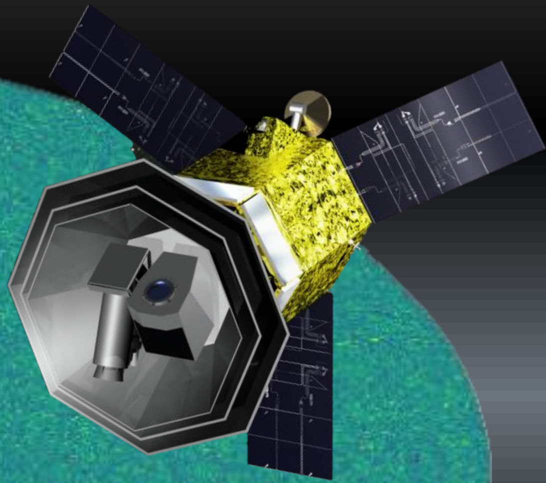
Simultaneous determination of the cosmic birefringence and miscalibrated polarisation angles



Based on:
- PTEP, 2020, 6, June (2020)
- arXiv:2006.15982
- arXiv:2008.02473

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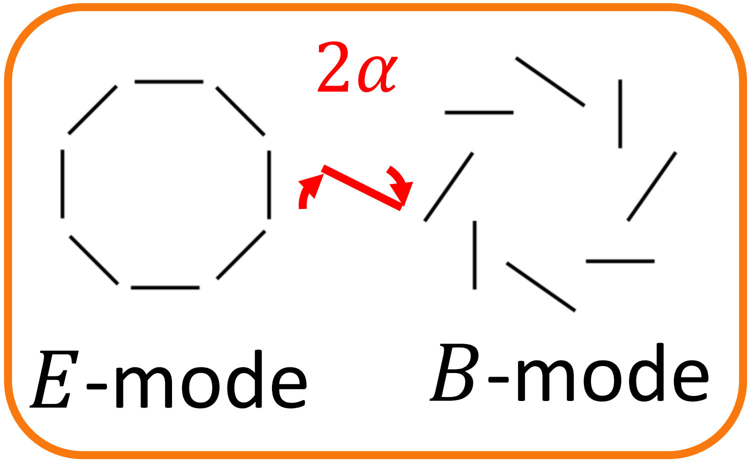
Introduction: miscalibration



- Miscalibration of detector rotation angle (α) creates spurious B−mode from E−mode

$$C_\ell^{BB,o} = C_\ell^{EE}\sin(2\alpha) + C_\ell^{BB}cos(2\alpha) \quad \cdots (1)$$

observed before detectors

We need to determine α to calibrate rotation angle

- In past experiments, this α was calculated assuming that EB correlation of CMB is zero:

$$C_\ell^{EB,o} = \frac{1}{2}\left(C_\ell^{EE,CMB} - C_\ell^{BB,CMB}\right)\sin(4\alpha) \quad \cdots (2)$$

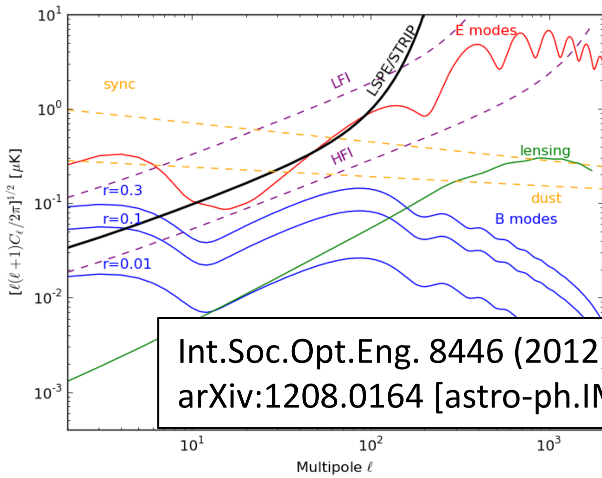
From theory

"Self-calibration" by Keating, Shimon, Yadav (2013).

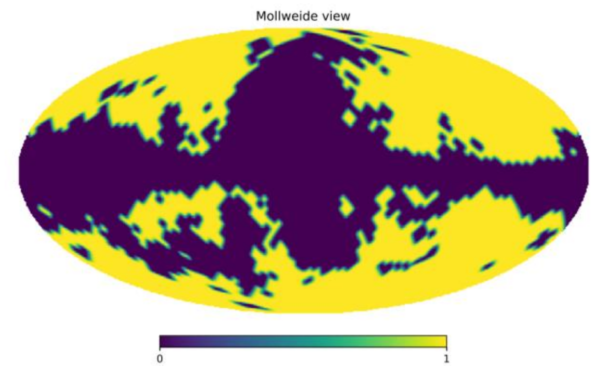
Restriction of "self-calibration" using theory

Foreground emissions should be small

- Because foreground signals also have α,
  - We need to know the foreground model
  - We need to mask the Galactic plane



Int.Soc.Opt.Eng. 8446 (2012) 84467C
arXiv:1208.0164 [astro-ph.IM]



Cosmological EB correlation should be zero

- We lose sensitivity to cosmic birefringence

To solve these issues

We relate observed *E*- and *B*- modes to the intrinsic ones as

$$E^{o}_{\ell,m} = E_{\ell,m}\cos(2\alpha) - B_{\ell,m}\sin(2\alpha)$$
$$B^{o}_{\ell,m} = E_{\ell,m}\sin(2\alpha) + B_{\ell,m}\cos(2\alpha) \quad \cdots (3)$$

From these equations, we find

$$C_\ell^{EB,o} = \frac{1}{2}\left(C_\ell^{EE,o} - C_\ell^{BB,o}\right)\tan(4\alpha) + \frac{C_\ell^{EB}}{\cos(4\alpha)} \quad \cdots (4)$$

G. B. Zhao et al.（2015）

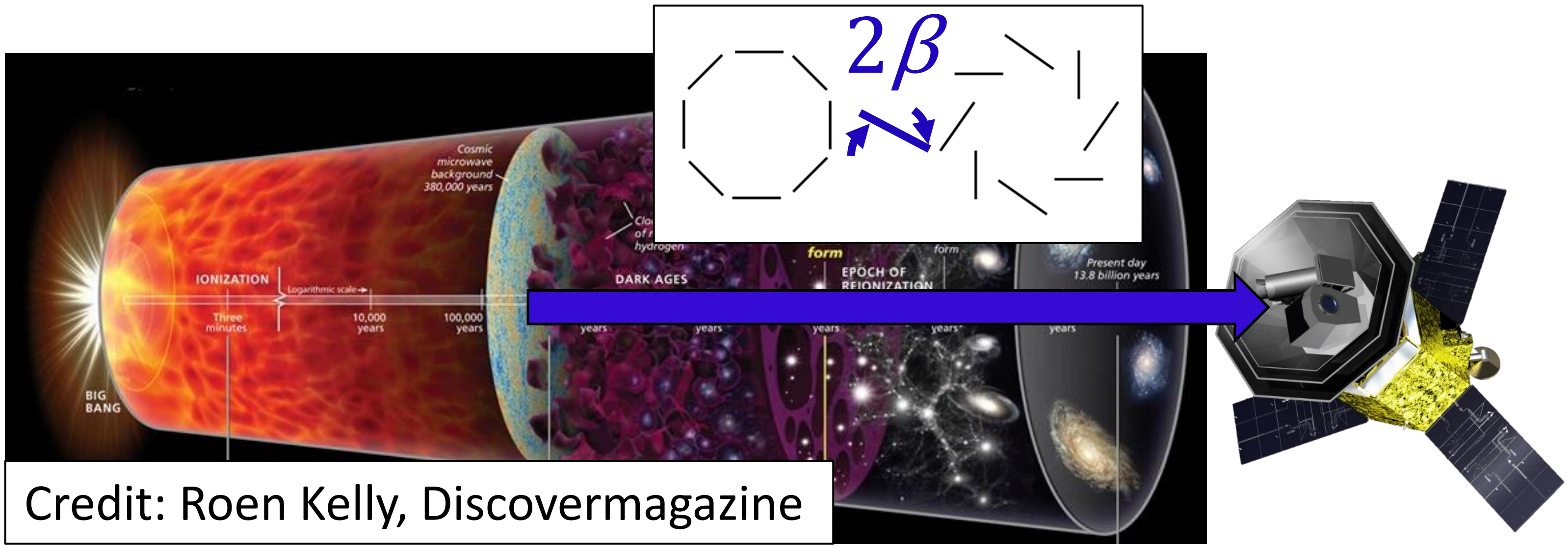
Our work

- We can estimate α with only observed data
- If we assume theory CMB power spectra, we can estimate an additional angle!

→ Cosmic birefringence

Cosmic birefringence

During the long travel from the last scattering surface to observer, parity-violating physics, e.g., axion-like particles (ALPs), rotate CMB linear polarization by



Credit: Roen Kelly, Discovermagazine

$$\beta = \frac{1}{2} g_{\phi\gamma} (\bar{\phi}_{obs} - \bar{\phi}_{LSS} + \delta\phi_{obs})$$

(From our new theoretical paper on ALPs, arXiv:2008.02473)

- Foreground: rotated only by α
- CMB: rotated by $\alpha + \beta$

Equations including birefringence rotation:

The coefficients become

$$E^{\mathrm{o}}_{\ell,m} = E^{\mathrm{fg}}_{\ell,m}\cos(2\alpha) - B^{\mathrm{fg}}_{\ell,m}\sin(2\alpha) + E^{\mathrm{CMB}}_{\ell,m}\cos(2\alpha+2\beta) - B^{\mathrm{CMB}}_{\ell,m}\sin(2\alpha+2\beta) + E^{\mathrm{N}}_{\ell,m}$$

$$B^{\mathrm{o}}_{\ell,m} = E^{\mathrm{fg}}_{\ell,m}\sin(2\alpha) + B^{\mathrm{fg}}_{\ell,m}\cos(2\alpha) + E^{\mathrm{CMB}}_{\ell,m}\sin(2\alpha+2\beta) + B^{\mathrm{CMB}}_{\ell,m}\cos(2\alpha+2\beta) + B^{\mathrm{N}}_{\ell,m}$$

$\cdots (5)$

From them, we derived

$$\langle C_\ell^{EB,\mathrm{o}}\rangle = \frac{\tan(4\alpha)}{2}\left(\langle C_\ell^{EE,\mathrm{o}}\rangle - \langle C_\ell^{BB,\mathrm{o}}\rangle\right) + \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(\langle C_\ell^{EE,\mathrm{CMB}}\rangle - \langle C_\ell^{BB,\mathrm{CMB}}\rangle\right) \quad \cdots (6)$$

$$+ \frac{1}{\cos(4\alpha)}\langle C_\ell^{EB,\mathrm{fg}}\rangle + \frac{\cos(4\beta)}{\cos(4\alpha)}\langle C_\ell^{EB,\mathrm{CMB}}\rangle \,.$$

Assume these to be zero

Therefore, we can determine both miscalibration and birefringence-rotation angles simultaneously!

Construct a likelihood for determination of α and β

$$\langle C_\ell^{EB,\mathrm{o}} \rangle = \frac{\tan(4\alpha)}{2}\left(\langle C_\ell^{EE,\mathrm{o}}\rangle - \langle C_\ell^{BB,\mathrm{o}}\rangle\right) + \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(\langle C_\ell^{EE,\mathrm{CMB}}\rangle - \langle C_\ell^{BB,\mathrm{CMB}}\rangle\right) \quad \cdots (6)$$

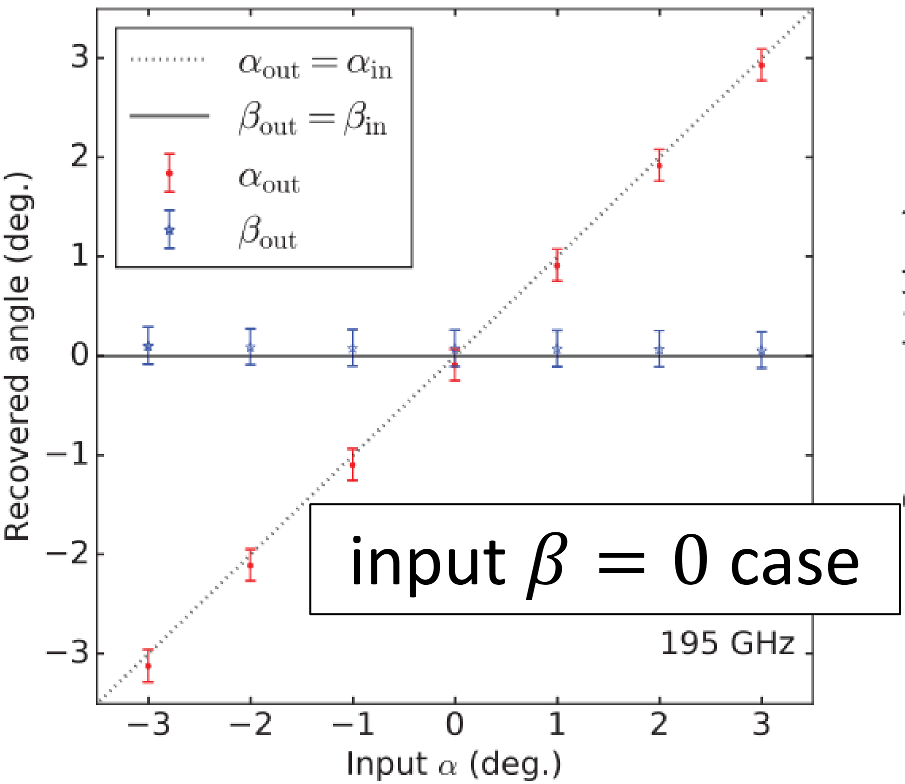
$$+ \frac{1}{\cos(4\alpha)}\langle C_\ell^{EB,\mathrm{fg}}\rangle + \frac{\cos(4\beta)}{\cos(4\alpha)}\langle C_\ell^{EB,\mathrm{CMB}}\rangle \,.$$

