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Searching for a fifth force with atomic and nuclear clocks

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We consider the general class of theories in which there is a new ultralight scalar field that mediates an equivalence principle violating, long-range force. In such a framework, the Sun and Earth act as sources of the scalar field, leading to potentially observable location-dependent effects on atomic and nuclear spectra. We determine the sensitivity of current and next-generation atomic and nuclear clocks to these effects and compare the results against the existing laboratory and astrophysical constraints on equivalence principle violating fifth forces. We show that, in the future, the annual modulation in the frequencies of atomic and nuclear clocks in the laboratory caused by the eccentricity of Earth's orbit around the Sun may offer the most sensitive probe of this general class of equivalence principle violating theories. Even greater sensitivity can be obtained by placing a precision clock in an eccentric orbit around Earth and searching for time variation in the frequency, as is done in anomalous redshift experiments. In particular, an anomalous redshift experiment based on current clock technology would already have a sensitivity to fifth forces that couple primarily to electrons at about the same level as the existing limits. Our study provides well-defined sensitivity targets to aim for when designing future versions of these experiments.

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