AstroParticle Symposium 2024, IAS, 18-22 November 2024

Cosmic Birefringence:

How Our Universe May Violate *Left-Right Symmetry*

Margherita Lembo

University of Ferrara

Presentation Roadmap

What is **Cosmic Birefringence**?
Why do we study it?

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A possible **theoretical background**

Impact on CMB polarization spectra

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A possible **theoretical background**
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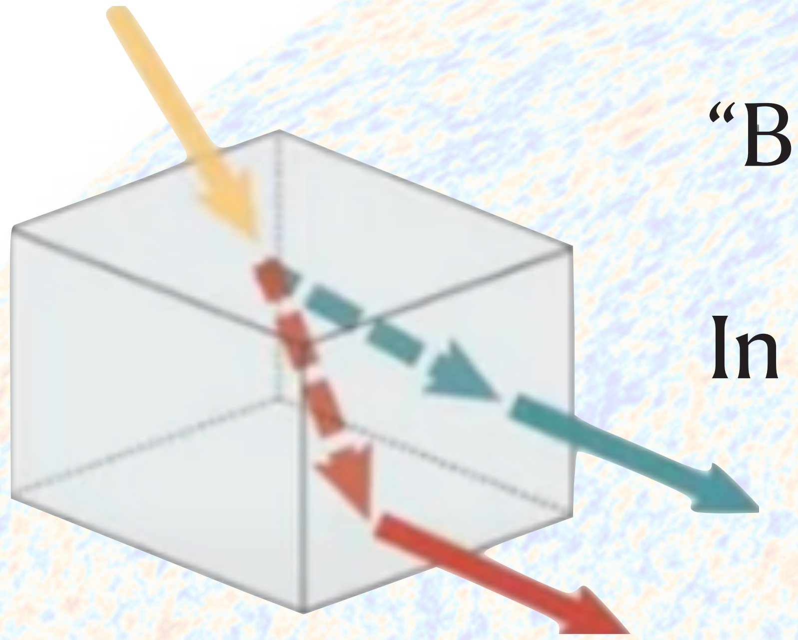
State of the art: isotropic and anisotropic birefringence

Beyond Cosmic Birefringence

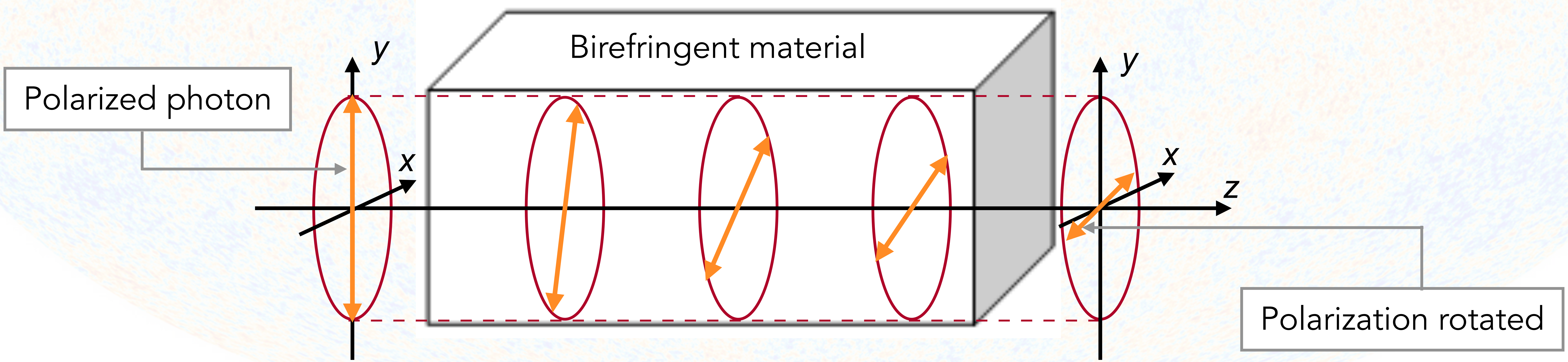
Summary and Future prospects

What is (Cosmic) Birefringence?

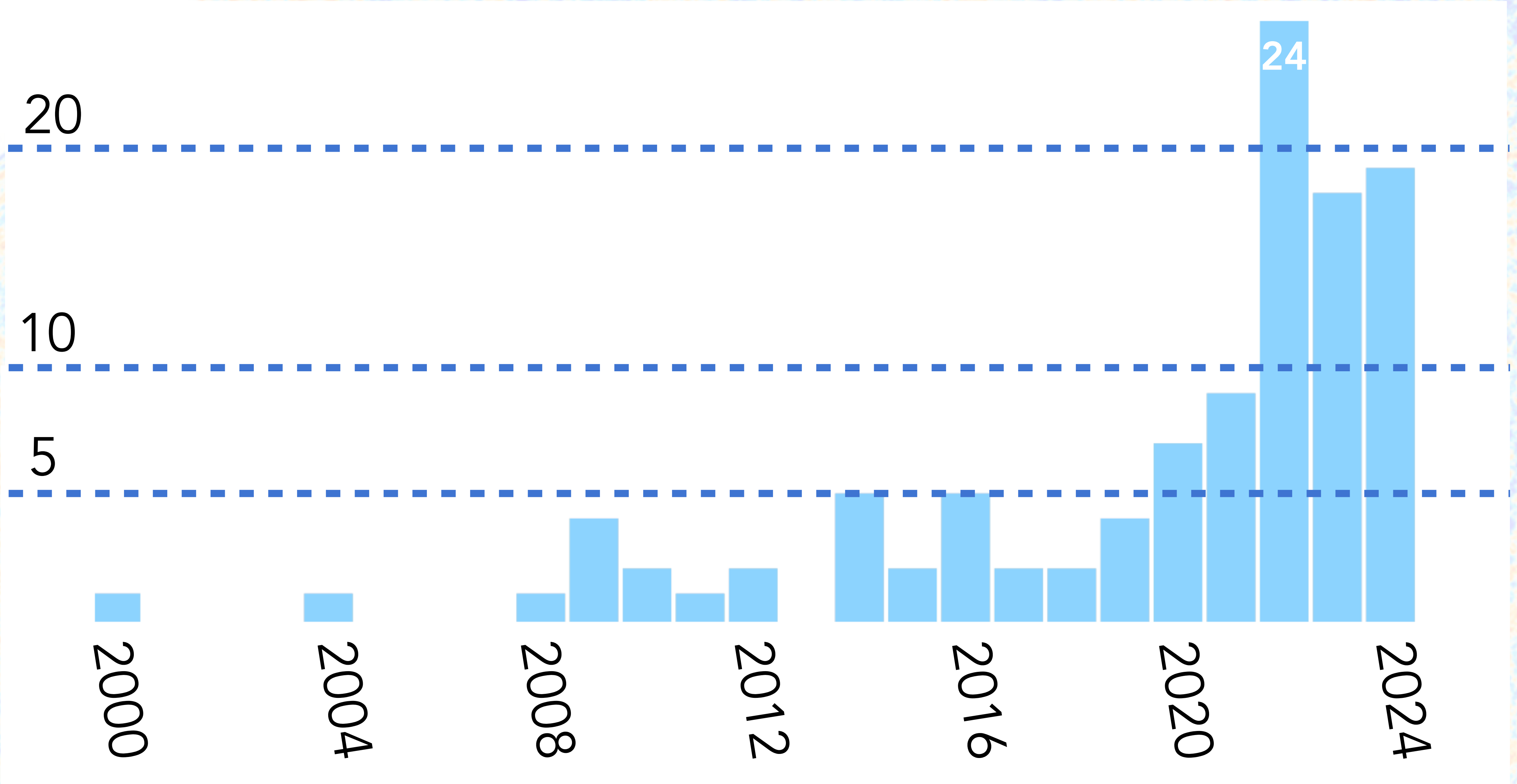


“Birefringence” refers generically to the fact that wave normal modes propagate at different velocities.

In the **cosmological literature**, the term “cosmic birefringence” describes the specific case of different propagation velocity of circular polarization states (**rotation of the linear polarization plane**).



“Cosmic Birefringence” popularity



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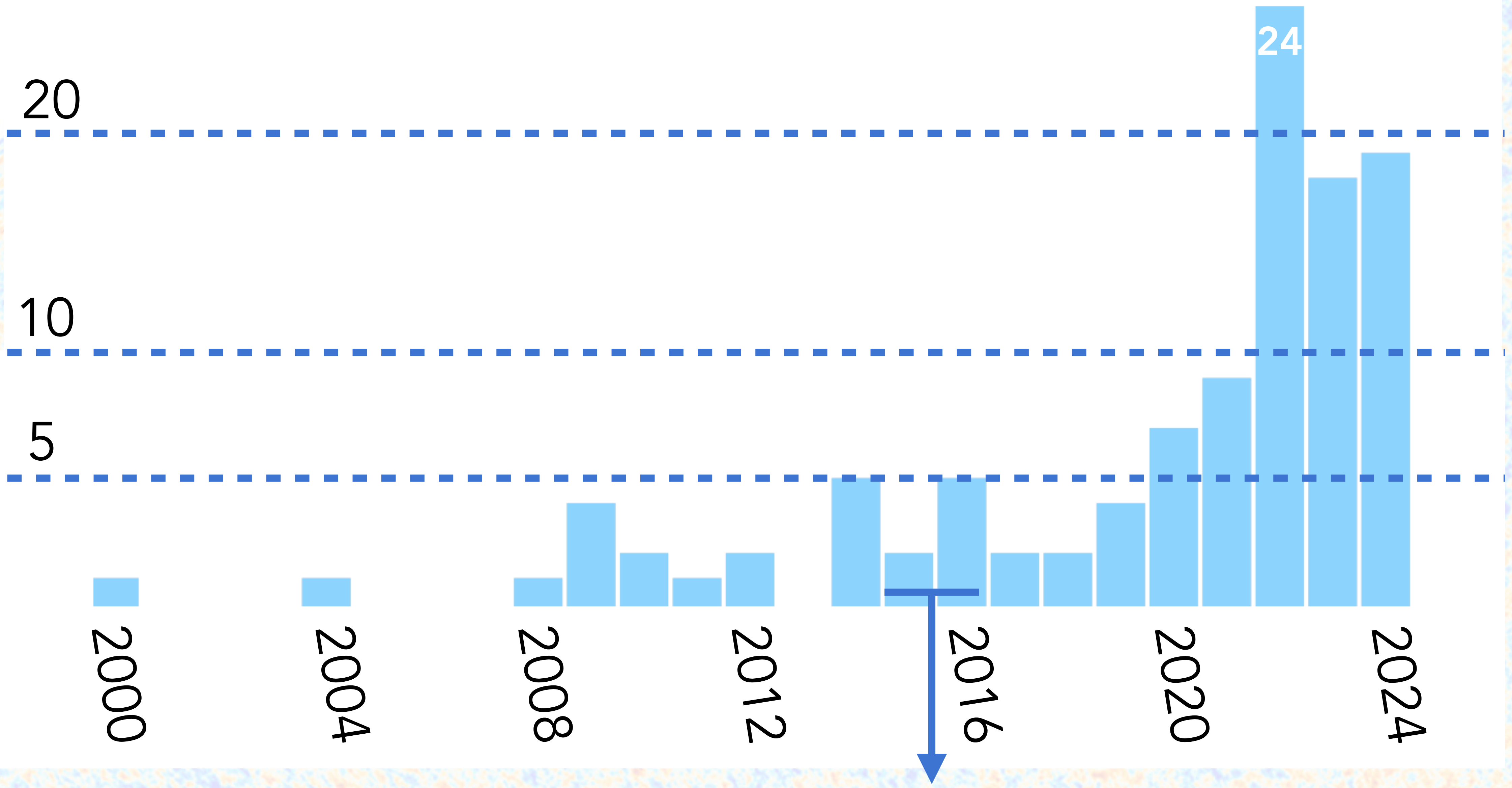

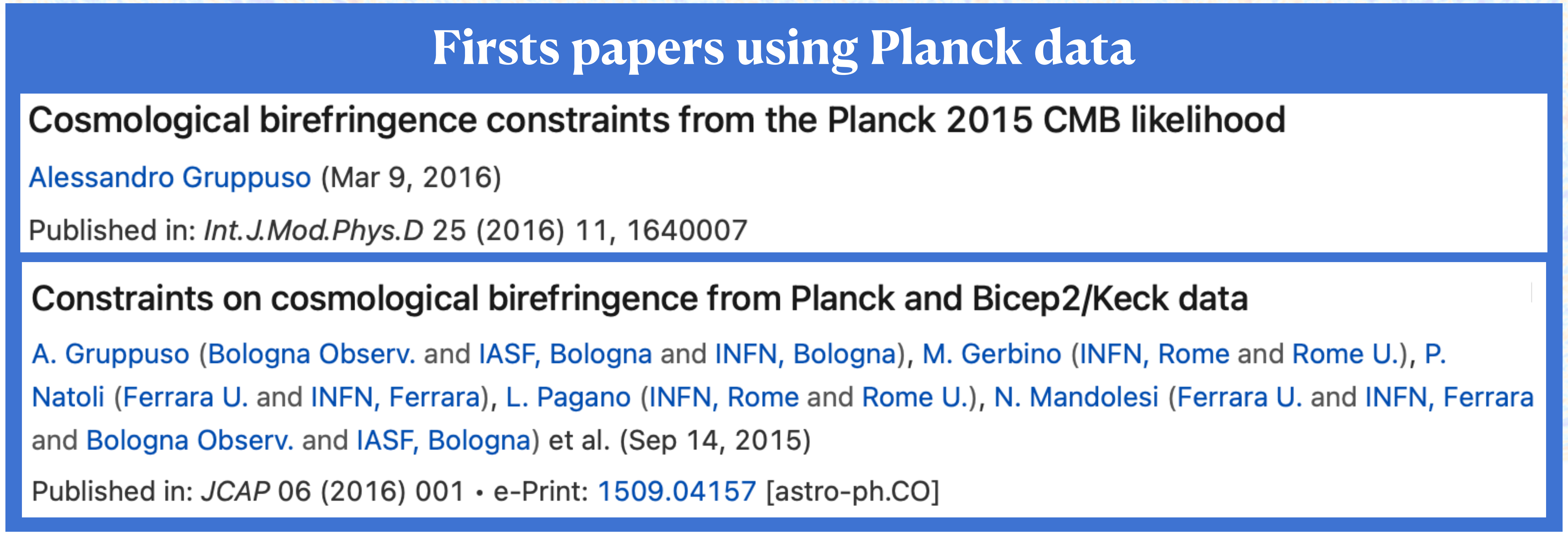
Firsts papers using Planck data

Cosmological birefringence constraints from the Planck 2015 CMB likelihood

Alessandro Gruppuso (Mar 9, 2016)

Published in: *Int.J.Mod.Phys.D* 25 (2016) 11, 1640007

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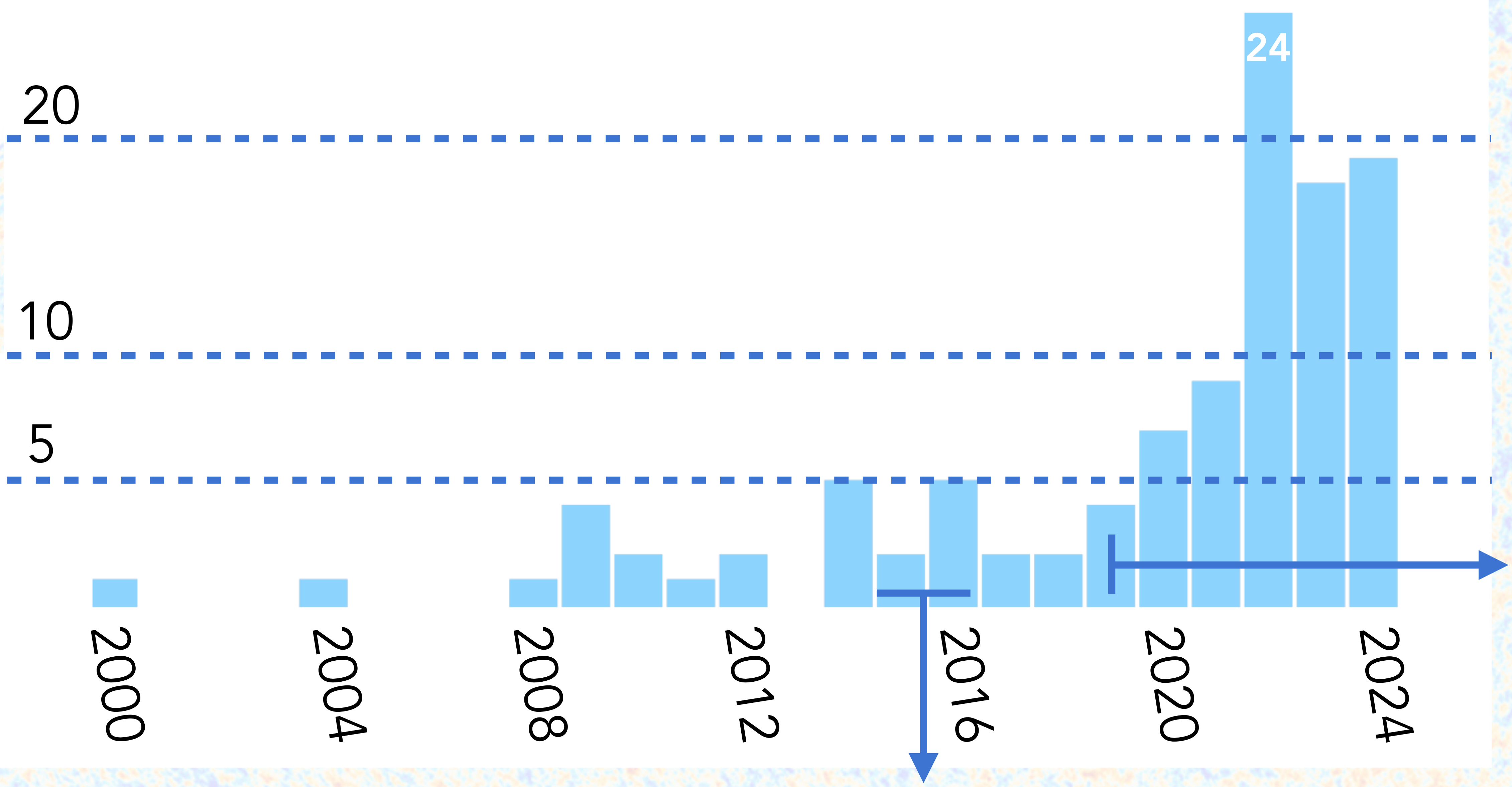

New technique by Y. Minami+2019

Simultaneous determination of the cosmic birefringence and miscalibrated polarization angles from CMB experiments

Yuto Minami (KEK, Tsukuba), Hiroki Ochi (Yokohama Natl. U.), Kiyotomo Ichiki (Nagoya U. (main) and KMI, Nagoya), Nobuhiko Katayama (Tokyo U., IPMU), Eiichiro Komatsu (Tokyo U., IPMU and Garching, Max Planck Inst.) et al. (Apr 29, 2019)

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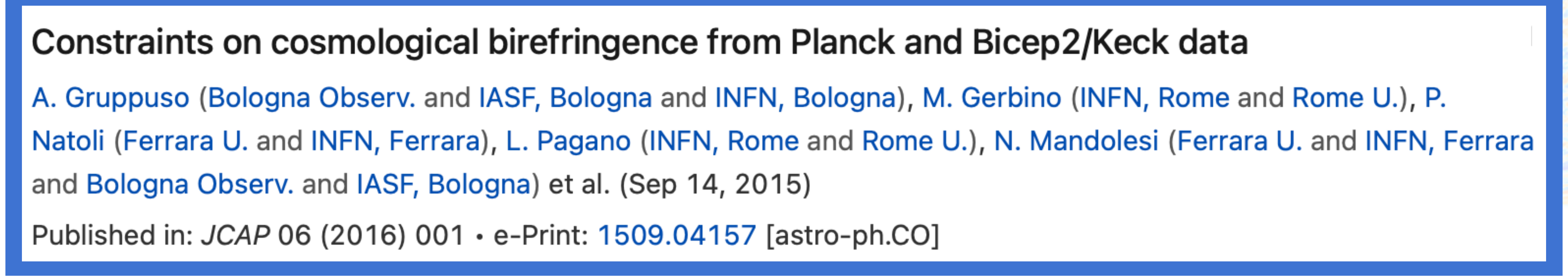

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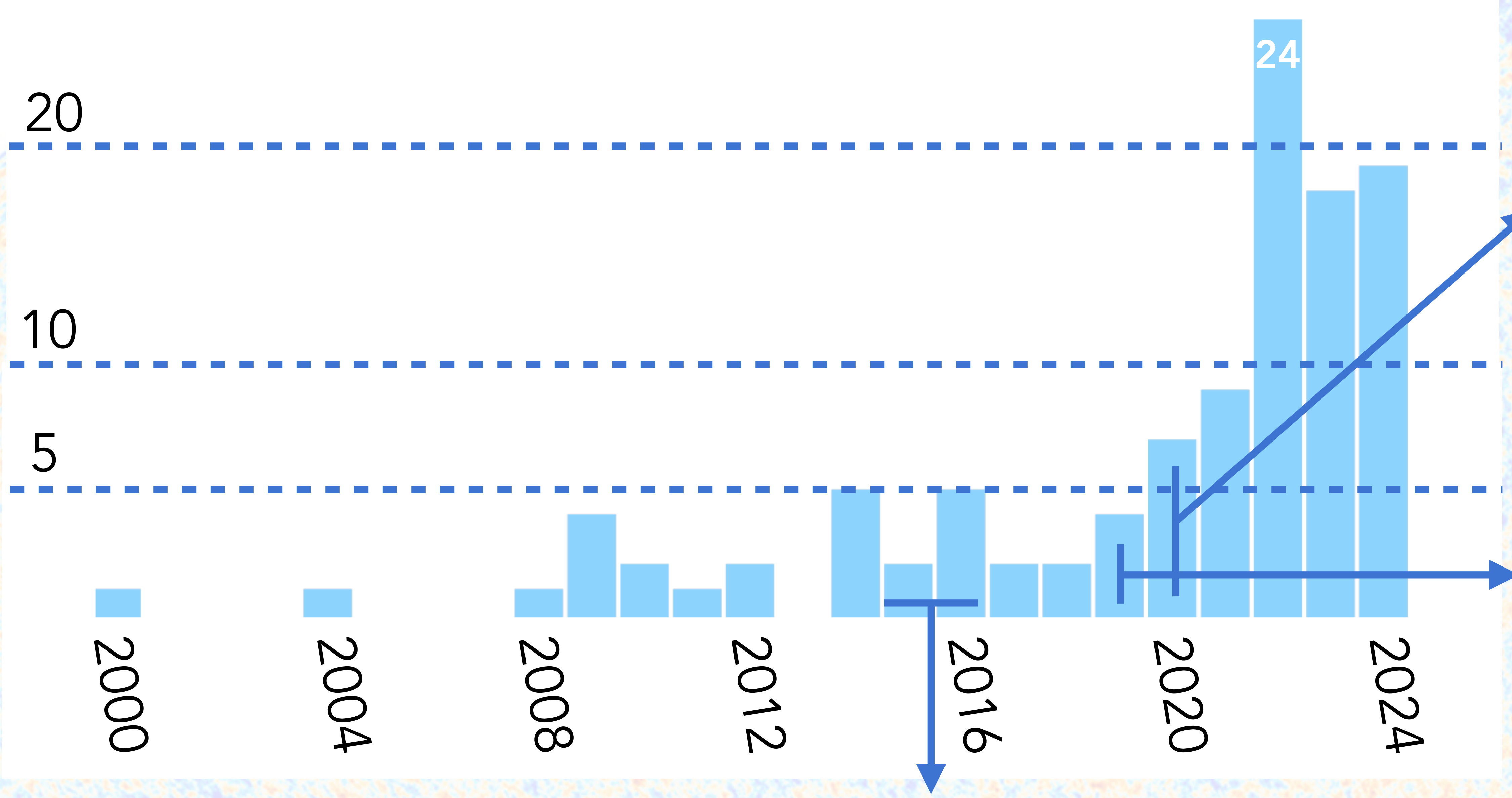
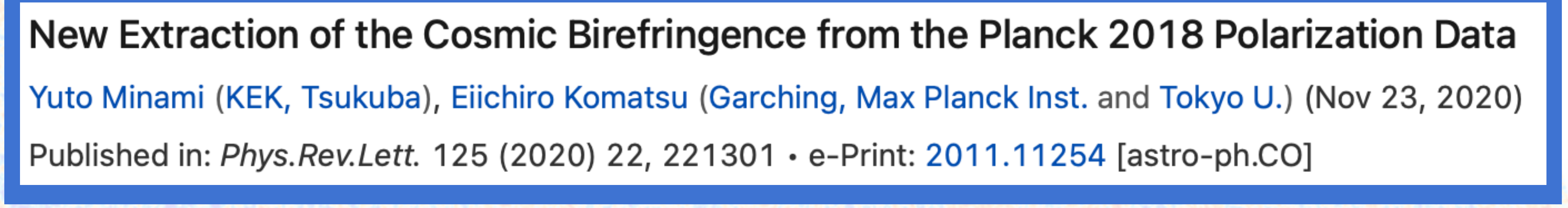


First 2.4 σ detection!



New Extraction of the Cosmic Birefringence from the Planck 2018 Polarization Data

Yuto Minami (KEK, Tsukuba), Eiichiro Komatsu (Garching, Max Planck Inst. and Tokyo U.) (Nov 23, 2020)

Published in: *Phys.Rev.Lett.* 125 (2020) 22, 221301 • e-Print: 2011.11254 [astro-ph.CO]

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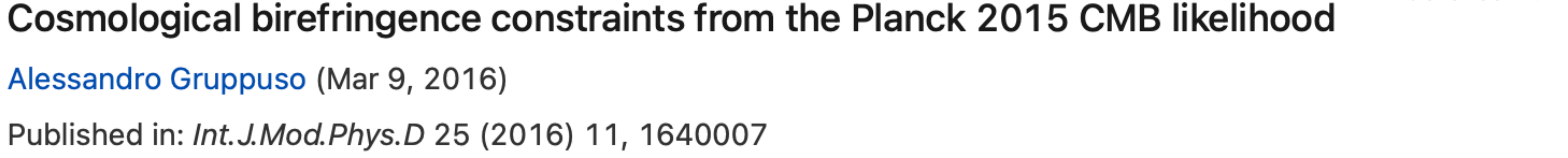

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Why is it interesting to study cosmic birefringence?

There is an
observational hint!

It is opening a window into **exciting theoretical scenarios:**

1. ALPs, that might be suitable candidates for both **dark matter** and **dark energy**
2. Modifications to the standard Maxwell electrodynamics

Plenty of **CMB polarization measurements available** over a wide range of scales will be available in the **next decade!**

The most widely explored theoretical framework

If the Universe is filled with a **parity-violating** pseudoscalar field (**axion-like particles, ALP**)

$$\phi(-\vec{n}) = -\,\phi(\vec{n})\,,$$

coupled to the electromagnetic tensor via a **Chern-Simons coupling**

$$\frac{1}{4} g_\phi\, \phi\, F_{\mu\nu}\tilde{F}^{\mu\nu}\,,$$

right- and left-handed helicity states of photons acquire different the phase velocities.

$$\Big\downarrow$$

Dispersion relation of left/right polarization is modified $\omega_{L/R}^2 = k^2\left[1 \pm \frac{g_\phi}{k}\dot{\phi}\right]$

Ni (1977), Turner&Widrow (1988), Carroll,Field,Jackiw(1990), Carroll&Field(1991)…..

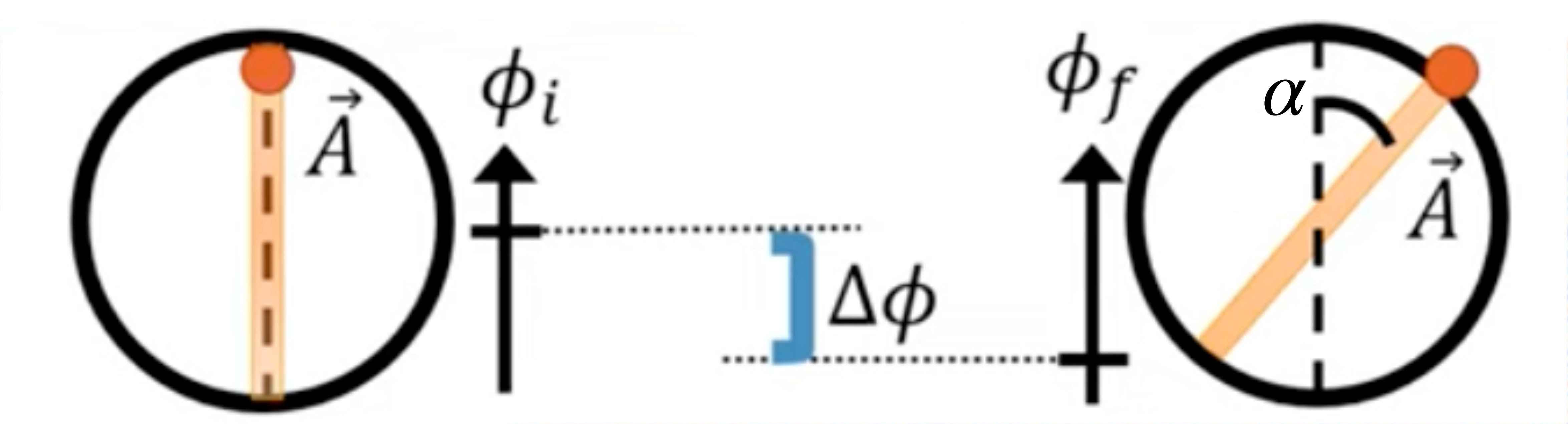
The most widely explored theoretical framework

This results in a **rotation of linear polarization** plane by an angle

$$\alpha(\vec{n}) = -\frac{g_\phi}{2}\int \mathrm{d}t\frac{\partial\phi}{\partial t} = \frac{g_\phi}{2}\Delta\phi$$

↓

ALP causes Cosmic Birefringence



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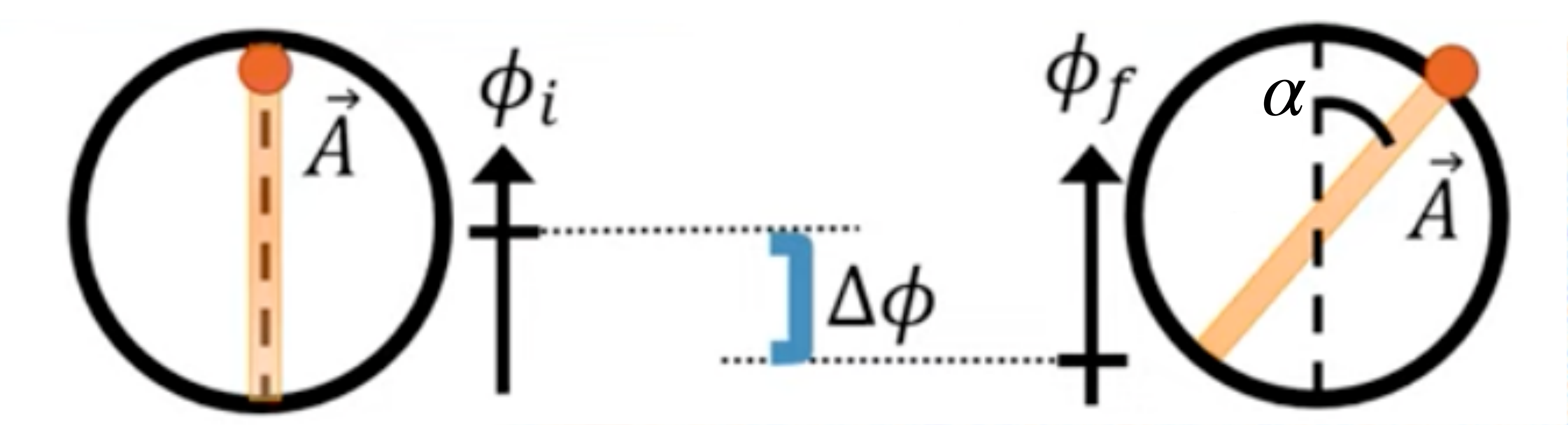
ALP causes Cosmic Birefringence

We can constrain ALP with a source that is:

- ☑ well-known
- ☑ linearly polarized
- ☑ very far away



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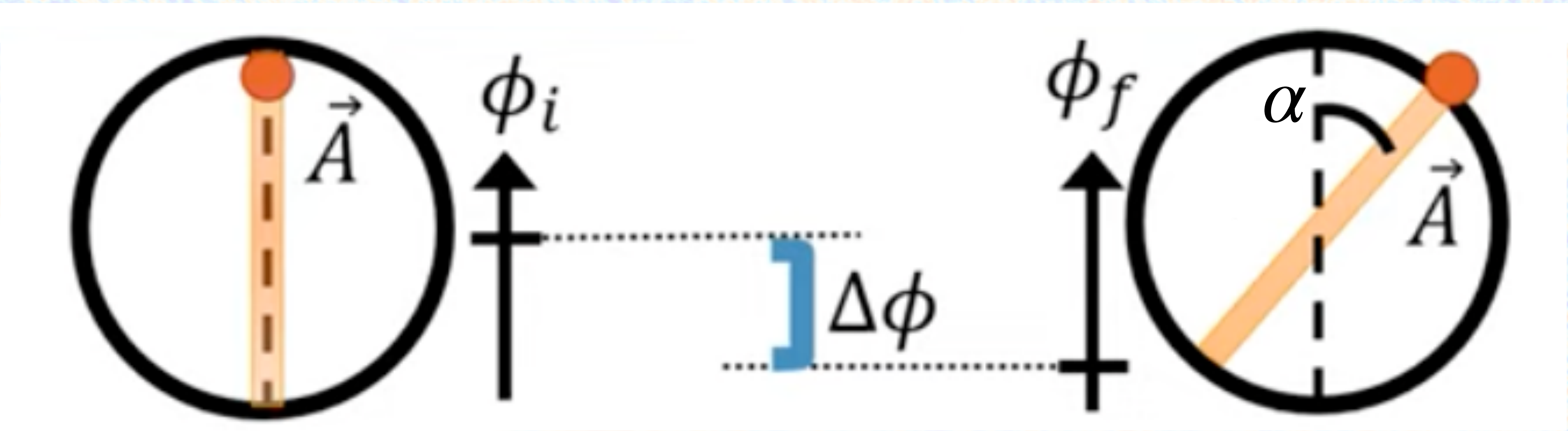

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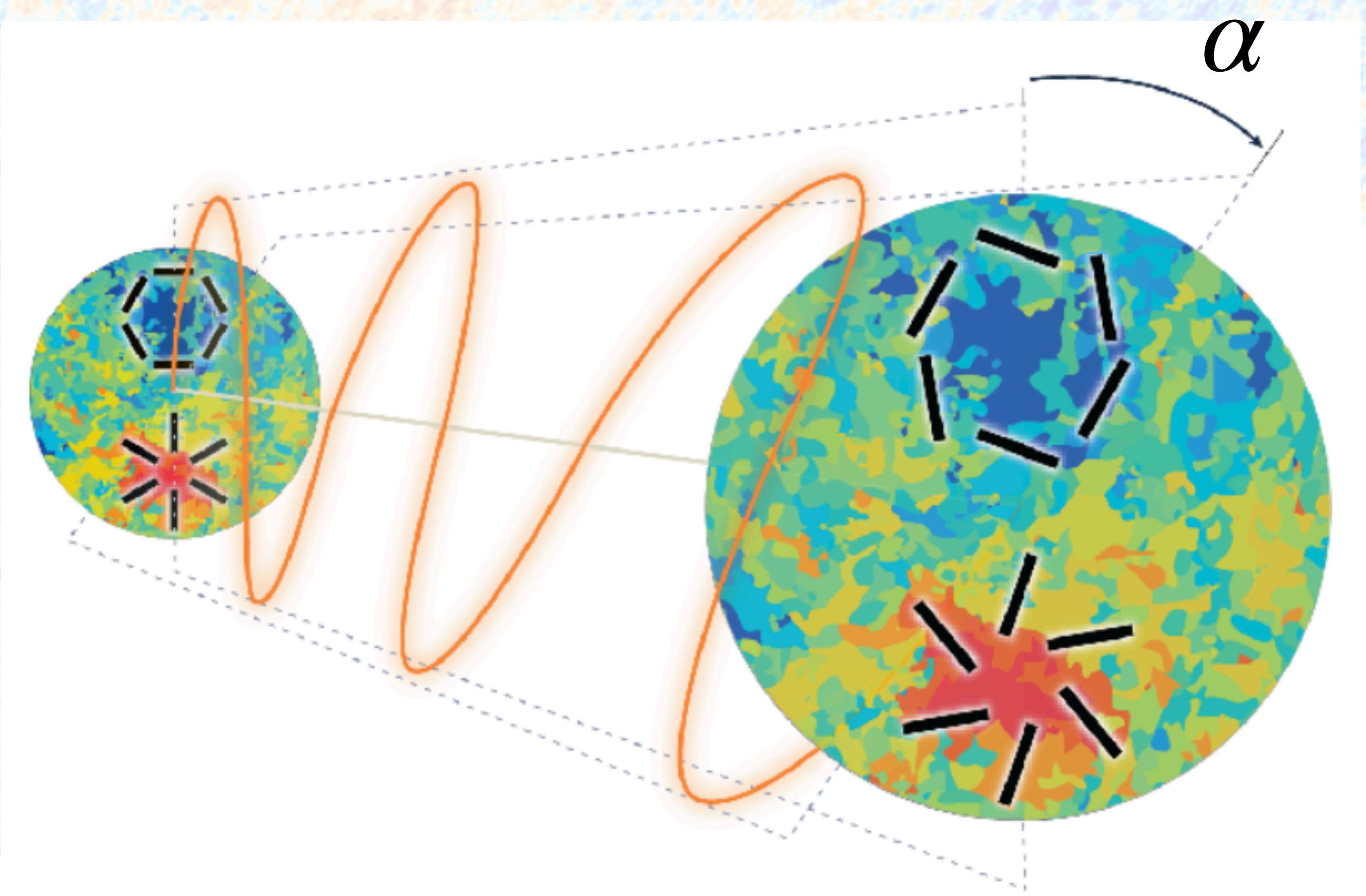
CMB



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Where the axion(-like) particles come from?

$$\mathscr{L}_{QCD} = \ldots + \underline{\boxed{\theta} \frac{g_s^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{a\mu\nu}}$$

Experimental observations implies an an unnaturally small value

This term is explicitly parity and CP violating

The **strong CP problem:**

- Why is θ so small, or effectively zero?
- This extreme fine-tuning lacks a natural explanation in the Standard Model.

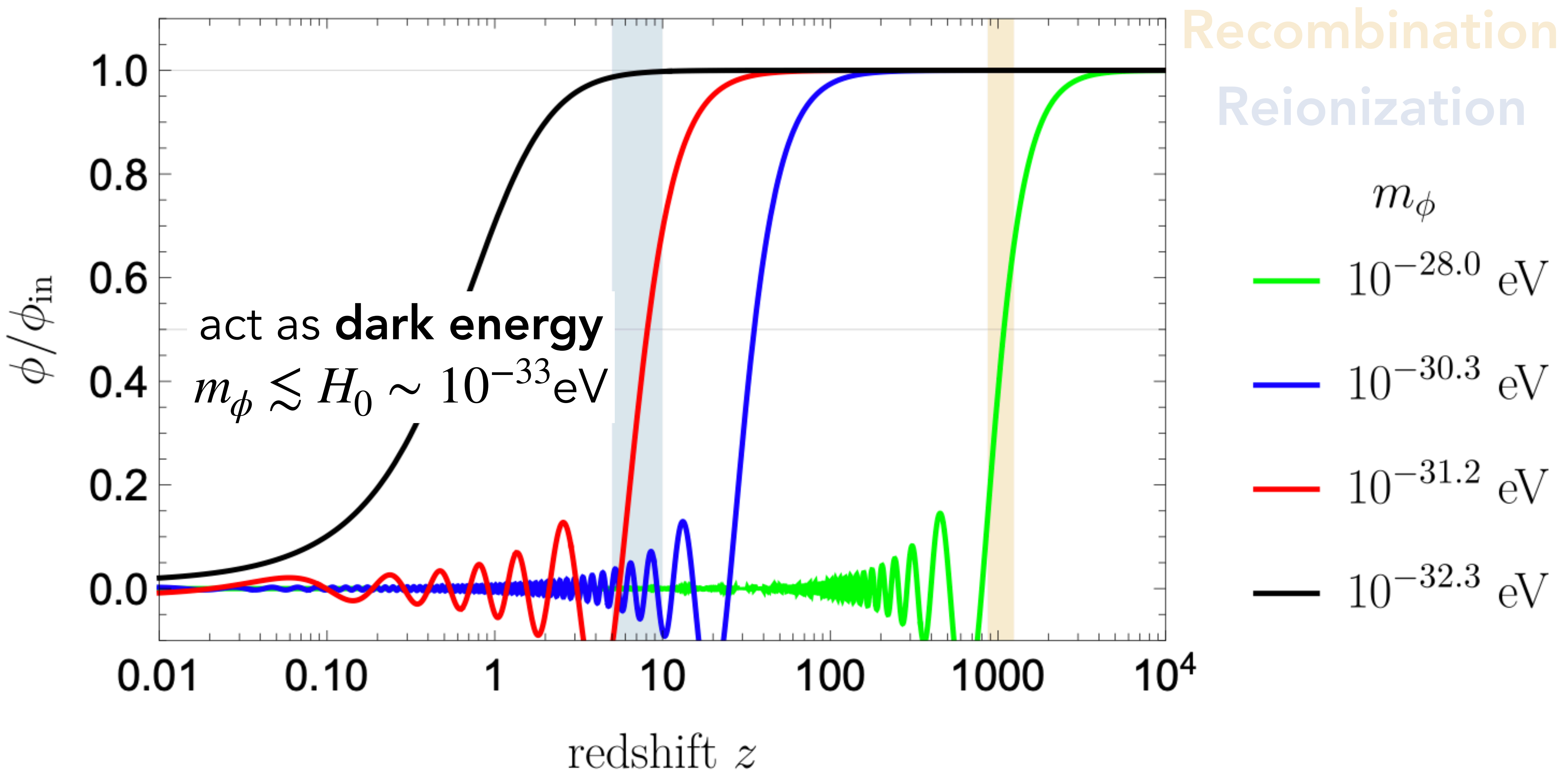
↓

Peccei-Quinn mechanism (1977)

new light pseudoscalar particle, the **axion**, that dynamically relaxes θ to zero

ALPs are generalizations of QCD axions which is a well-motivated solution to the strong CP problem

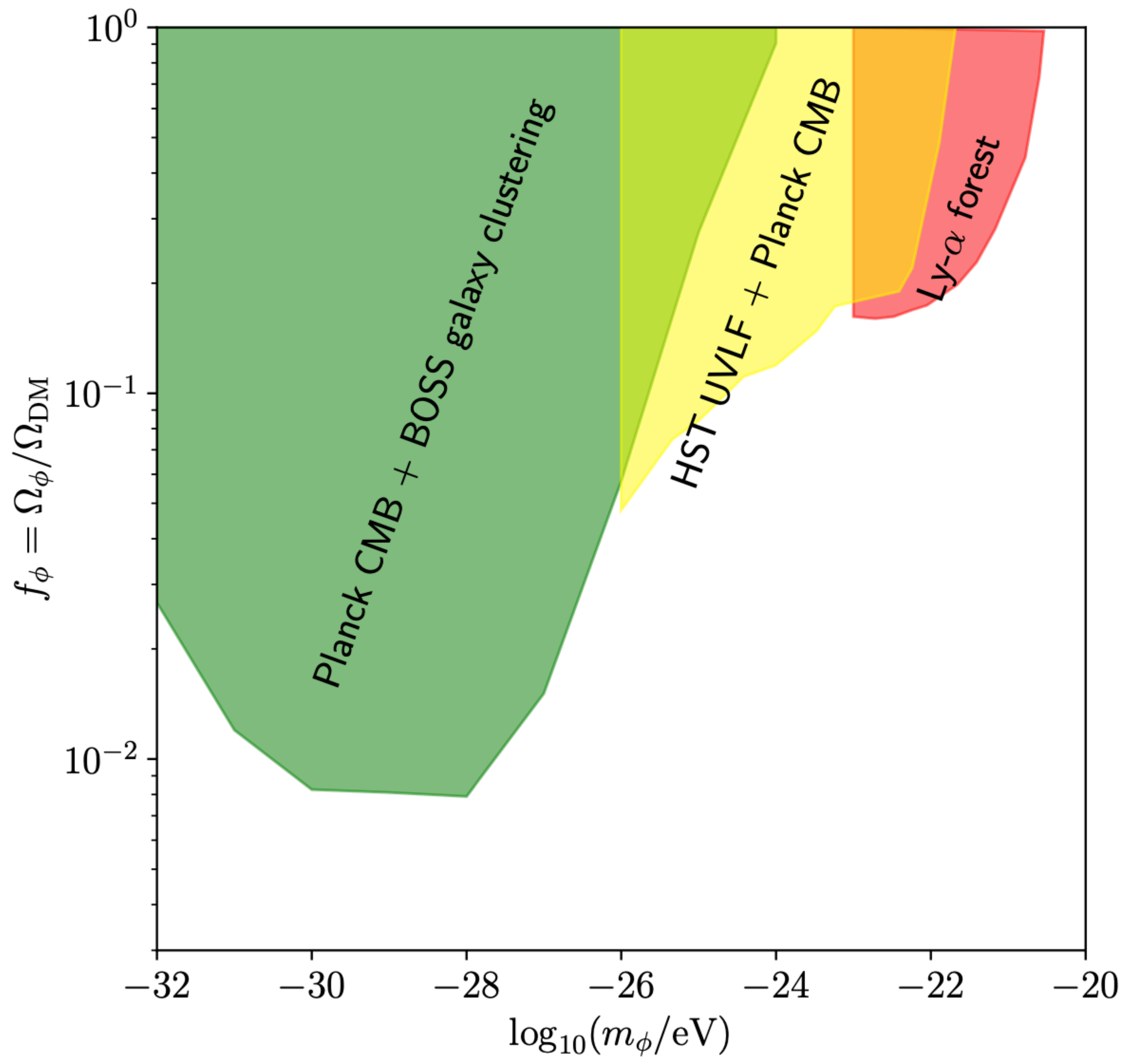
Which ALPs can we look at with cosmic birefringence?



act as **dark energy**
$m_\phi \lesssim H_0 \sim 10^{-33}$eV

Nakatsuka, Namikawa, Komatsu (2022) arXiv:2203.08560

act as fraction of **dark matter** $m_\phi \gtrsim 10^{-32}$eV



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Only **ultralight axions** with (**isotropic**) **cosmic birefringence**: $m_a \lesssim 10^{-28}$eV, ALPs with higher masses oscillate too rapidly to leave observable imprints on the CMB polarization

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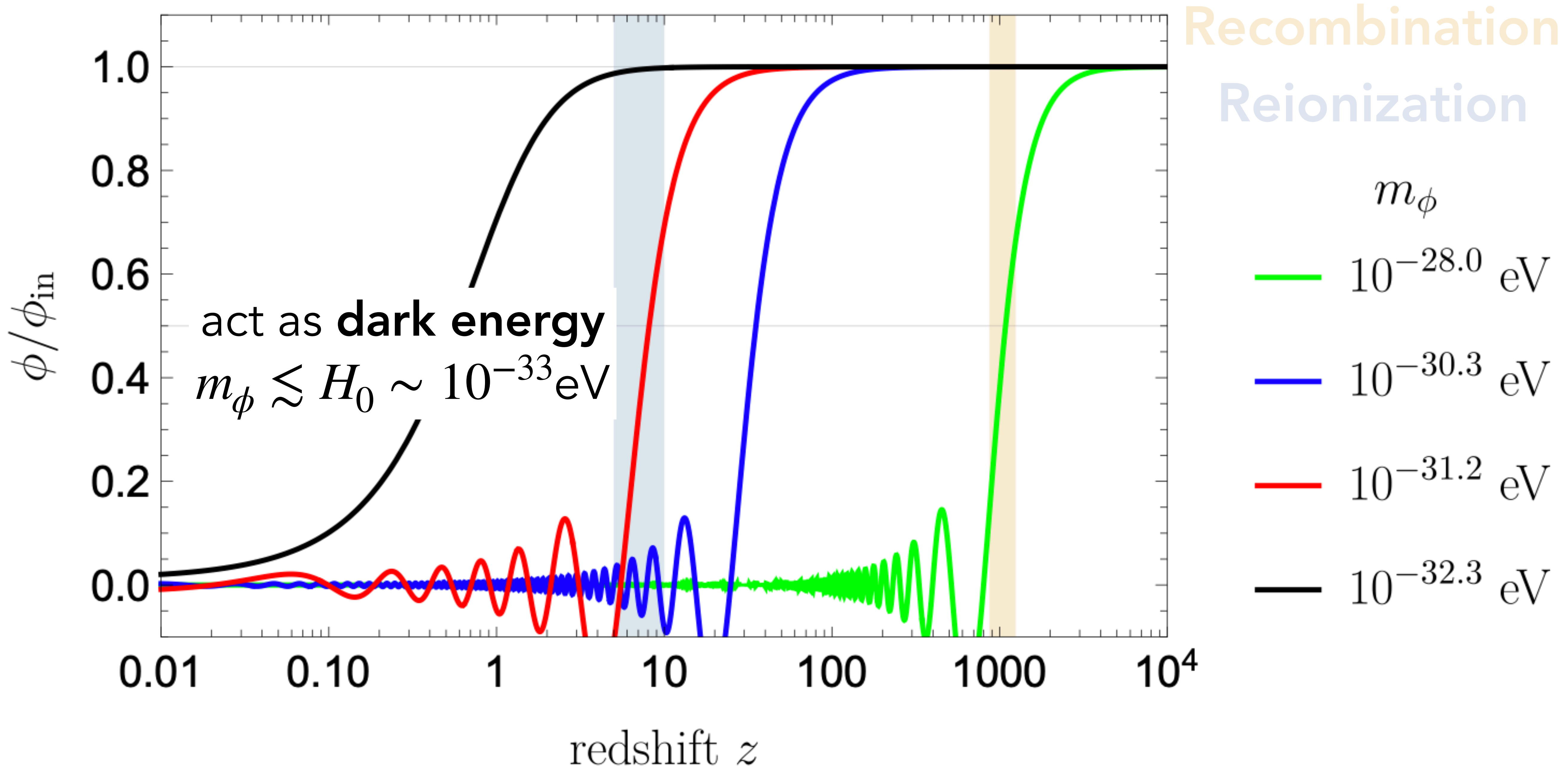

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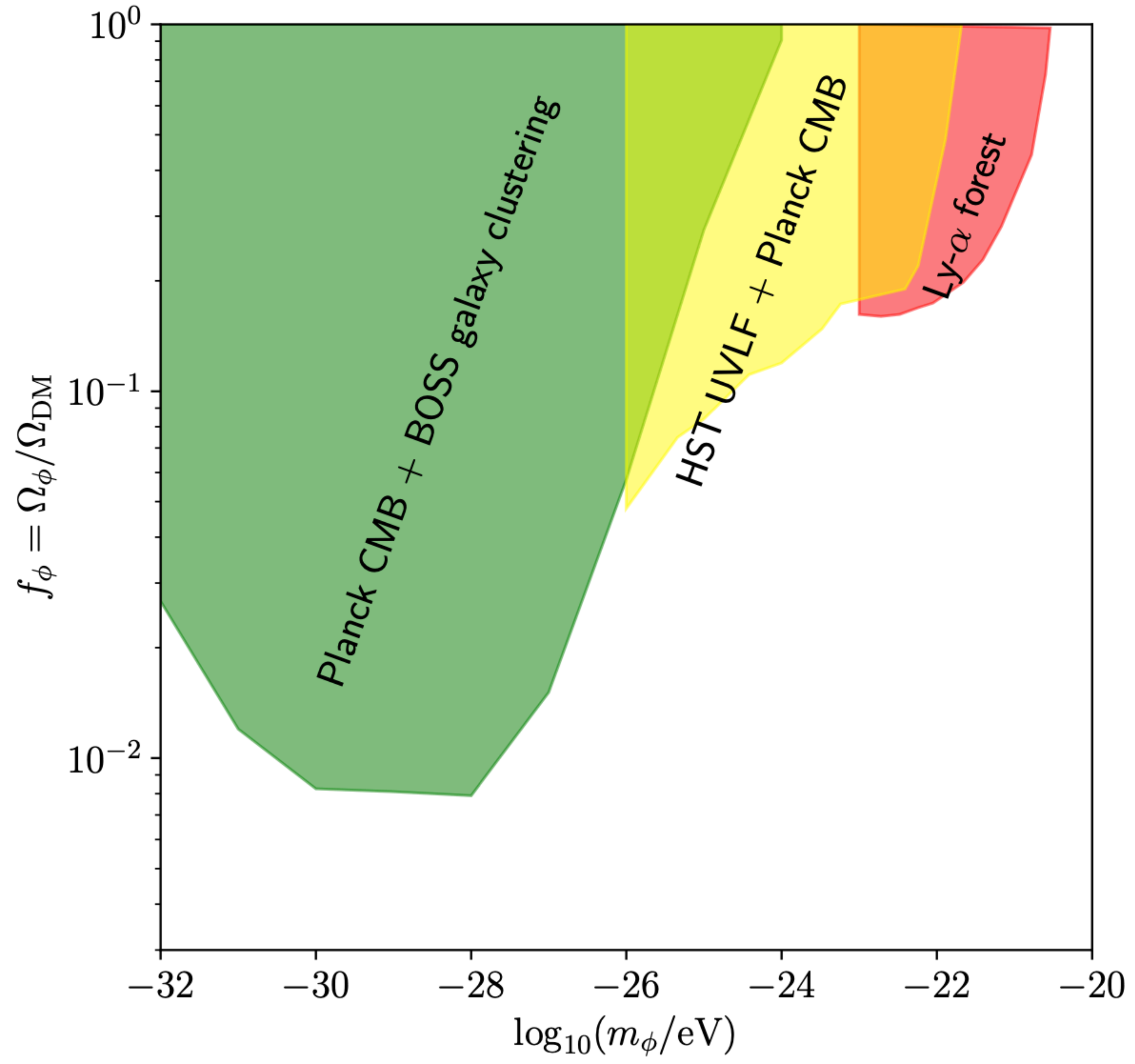

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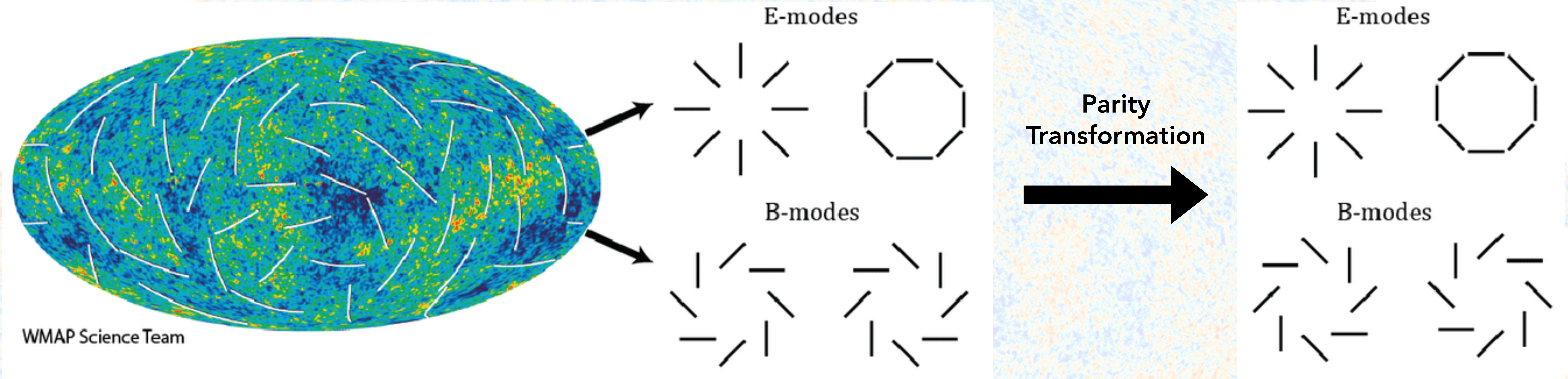
Only **ultralight axions** with (**isotropic**) **cosmic birefringence**: $m_a \lesssim 10^{-28}$eV, ALPs with higher masses oscillate too rapidly to leave observable imprints on the CMB polarization

With **anisotropic birefringence**, you can probe higher masses because faster oscillating axion-like particles (ALPs) induce localized or directional birefringence effects in the CMB polarization

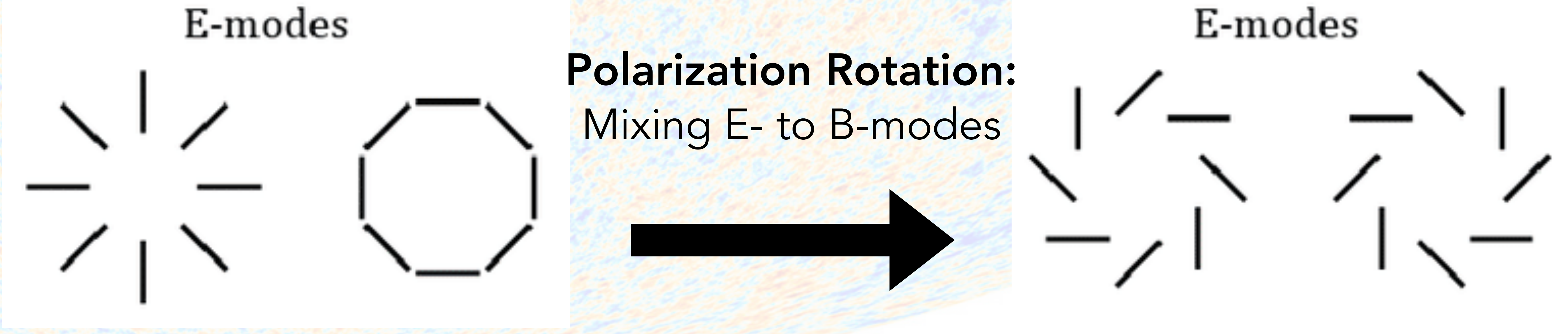
Impact on CMB polarization spectra



$$\boxed{\alpha = \alpha_0 + \delta\alpha(\vec{n})}$$

Isotropic :
non-vanishing EB and TB spectra and the mixing between EE and BB spectra

Anisotropic:
mixes the EE and BB spectra by introducing a coupling among different multipoles



Polarization Rotation:
Mixing E- to B-modes

Impact on CMB polarization spectra

$$\boxed{\alpha = \alpha_0}$$

Isotropic

$$C_\ell^{TT} = \tilde{C}_\ell^{TT}$$

$$C_\ell^{TE} = \tilde{C}_\ell^{TE}\cos(2\alpha_0)$$

$$C_\ell^{TB} = \tilde{C}_\ell^{TE}\sin(2\alpha_0)$$

$$C_\ell^{EE} = \left[\tilde{C}_\ell^{EE}\cos^2(2\alpha_0)+\tilde{C}_\ell^{BB}\sin^2(2\alpha_0)\right]$$

$$C_\ell^{BB} = \left[\tilde{C}_\ell^{BB}\cos^2(2\alpha_0)+\tilde{C}_\ell^{EE}\sin^2(2\alpha_0)\right]$$

$$C_\ell^{EB} = \sin(4\alpha_0)\,\frac{1}{2}\left(\tilde{C}_\ell^{EE} - \tilde{C}_\ell^{BB}\right)$$

Impact on CMB polarization spectra

$$\boxed{\alpha = \alpha_0 + \delta\alpha(\vec{n})}$$

Isotropic

Anisotropic

$$L = \ell + \ell_1 + \ell_3$$

$$M_{\ell\ell_1\ell_3} = \frac{(2\ell_1+1)(2\ell_3+1)}{\pi}\begin{pmatrix} \ell & \ell_1 & \ell_3 \\ 2 & -2 & 0 \end{pmatrix}^2$$

$$4\pi V_\alpha = \sum_\ell (2\ell+1)\ C_\ell^{\alpha\alpha}$$

$$C_\ell^{TT} = \tilde{C}_\ell^{TT}$$

$$C_\ell^{TE} = \tilde{C}_\ell^{TE}\cos(2\alpha_0)\left(1 - 2V_\alpha\right)$$

$$C_\ell^{TB} = \tilde{C}_\ell^{TE}\sin(2\alpha_0)\left(1 - 2V_\alpha\right)$$

$$C_\ell^{EE} = \left[\tilde{C}_\ell^{EE}\cos^2(2\alpha_0)+\tilde{C}_\ell^{BB}\sin^2(2\alpha_0)\right]\left(1-4V_\alpha\right) + \sum_{\ell_1\ell_3}\left[\left(1-(-1)^L\cos(4\alpha_0)\right)\tilde{C}_{\ell_1}^{EE} + \left(1+(-1)^L\cos(4\alpha_0)\right)\tilde{C}_{\ell_1}^{BB}\right] C_{\ell_3}^{\alpha\alpha}\frac{M_{\ell\ell_1\ell_3}}{2}$$

$$C_\ell^{BB} = \left[\tilde{C}_\ell^{BB}\cos^2(2\alpha_0)+\tilde{C}_\ell^{EE}\sin^2(2\alpha_0)\right]\left(1-4V_\alpha\right) + \sum_{\ell_1\ell_3}\left[\left(1-(-1)^L\cos(4\alpha_0)\right)\tilde{C}_{\ell_1}^{BB} + \left(1+(-1)^L\cos(4\alpha_0)\right)\tilde{C}_{\ell_1}^{EE}\right] C_{\ell_3}^{\alpha\alpha}\frac{M_{\ell\ell_1\ell_3}}{2}$$

$$C_\ell^{EB} = \sin(4\alpha_0)\frac{1}{2}\left(\tilde{C}_\ell^{EE} - \tilde{C}_\ell^{BB}\right)\left(1-4V_\alpha\right) + \sin(4\alpha_0)\sum_{\ell_1\ell_3}\left[\frac{1}{2}\left(\tilde{C}_{\ell_1}^{EE} - \tilde{C}_{\ell_1}^{BB}\right)\right] C_{\ell_3}^{\alpha\alpha}(-1)^{L+1}M_{\ell\ell_1\ell_3}$$

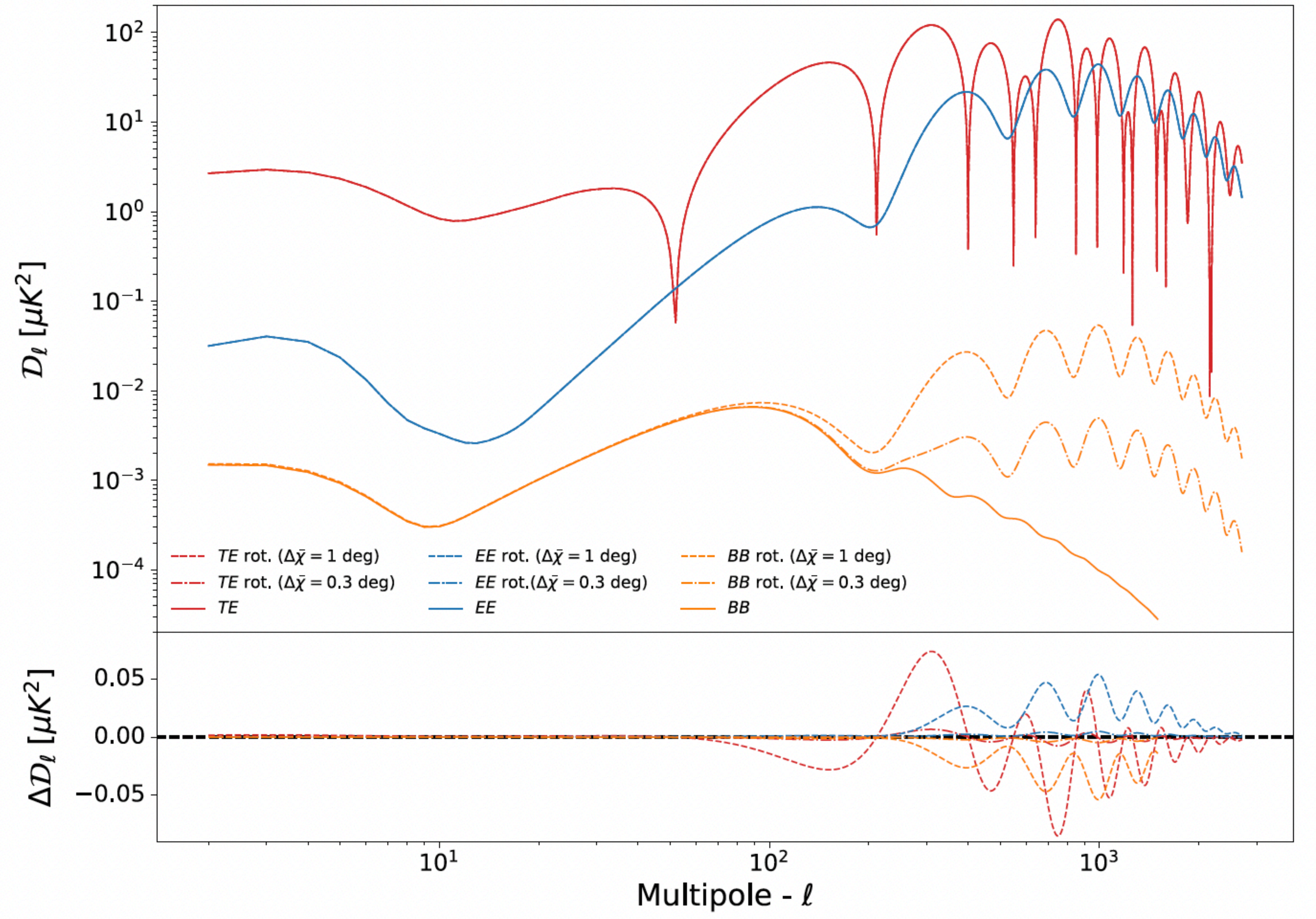
Impact on CMB polarization spectra

$$\alpha = \Delta\bar{\chi} + \delta\chi(\vec{n})$$

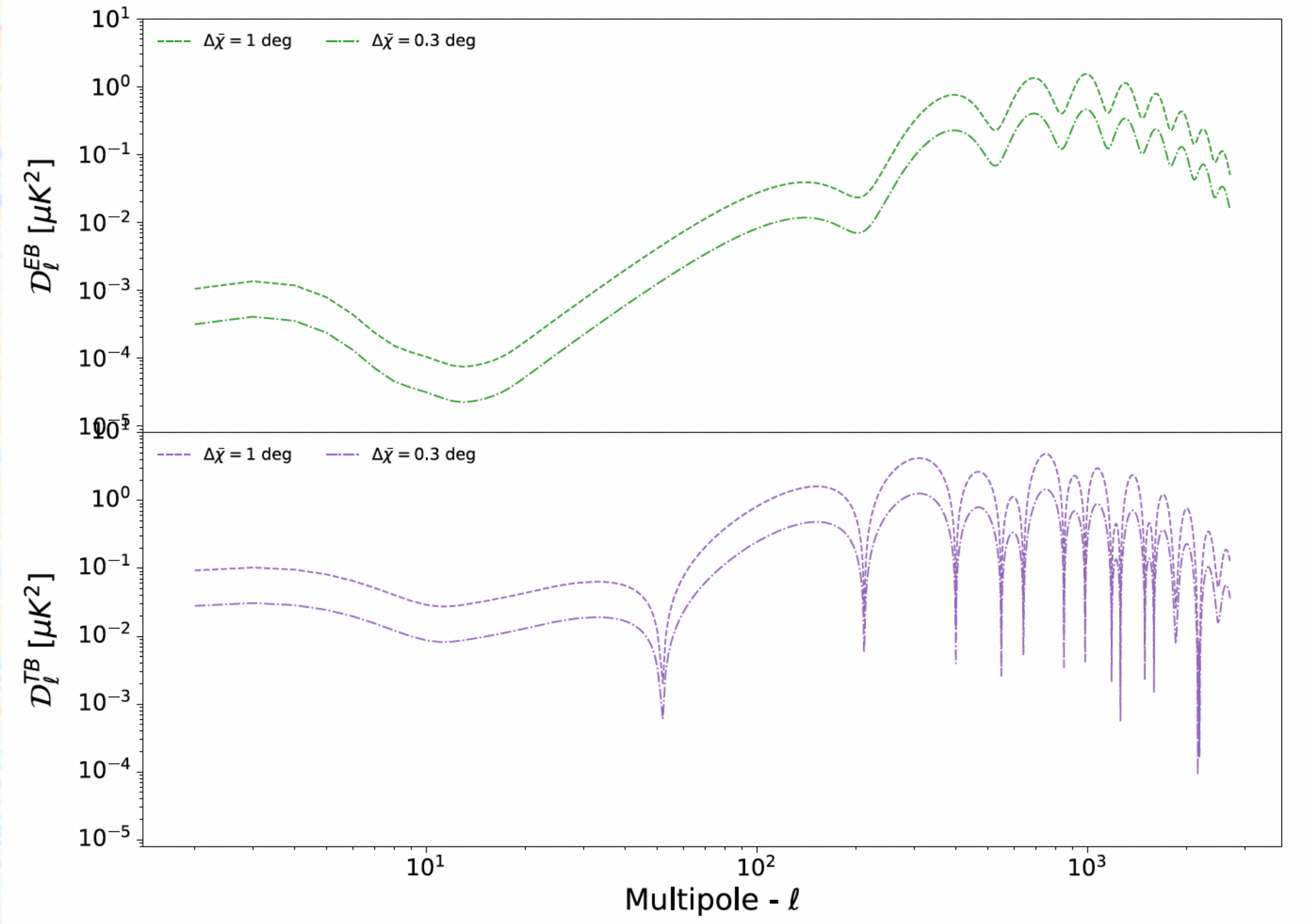
Isotropic

Anisotropic

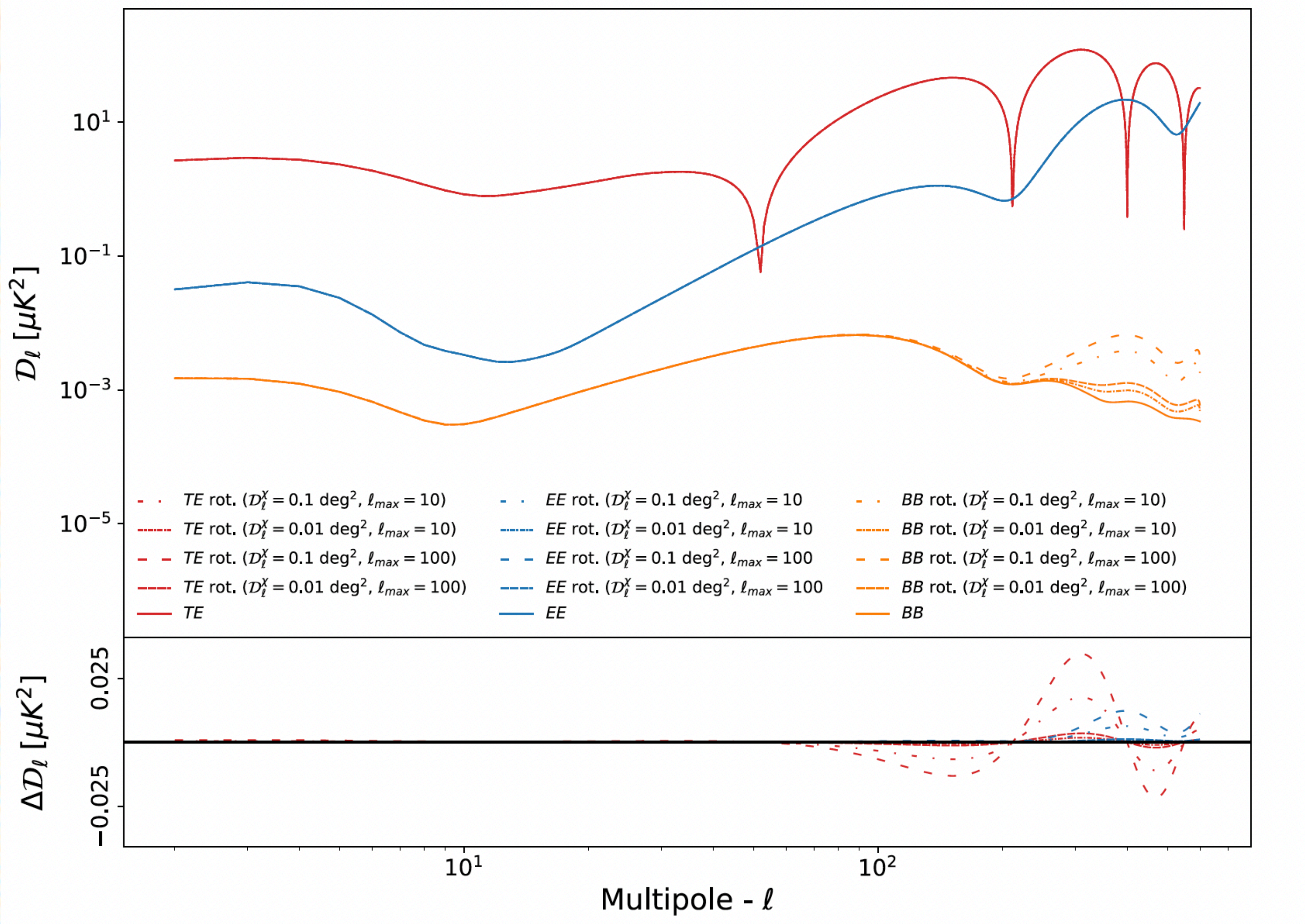
Isotropic (effect on TE, EE and BB)



Isotropic (non-zero EB and TB)



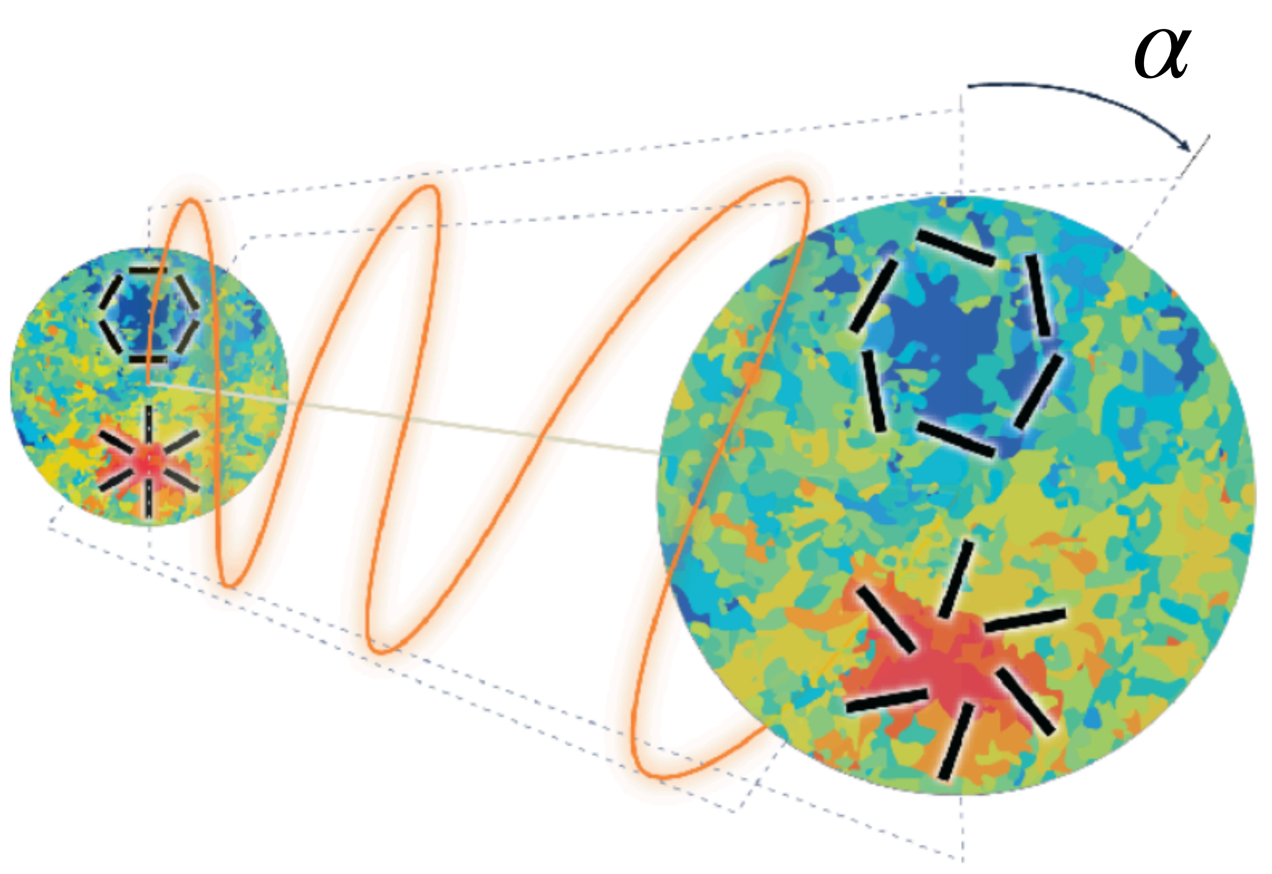
Anisotropic



Take-home messages (1)

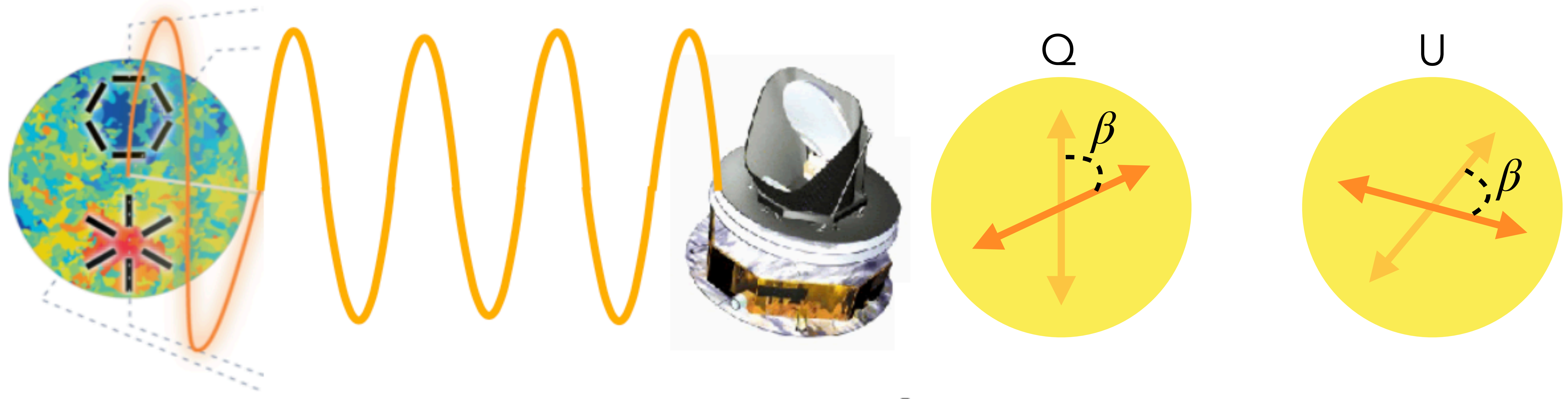
- ☑ Cosmic birefringence (CB) is the **rotation of the linear polarization plane** of CMB photon.
- ☑ This rotation might be both **isotropic** and **anisotropic**, and induces non-zero **parity violating** power spectra and **mixing between the EE and BB** power spectra.
- ☑ This mixing generates **spurious B-mode component** that acts as a potential **contaminant** for all the measurements of primordial B-modes.
- ☑ **Ultralight APLs** can explain the observational hint of cosmic birefringence. Axions already **well-motivated** by the strong CP problem.
- ☑ Depending on their mass APLs might act as **dark energy** or part of **dark matter**.

Cosmic or Instrumental?



Cosmic birefringence rotates CMB linear polarization plane by α angle

or



Miscalibration of detector's polarization angle β: degenerate with cosmic birefringence angle α

Krachmalnicoff+(2022) - LiteBIRD collab.

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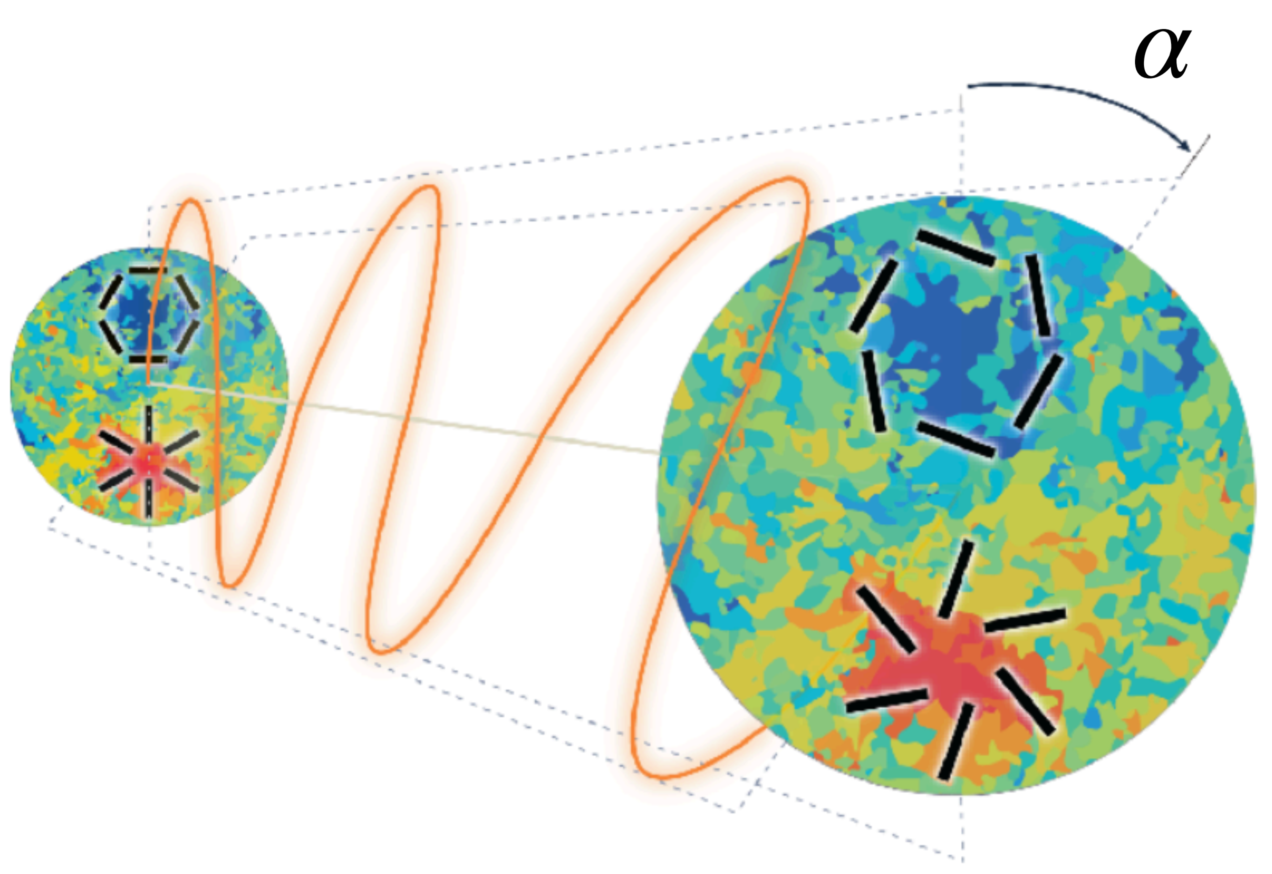


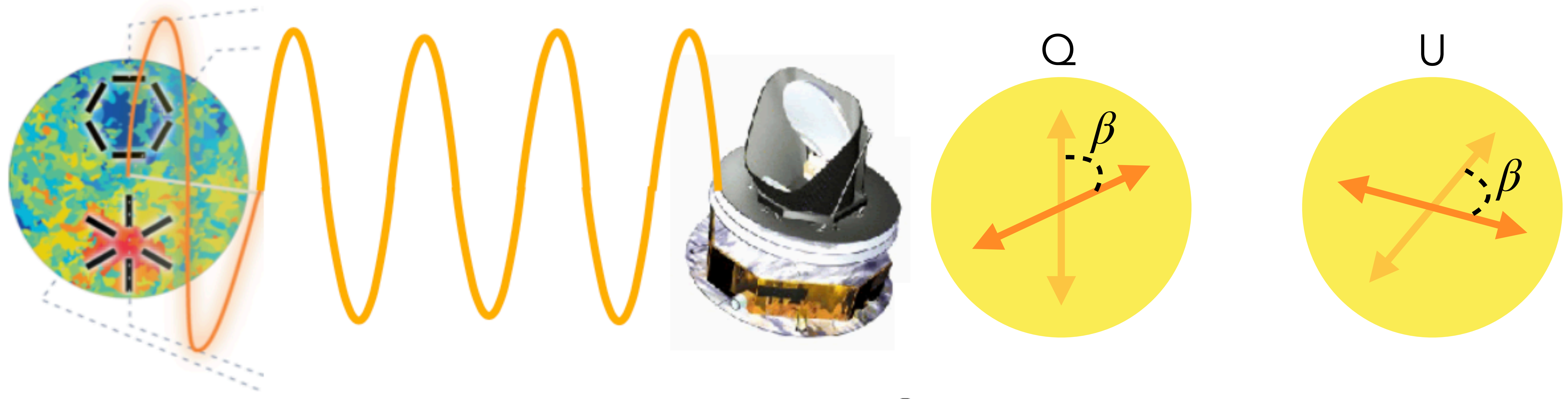
Cosmic birefringence rotates CMB linear polarization plane by α angle

Minami+2019

The sky contains: CMB+Galactic foreground emission. Photons of the **foreground emission do not travel for a long distance**, receiving only a negligible amount of α.

We can **assume** that the **foreground polarization** is **rotated only by** the **miscalibration angle** β.

or



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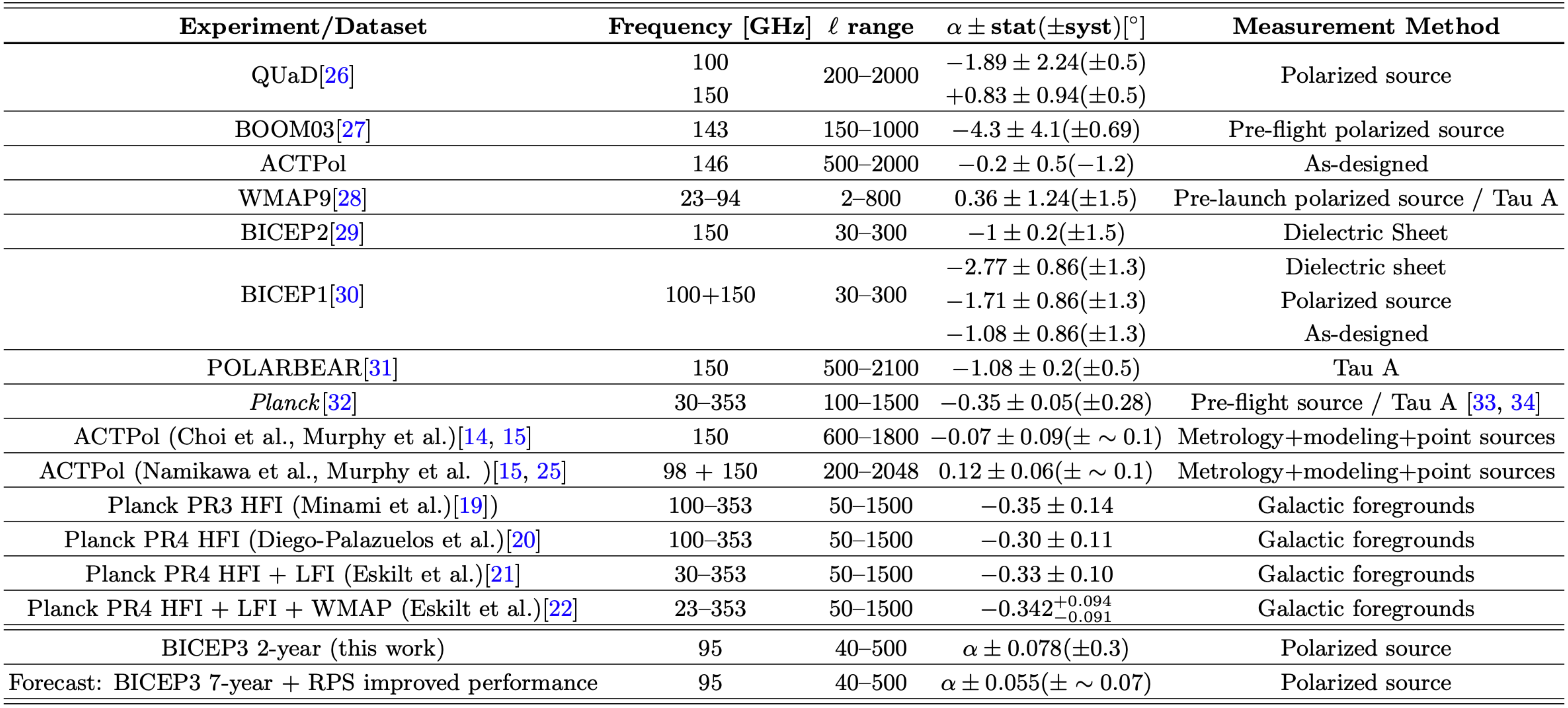
Constraining isotropic birefringence angle

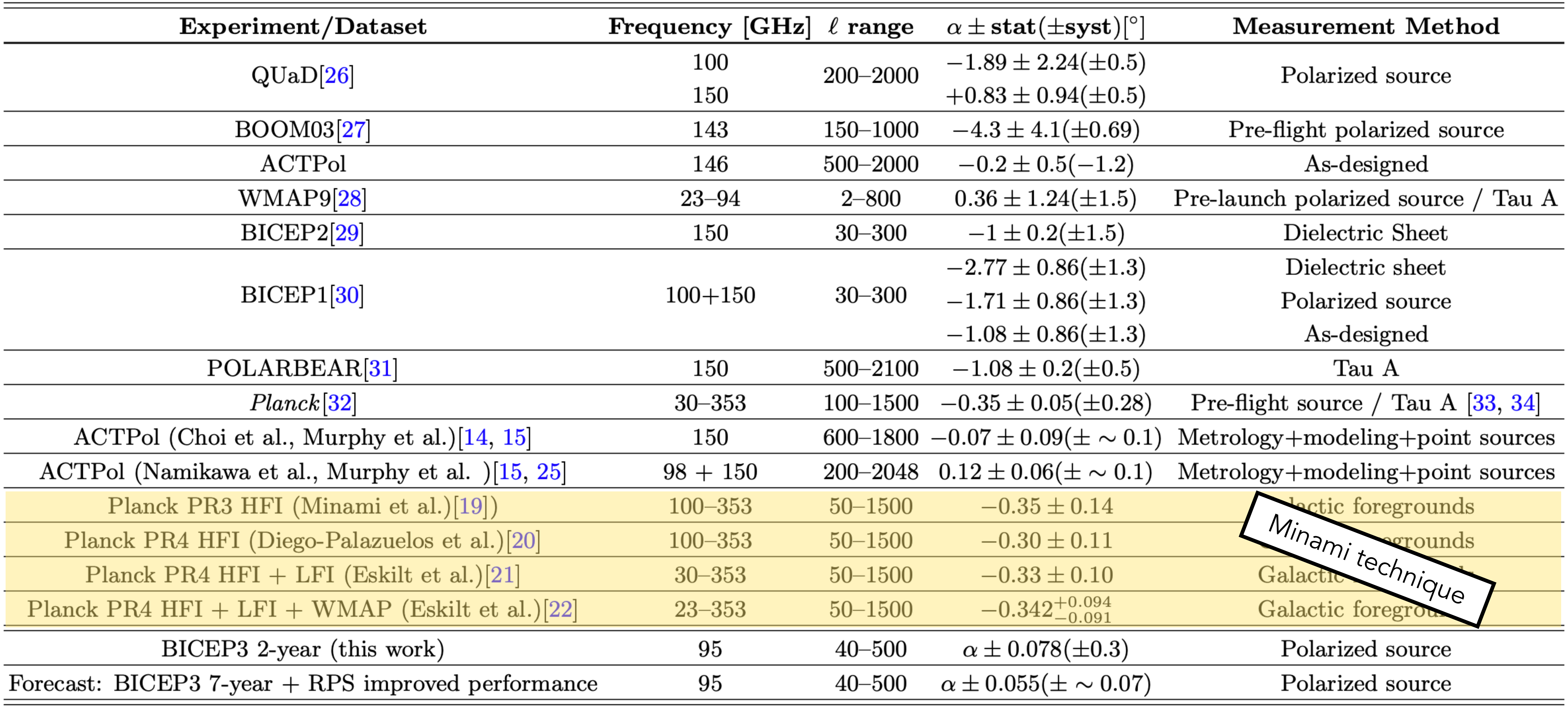


Experiment/Dataset	Frequency [GHz]	ℓ range	$\alpha \pm$ stat$(\pm$syst$)[^\circ]$	Measurement Method
QUaD[26]	100 150	200–2000	$-1.89 \pm 2.24(\pm 0.5)$ $+0.83 \pm 0.94(\pm 0.5)$	Polarized source
BOOM03[27]	143	150–1000	$-4.3 \pm 4.1(\pm 0.69)$	Pre-flight polarized source
ACTPol	146	500–2000	$-0.2 \pm 0.5(-1.2)$	As-designed
WMAP9[28]	23–94	2–800	$0.36 \pm 1.24(\pm 1.5)$	Pre-launch polarized source / Tau A
BICEP2[29]	150	30–300	$-1 \pm 0.2(\pm 1.5)$	Dielectric Sheet
BICEP1[30]	100+150	30–300	$-2.77 \pm 0.86(\pm 1.3)$ $-1.71 \pm 0.86(\pm 1.3)$ $-1.08 \pm 0.86(\pm 1.3)$	Dielectric sheet Polarized source As-designed
POLARBEAR[31]	150	500–2100	$-1.08 \pm 0.2(\pm 0.5)$	Tau A
Planck[32]	30–353	100–1500	$-0.35 \pm 0.05(\pm 0.28)$	Pre-flight source / Tau A [33, 34]
ACTPol (Choi et al., Murphy et al.)[14, 15]	150	600–1800	$-0.07 \pm 0.09(\pm \sim 0.1)$	Metrology+modeling+point sources
ACTPol (Namikawa et al., Murphy et al.)[15, 25]	98 + 150	200–2048	$0.12 \pm 0.06(\pm \sim 0.1)$	Metrology+modeling+point sources
Planck PR3 HFI (Minami et al.)[19])	100–353	50–1500	-0.35 ± 0.14	Galactic foregrounds
Planck PR4 HFI (Diego-Palazuelos et al.)[20]	100–353	50–1500	-0.30 ± 0.11	Galactic foregrounds
Planck PR4 HFI + LFI (Eskilt et al.)[21]	30–353	50–1500	-0.33 ± 0.10	Galactic foregrounds
Planck PR4 HFI + LFI + WMAP (Eskilt et al.)[22]	23–353	50–1500	$-0.342^{+0.094}_{-0.091}$	Galactic foregrounds
BICEP3 2-year (this work)	95	40–500	$\alpha \pm 0.078(\pm 0.3)$	Polarized source
Forecast: BICEP3 7-year + RPS improved performance	95	40–500	$\alpha \pm 0.055(\pm \sim 0.07)$	Polarized source

Constraints originally reported using the HEALPix polarization convention have been sign-flipped to match the **IAU polarization convention**

arXiv:2410.12089v2 BICEP/Keck Collaboration

Constraining isotropic birefringence angle



Experiment/Dataset	Frequency [GHz]	ℓ range	$\alpha \pm \text{stat}(\pm\text{syst})[^\circ]$	Measurement Method
QUaD[26]	100 150	200–2000	$-1.89 \pm 2.24(\pm 0.5)$ $+0.83 \pm 0.94(\pm 0.5)$	Polarized source
BOOM03[27]	143	150–1000	$-4.3 \pm 4.1(\pm 0.69)$	Pre-flight polarized source
ACTPol	146	500–2000	$-0.2 \pm 0.5(-1.2)$	As-designed
WMAP9[28]	23–94	2–800	$0.36 \pm 1.24(\pm 1.5)$	Pre-launch polarized source / Tau A
BICEP2[29]	150	30–300	$-1 \pm 0.2(\pm 1.5)$	Dielectric Sheet
BICEP1[30]	100+150	30–300	$-2.77 \pm 0.86(\pm 1.3)$ $-1.71 \pm 0.86(\pm 1.3)$ $-1.08 \pm 0.86(\pm 1.3)$	Dielectric sheet Polarized source As-designed
POLARBEAR[31]	150	500–2100	$-1.08 \pm 0.2(\pm 0.5)$	Tau A
Planck[32]	30–353	100–1500	$-0.35 \pm 0.05(\pm 0.28)$	Pre-flight source / Tau A [33, 34]
ACTPol (Choi et al., Murphy et al.)[14, 15]	150	600–1800	$-0.07 \pm 0.09(\pm \sim 0.1)$	Metrology+modeling+point sources
ACTPol (Namikawa et al., Murphy et al.)[15, 25]	98 + 150	200–2048	$0.12 \pm 0.06(\pm \sim 0.1)$	Metrology+modeling+point sources
Planck PR3 HFI (Minami et al.)[19])	100–353	50–1500	-0.35 ± 0.14	lactic foregrounds
Planck PR4 HFI (Diego-Palazuelos et al.)[20]	100–353	50–1500	-0.30 ± 0.11	egrounds
Planck PR4 HFI + LFI (Eskilt et al.)[21]	30–353	50–1500	-0.33 ± 0.10	Galactic
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Minami technique

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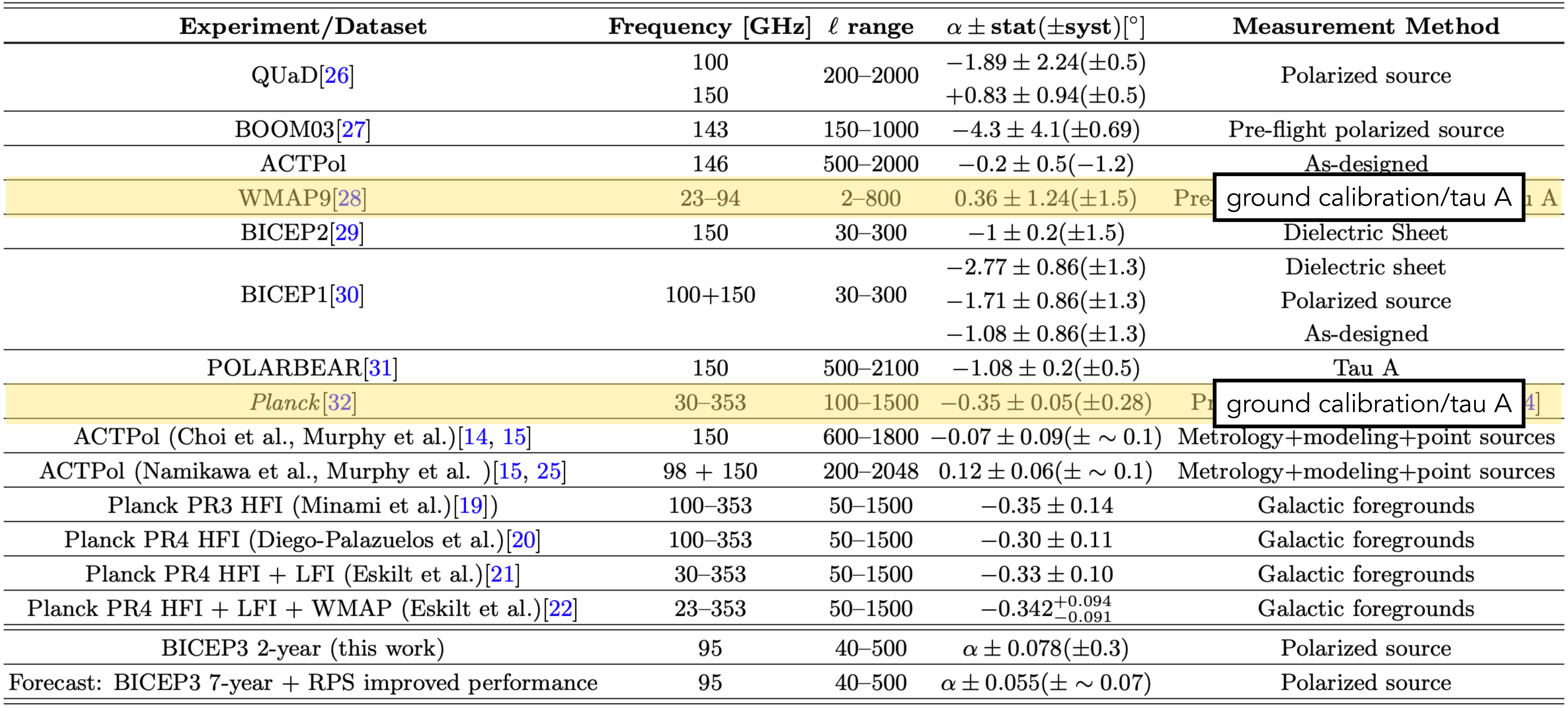
arXiv:2410.12089v2 BICEP/Keck Collaboration

Constraining isotropic birefringence angle



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Constraining isotropic birefringence angle

D estimators:

$$D_{TB,\ell}(\alpha_0) = C_\ell^{TB,obs}\cos(2\alpha_0) - C_\ell^{TE,obs}\sin(2\alpha_0)$$

$$D_{EB,\ell}(\alpha_0) = C_\ell^{EB,obs} - \frac{1}{2}\left(C_\ell^{BB,obs} + C_\ell^{EE,obs}\right)\sin(4\alpha_0)$$

This has **more** constraining power

$\downarrow$ minimising $\chi^2_{\color{blue}Y}(\alpha_0) = \sum_{\ell\ell'} D_\ell^{\color{blue}Y} {\color{red}M_{\ell\ell'}^{YY^{-1}}} D_{\ell'}^{\color{blue}Y}$

${\color{blue}Y = EB, TB}$

covariance matrix

α_0 angle

- QUaD collaboration (2009)
- Gruppuso+ (2012) - WMAP 7 year
- *Planck* intermediate results (2016)
- Gruppuso+ (2020) - *Planck* 2018
- Minami+ (2020) - *Planck* 2018
- Bortolami+ (2022) - *Planck* 2018
- …

Constraining isotropic birefringence angle

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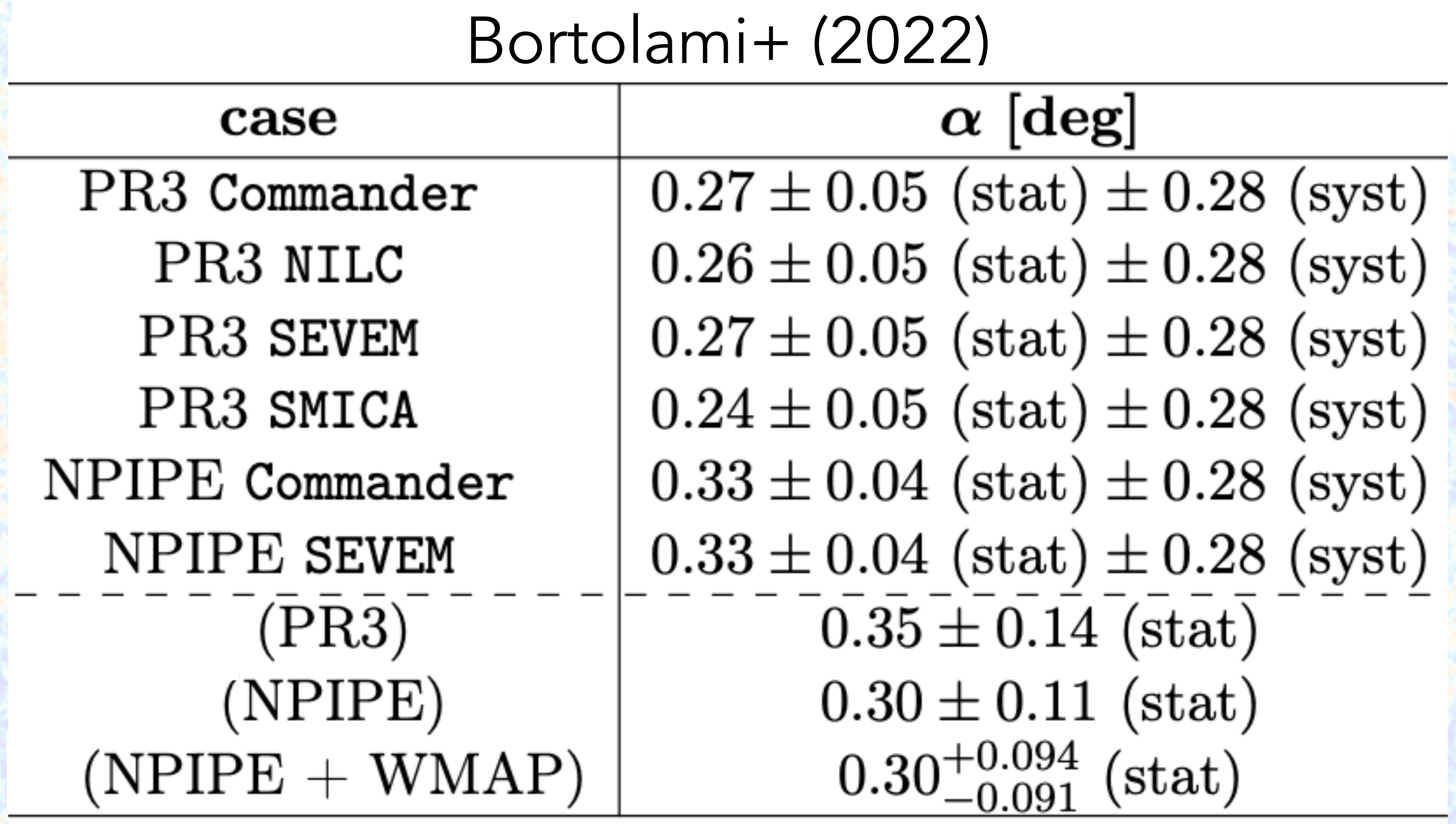
Cosmic birefringence maps

Pipeline:

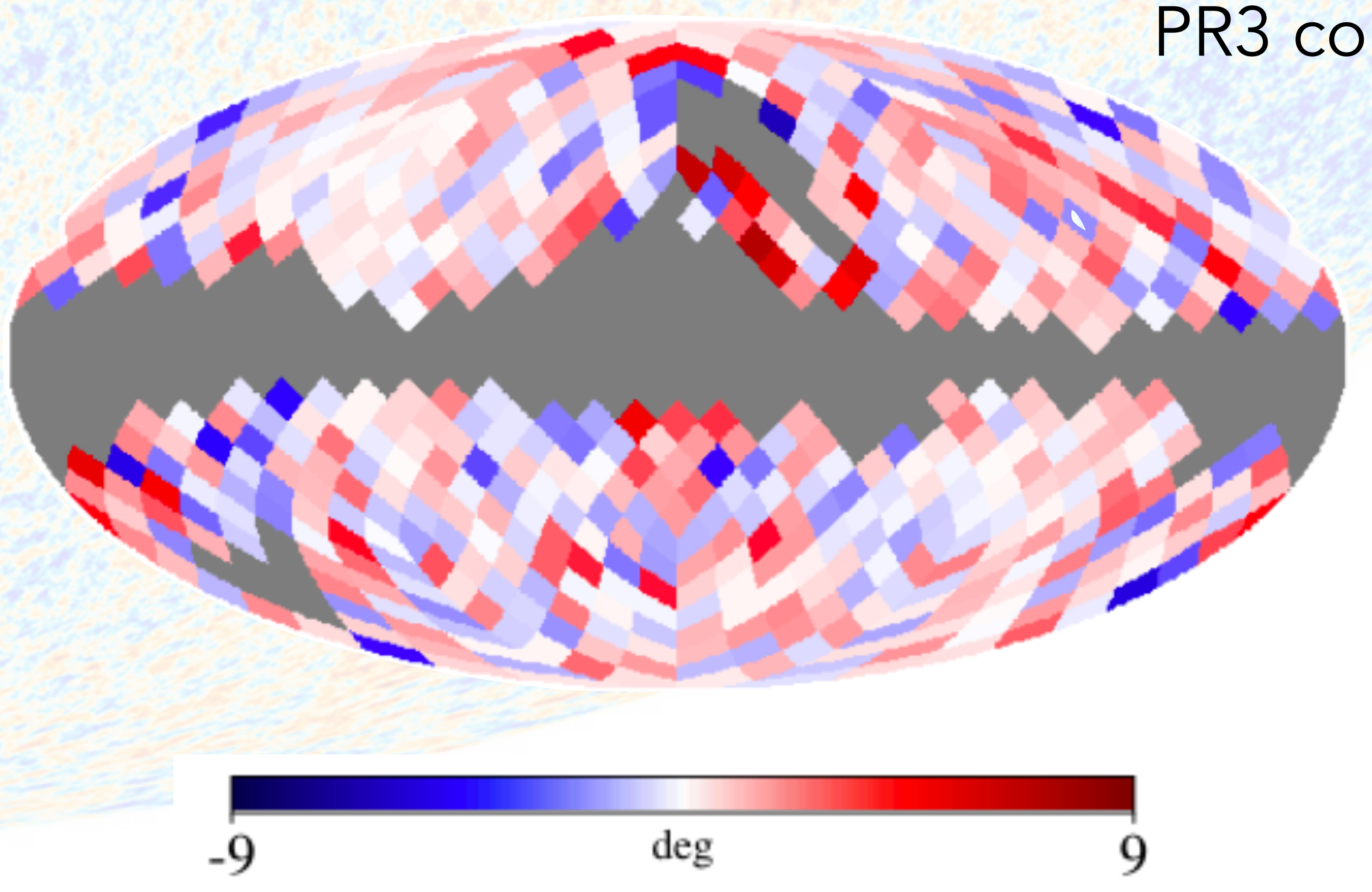
- Cleaned PR3 and NPIPE maps (Commander/NILC/SEVEM/SMICA)
- **Dividing the sky in "patches"** ($N_{side} = 8$, $f_{sky,p} \simeq 0.13\,\%$, $N_{tot\,p} = 768$)
- Applying masks (Galactic foreground and bad pixel)
- SkyPatches to Spectra with NaMaster
- Assuming **isotropic CB in each patches** and applying D^{EB} estimator
- In each patch, estimation of α_0 maximizing the log-likelihood function —> map of CB angles
- Estimation of α_0 **as monopole of the CB map**



Bortolami+ (2022)

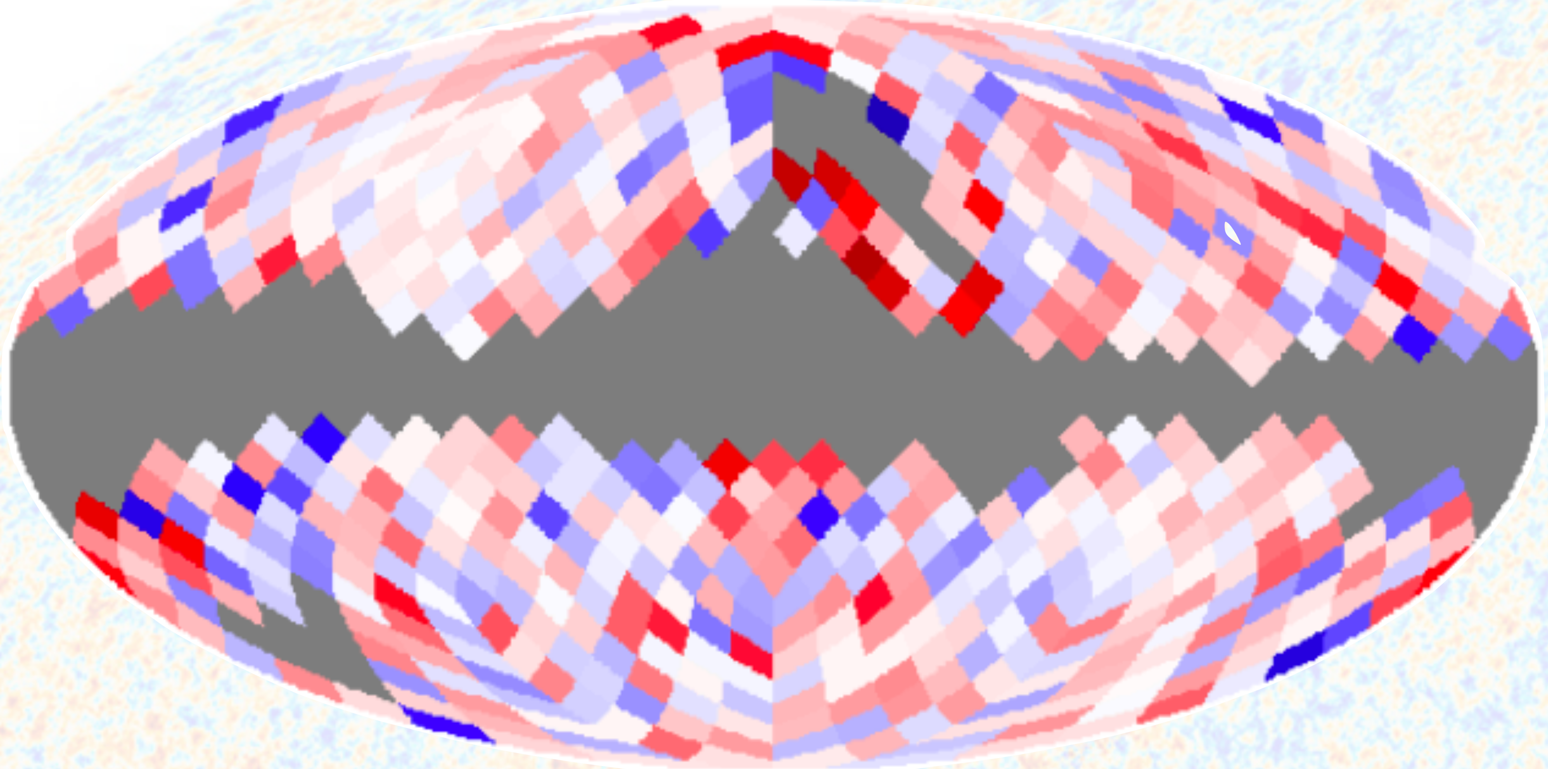
case	$\boldsymbol{\alpha}$ **[deg]**
PR3 `Commander`	0.27 ± 0.05 (stat) ± 0.28 (syst)
PR3 `NILC`	0.26 ± 0.05 (stat) ± 0.28 (syst)
PR3 `SEVEM`	0.27 ± 0.05 (stat) ± 0.28 (syst)
PR3 `SMICA`	0.24 ± 0.05 (stat) ± 0.28 (syst)
NPIPE `Commander`	0.33 ± 0.04 (stat) ± 0.28 (syst)
NPIPE `SEVEM`	0.33 ± 0.04 (stat) ± 0.28 (syst)
(PR3)	0.35 ± 0.14 (stat)
(NPIPE)	0.30 ± 0.11 (stat)
(NPIPE + WMAP)	$0.30^{+0.094}_{-0.091}$ (stat)

PR3 commander



This extends previous work ($N_{side} = 4$) Gruppuso+ (2020)

Cosmic birefringence maps



↓ QML estimator

$$\hat{C}_\ell^{\alpha\alpha}$$

↓ Assuming scale invariant spectrum

constraints on $A_\ell^\alpha = \ell(\ell+1)\, C_\ell^{\alpha\alpha}/2\pi$

Bortolami+ (2022) $(L = 24)$

parameter	Commander	NILC	SEVEM	SMICA
$A^{\alpha\alpha}$ [deg^2] PR3	< 0.007	< 0.007	< 0.010	< 0.007
$A^{\alpha\alpha}$ [deg^2] NPIPE	< 0.010	-	< 0.009	-

$A^{\alpha\alpha}_{\mathtt{SMICA}} < 0.104\,\mathrm{deg}^2$ at 95%C.L. $(L = 12)$ Gruppuso+ (2020)

Other constraints on the scale-invariant amplitude A^α :

Contreras, Boubel, Scott(2018) - Planck data $\leq 0.018\,\mathrm{deg}^2$

Bianchini, SPT collaboration (2020)

Namikawa, ACT collaboration (2020)

$\leq 0.033\,\mathrm{deg}^2$

All results compatible with **no anisotropic birefringence** signal

Cosmic Birefringence map from PR4

$D^{EB}(\alpha)$ estimator —> α angle

Bortolami, Billi, Gruppuso, Natoli, Pagano (2022)
Gruppuso, Molinari, Natoli, Pagano (2020)

Kind of estimator as in Gluscevic+ (2012)

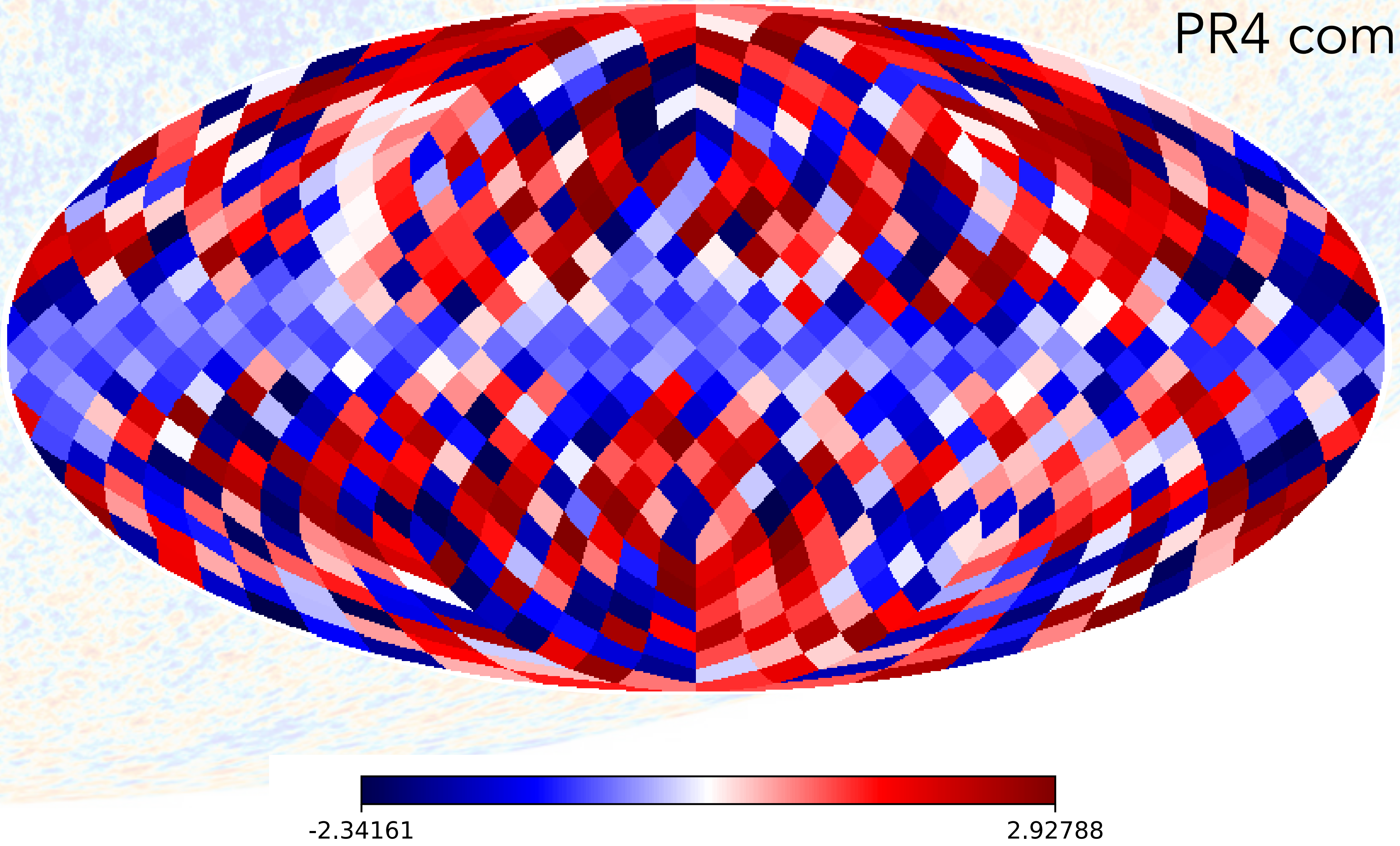
$\hat{\alpha}^{EB}_{LM}$ estimator —> α_{LM}

Zagatti, Bortolami, Gruppuso, Natoli, Pagano (2024)

See her talk tomorrow! 😲

- L up to $2\,\ell_{max}$ of CMB maps
- Computationally less expensive
- CB spectrum compatible with 0 at $\sim 2\sigma$ (w/o assuming a scale invariant spectrum)

PR4 commander



Take-home messages (2)

- ☑ **Miscalibration** of detector's polarization angle **degenerate with CB angle**.
- ☑ **Minami+2019 developed a new technique** to independently constrain both these angles using CMB observations.
- ☑ Using this technique several papers claimed **2-3 σ detection of isotopic CB angle. Anisotropic CB spectrum still compatible with zero**.
- ☑ **D-estimators** (based on C_ℓ) is the most largely used estimator (see Giorgia's talk for harmonic estimator).

Beyond Cosmic Birefringence

We consider the ***minimal Standard Model Extension*** - contains only renormalizable operators with mass dimension ≤ 4

$$\mathcal{S} = \int d^4x \sqrt{-g} \left[-\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} \varepsilon^{\alpha\beta\mu\nu} A_\beta (k_{AF})_\alpha F_{\mu\nu} - \frac{1}{4} (k_F)^{\alpha\beta\mu\nu} F_{\alpha\beta} F_{\mu\nu} \right]$$

Standard Maxwell term

CPT-odd term

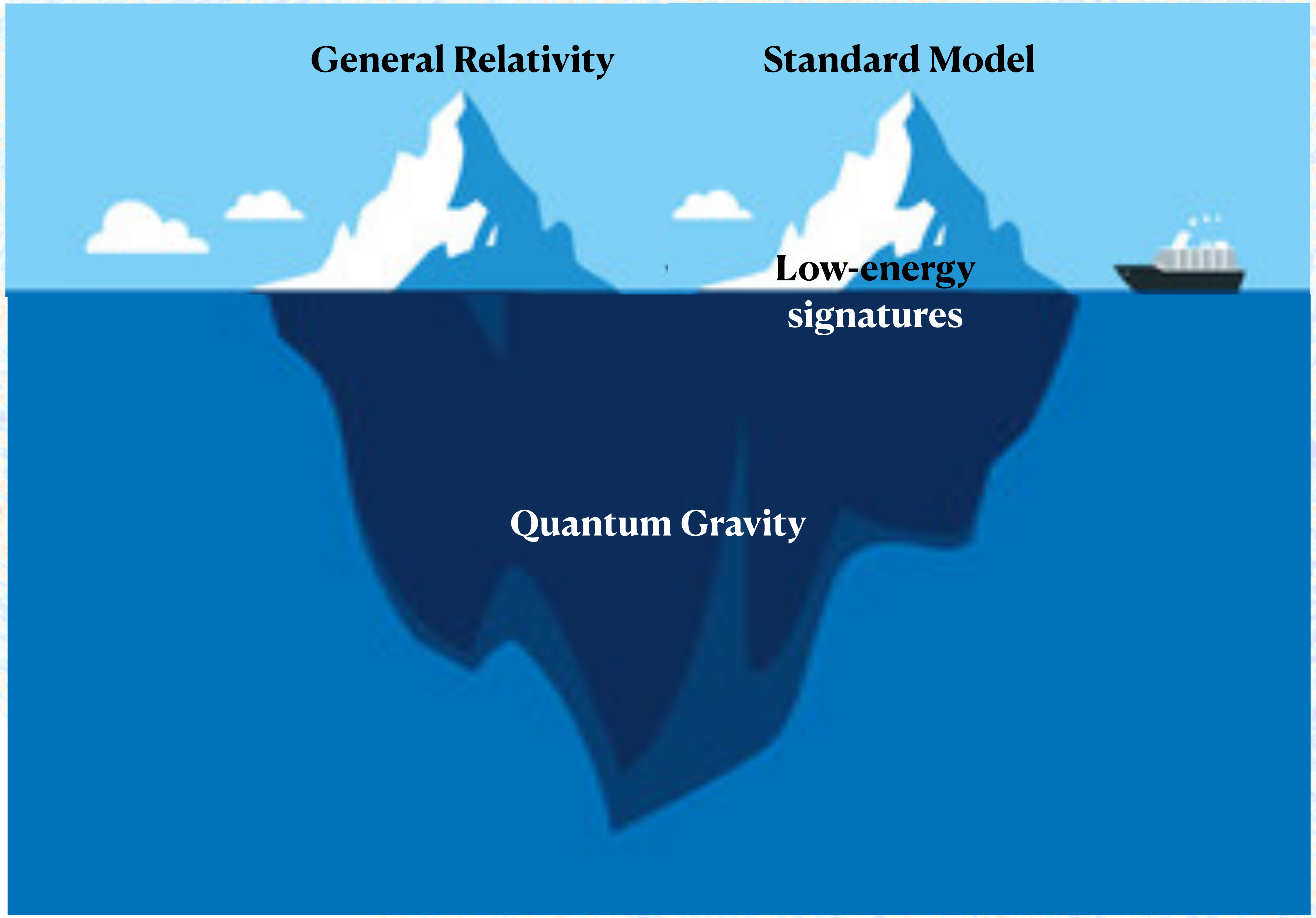
The time and the space components of the coupling k_{AF} lead to isotropic and anisotropic birefringence, respectively

CPT-even term

The couplings k_F lead to a conversion of linear polarization (EE and BB spectra) into circular polarization (VV spectrum)

Caloni, Giardiello, **Lembo**, Gerbino, Gubitosi, Lattanzi, Pagano (2023)

Motivations: Why Lorentz-violating theories?



