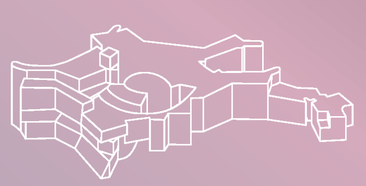


MAX-PLANCK-INSTITUT
FÜR ASTROPHYSIK

Lena Scheuchl

GGI Cosmology Workshop - 10.07.2026

Cosmic Birefringence and Axion Dark Energy

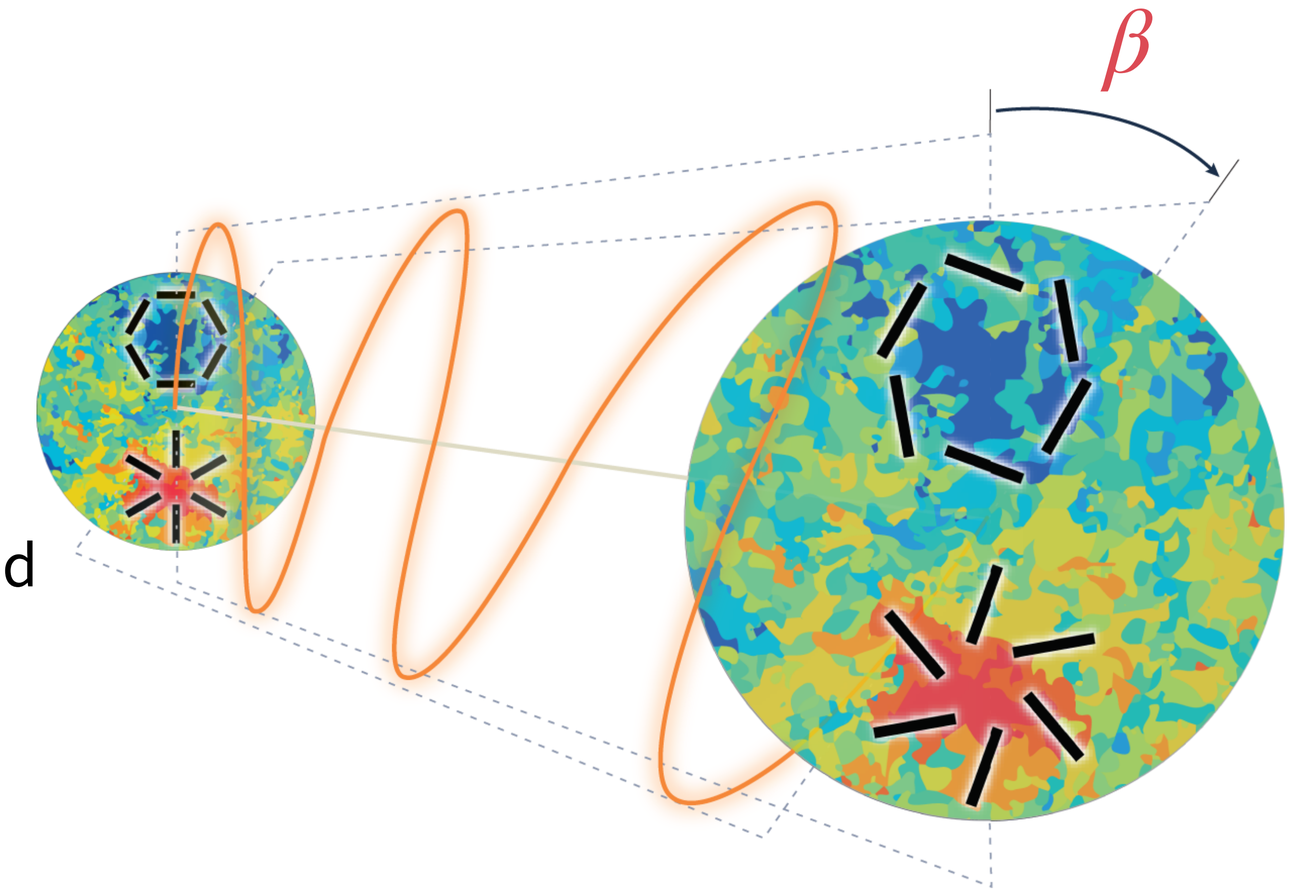
Cosmic Birefringence

Parity violation in the CMB

- Parity transformation $P : x \rightarrow -x$
- Polarization modes of the CMB have opposite parity $P(EB) = -EB$

  $\rightarrow$ their cross-correlation is parity odd
- Non-zero EB for uniform rotation

$$C_\ell^{\mathrm{EB,o}} = \frac{1}{2}\sin(4\beta)\left(C_\ell^{\mathrm{EE}} - C_\ell^{\mathrm{BB}}\right)$$