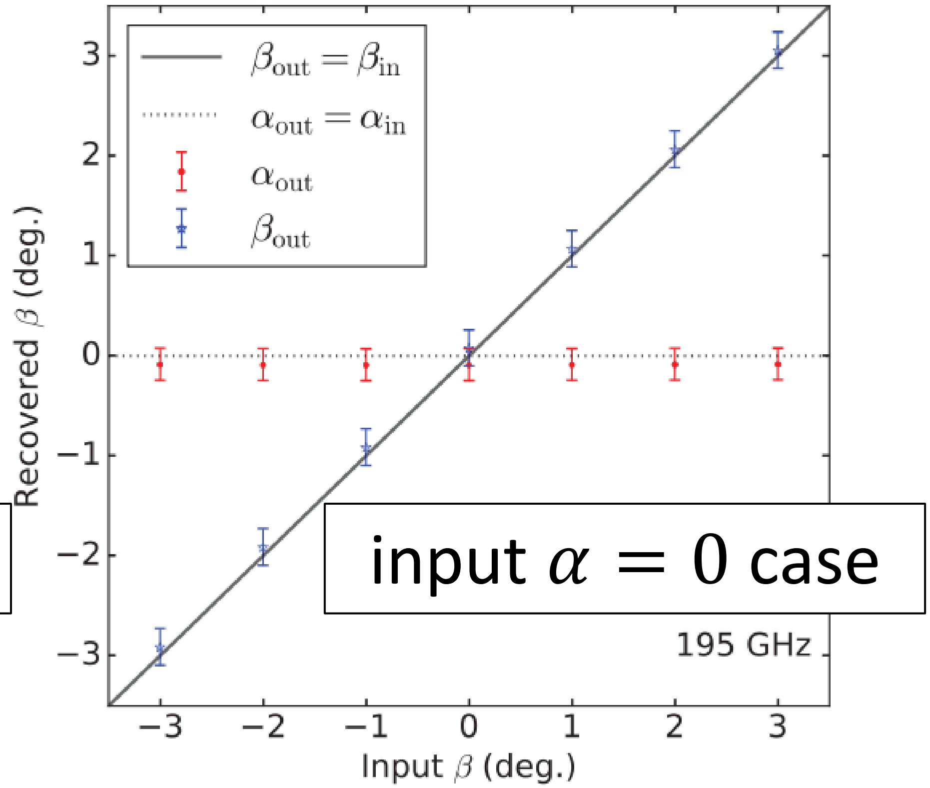
Assume these to be zero

$$-2\ln\mathcal{L} = \sum_{\ell=2}^{\ell_{\max}} \frac{\left[C_\ell^{EB,\mathrm{o}} - \frac{\tan(4\alpha)}{2}\left(C_\ell^{EE,\mathrm{o}} - C_\ell^{BB,\mathrm{o}}\right) - \frac{\sin(4\beta)}{2\cos(4\alpha)}\left(C_\ell^{EE,\mathrm{CMB}} - C_\ell^{BB,\mathrm{CMB}}\right)\right]^2}{\mathrm{Var}\left(C_\ell^{EB,\mathrm{o}} - \frac{\tan(4\alpha)}{2}\left(C_\ell^{EE,\mathrm{o}} - C_\ell^{BB,\mathrm{o}}\right)\right)} \quad \cdots (7)$$

