Cosmic Birefringence from a stiff axion field

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Exploring New Frontiers in Cosmology

GGI
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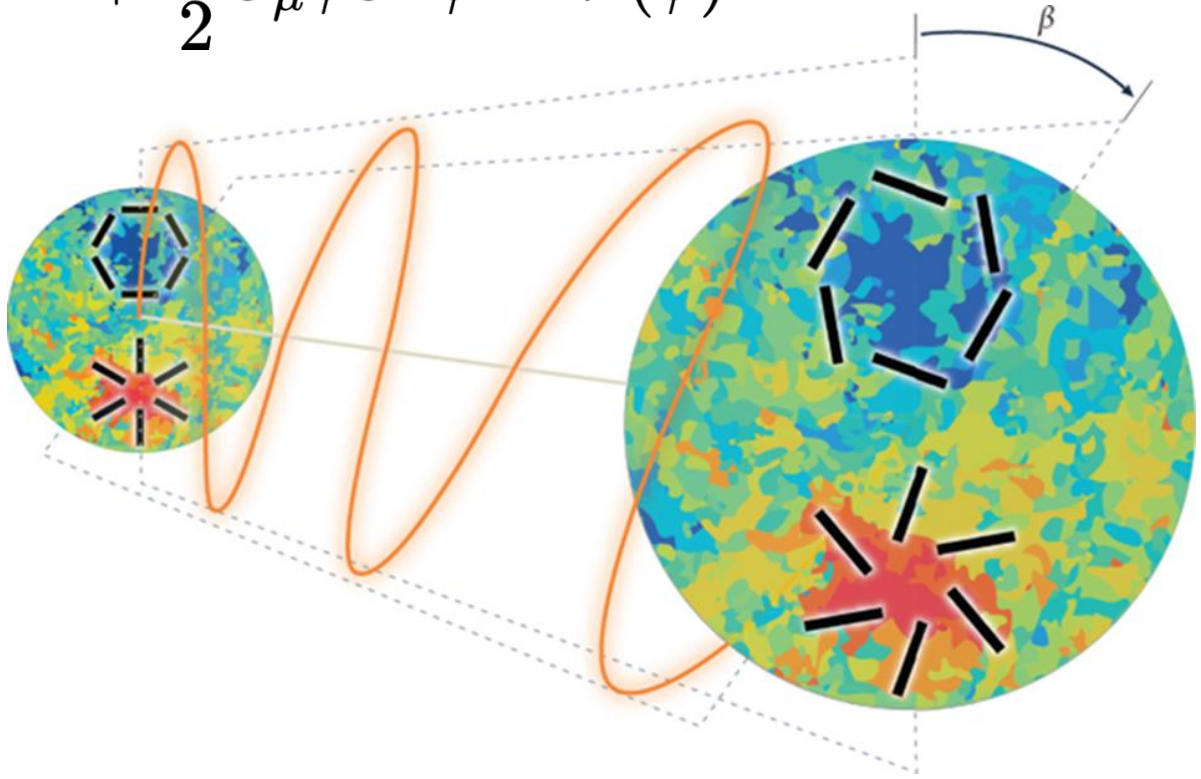
Cosmic Birefringence

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - A_\mu J^\mu - \frac{g_{\phi\gamma}}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi)$$