Credit: Yuto Minami

Cosmic Birefringence

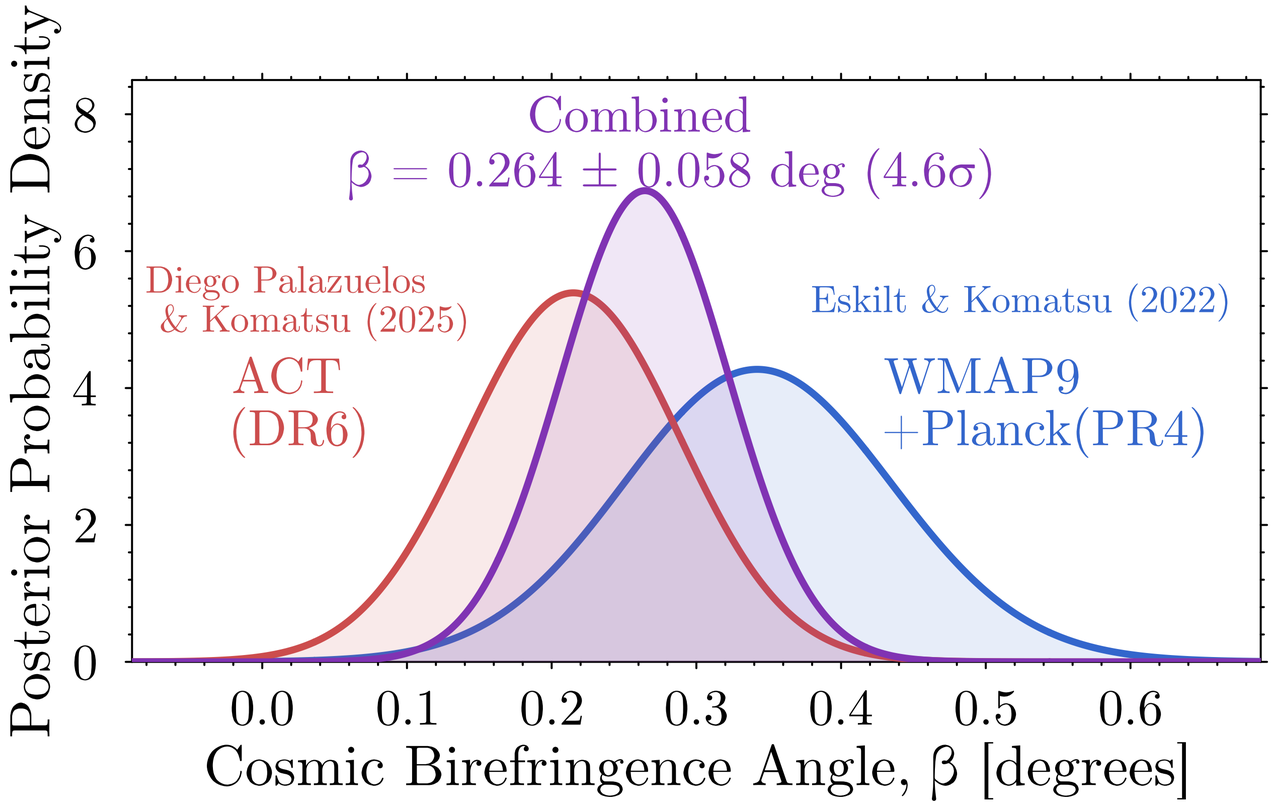
Observational Evidence

Different phase velocity for the two photon helicities:

$$\omega_{\pm} \simeq k \mp \frac{g}{2}\frac{d\phi}{dt}$$

Rotation of linear polarization plane by:

$$\beta(t) = -\frac{1}{2}\int_{t}^{t_0} d\tilde{t}\,(\omega_{+} - \omega_{-})$$



Credit: Eiichiro Komatsu

Cosmic Birefringence

Which models can explain this signal?

Chern-Simons coupling

$$\mathscr{L} \supset -\frac{g}{4}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

non-zero EB-power spectrum

$$C_\ell^{\mathrm{EB,o}} = \frac{1}{2}\sin(4\beta)\left(C_\ell^{\mathrm{EE}} - C_\ell^{\mathrm{BB}}\right)$$

time-dependent birefringence

$$\beta(t) = -\frac{g}{2}\int \frac{\partial\phi}{\partial t}dt$$

Which models can explain this signal?

Time evolution of the pseudo scalar field (axion-like particle, ALP)

