PROCEEDINGS OF SCIENCE

Birefringence in CMB anisotropies due to cosmological pseudoscalar fields

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We review the data on isotropic cosmic birefringence coming from Cosmic Microwave Background (CMB) linear polarization observations. We show the different constraints on the coupling constant g_ϕ between photons and axion-like particles acting as dark matter.

1st General Meeting and 1st Training School of the COST Action COSMIC WSIPers (COSMICWISPers)
5-14 September, 2023
Bari and Lecce, Italy

*Speaker

https://pos.sissa.it/

PoS(COSMICWISPers)016

1. Introduction - Cosmological pseudoscalar field acting as dark matter

The usual coupling between the electromagnetic tensor $F_{\mu\nu}$ and a pseudoscalar field ϕ $-1/4 g_\phi \phi F_{\mu\nu}\tilde{F}^{\mu\nu}$ induces a rotation of the linear polarization plane during propagation. For a single photon this rotation angle is proportional to the coupling constant g_ϕ and to the variation of the field during propagation [1, 2]:

$$\frac{g_\phi}{2}\left[\phi(x) - \phi(x_{\rm em})\right] \ . \tag{1}$$

In presence of a cosmological pseudoscalar field acting as dark matter - e.g. assuming for the pseudoscalar field a potential of the form $V(\phi) = m^2 f^2 (1 - \cos\phi/f)$ - it is possible to study the effects of this coupling over cosmological distances.

In Section 2 we summarize the results for isotropic CMB polarization data. In Section 3 we show how these observations induce constraints in the (m, g_ϕ)-plane for axion-like particles acting as dark matter.

2. CMB constraints on isotropic cosmic birefringence

Many experiments and satellites [3–10] provide data on the birefringence angle α describing the rotation of CMB linear polarization during propagation from last scattering surface to today (cosmic birefringence). We summarize the main results on the isotropic effect in Fig. 1.

In the approximation of a *redshift/time independent isotropic rotation angle* $\bar{\alpha}$, cosmic birefringence is degenerate with an angular miscalibration of the detector [11, 12]:

$$\begin{aligned} C_\ell^{TE,{\rm const}} &= C_\ell^{TE,{\rm rec}}\cos(2\bar{\alpha})\,, C_\ell^{EE,{\rm const}} = C_\ell^{EE,{\rm rec}}\cos^2(2\bar{\alpha})\,, C_\ell^{BB,{\rm const}} = C_\ell^{EE,{\rm rec}}\sin^2(2\bar{\alpha})\,, \\ C_\ell^{TB,{\rm const}} &= C_\ell^{TE,{\rm rec}}\sin(2\bar{\alpha})\,, C_\ell^{EB,{\rm const}} = \frac{1}{2}C_\ell^{EE,{\rm rec}}\sin(4\bar{\alpha})\,. \end{aligned} \tag{2}$$

Recently the detection of a nonzero isotropic cosmic birefringence was claimed using polarized galactic foreground emission to disentangle cosmic birefringence from miscalibration of the detector, see [13–15] (e.g. $\bar{\alpha} = 0.342^{+0.094}_{-0.091}$ deg in [15]). These hints of a non-zero isotropic cosmic birefringence - see the last three data points in Fig. 1 - are still quite controversial since it is very difficult to model foreground emissions, in particular interstellar dust polarization.

These observations can be used to constrain g_ϕ, the coupling constant between axion-like particles and photons. In [19] we modified the Boltzmann equation for linear polarization considering a *redshift/time dependent isotropic birefringence angle*, overcoming the wildly used approximation of a redshift/time independent rotation angle, see Eqs. (2). We showed that the impact of the birefringence angle on the CMB power spectra depends on the evolution profile of the pseudoscalar field and not only on the total variation of the field. We later extended and updated our considerations in [20, 21].

We plot CMB birefringence constraints in the (m, g_ϕ)-plane in Fig. 2 assuming that the pseudoscalar field is contributing to the dark matter content of the universe. We also show the values the coupling constant g_ϕ should have in order to induce an isotropic cosmic birefringence of 0.34 deg [15, 21].

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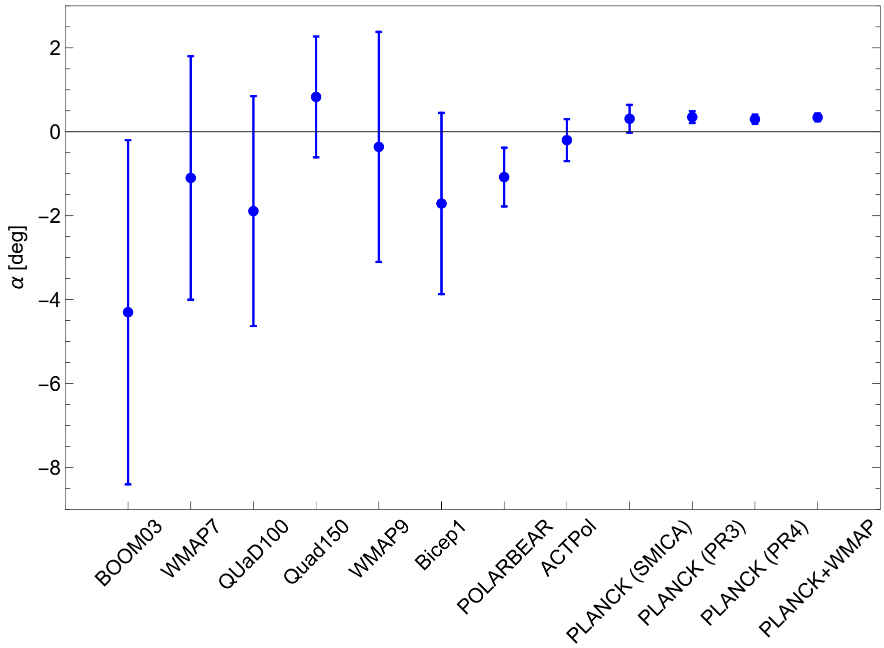

