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An ytterbium ion clock and its role in the search for dark matter

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Optical atomic clocks are amongst the most sensitive instruments ever to have been created. Although their only output is a stable frequency, their intense precision allows them to probe tiny effects at the edge of our understanding of physics. These devices measure the energy difference between two atomic energy levels by relating it to the frequency of light. In doing so, they create astonishingly accurate frequency references: the current state-of-the-art has an estimated fractional frequency uncertainty of 9.5×10^{-19} [1].

This ability to resolve even the tiniest effects means that optical atomic clocks have more applications than simply timekeeping: they are sensitive probes of our universe. The field of laboratory cosmology might sound unlikely but is emerging as a new frontier in physics [2]. As a fledgeling research area, its contributions will soon grow further, but already are substantial.

At NPL, a frequency standard based on the octupole transition of a trapped ytterbium ion is operated as an optical clock. The structure of $^{171}\mathrm{Yb}^{+}$ is particularly well-suited for tests of fundamental physics - the excitation of an electron from deep within the ion gives ytterbium the highest sensitivity to change in the fine-structure constant of optical clock candidate species currently in use, as well as an exceptional sensitivity to effects violating Lorentz symmetry [2,3].

In this work, we give an example of how a single ion of ytterbium can help us address questions about the universe's makeup. We briefly cover the design of our clock, and those features relevant to searches for change in the fine structure constant. We also present a recent collaboration amongst European partners where a network of clocks was used to search for transient variation in the fine structure constant, a proposed indicator of topological dark matter in the form of an ultralight boson field [4]. By operating six clocks simultaneously across three institutions over a month, constraints for this form of dark matter were extended over several orders of magnitude, particularly for transients of long duration [5].

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