$$\beta = \frac{g_{\phi\gamma}}{2}(\phi_0 - \phi_*)$$

$$\beta = (0.215 \pm 0.074)\ \text{deg}$$

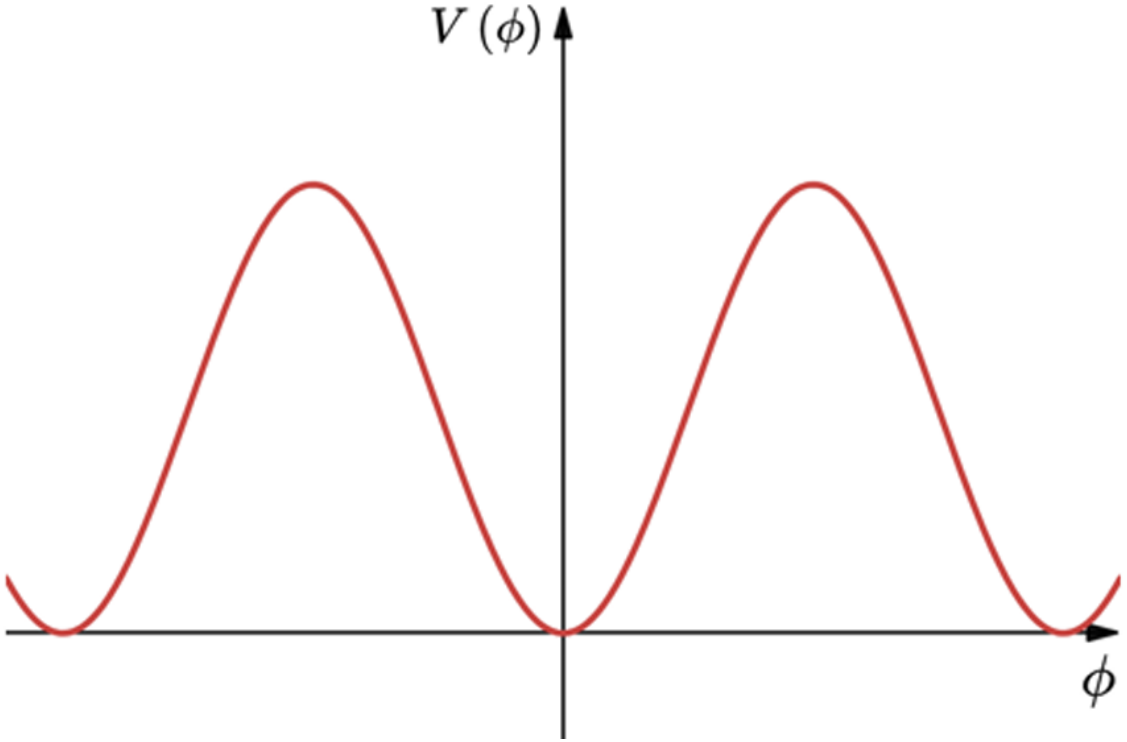
Diego-Palazuelos and
Komatsu (2026) ACT DR6



Credit: Y.Minami

The effect **does not depend on the frequency** of the radiation!

CB from DM or DE



$$V(\phi) = m^2 f^2 \left[1 - \cos\left(\frac{\phi}{f}\right)\right]$$

$$\ddot{\phi} + 3H\dot{\phi} + m^2 f \sin\left(\frac{\phi}{f}\right) = 0$$

	DM	DE
m	$\sim 10^{-20}\ eV$	$\sim 10^{-33}\ eV$
ϕ/f	~ 0	$\sim -\pi$

Stiff axion-like field

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{g_{\phi\gamma}}{4}\phi F_{\mu\nu}\widetilde{F}^{\mu\nu}$$

$$\ddot{\phi} + 3H\dot{\phi} - g_{\phi\gamma}\left(\mathbf{E}\cdot\mathbf{B}\right) = 0$$

Equation of motion

$$w_\phi = \frac{\dot{\phi}^2/2 + g_{\phi\gamma}\phi\left(\mathbf{E}\cdot\mathbf{B}\right)}{\dot{\phi}^2/2 - g_{\phi\gamma}\phi\left(\mathbf{E}\cdot\mathbf{B}\right)}$$

Equation of state

Stiff axion-like field

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{g_{\phi\gamma}}{4}\phi F_{\mu\nu}\widetilde{F}^{\mu\nu}$$

$$\ddot{\phi} + 3H\dot{\phi} = 0 \quad \Longrightarrow \quad \dot{\phi}(z) = \dot{\phi}_* \left(\frac{1+z}{1+z_*}\right)^3$$

$$w_\phi = 1 \quad \Longrightarrow \quad p_\phi(z) = \rho_\phi(z) = \frac{\dot{\phi}_*^2}{2}\left(\frac{1+z}{1+z_*}\right)^6$$

