Birefringence angle estimation using D-estimators [ID 240]

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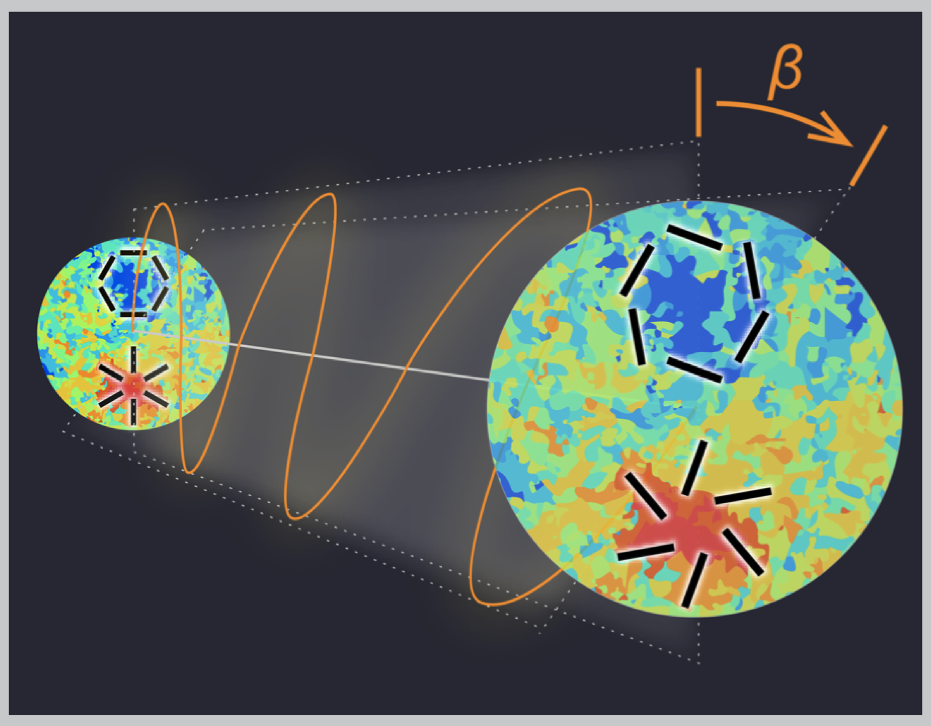
1. Introduction

This poster focuses on harmonic estimators for the cosmic birefringence (CB) effect, the "in vacuo" rotation of the linear polarisation plane of photons during propagation. This effect is a tracer of parity-violating extensions beyond standard electromagnetism and may point to the existence of a new cosmological field (i.e. an axion) acting as dark matter or dark energy. When such an extension is modelled by a Chern-Simons interaction, the amplitude of the CB rotation is proportional to the distance traveled by photons. Hence CMB photons represent the best observable we have in nature to investigate this effect since they are linearly polarised and have traveled the longest distance in the Universe. In this poster, we describe in detail the so-called D-estimators, a methodology used for measuring the CB angle from CMB observations. Additionally, we examine the performance of these estimators when applied to subranges of the complete harmonic domain, a test that could yield valuable insights into the parameters of the axion, such as its mass.

2. How CB works

Cosmic Birefringence is the rotation of the CMB plane of an angle β induced by unknown new Physics which breaks the Standard Model parity symmetry. In 2020 Y. Minami, E. Komatsu et al., using the 2018 Planck satellite data [1] have found [2]:

$$\beta = 0.35^\circ \pm 0.14^\circ \tag{1}$$



Credits: Y. Minami.

4. D-estimators

Among several ways to constrain β, we can use harmonic based estimators, called D-estimators, defined with the CMB spectra and directly depend on ℓ [4]:

$$\begin{cases} D_\ell^{TB,obs} = C_\ell^{TB,obs}\cos(2\beta) - C_\ell^{TE,obs}\sin(2\beta) \\ D_\ell^{EB,obs} = C_\ell^{EB,obs}\cos(4\beta) \\ \qquad - \dfrac{1}{2}(C_\ell^{EE,obs} - C_\ell^{BB,obs})\sin(4\beta). \end{cases} \tag{5}$$

7. References

[1] Planck 2018 results. AA Volume 641.

[2] Y. Minami et al., Prog. Theor. Exp. Phys. 2019, 083E02.

[3] E. Komatsu, Nature Reviews Physics 4, 452-459, 2022.

[4] Gruppuso et. al., JCAP 05 (2016) 020.

3. How CB affects the CMB power spectra

The breaking of parity symmetry generates EB and TB correlations in the CMB signal. Moreover, all observed power spectra are combinations of the primordial power spectra through trigonometric functions that depend on β [3]:

$$\begin{cases} C_\ell^{EE,obs} = C_\ell^{EE}\cos^2(2\beta) + C_\ell^{BB}\sin^2(2\beta) - C_\ell^{EB}\sin(4\beta) \\ C_\ell^{BB,obs} = C_\ell^{EE}\sin^2(2\beta) + C_\ell^{BB}\cos^2(2\beta) + C_\ell^{EB}\sin(4\beta) \\ C_\ell^{EB,obs} = \frac{1}{2}\sin(4\beta)\left(C_\ell^{EE} - C_\ell^{BB}\right) + \cos(4\beta)C_\ell^{EB} \\ C_\ell^{TT,obs} = C_\ell^{TT} \\ C_\ell^{TE,obs} = C_\ell^{TE}\cos(2\beta) - C_\ell^{TB}\sin(2\beta) \\ C_\ell^{TB,obs} = C_\ell^{TE}\sin(2\beta) + C_\ell^{TB}\cos(2\beta) \end{cases} \tag{2}$$

where the $C^{XY,obs}$ are the observed power spectra, whereas the C^{XY} are the primordial power spectra, i.e. the theoretical ones.

5. The project

Starting from a set of realization of CMB power spectra, it is possible to compute the covariance matrices, $\mathrm{Cov}^{XY} \equiv C_{\ell\ell'}^{XY}$, and then to define the following χ^2 quantities:

$$\begin{cases} \chi^2_{TB} = D_\ell^{TB}(C_{\ell\ell'}^{TB})^{-1}D_{\ell'}^{TB} \\ \chi^2_{EB} = D_\ell^{EB}(C_{\ell\ell'}^{EB})^{-1}D_{\ell'}^{EB} \end{cases} \tag{3}$$

and by minimizing them it is possible to infer β.

Our idea is to perform this minimization by considering the quantities not on the whole harmonic range ℓ, but by dividing the latter in different sub-ranges/bins:

$$\ell \to b. \tag{4}$$

6. Intermediate results

Our statistics is being processed on 76 bins of the harmonic range ($\Delta\ell = 20$ and $50 \leq \ell \leq 1550$), 300 simulations of CMB map to compute the covariance matrix and the variances, and the *Planck* PR3 data to compute the estimations.

Our results agree with a not zero β: