fine structure constant and exclude regions of parameter space in theories beyond the Standard Model, such as those which include ultralight scalar dark matter [2,5].

References

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