CB from a stiff axion-like field

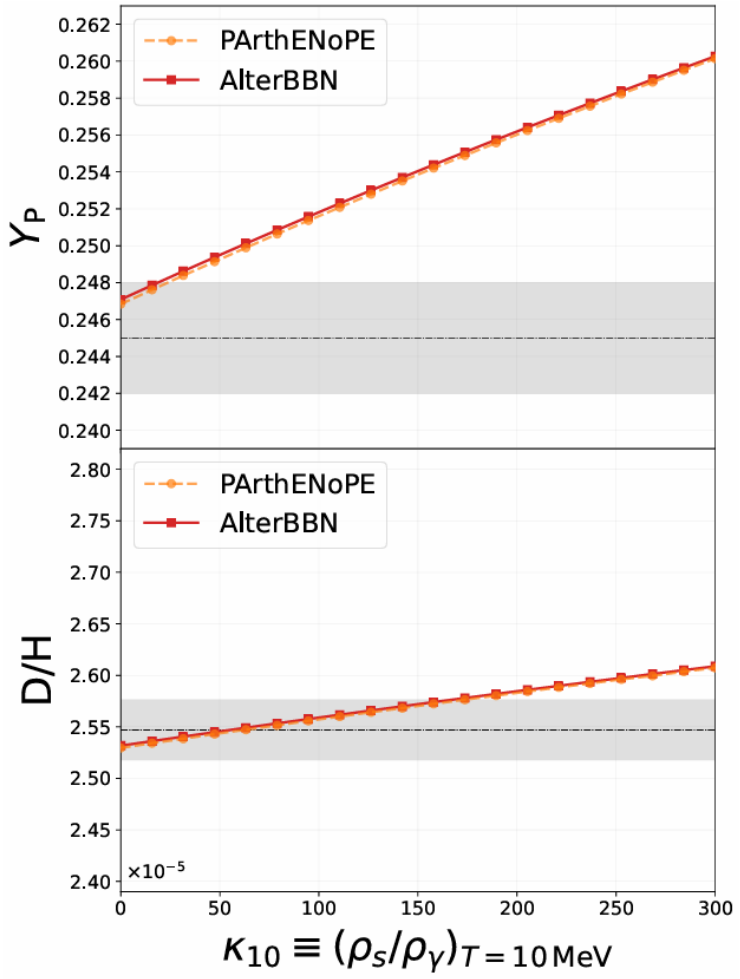
$$\beta = \frac{g_{\phi\gamma}}{2}(\phi_0 - \phi_*)$$

$$\phi_0 - \phi_* \equiv t_A \dot{\phi}_*$$

$$g_{\phi\gamma} = \left(\frac{2\beta}{t_A}\right)\frac{1}{\dot{\phi}_*}$$

The axion-photon coupling is related to to the time derivative of the axion field at recombination.

