CMB birefringence from axion string-wall networks

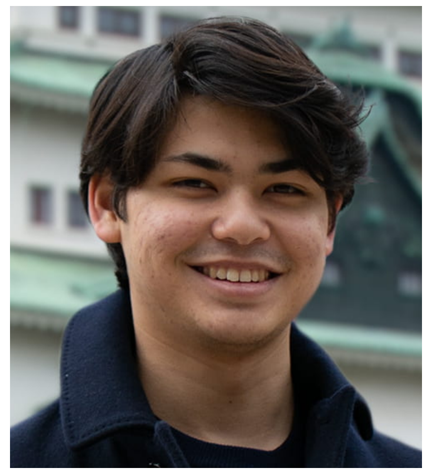
Mudit Jain
(Rice University)

Based on:

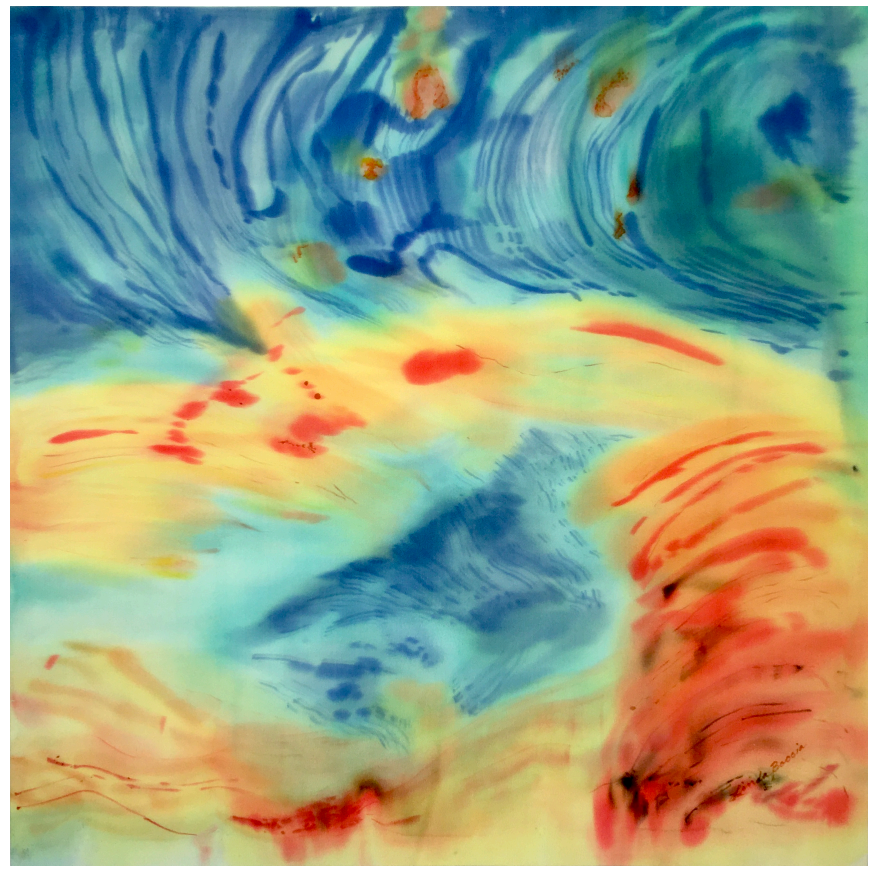
"CMB birefringence from ultralight-axion string networks",
M.J., Andrew J. Long, and Mustafa A. Amin JCAP05(2021)055

"Searching for axion-like particles through CMB birefringence from string-wall networks",
M.J., Ray Hagimoto, Andrew J. Long, and Mustafa A. Amin arXiv:2208.08391

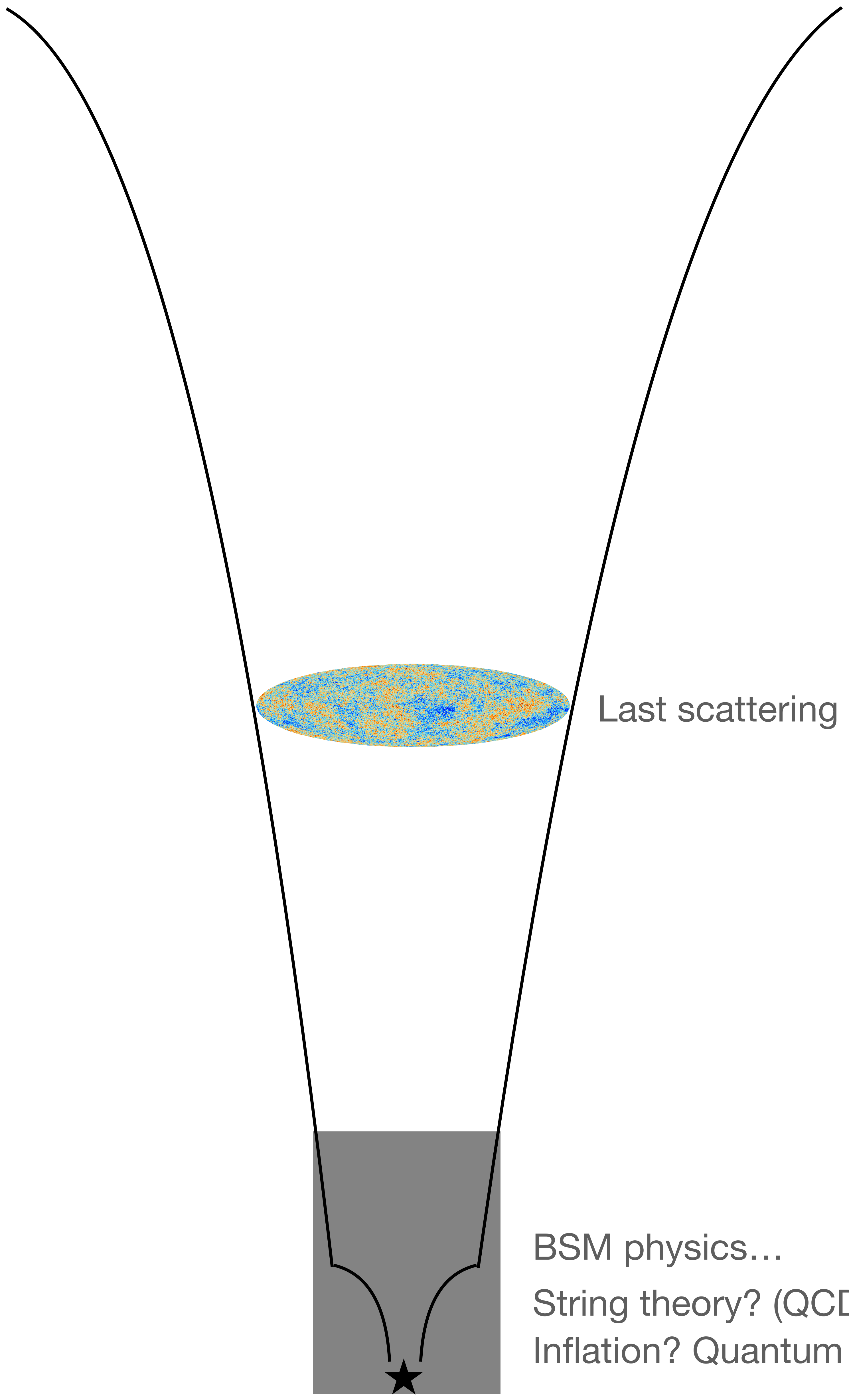
fresh from the oven!



