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ULDM-Induced Variations of Fundamental Constants in Space-Based Laser Interferometers

Ultralight dark matter (ULDM) coupled to the Standard Model can induce coherent oscillations of effective fundamental constants and thereby generate narrow-band signals in precision interferometric experiments. In this work, we investigate how such oscillations imprint signatures on space-based laser interferometers such as LISA and Taiji. Starting from the one-way inter-spacecraft link observables, we analyze several detector-level effects induced by ULDM, including composition-dependent acceleration of test masses, laser-frequency variations associated with cavity-length modulation, refractive-index effects, and clock-related contributions. We then propagate these signals through the standard calibration chain, including clock-noise suppression and time-delay interferometry (TDI). We show that the observability of a ULDM-induced effect is determined by the structure of its single-link response. In particular, the signal generated by ULDM-induced laser-frequency variation enters the raw link observable with the same operator structure as laser phase noise. As a consequence, it is strongly suppressed in realistic TDI combinations. By contrast, signals with explicit directional structure, such as Doppler responses induced by ULDM-driven test-mass motion, are not removed in the same way by TDI. We further construct the ξ observable, which isolates the differential motion between the test mass and the optical bench, and derive its sensitivity to the dilaton–gluon coupling for LISA, Taiji, and BBO. Our results identify a class of ULDM signatures to which TDI-based space interferometers are intrinsically insensitive, while clarifying which types of couplings can still leave measurable imprints in the final observables.

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