Constraint from BBN



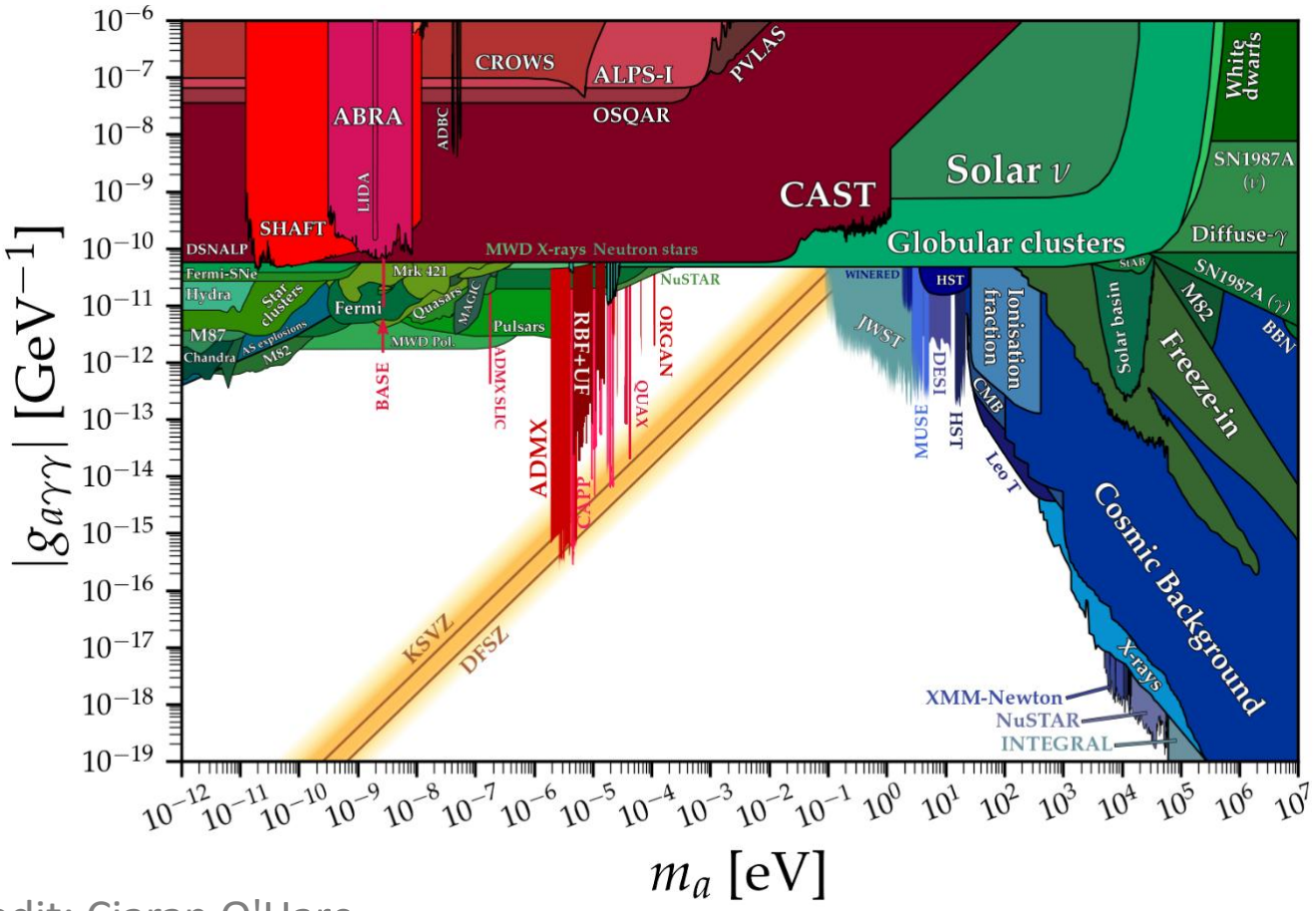
Zhang et al. (2025)

$$Y_p = 0.2458(13)$$ Aver et al. (2026)

$$\rho_\phi(T_{10}) < 28.5\ \rho_\gamma(T_{10}) \qquad T_{10} \equiv 10\ \mathrm{MeV}$$

$$g_{\phi\gamma} > 3.7 \times 10^{-14}\ \mathrm{GeV}^{-1} \qquad (2\sigma)$$

Constraint from conversion into γ



Credit: Ciaran O'Hare

quasar H1821+643:

$$g_{\phi\gamma} < 5.0 \times 10^{-13}\ \mathrm{GeV}^{-1} \quad (2\sigma)$$

for $m_\phi < 10^{-12}$ eV.