CMB-S4 SUMMER 2022



OUTLINE



Today $H_0 \sim 10^{-33}\,\mathrm{eV}$

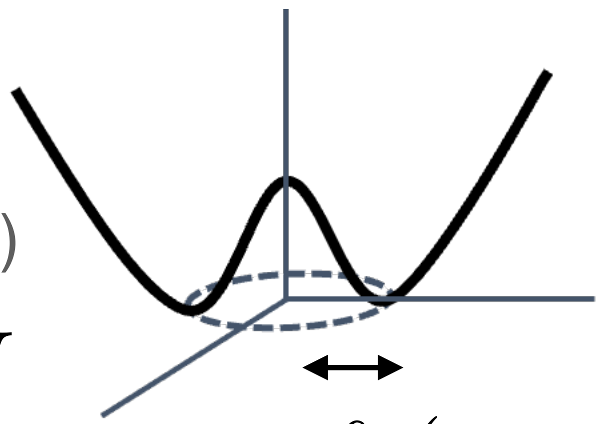
Last scattering surface $H_{\mathrm{cmb}} \sim 10^{-28}\,\mathrm{eV}$

BSM physics…

String theory? (QCD axion, axion like particles (ALPs))

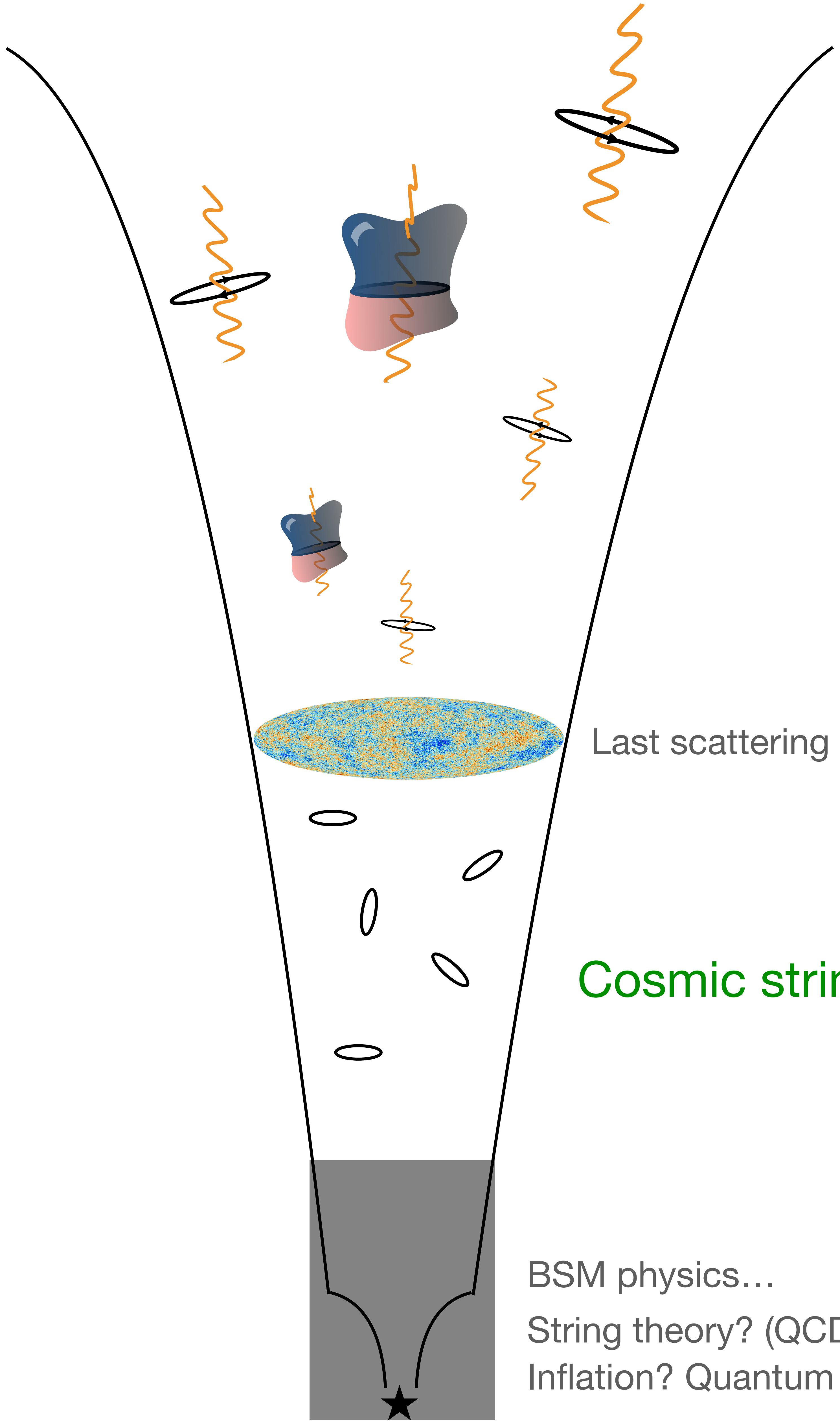
Inflation? Quantum gravity? etc.

