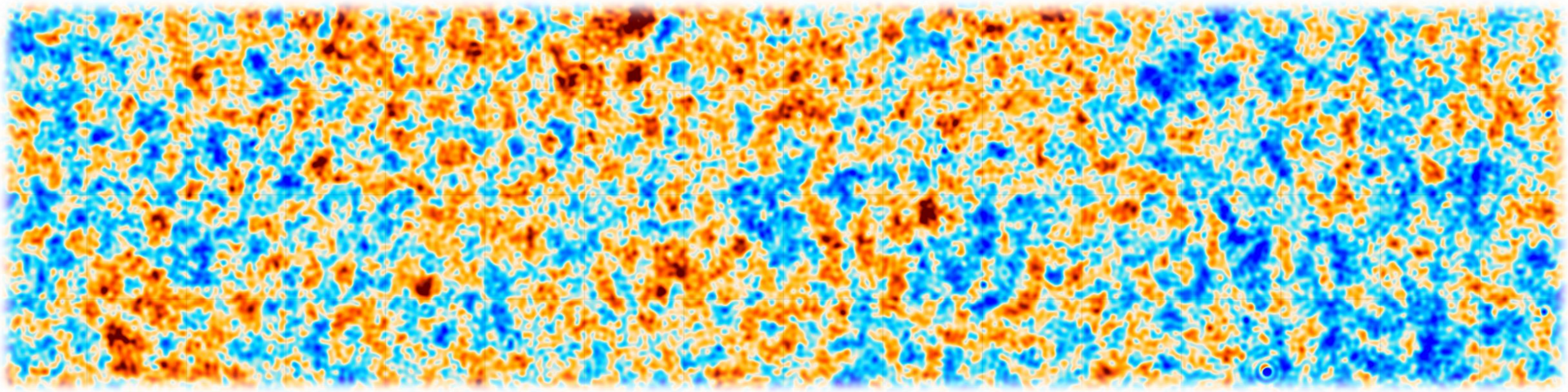


LOOKING FOR COSMIC ALP STRINGS IN CMB DATA

Ray Hagimoto

RICE UNIVERSITY

arXiv:2208.08391

[Published in JCAP 2022]

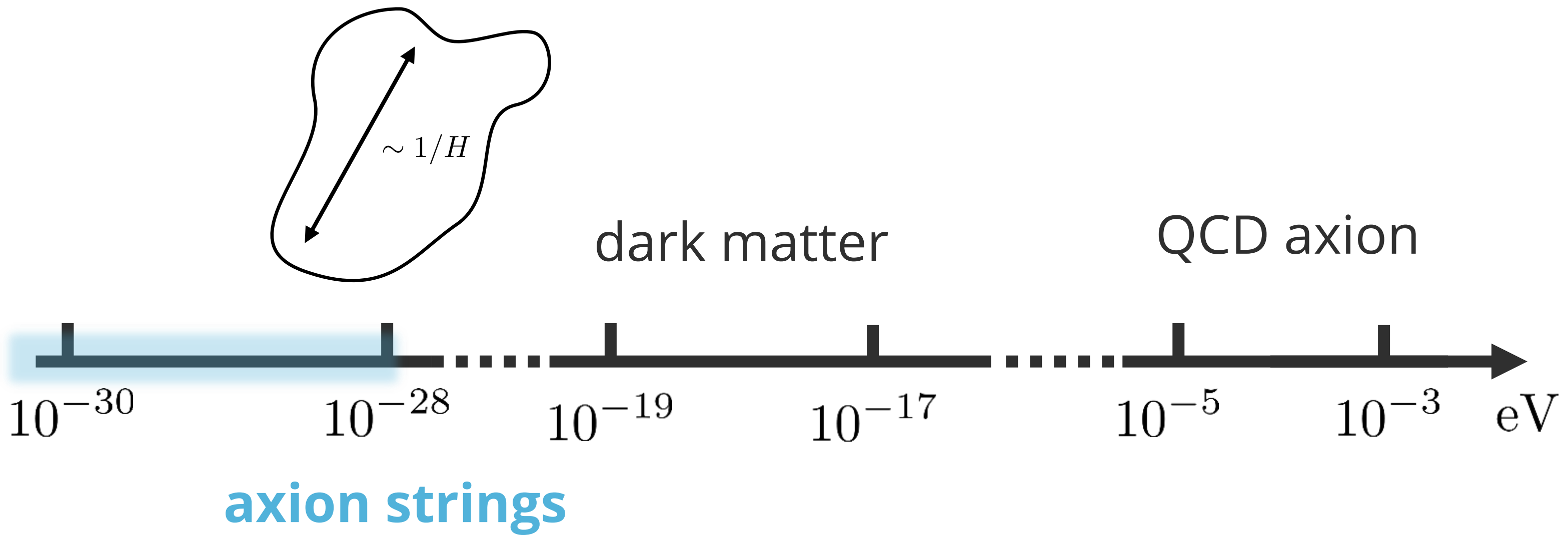
Searching for axion-like particles through CMB birefringence from string-wall networks

Mudit Jain, Ray Hagimoto, Andrew J. Long, Mustafa A. Amin

RICE



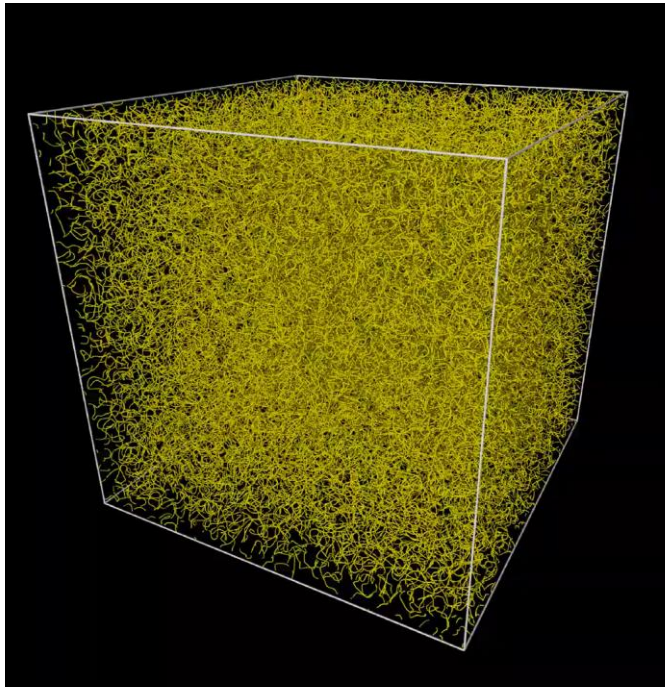

Which ALPs are we considering?



This talk: axion mass $< 3H_{\mathrm{CMB}} \approx 10^{-28}\,\mathrm{eV}$

Axion strings

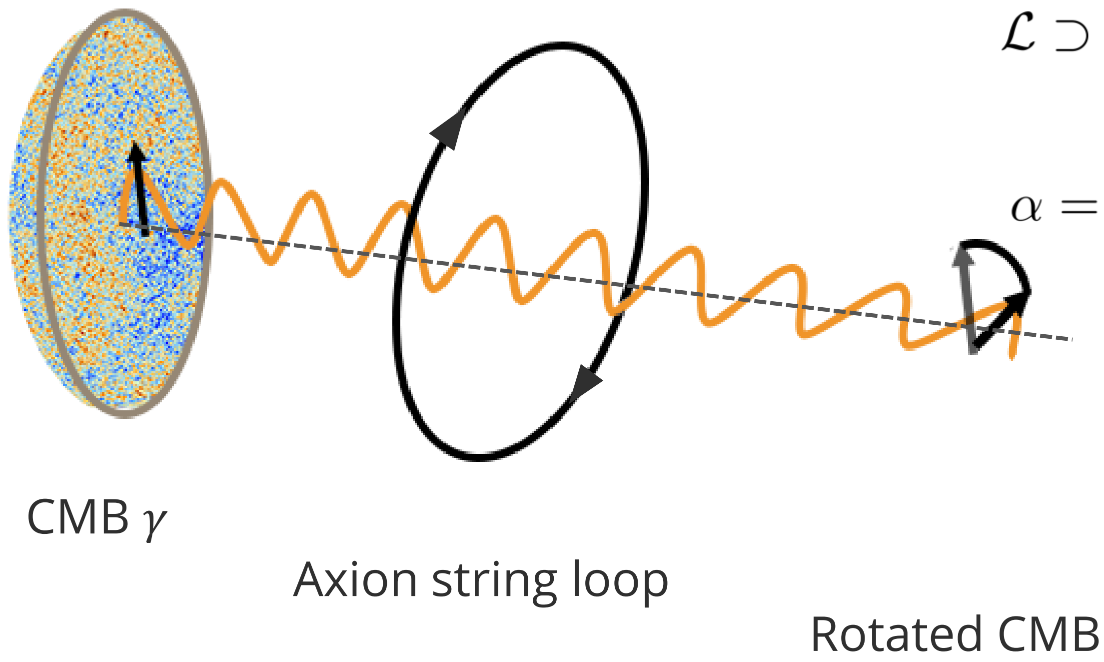
- one-dimensional topological defects in the axion field configuration.
  - formed by a topological phase transition in the early universe.
  - can only survive beyond recombination if $m_a < 3\,H_{CMB} \sim 10^{-28}$ eV*.



M. Buschmann et. al. (arXiv:2108.05368)

* For dark matter axions $m_a > 10^{-19}$ eV so the "hyperlight" axions we consider cannot make up a significant fraction of DM.

