Optical Clocks in Space for New Physics Searches

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The extraordinary advances in quantum control of matter and light have been transformative for atomic and molecular precision measurements, enabling probes of the most basic laws of nature to gain a fundamental understanding of the physical universe. The development of high-precision optical atomic, molecular, and nuclear clocks enables searches for the variation of fundamental constants, dark matter, violations of Lorentz invariance, tests of gravity, and detection gravitational waves. Precision of the world best clocks already corresponds to better than one second uncertainty for the lifetime of the Universe.

I will describe recent proposals for deployment of high-precision optical clocks and spectroscopy experiments in space for precision tests of gravity and relativity [1], searches for a dark-matter halo bound to the Sun and Jupiter [2, 3], and detecting transient effects [4, 5, 6].

In a broad class of theories, the accumulation of ultralight dark matter (ULDM) leads to formation of long-lived bound states known as boson stars. When the ULDM exhibits self-interactions, prodigious bursts of energy carried by relativistic bosons are released from collapsing boson stars in bosenova explosions. I will discuss the potential reach of terrestrial and space-based experiments for detecting transient signatures of emitted relativistic bursts of scalar particles, including ULDM coupled to photons, electrons, and gluons, capturing a wide range of motivated theories [4 - 6]. For the scenario of relaxion ULDM, we demonstrate that upcoming experiments and technology such as nuclear clocks as well as space-based interferometers will be able to sensitively probe orders of magnitude in the ULDM coupling-mass parameter space, challenging to study otherwise, by detecting signatures of transient bosenova events. Screening of ULDM with quadratic couplings near the surface of the Earth can significantly impact observations of transient effects. The quantum sensors can probe quadratic couplings orders below existing constraints by detecting bosenova events [5]. I will also discuss new work [6] on the possibility of coincidentally detecting ultralight bosons and a SM signal (GW/γ/ν) from the same source.

Finally, I will discuss recent work on the sensitivity of the nuclear clock to the variation of fine-structure constant and corresponding dark matter searches [7].

References

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