$m_a \lesssim 10^{-33}\,\mathrm{eV}$



$f_a(\text{usually } \gtrsim 10^{10}\ \mathrm{GeV})$

OUTLINE



Today $H_0 \sim 10^{-33}\,\mathrm{eV}$

Anomaly coefficient (charges of heavy/UV particles)

Coupling to electromagnetism: $\frac{\mathcal{A}\alpha_{em}}{4\pi f_a} aF\tilde{F}$ → CMB birefringence

Last scattering surface $H_{\mathrm{cmb}} \sim 10^{-28}\,\mathrm{eV}$

$\alpha = \pm \mathcal{A}\alpha_{em}$

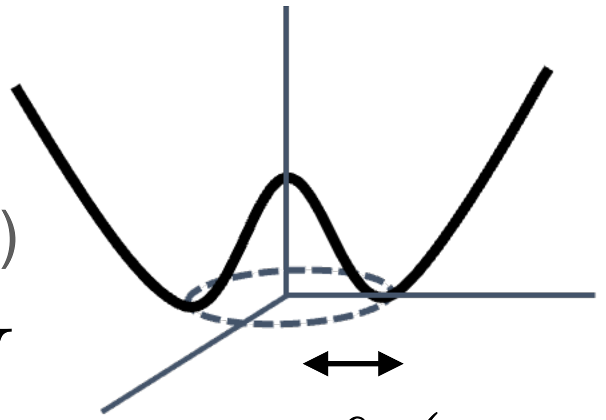
independent of f_a!

Cosmic string / string-wall network

Search for ALPs
using CMB polarization measurements

BSM physics…
String theory? (QCD axion, axion like particles (ALPs))
Inflation? Quantum gravity? etc.

$m_a \lesssim 10^{-33}\,\mathrm{eV}$



$f_a (\text{usually} \gtrsim 10^{10}\ \mathrm{GeV})$

DEFECT NETWORKS

Networks that survive till today

Size of loops in units of H^{-1}

$$C_\ell^\alpha \approx \mathcal{A}^2 \xi_0 \, \text{Shape}(\zeta_0)$$

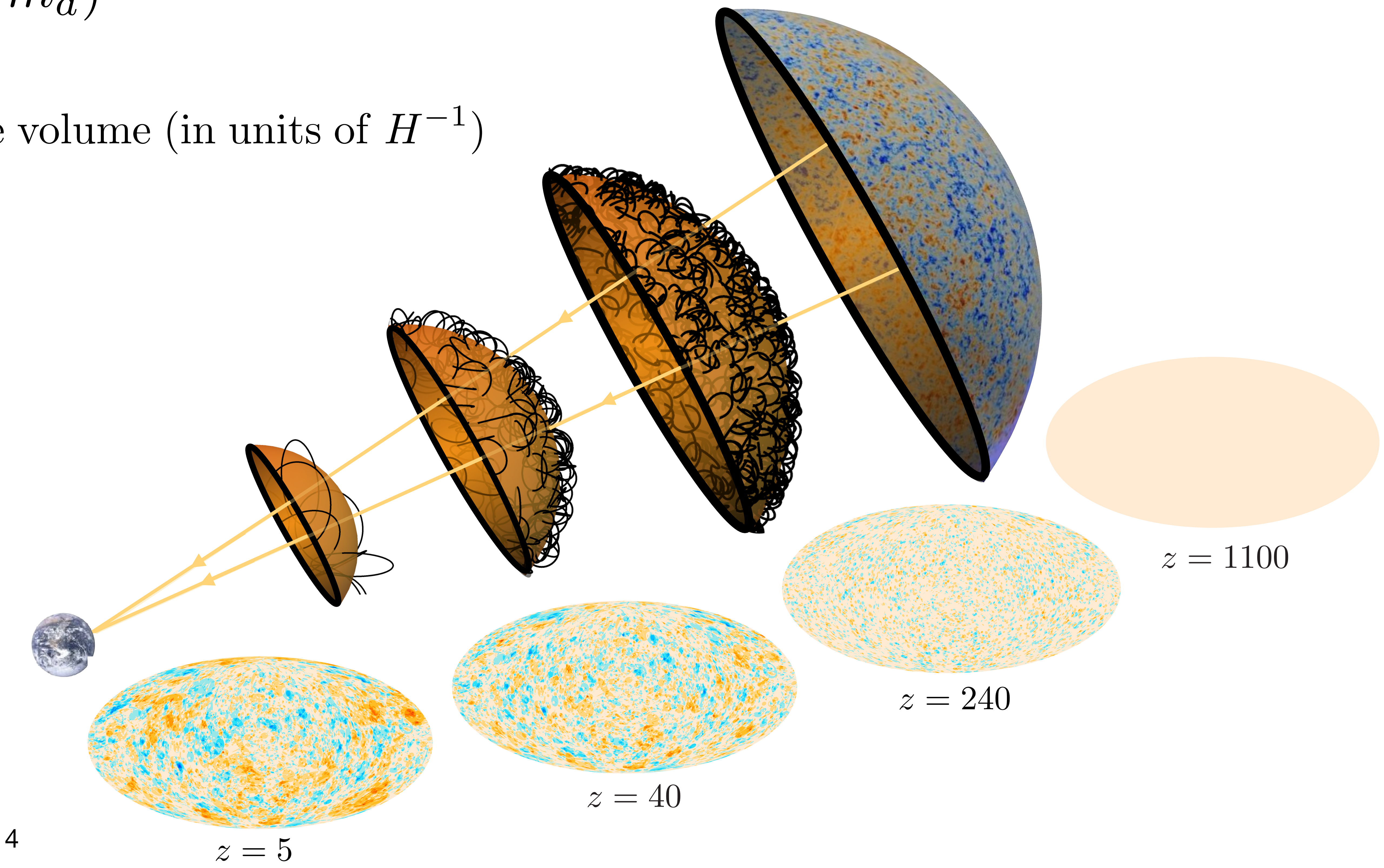
Networks that collapse in between

$$C_\ell^\alpha \approx \mathcal{A}^2 \xi_0 \, \text{Shape}(\zeta_0, m_a)$$

Total length of string in a a Hubble volume (in units of H^{-1})