Cosmic birefringence



$$\mathcal{L} \supset \frac{\mathcal{A}\alpha_{\rm em}}{4\pi}\frac{a}{f}F\tilde{F}$$
$$\Downarrow$$
$$\alpha = \mathcal{A}\alpha_{\rm em}$$

Agrawal, Hook, and Huang (arXiv:1912.02823)

The Loop Crossing Model

- Simulating string networks is *(very!)* hard
- Approximate birefringence maps $\alpha(\hat{n})$ as a random walk through circular planar loops

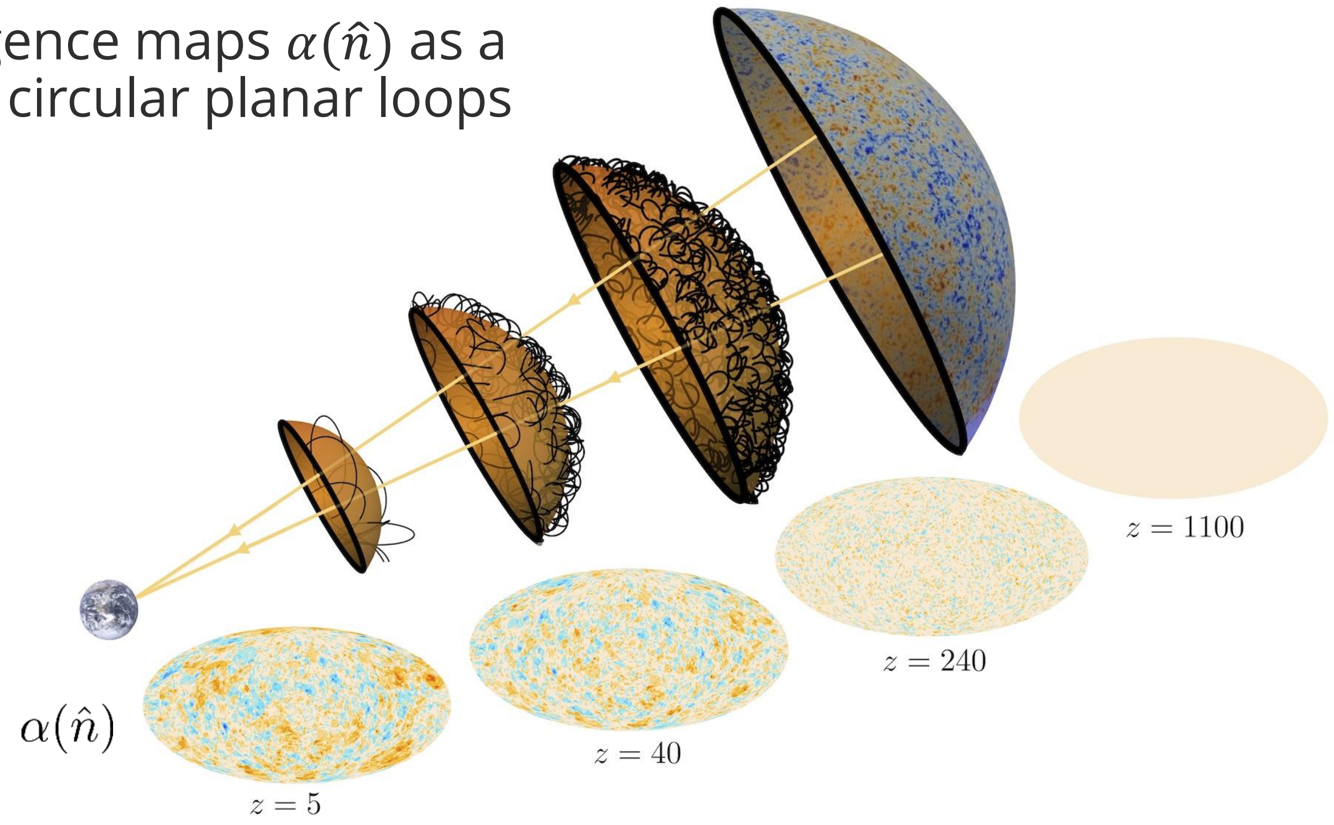
Model parameters:

$\mathcal{A}$ = EM anomaly

ζ_0 = loop radius

ξ_0 = # of loops

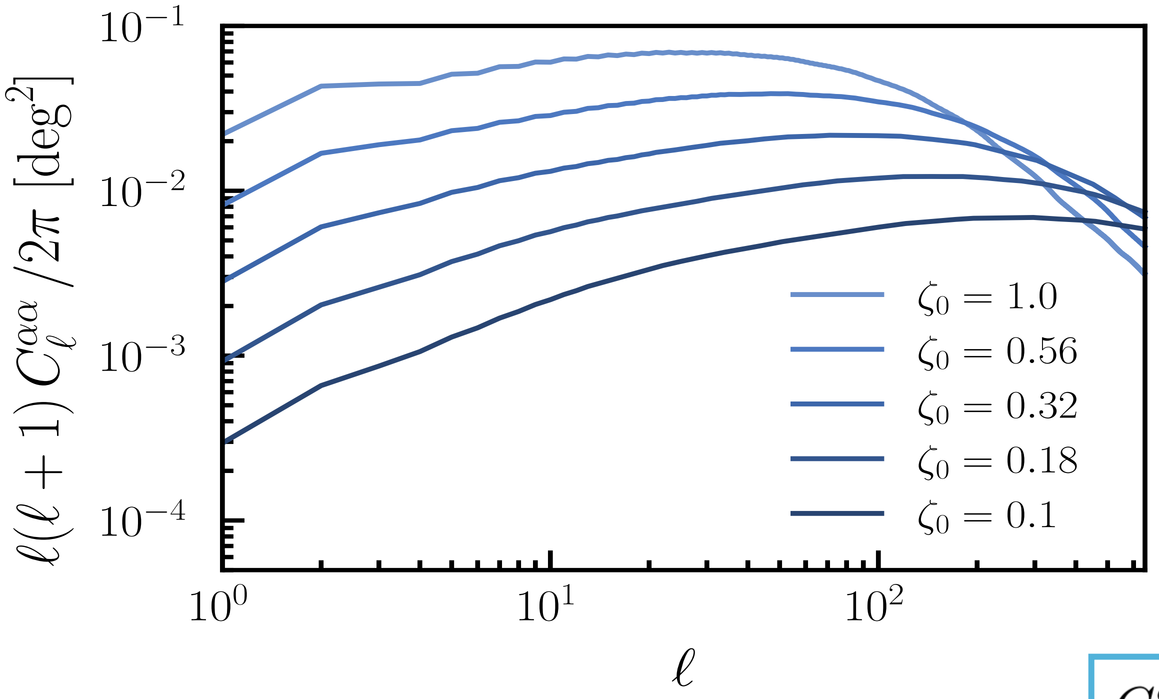
m_a = axion mass



Jain, Amin, Long, RH (arXiv:2103.10962, arXiv:2208.08391)

The Signal

- Calculate the power spectrum of $\alpha(\hat{n})$ maps in the loop crossing model.
- Can compare this to measurements!

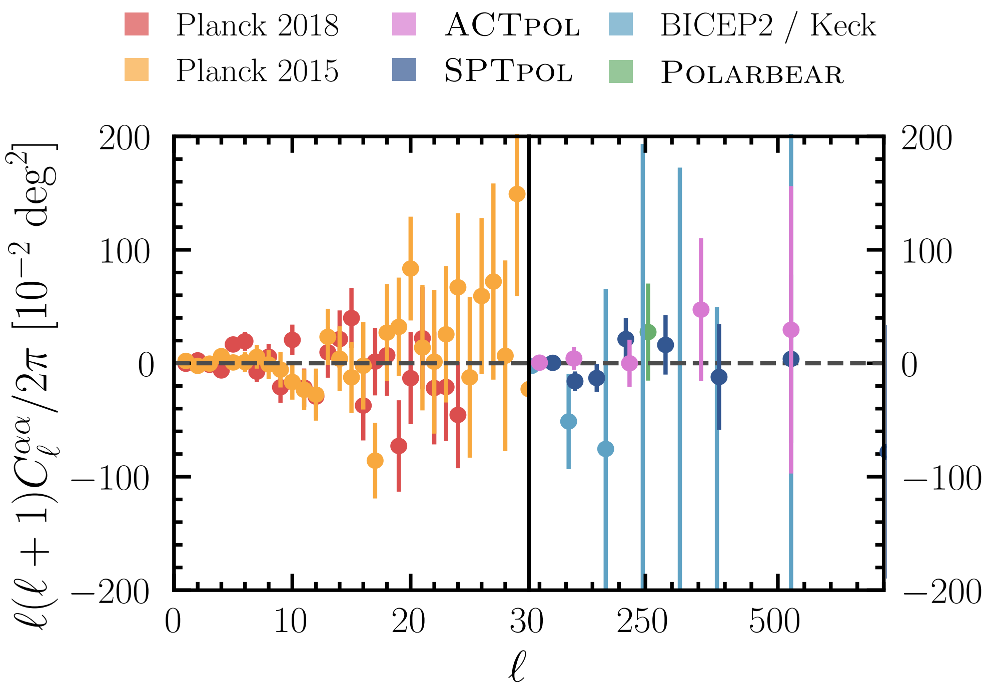


ζ_0 = loop radius
ξ_0 = # of loops

$$\boxed{C_\ell^{\alpha\alpha} \propto \mathcal{A}^2 \xi_0}$$

Cosmic birefringence measurements

Anisotropic birefringence



Isotropic birefringence

$$\alpha = 0.342^{\circ}{}^{+0.094^{\circ}}_{-0.091^{\circ}}$$

Eskilt and Komatsu 2022
Palazuelos et. al. 2022
Minami and Komatsu 2018

1. Can axions explain isotropic and anisotropic birefringence data?
2. What constraints are obtained from anisotropic birefringence?