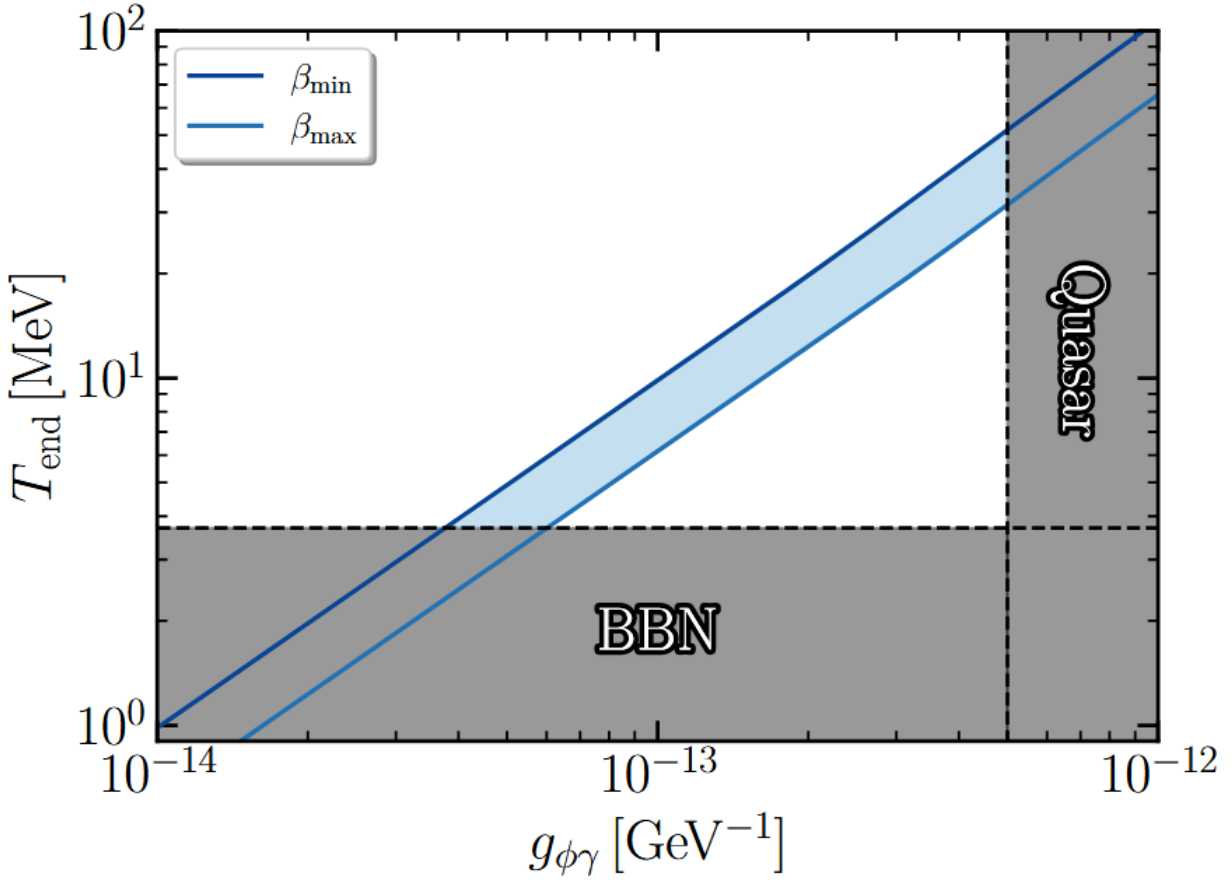
Reyn´es et al. (2021)