Quantum gravity?

Problem: typical energy scale **well above** the capabilities of any Earth based experiment as well as any observationally **accessible regime**

↓

Solution: looking for low energy **"relic signatures"**, which would lead to deviation from the standard theory predictions (standard model of particle interactions (SM) plus GR) in specific regimes

"QG phenomenology":

- **Violation of symmetries**
- imprint on initial cosmological perturbations
- Cosmological variation of couplings
- TeV Black Holes, related to extra-dimensions
- Quantum decoherence and state collapse
- ...

Beyond Cosmic Birefringence

$$\mathcal{S} = \int d^4x\sqrt{-g}\left[-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}+\frac{1}{2}\varepsilon^{\alpha\beta\mu\nu}A_\beta(k_{AF})_\alpha F_{\mu\nu}-\frac{1}{4}(k_F)^{\alpha\beta\mu\nu}F_{\alpha\beta}F_{\mu\nu}\right]$$

applying the *dark crystal formalism* as described in

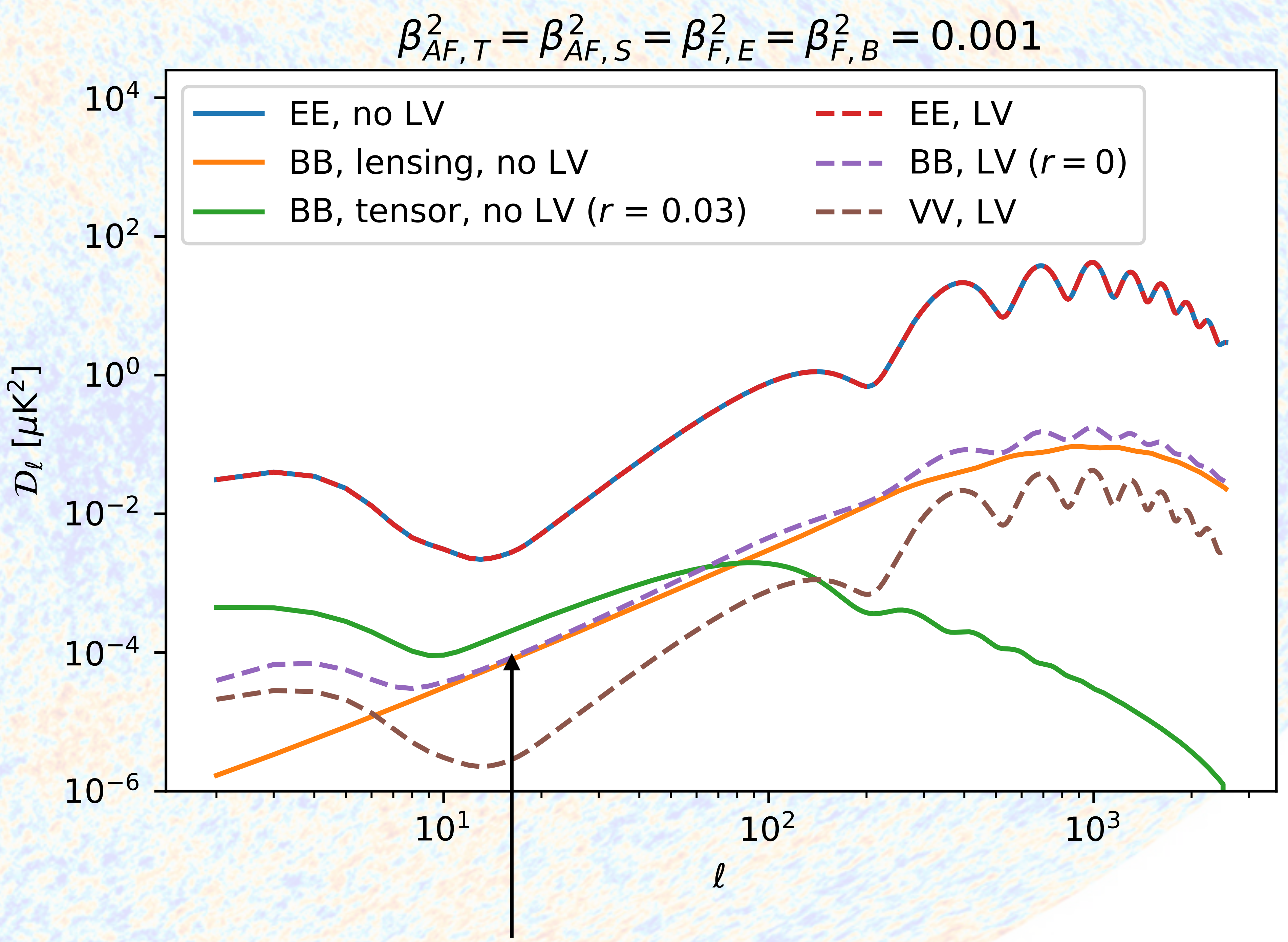
Lembo, Lattanzi, Pagano, Gruppuso, Natoli, Forastieri (PRL2021)

CMB spectra (including EB, TB, VV $\neq 0$) as function of some effective parameters:

$\beta^2_{AF,\,T/S}$ related to time/space components of k_{AF} **(CPT-odd)**

β^2_F depends of the components of k_F in a non-trivial way **(CPT-even)**

The spectra are generated using `camb-cpt` (our custom-made version of `camb`)



Spurious B-mode component even in absence of tensor modes (dashed purple line).

Caloni, Giardiello, **Lembo**, Gerbino, Gubitosi, Lattanzi, Pagano (2023)

Beyond Cosmic Birefringence

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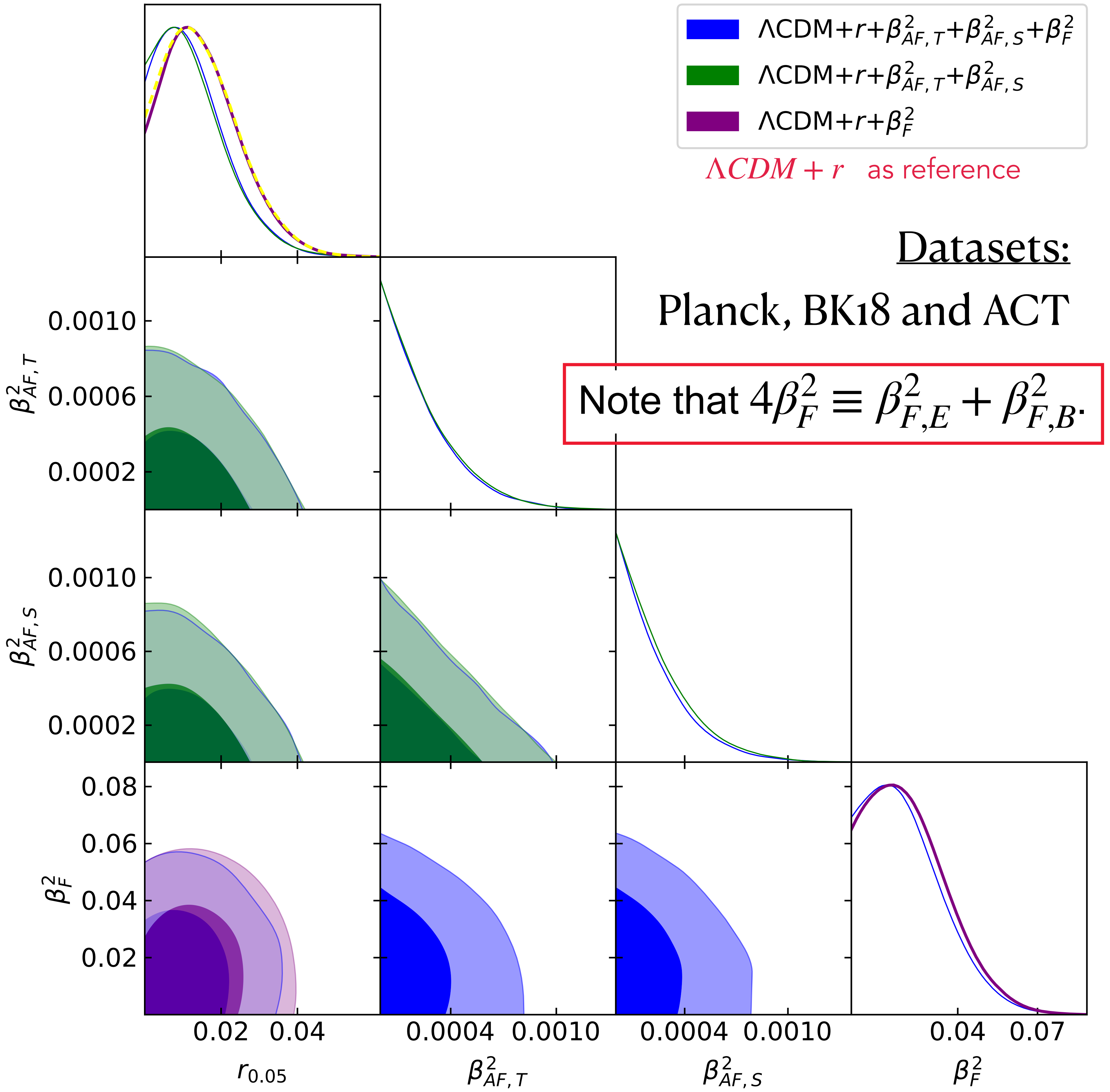


Datasets:

Planck, BK18 and ACT

Note that $4\beta^2_F \equiv \beta^2_{F,E} + \beta^2_{F,B}$.

Comparison with previous works

First comprehensive study of the signatures of Lorentz violation in electrodynamics on CMB anisotropies.

(see V.A. Kostelecky and N. Russell, Data Tables for Lorentz and CPT Violation arXiv:0801.0287)

CPT-odd

Our bounds are the strongest to date, both considering CMB and other sources.

CPT-even

Our bound improves previous constraints by roughly one order of magnitude. This bound is only overcome by those obtained from optical polarimetry of extragalactic sources.

Caloni, Giardiello, **Lembo**, Gerbino, Gubitosi, Lattanzi, Pagano (2023)

Take-home messages (3)

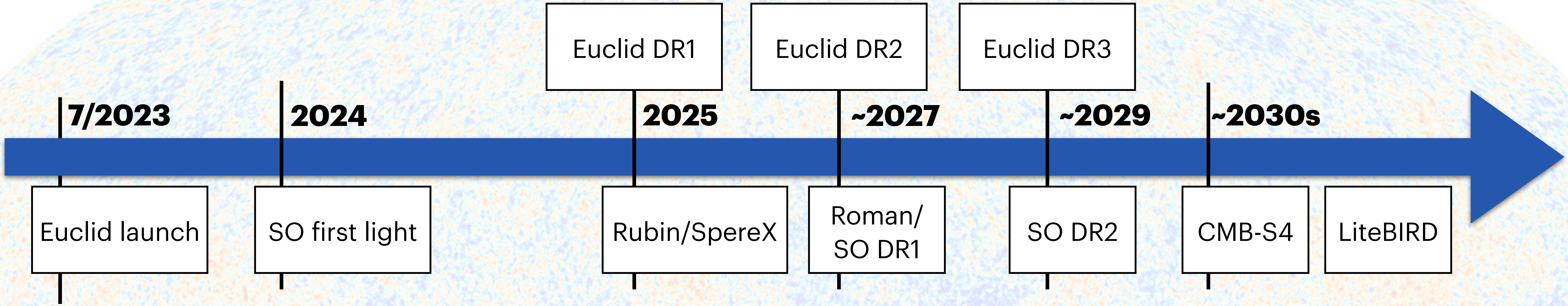
☑ **Lorentz invariance violations** leave a signature in CMB anisotropies.

☑ The main features are: **cosmic birefringence** and conversion of linear to **circular polarization.**

☑ We can use measurements of **V-modes as *independent* probe** of such effects (is it possible to exploiting the coupling between total intensity and circular polarisation introduced by a **non-ideal HWP?)**

☑ Again we have the generation of spurious B-mode component that acts as a **potential contaminant for all the measurements of primordial B-modes.**

Summary and future prospects



7/2023
Euclid launch

2024
SO first light

2025
Euclid DR1
Rubin/SpereX

~2027
Euclid DR2
Roman/ SO DR1

~2029
Euclid DR3
SO DR2

~2030s
CMB-S4
LiteBIRD

- Minami&Komatsu (2020), Diego-Palazuelos+(2022) e Eskilt&Komatsu (2022) have suggested **an hint of detection of isotopic birefringence**, excluding $\alpha_0 = 0$ with a significance ranging from 2.4σ to 3.6σ. This motivates further investigations and suggests us to **improve our knowledge of Galactic foregrounds**.

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for all the measurem

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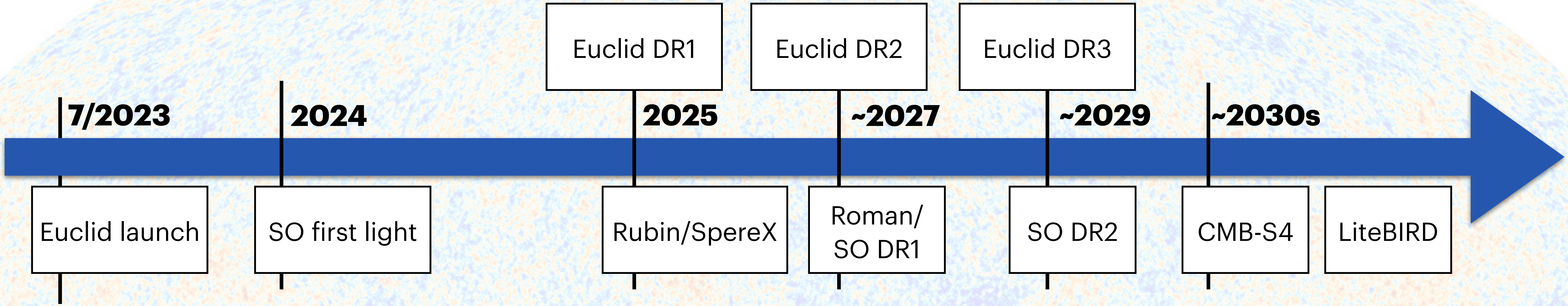

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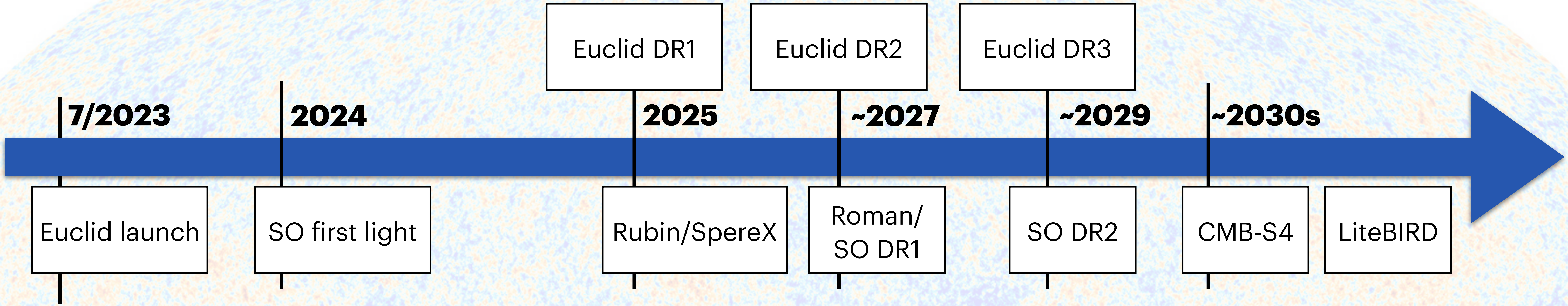

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- Constraining Cosmology through **CMB polarization** is the **focus of next-decade CMB experiments.**

7/2023

0s

Euclid launch

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LiteBIRD

Thanks for your attention!

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