Bayesian inference

likelihood prior

posterior

$$P(\theta|X,H) = \frac{\mathcal{L}(\theta)P(\theta|H)}{P(X|H)}$$

"which parameters are most favoured?"

evidence

$$\theta = \text{model parameters} = \{\mathcal{A}^2\xi_0, \zeta_0, m_a\}$$

amplitude radius mass

$$X = \text{data} = C_\ell^{\text{obs}}$$

$$H = \text{model/hypothesis}$$

Bayesian inference

Likelihood

$$\ln \mathcal{L}\left(C_\ell^{\mathrm{obs}} | \theta\right) = \sum_\ell -\frac{1}{2\sigma_\ell^2}\left[C_\ell^{\mathrm{obs}} - C_\ell^{\mathrm{theory}}(\theta)\right]^2$$

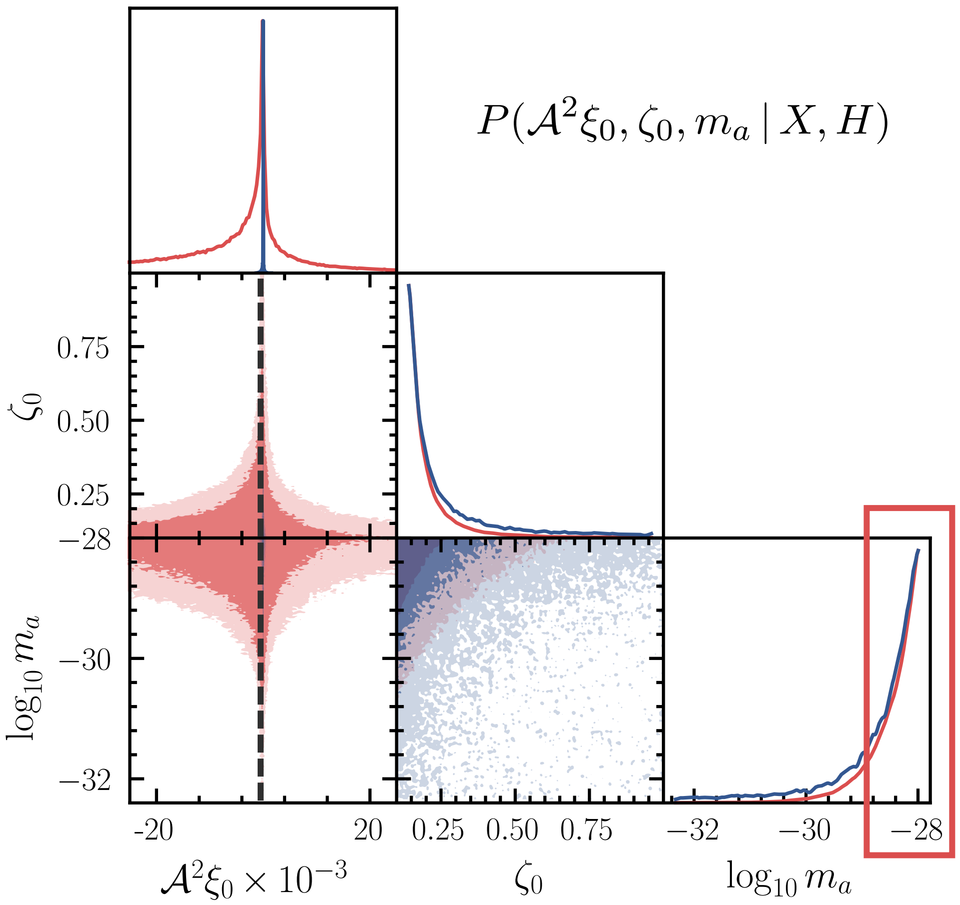
$$\theta = \{\mathcal{A}^2\xi_0, \zeta_0, m_a\}$$

Priors

$$\mathcal{A}^2\xi_0 \sim \mathrm{Uniform}\left(-\infty, \infty\right)$$
$$\zeta_0 \sim \mathrm{Uniform}\left(0.1, 1.0\right)$$
$$\log_{10}\left(m_a/\mathrm{eV}\right) \sim \mathrm{Uniform}(-32.4, -28.0)$$