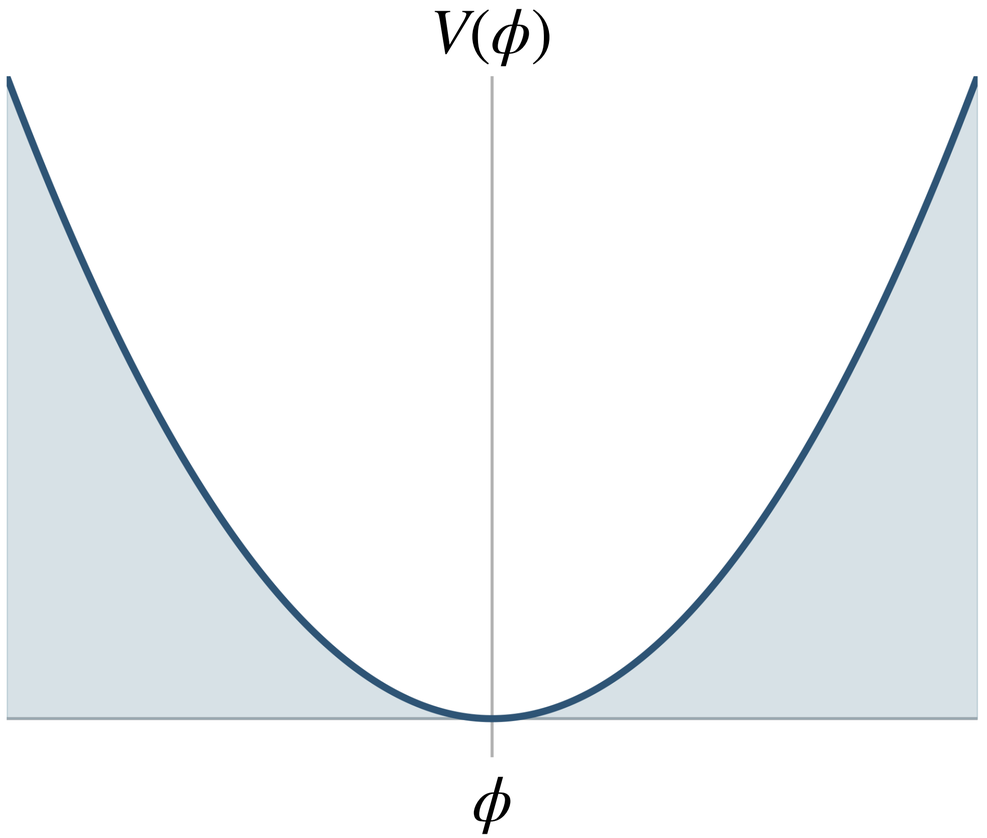
$$\beta(t) = -\frac{g}{2}\int \frac{\partial \phi}{\partial t} dt$$

