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Observing invisible axions with gravitational waves

If the Peccei-Quinn symmetry associated to an axion has ever been restored after inflation, axion strings inevitably produce a contribution to the stochastic gravitational wave background. Combining effective field theory analysis with numerical simulations, we show that the resulting gravitational wave spectrum has logarithmic deviations from a scale invariant form with an amplitude that is significantly enhanced at low frequencies. As a result, a single ultralight axion-like particle with a decay constant larger than 1014 GeV and any mass between 10-18 eV and 10-28 eV leads to an observable gravitational wave spectrum and is compatible with constraints on the post-inflationary scenario from dark matter overproduction, isocurvature and dark radiation. Since the spectrum extends over a wide range of frequencies, the resulting signal could be detected by multiple experiments. We describe straightforward ways in which the Peccei-Quinn symmetry can be restored after inflation for such decay constants. We also comment on the recent possible NANOgrav signal in light of our results.

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