- We sampled the posterior using MCMC methods
- Obtained parameter constraints

Planck, SPTpol posteriors with 68% and 95% CL contours



95% CL constraints on $\mathcal{A}^2\xi_0$

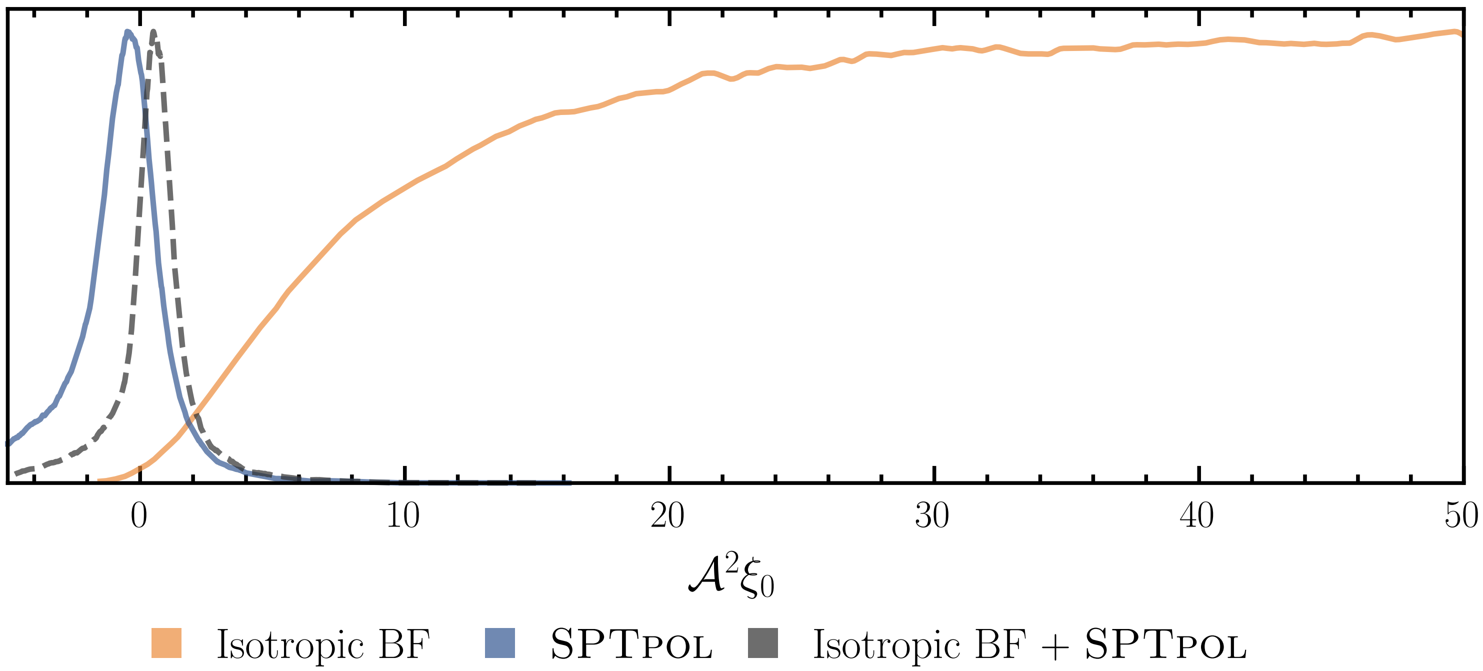
- Planck 2018 $\mathcal{A}^2\xi_0 < 55{,}000$
- SPTpol $\mathcal{A}^2\xi_0 < 390$

Degeneracy direction at $\mathcal{A}^2\xi_0 = 0$

Marginal m_a posterior peaks at upper bound $m_a = 10^{-28}$ eV
(consistent with no signal)

Model parameters:
ζ_0 = loop radius (in units of Hubble length)
ξ_0 = effective # of loops in Hubble vol.

What about isotropic birefringence? $(\alpha = 0.342^{\circ}{}^{+0.094^{\circ}}_{-0.091^{\circ}})$



Conclusion: The *detection* of isotropic bir. + the *non-detection* of anisotropic bir. is difficult to explain with axion-strings.

Summary

- Ultralight axions ($m_a < 10^{-28}$ eV) can form long-lived string networks and may rotate CMB photon polarization (cosmic birefringence.)
- We used Bayesian methods to obtain constraints on axion string network parameters $\text{Planck 2018 } \mathcal{A}^2\xi_0 < 55,000 \quad \text{SPTPOL } \mathcal{A}^2\xi_0 < 390$
- We found that if axion strings can explain the detection of isotropic birefringence, then it is difficult for them to explain the absence of anisotropic birefringence.

Next steps

- Study non-Gaussianity
- Look for evidence of more 'realistic' axion network models
- Ray-tracing of photons through axion network

DISTINGUISHING SOURCES OF B-MODES

Other sources of B-modes include:

Weak gravitational lensing

Leads to parity-conserving correlators; hence distinguishable from axion birefringence.

Primordial gravitational waves

In most models, PGWs conserve parity. However, even in models which induce parity-violating correlations. In this case the scale-dependence of correlators, and higher-order correlators could distinguish sources.

Faraday rotation

This effect is frequency-dependent, whereas axion birefringence is not.

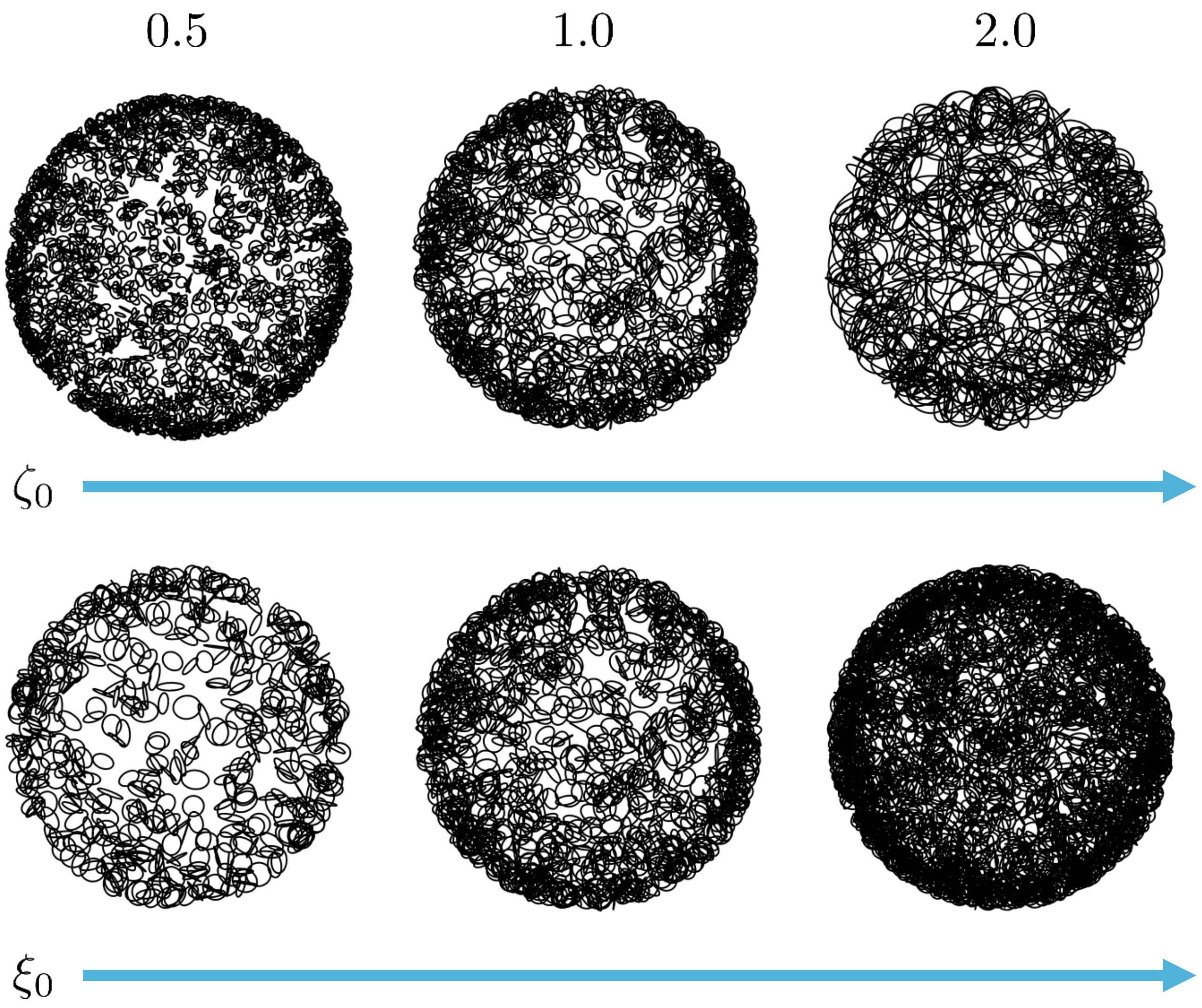
Model parameters

loop radius $= \zeta_0 / H(z)$

string tension

energy density $= \xi_0 \mu H^2$

number density $= \dfrac{\xi_0 H^3}{2\pi\zeta_0}$



$\alpha(\hat{n})$ reconstruction

- E.g. can estimate using E and B-mode measurements
- (tildes denote primordial quantities (before birefringence)

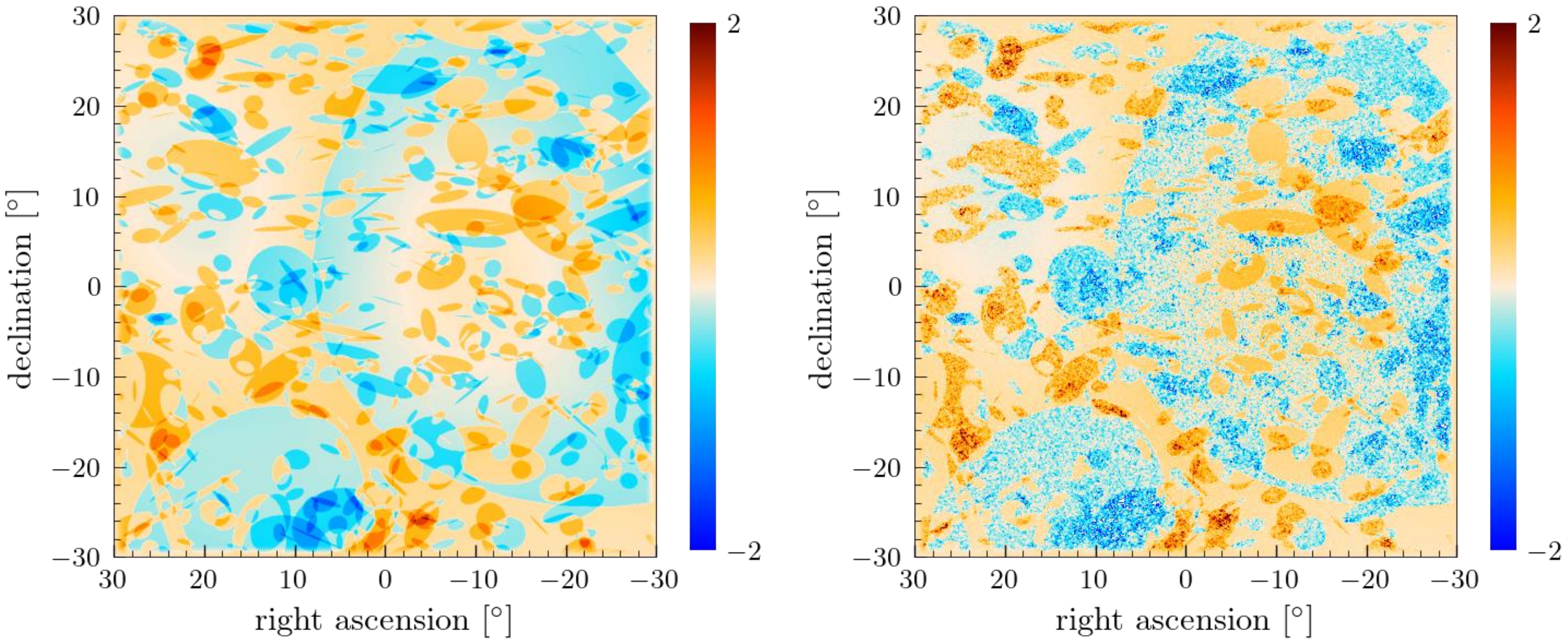
$$\boxed{\hat{\alpha}_{EB}(\mathbf{L}) = \int \frac{\mathrm{d}^2\mathbf{l}_1 \mathrm{d}^2\mathbf{l}_2}{(2\pi)^2} \delta(\mathbf{l}_1 - \mathbf{l}_2 - \mathbf{L}) E(\mathbf{l}_1) B^*(\mathbf{l}_2) F_{EB}(\mathbf{l}_1, \mathbf{l}_2)}$$