$$3H_{\rm cmb} \gtrsim m_a \gtrsim 3H_0$$

$$N_{\rm dw} = 1$$



Theory expectation

$$\xi_0 \sim \mathcal{O}(1 - 100) \qquad \mathcal{A} \sim \mathcal{O}(0.1 - 1) \qquad \zeta_0 \sim \mathcal{O}(0.1 - 1)$$

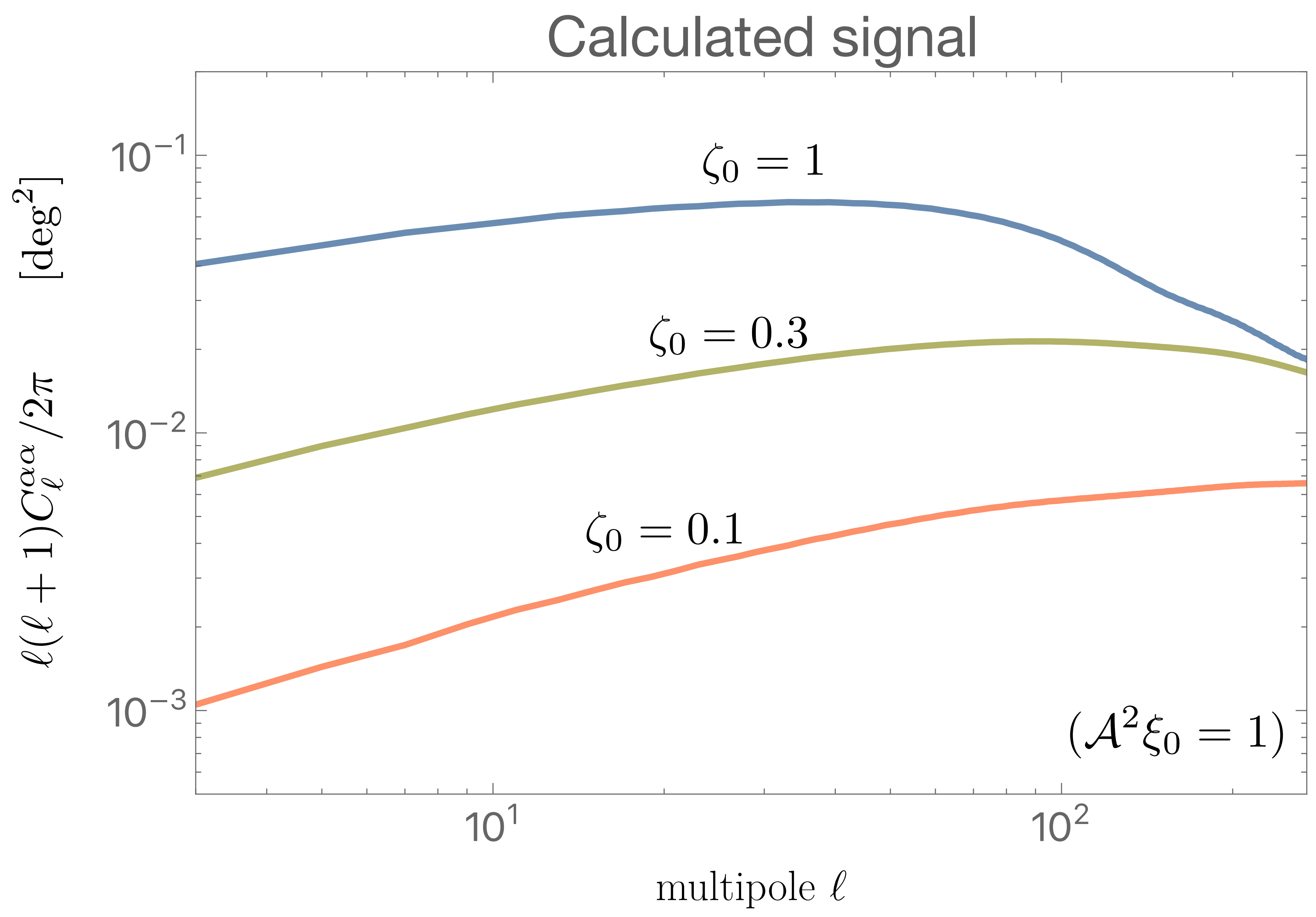
Networks that survive till today

Amplitude

Size of loops in units of H^{-1}

$$C_\ell^\alpha \approx \mathcal{A}^2 \xi_0 \, \text{Shape}(\zeta_0)$$

$\xi_0 =$ Total length of string in a a Hubble volume (in units of H^{-1})



Networks that survive till today

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Size of loops in units of H^{-1}

