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Axion-like Dark Matter and the Cosmic Birefringence Signal

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A detection of cosmic birefringence (rotation of linear polarization) has the potential to revolutionize our understanding of fundamental physics and cosmology. Several recent analyses of Planck 2018 and WMAP data have reported tentative evidence, at ~3σ significance, of a cosmic microwave background (CMB) birefringence signal which appears isotropic, static and achromatic.

Dark matter in the form of axion-like particles (ALPs) can source cosmic parity violation. We calculate and present a distinct signal of isotropic CMB birefringence produced by ultra-light ALPs present at recombination as well as locally. Incorporating the allowed dark matter fractions over a large range of ultra-light ALP masses, strong constraints can be placed on the ALP-photon coupling: up to $g_{a\gamma} < 10^{-16}$ GeV^{-1} (from recombination) and up to $g_{a\gamma} < 10^{-13}$ GeV^{-1} (local).

Upcoming CMB experiments (SO, CMB-S4, PICO & CMB-HD) have the promise to confirm or refute the evidence for birefringence and test its origin. Our forecasts show that calculated constraints on $g_{a\gamma}$ can tighten further by 1-2 orders, extending them to higher ALP masses. If a cosmic birefringence signal is confirmed, one can specify the properties of ALP dark matter responsible for it.

CMB birefringence constraints on ALPs scale weakly with dark matter fraction. They are also unaffected by uncertainties which are common in other astrophysical ALP probes: the strength and spectrum of magnetic fields; an assumed over-density of ALP dark matter in structures or at centers of objects; and intrinsic polarization orientation.

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