PROCEEDINGS OF SCIENCE

# Constraining ALPs with Cosmic Microwave Background Polarization Birefringence

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Cosmic birefringence - the frequency-independent rotation of the linear polarization plane - offers a powerful probe of photon interactions with axion-like particles (ALPs). Its accurate characterization requires resolving two opposite conventions for the linear polarization angle. Here we summarize the latest data on the isotropic effect from cosmic microwave background (CMB) observations.

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## 1. Introduction and conventions on the linear polarization angle

Birefringence - frequency independent rotation of the linear polarization plane over cosmological distances - is widely used to test the coupling between photons and an axion-like particles (ALPs): [1–3]:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\nabla_\mu\phi\nabla^\mu\phi - V(\phi) - \frac{g_\phi}{4}\phi F_{\mu\nu}\widetilde{F}^{\mu\nu}\,. \tag{1}$$

where $F^{\mu\nu}$ is the electromagnetic tensor, $\widetilde{F}^{\mu\nu} \equiv \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$ its dual and $\phi$ a pseudoscalar field.

Before presenting the current constraints on isotropic birefringence from CMB, it is important to remember that there are two opposite conventions for the sign of the linear polarization angle.

According to IAU/IEEE (International Astronomical Union/Institute of Electrical and Electronics Engineers) there is a right-handed reference frame associated with each point on the sky sphere with $X$ pointing toward North, $Y$ pointing toward East and $Z$ pointing toward the observer (inward) [4, 5]. Therefore, looking from observer toward the source, the linear polarization angle increases anti-clockwise, see Fig. 1.

Following HEALPix (Hierarchical, Equal Area, and iso-Latitude Pixelisation of the sphere) convention, there is a right-handed reference frame associated with each point on the sky sphere with $X$ pointing toward South, $Y$ pointing toward East and $Z$ pointing toward the source (outward) [6]. Therefore, looking from observer toward the source, the linear polarization angle increases clockwise. See also Fig. 1 and [7, 8] for a review.

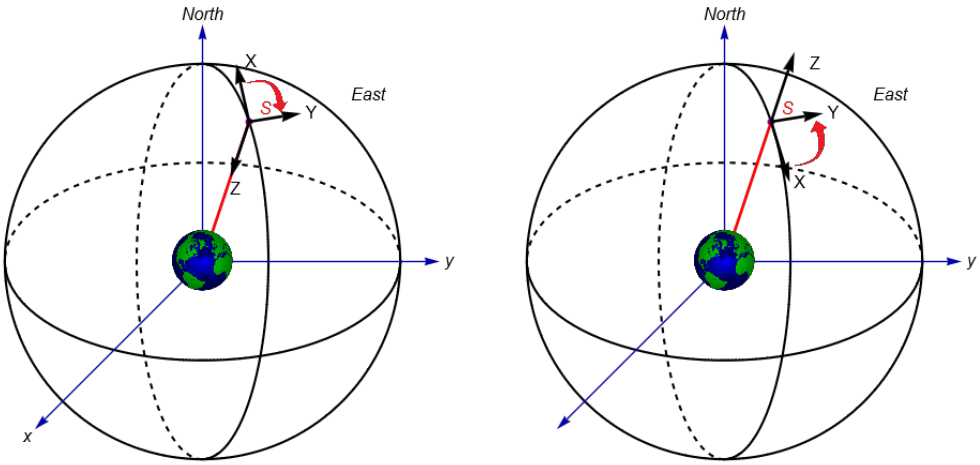


**Figure 1:** *Left:* According to IAU/IEEE convention the linear polarization angle increases anti-clockwise looking from observer toward the source $S$. *Right:* Folloeing HEALPix convention the linear polarization angle increases clockwise looking from observer toward the source $S$.

## 2. CMB constraints on isotropic cosmic birefringence

The first constraints on cosmic birefrincence obtained from CMB data had uncertainty of the order of degrees [9–11]. In the following years, there has been a noticeable improvement. In

particular [12] using polarized galactic foreground emission to disentangle cosmic birefringence from miscalibration of the detector and suggested a hint of an isotropic rotation of the order of 0.3 degrees, see also [13] and the references therein. In Fig. 2 we plot the latest data for the birefringence angle $\alpha$ [12, 14–20]. For other older constraints see [21–26] and references therein.