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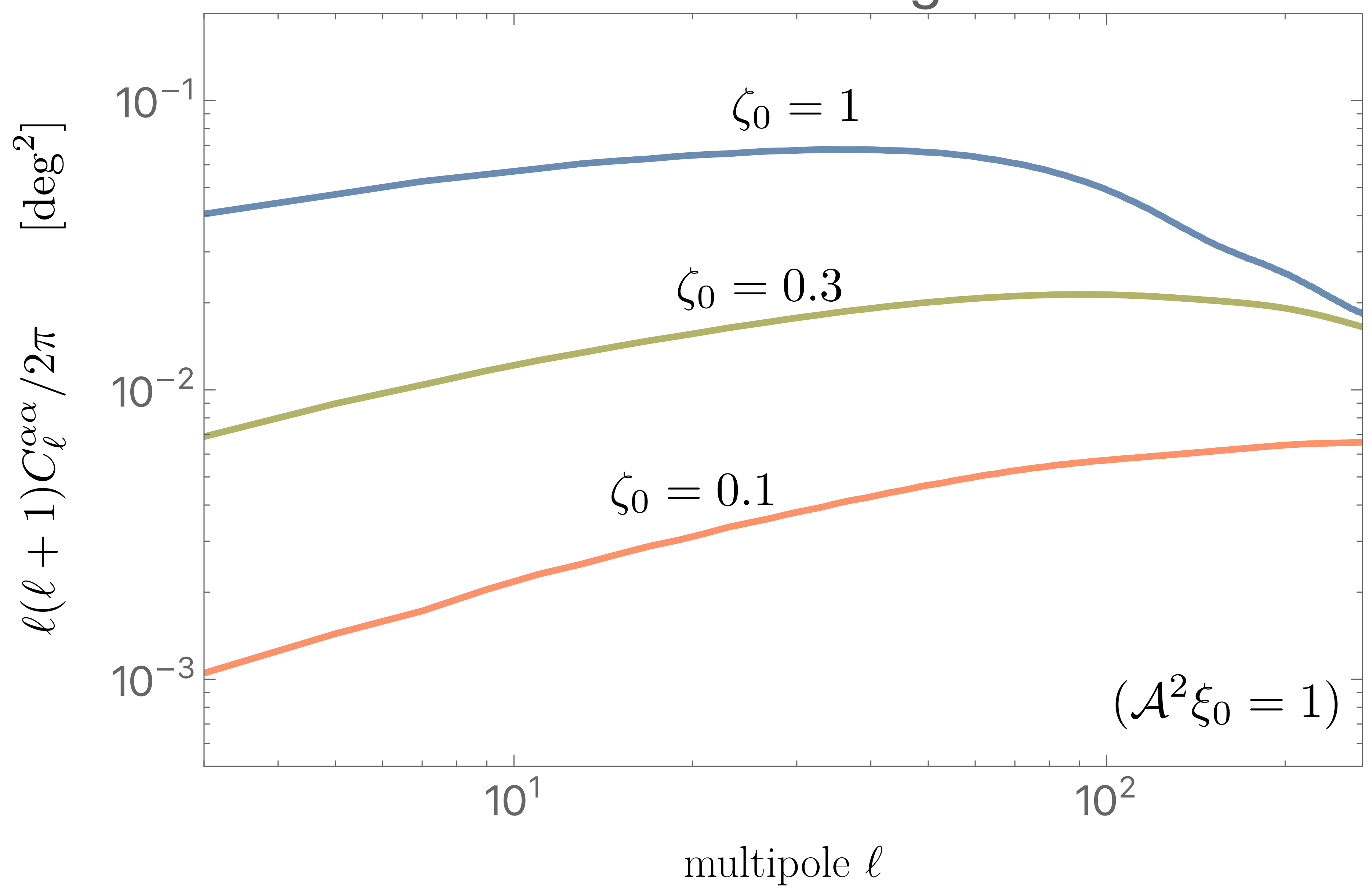