evolution of the field in potential

$$V(\phi) = \frac{1}{2} m^2 \phi^2$$

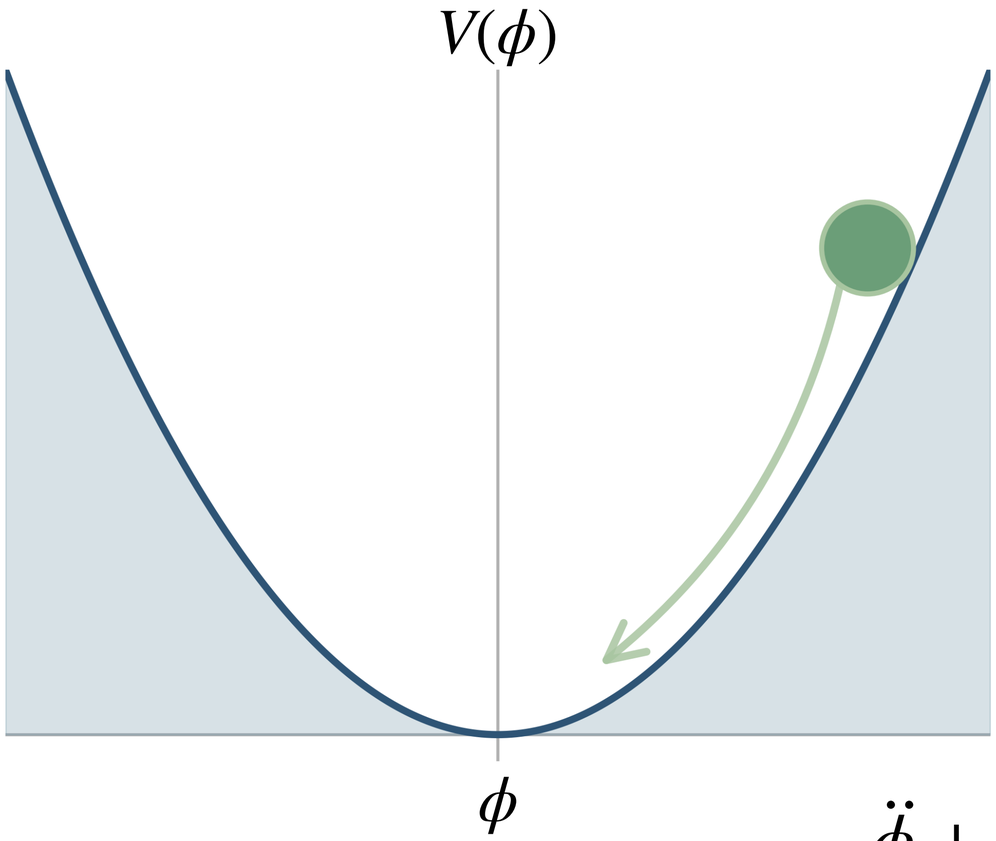
is given by Klein-Gordon-equation

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

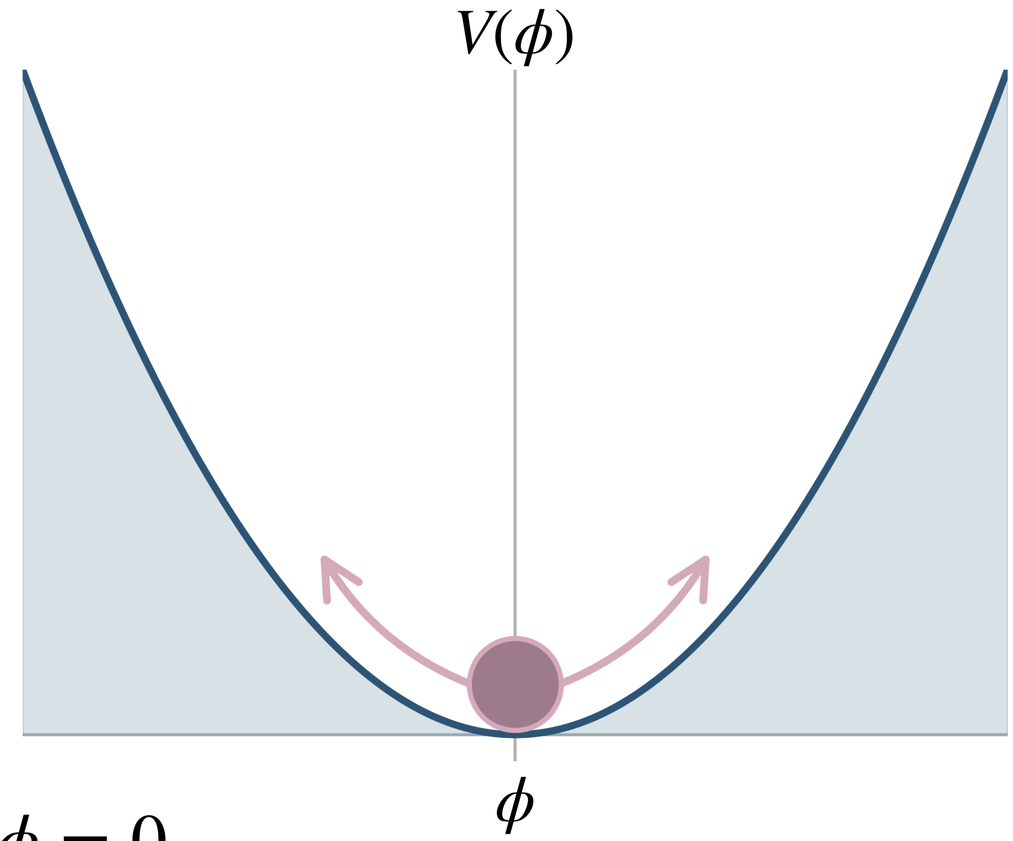


Which models can explain this signal?

Axion Dark Energy



Axion Dark Matter



$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

Axion Dark Energy

Axion Dark Matter

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

overdamped regime

$$m \ll H$$

$$3H\dot{\phi} \simeq -m^2\phi$$

oscillatory regime

$$m \gg H$$

$$\ddot{\phi} + m^2\phi \simeq 0$$

$$w_\phi = \frac{p_\phi}{\rho_\phi}$$

$$= \frac{\langle\dot{\phi}^2\rangle - m^2\langle\phi^2\rangle}{\langle\dot{\phi}^2\rangle + m^2\langle\phi^2\rangle}$$