End of kination

$$\rho_\phi(T_{\rm end}) = \rho_r(T_{\rm end})$$

$$3.7\ {\rm MeV} < {\rm T_{end}} < 51.9\ {\rm MeV}$$

$$2.2 \times 10^{10} < z_{\rm end} < 3.4 \times 10^{11}$$

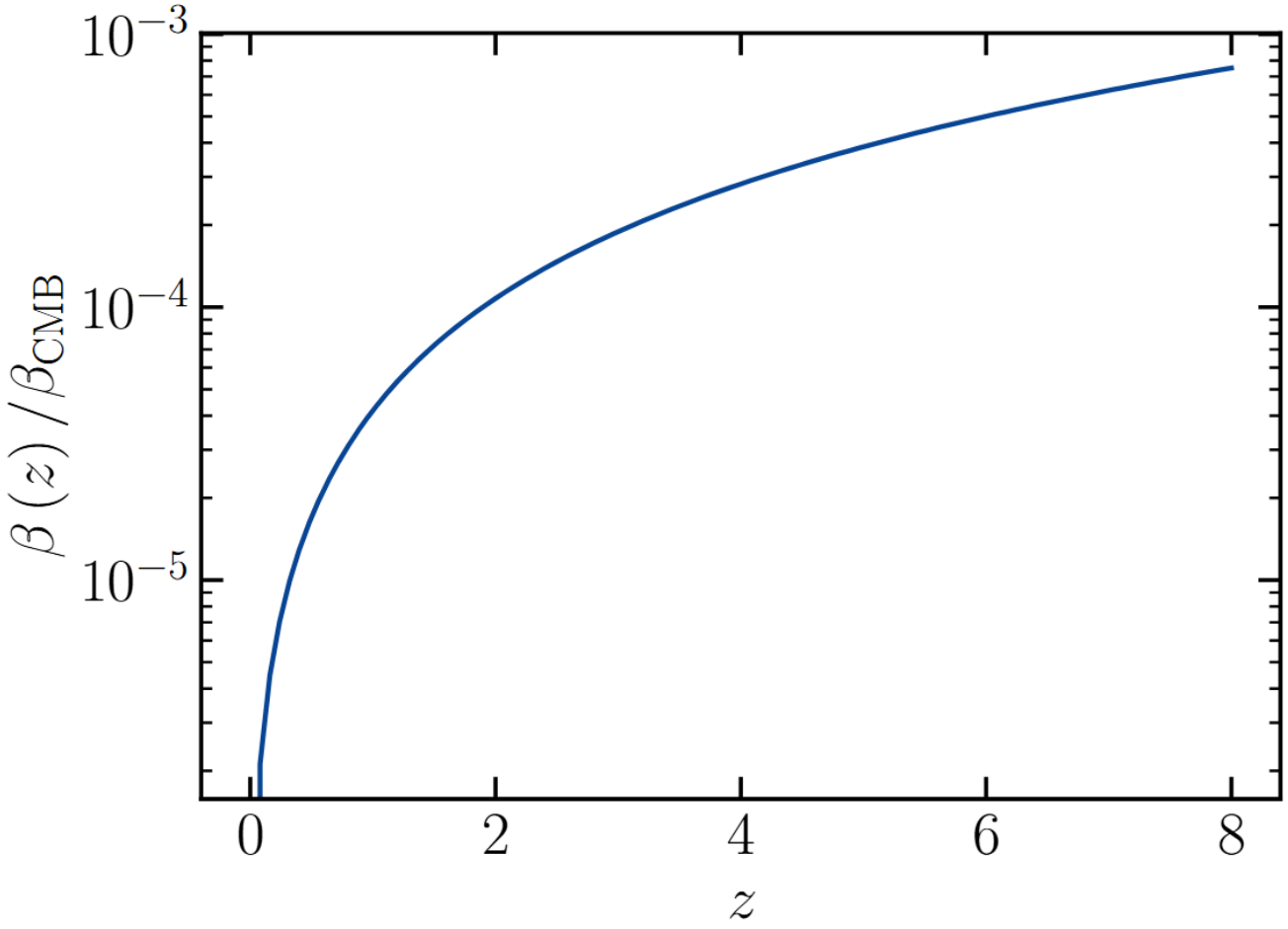


CB of reionization photons

$$\frac{\beta(z)}{\beta_{\rm CMB}} = \frac{\phi_0 - \phi(z)}{\phi_0 - \phi_*} = \frac{\int_z^0 \frac{(1+z')^2}{H(z')}\, dz'}{\int_{z_*}^0 \frac{(1+z')^2}{H(z')}\, dz'}$$

Can be easily distinguished from dark energy!