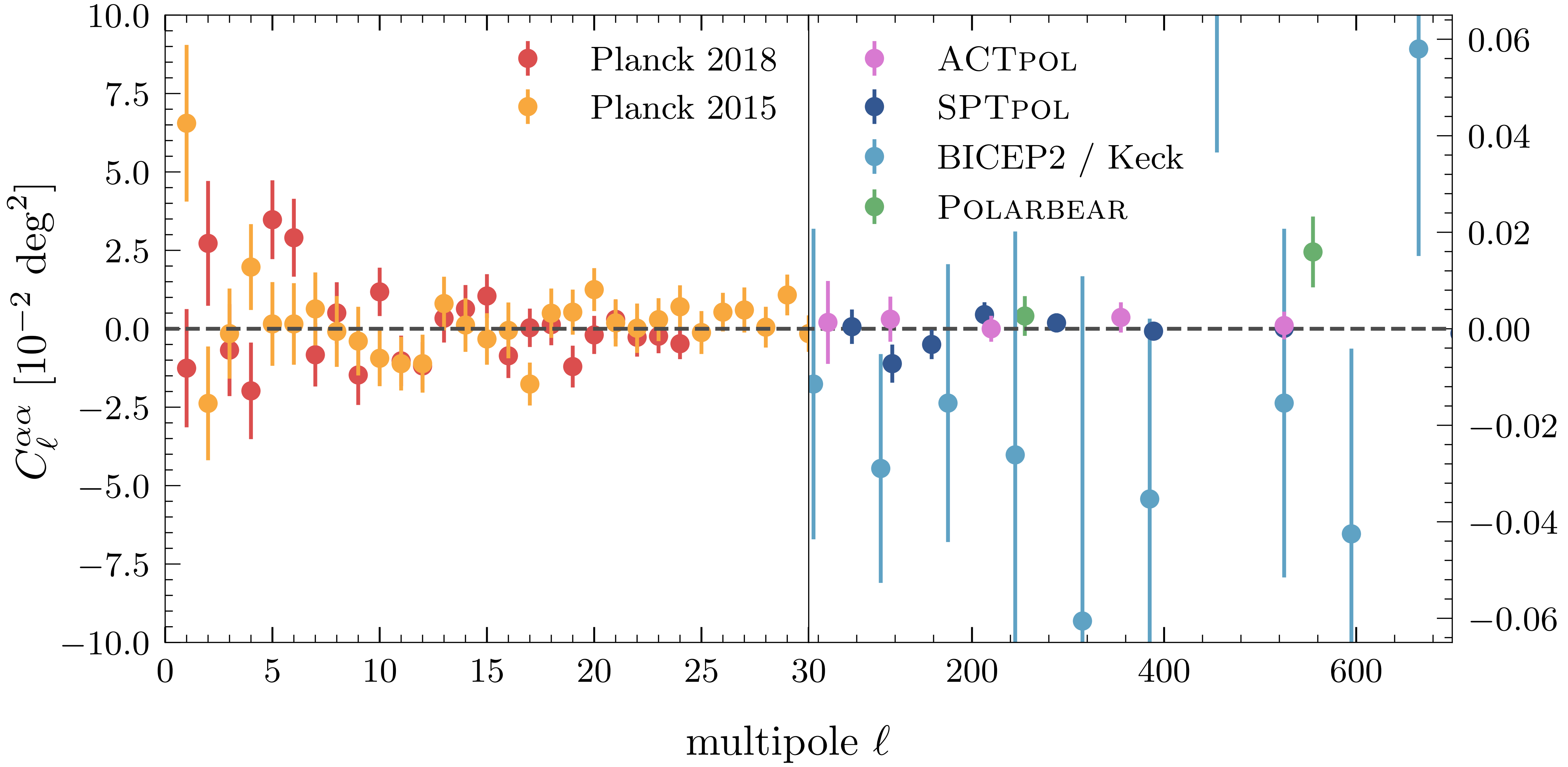
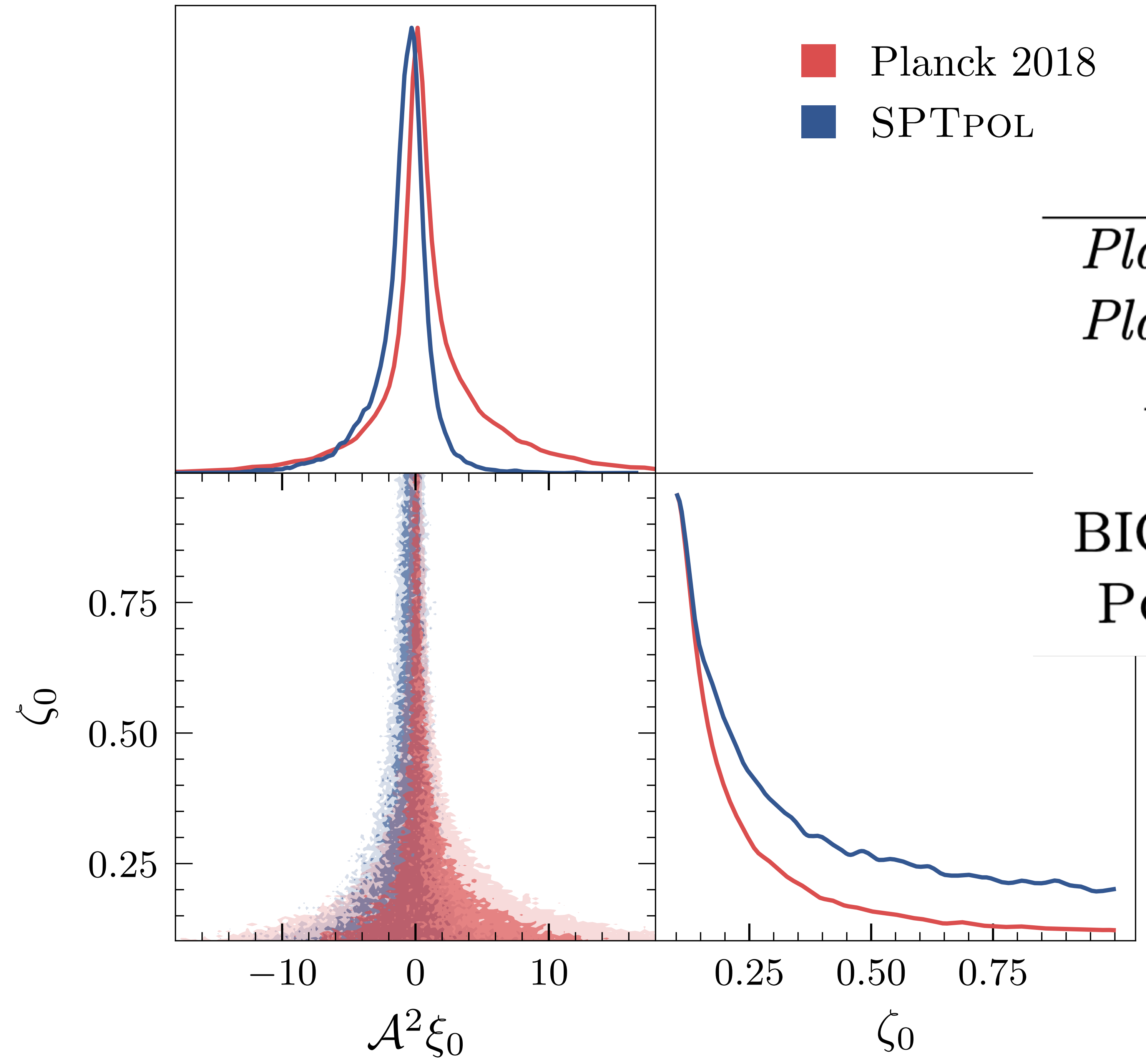
Calculated signal