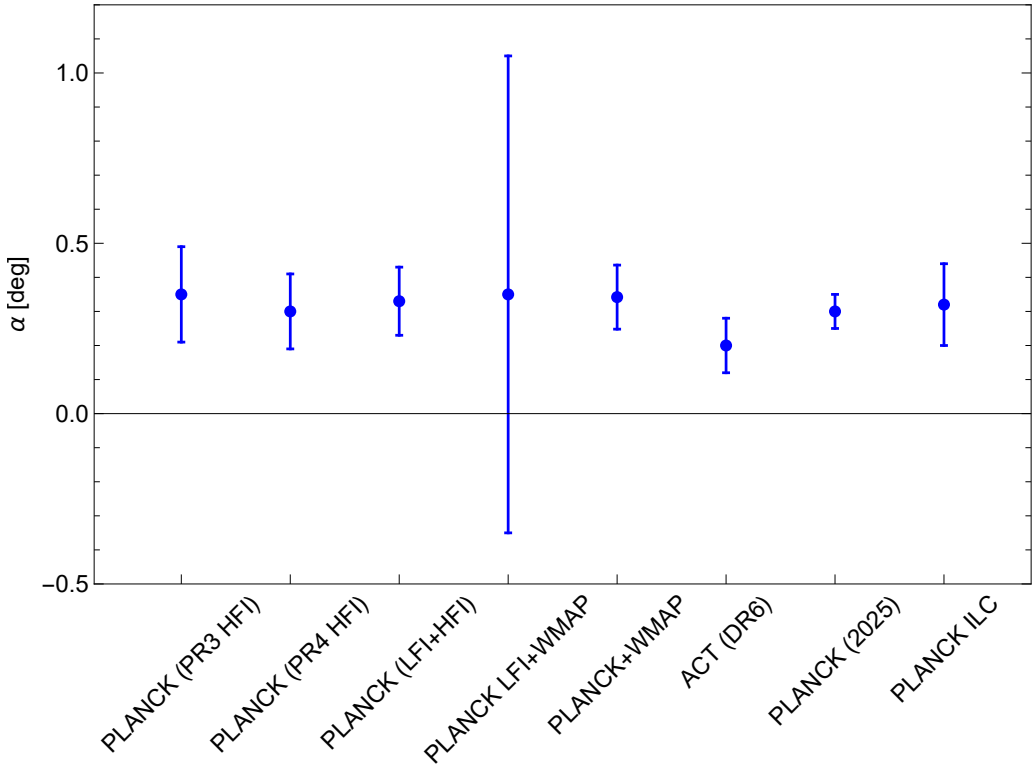


**Figure 2:** Isotropic cosmic birefengence contraints from CMB obtained by Planck satellite maps from data Release 3 High Frequency Instrument (PR3 HFI) [12], Planck satellite maps from Data Release 4 (PR4 HFI) [14], Planck satellite maps from Data Release 4 PR4 Low Frequency Instrument (LFI+HFI) [15], Planck satellite maps from LFI combined with WMAP (LFI+WMAP) [16], WMAP and Planck maps [17], Atacama Cosmology Telescope (ACT DR6) [18], Planck constraints on the scale dependence of isotropic cosmic birefringence [19], Internal Linear Combination (ILC) method on Planck Release 4 (PR4) maps [20]. Here we follow the HEALPix convention on the sign of the polarization angle.

## 3. Conclusions

The first constraints on cosmic birefringence were obtained looking at position angle and linear polarization angle of distant radio galaxies: $|\alpha| \leq 6.0$ deg at 95% confidence level [1]. Always looking at radio galaxies [27] claimed a detection of anisotropic linear polarization rotation, independent from the Faraday rotation; however, further analysis of the data did not confirm this claim [28–31]. Today the latest analyses of CMB data suggest the presence of a 0.3 deg isotropic cosmic birefringence. Comparison and combination with other datasets, including radio galaxies, pulsars, gamma-ray bursts, Crab supernova remnant and other polarized sources is very important, but always keeping in mind the opposite conventions on the linear polarization angle used in different communities.

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