$$w \approx -1$$

$$w \approx 0$$

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Axion Dark Energy

overdamped regime

$$m \ll H_0$$

$$w \approx -1$$

today

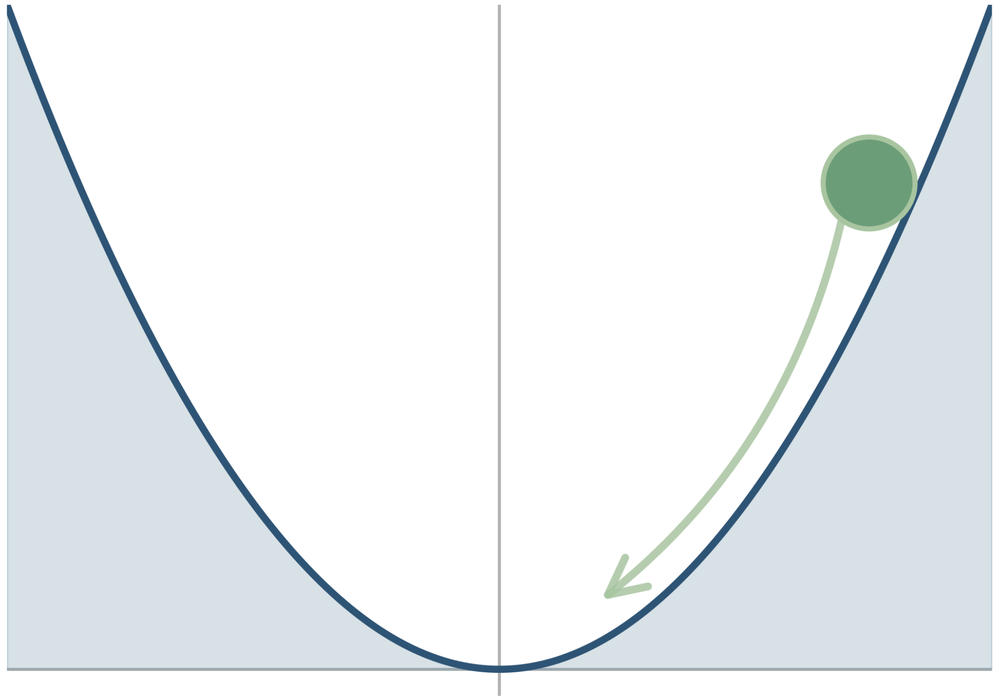
$$H_0 \approx 10^{-33}\text{eV}$$