(Processed-) Data



Result



	stable strings
Planck (2015):	$\mathcal{A}^2\xi_0 < 13$
Planck (2018):	$\mathcal{A}^2\xi_0 < 13$
ACTPOL:	$\mathcal{A}^2\xi_0 < 7.1$
SPTPOL:	$\mathcal{A}^2\xi_0 < 3.7$
BICEP2/*Keck*:	$\mathcal{A}^2\xi_0 < 11$
POLARBEAR:	$\mathcal{A}^2\xi_0 < 81$

$(\mathcal{A}^2\xi_0 \geq 0)$

Networks that collapse in between

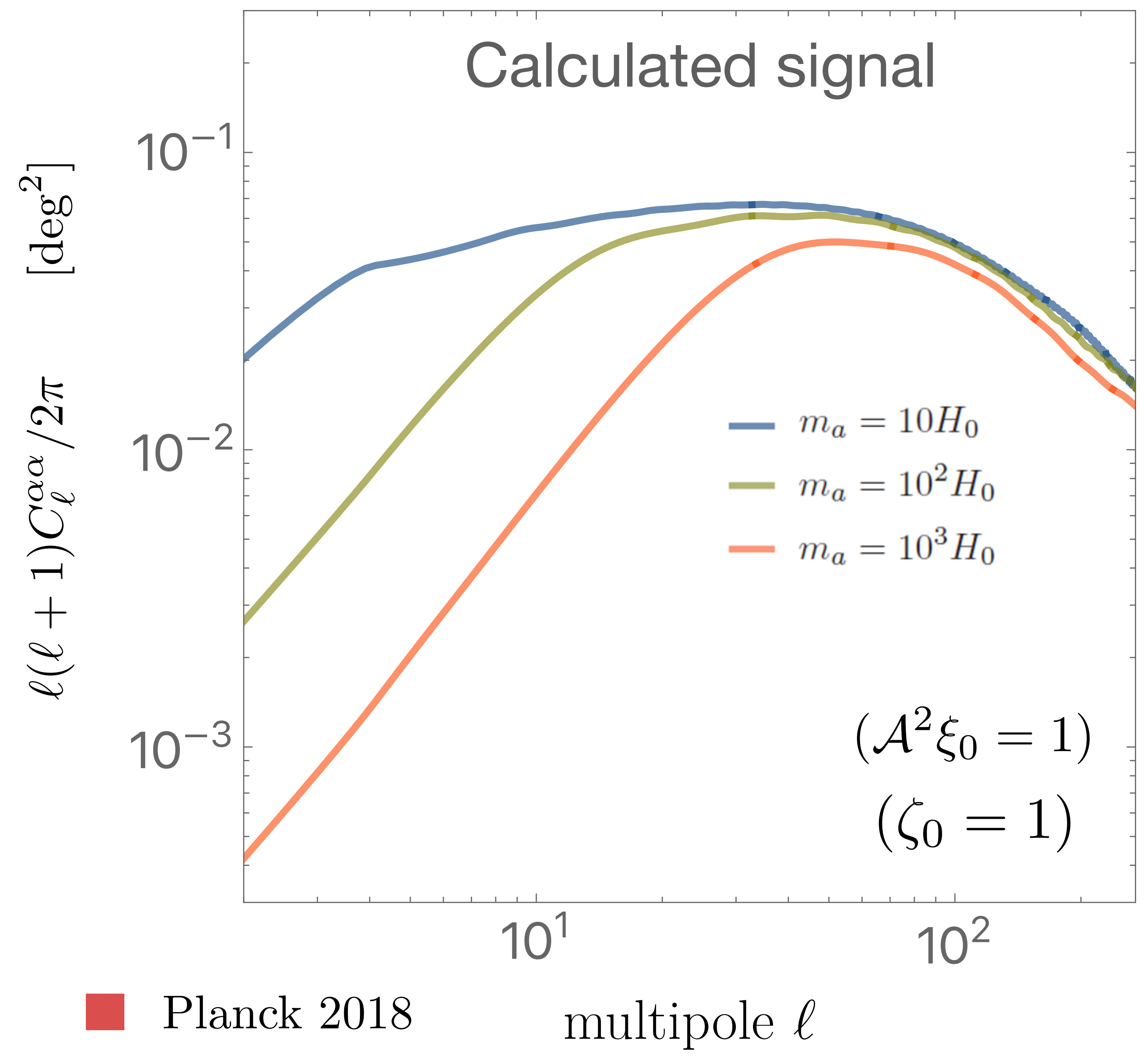
$3H_{\rm cmb} \gtrsim m_a \gtrsim 3H_0\ ;\ N_{\rm dw}=1$