Minimise $-2\ln\mathcal{L}$ to determine α and β

Simultaneous determination with simulations: at LiteBIRD 195 GHz



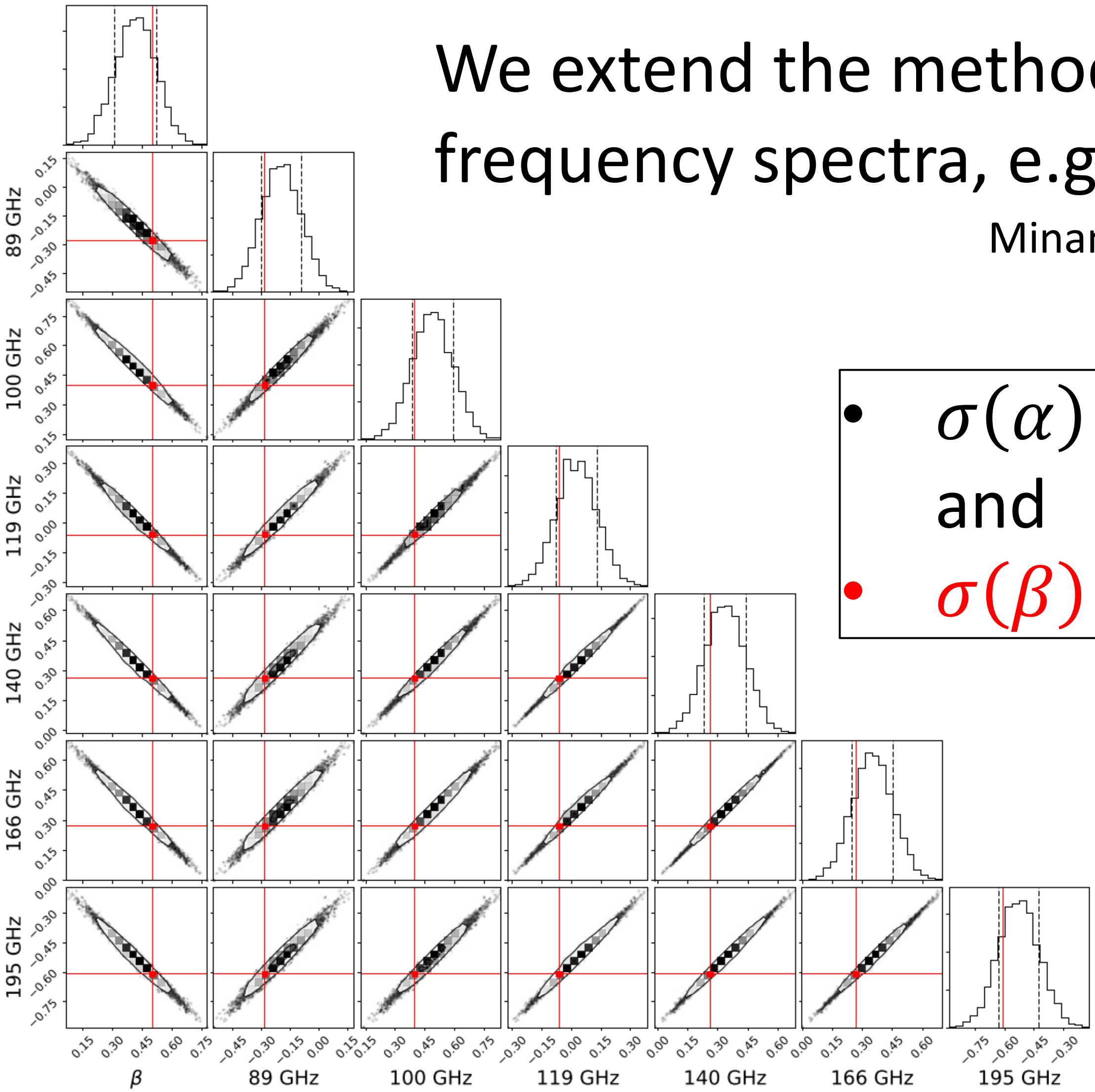


$\sigma(\alpha) = 9.6$ arcmin and $\sigma(\beta) = 11$ arcmin

(current 1σ upper bound for β is 36 arcmin by Planck)

We can recover the correct α and β simultaneously

Extend to cross frequency spectra: LiteBIRD 6 freqs. From 15 freqs



We extend the method by including cross frequency spectra, e.g., $E^{89}B^{195}$

Minami and Komatsu, arXiv:2006.15982

- $\sigma(\alpha) \approx 6.0$ arcmin and
- $\sigma(\beta) = 6.1$ arcmin

Summary

- Cosmic birefringence and miscalibration angle are degenerate in the CMB signal
- We lift the degeneracy using foreground power spectra
- We can constrain the birefringence angle with the precision of 6 arcmin with LiteBIRD

Why don’t you apply this method to other future experiments?