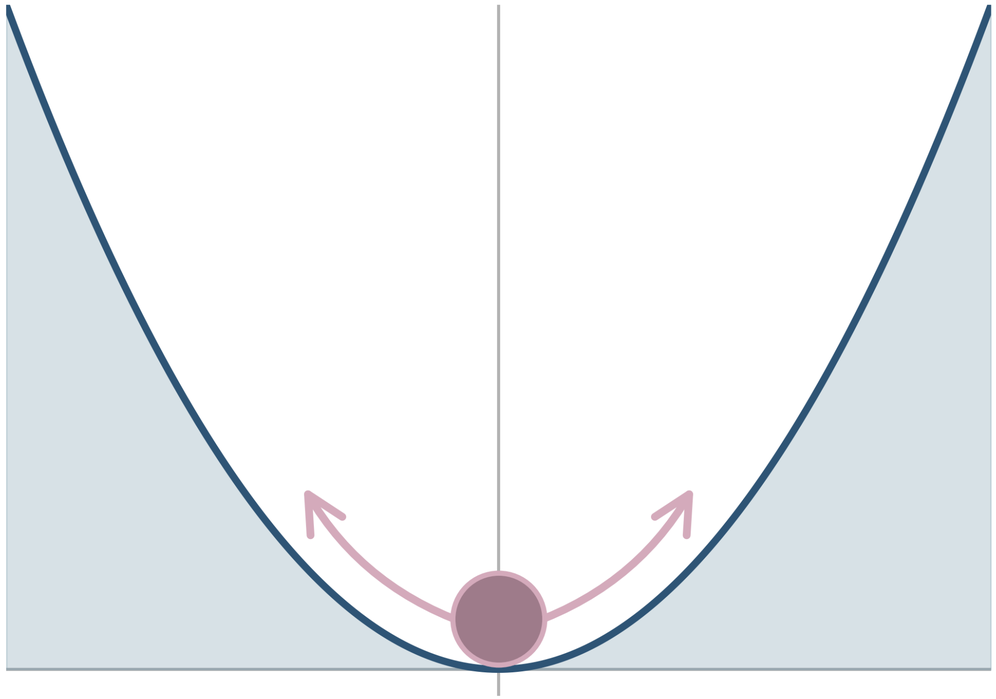
Axion Dark Matter

oscillatory regime

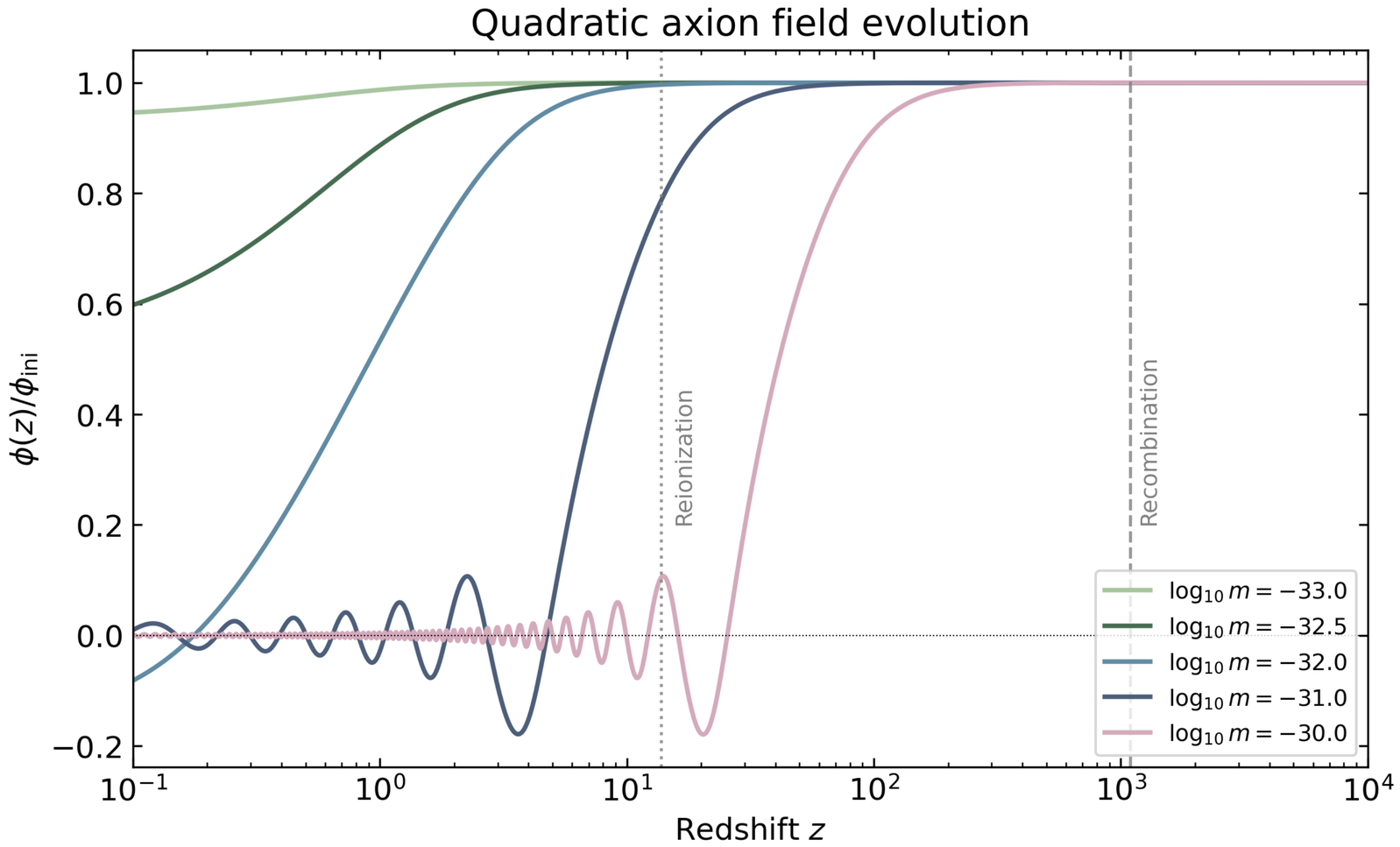
$$m \gg H_0$$

$$w \approx 0$$





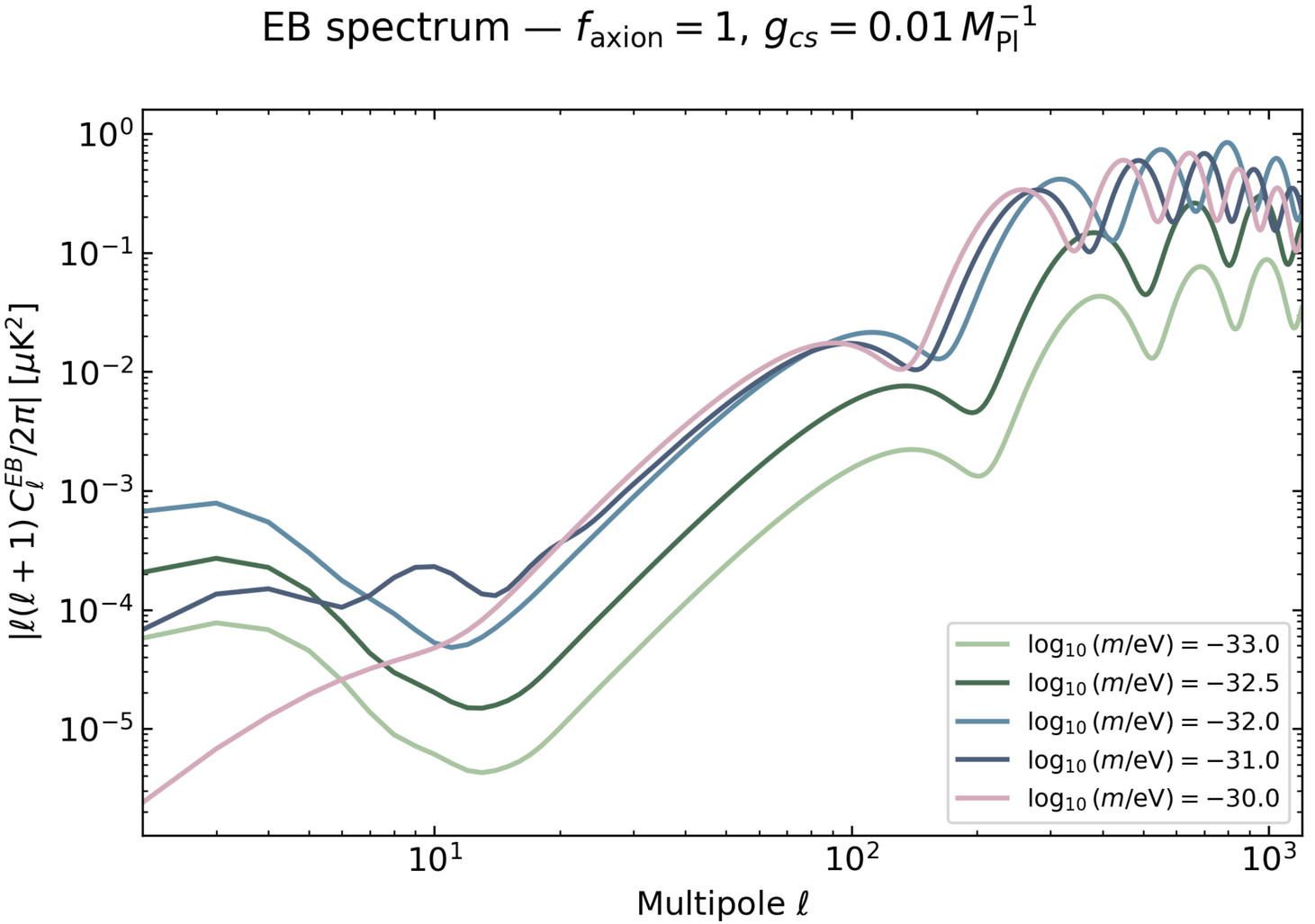
Time evolution of the pseudo scalar field