Prediction for the reionization birefringence angle!



Conclusions

- CB can be explained by a **subdominant stiff axion-like field.**
- The model **will soon be tested!** $3.7 \times 10^{-14}\ \mathrm{GeV}^{-1} < g_{\phi\gamma} < 5.0 \times 10^{-13}\ \mathrm{GeV}^{-1}$
- The model predicts a very **distinctive behavior** of the birefringence angle **at low redshifts**.

THANK YOU!

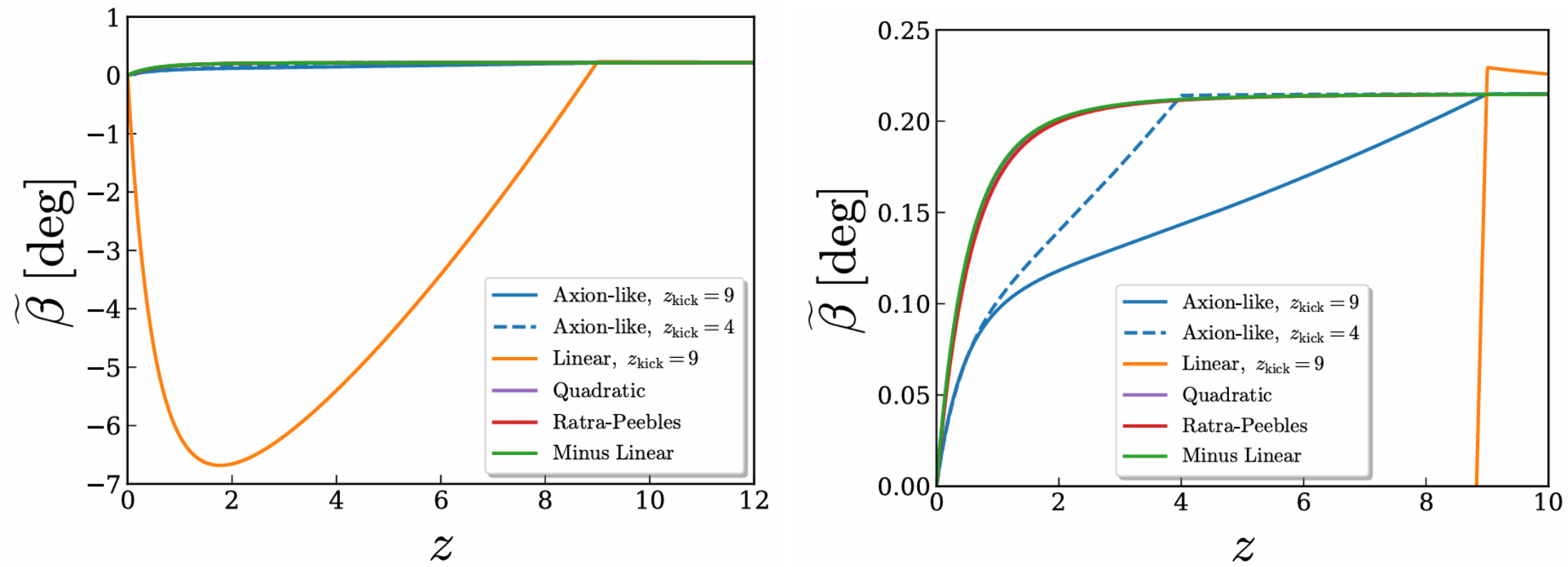
BACKUP

Cosmic Birefringence

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

	WMAP + Planck (September 12, 2022)	ACT (April 14, 2026)	COMBINATION
$\boldsymbol{\beta}$	$0.342^{\circ}{}^{+0.094^{\circ}}_{-0.091^{\circ}}$	$0.215^{\circ} \pm 0.074^{\circ}$	$0.264^{\circ} \pm 0.058^{\circ}$
Statistical significance	3.6σ	2.9σ	4.6σ

CB from axion dark energy



Minotti et al. (2026)