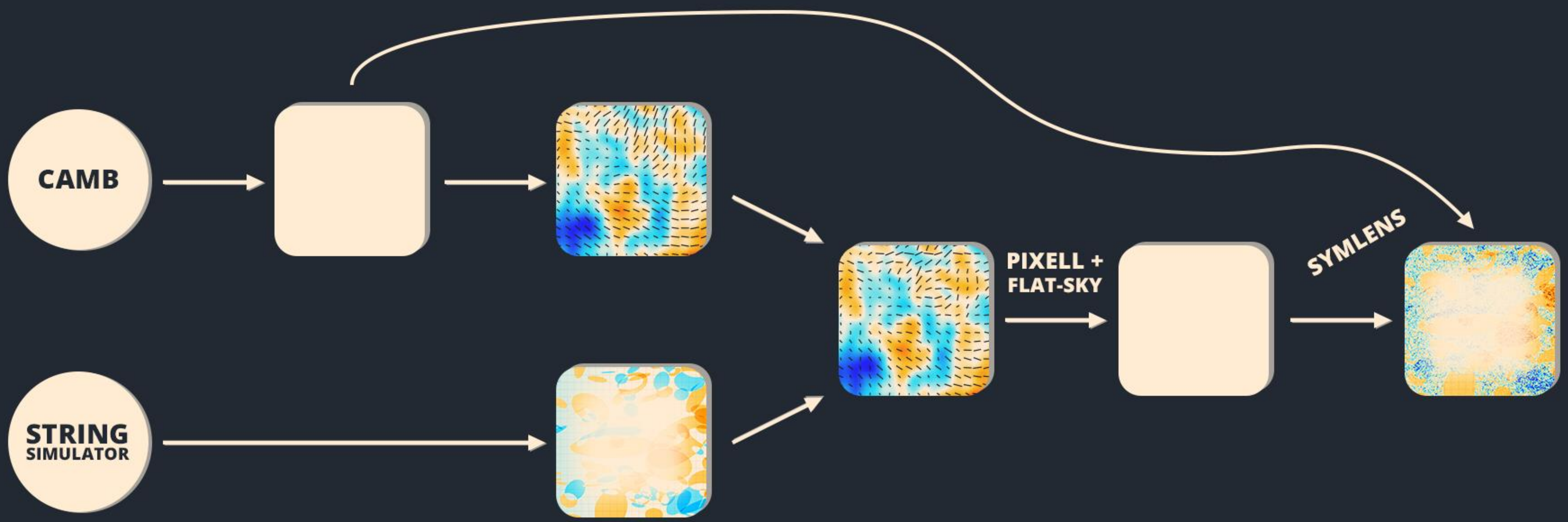
$$F_{EB}(\mathbf{l}_1, \mathbf{l}_2) = \lambda_{EB}(\mathbf{L}) \frac{2\left(\tilde{C}_{l_1}^{EE} - \tilde{C}_{l_2}^{EE}\right)\cos 2\phi_{12}}{C_{l_1}^{EE} C_{l_2}^{BB}}$$

$$[\lambda_{EB}(\mathbf{L})]^{-1} = \int \frac{\mathrm{d}^2\mathbf{l}_1 \mathrm{d}^2\mathbf{l}_2}{(2\pi)^2} \delta(\mathbf{l}_1 - \mathbf{l}_2 - \mathbf{L}) \frac{\left[2\left(\tilde{C}_{l_1}^{EE} - \tilde{C}_{l_2}^{EE}\right)\cos 2\phi_{12}\right]^2}{C_{l_1}^{EE} C_{l_2}^{BB}}$$

Yin, Dai, Ferraro (arXiv:2111.12741)

$\alpha(\hat{n})$ reconstruction




CAMB
STRING SIMULATOR
PIXELL + FLAT-SKY
SYMLENS

Non-gaussianity