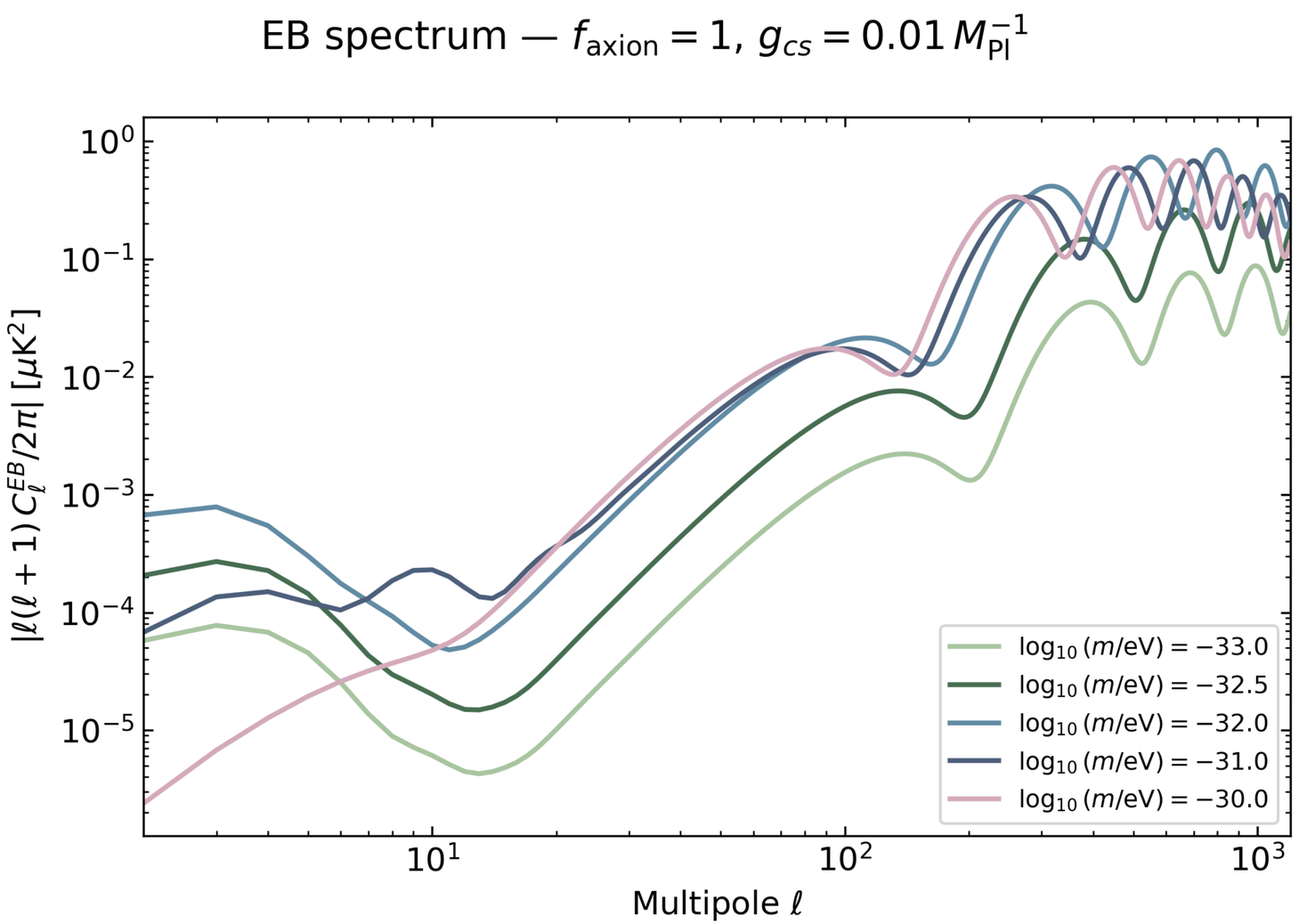
C_ℓ^{EB} predictions

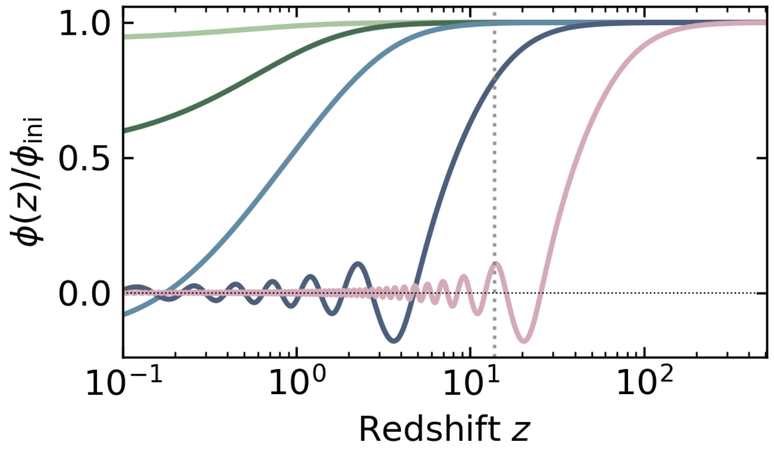
Modification of CLASS:

- Parity odd observables
- Axion contributing to background evolution



C_ℓ^{EB} predictions





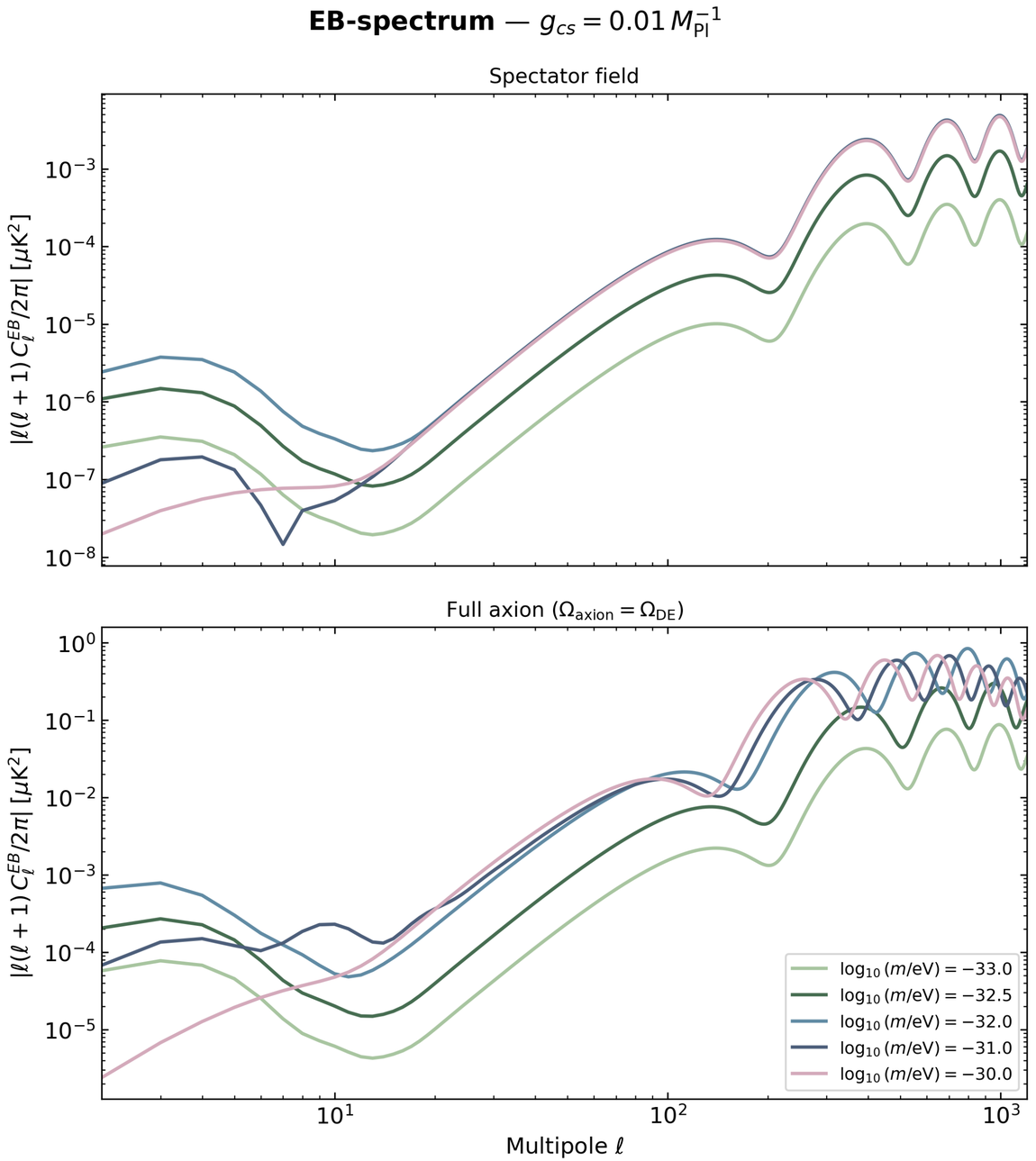
C_ℓ^{EB} predictions

Literature:

- Axion as spectator field

Now:

- Axion contributing to background evolution



Summary

- WMAP, Planck and ACT C_ℓ^{EB} analysis hints for cosmic birefringence
- Axion coupled to electromagnetism provides natural explanation
- Birefringence angle emerges dynamically from the axion field evolution
- Modified CLASS computes cosmological observables self-consistently
- Different axion masses produce distinct spectral features

Thank you!