Figure 1: Isotropic cosmic birefringence from CMB experiments with 1σ errors (statistical and systematic uncertainties summed linearly) for: BOOMERanG 2003 experiment [3], WMAP satellite seven-year data [4], QUaD experiment (100 GHz) [5], QUaD experiment (150 GHz) [5], WMAP satellite nine-year data [6], BICEP1 experiment (far-field wire grid calibration) [7], POLARBEAR experiment [8], Atacama Cosmology Telescope (ACTPol) [9], Planck satellite maps from Data Release 2 - SMICA pipeline [10], Planck satellite maps from Data Release 3 (PR3) [13], Planck satellite maps from Data Release 4 (PR4) [14], WMAP and Planck maps [15]. See also similar plots and references in [10, 16–18].

3. Conclusions

We summarized CMB isotropic birefringence observations and corresponding constraints for axion-like particles acting as acting as dark matter in Fig. 2. CMB observations put interesting constraints on pseudoscalar-photon coupling constant g_ϕ for small values of the mass m. For higher values of the mass the pseudoscalar field oscillates very quickly and the effect rapidly decreases.

Other interesting constraints, in this area of the axion-like particle parmeter space (m, g_ϕ), are obtained looking at ultraviolet polarization of distant radio galaxies [22]. In this low mass region there are also data coming from periodic oscillations of the polarization coming from the Crab supernova remnant (observed by the QUIJOTE MFI instrument) and pulsars from the Parkers Pulsar Timing Array (PPTA) [23].

Acknowledgments

This publication is based upon work from COST Action COSMIC WISPers CA 21106, supported by COST (European Cooperation in Science and Technology)

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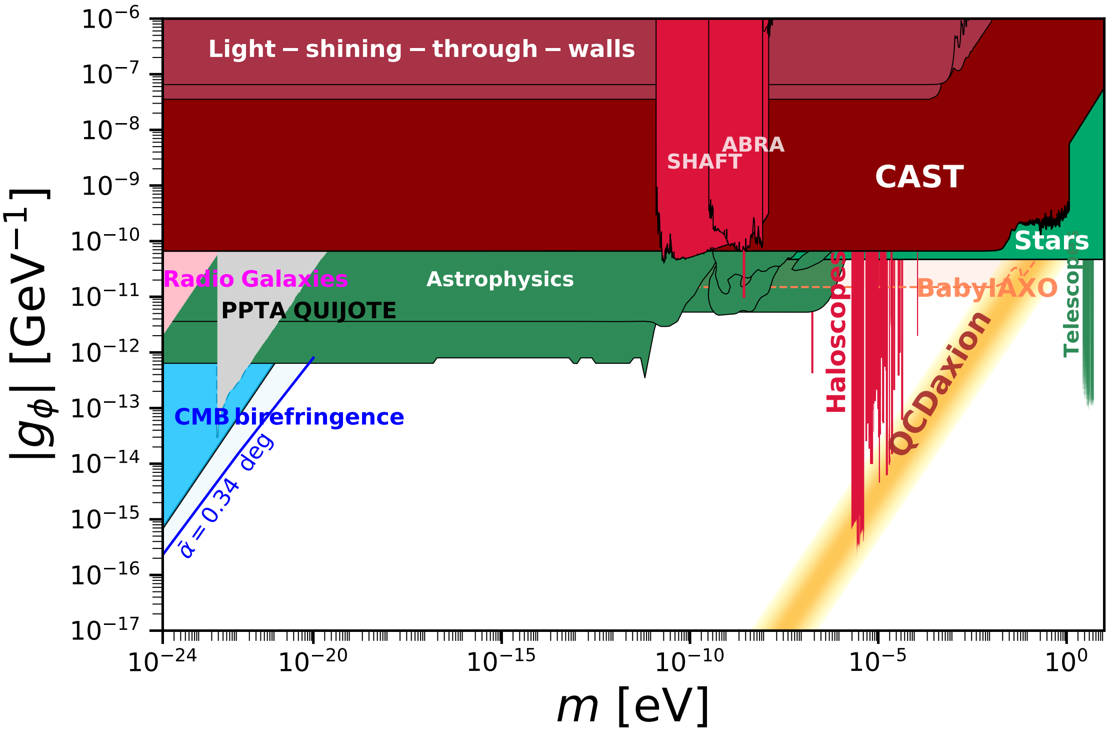

Figure 2: Coupling constant g_ϕ as a function of the mass m of the pseudoscalar field. Plot created with the `AxionLimits` code [24], see online documentation for references on different constraints. We added the constraints coming from CMB birefringence in blue [20] (light blue [21]); we plotted the values the coupling constant g_ϕ should have in order to induce an isotropic cosmic birefringence of 0.34 deg [15, 21] (blue continuous line). The constraint coming from ultraviolet polarization of distant radio galaxies is plotted in pink [22].

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