Amplitude

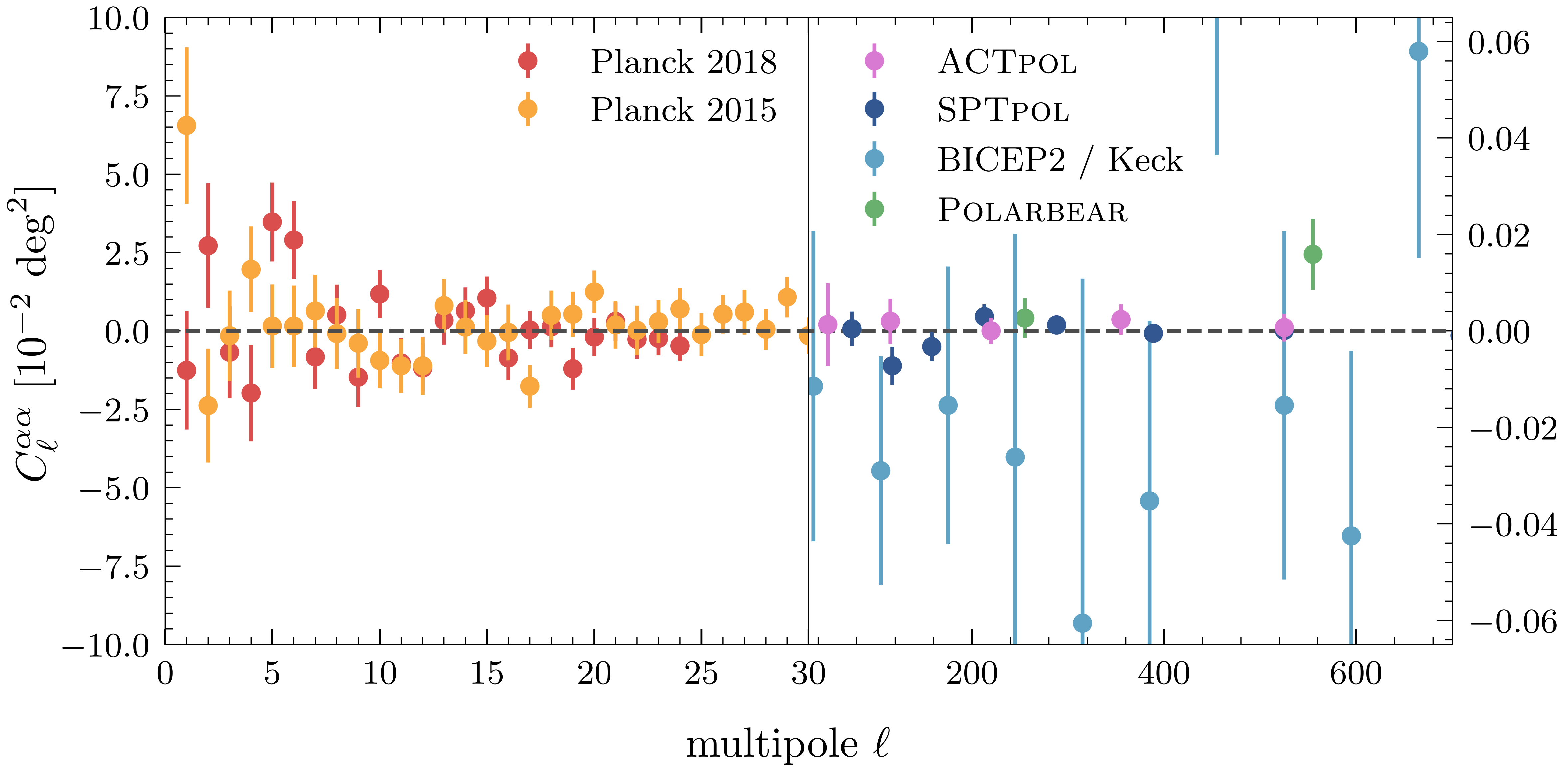
Size of loops in units of H^{-1}

$$C_\ell^\alpha \approx \mathcal{A}^2 \xi_0\,\mathrm{Shape}(\zeta_0, m_a)$$

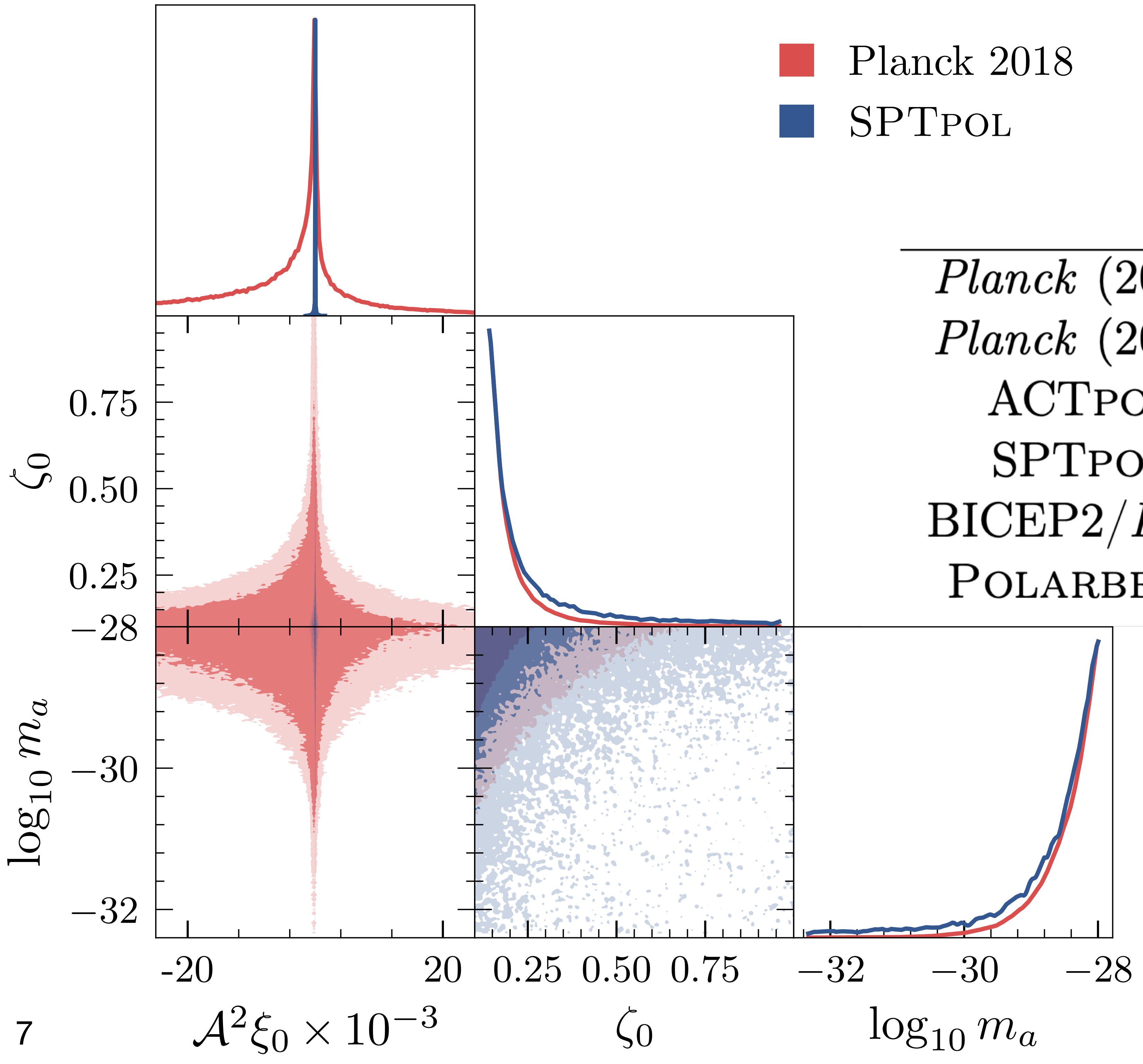
ξ_0 = Total length of string in a a Hubble volume (in units of H^{-1})



(Processed-) Data



Result



	collapsing string-wall
Planck (2015):	$\mathcal{A}^2\xi_0 < 55,000$
Planck (2018):	$\mathcal{A}^2\xi_0 < 18,000$
ACTPOL:	$\mathcal{A}^2\xi_0 < 1,100$
SPTPOL:	$\mathcal{A}^2\xi_0 < 390$
BICEP2/*Keck*:	$\mathcal{A}^2\xi_0 < 3,200$
POLARBEAR:	$\mathcal{A}^2\xi_0 < 3,300$

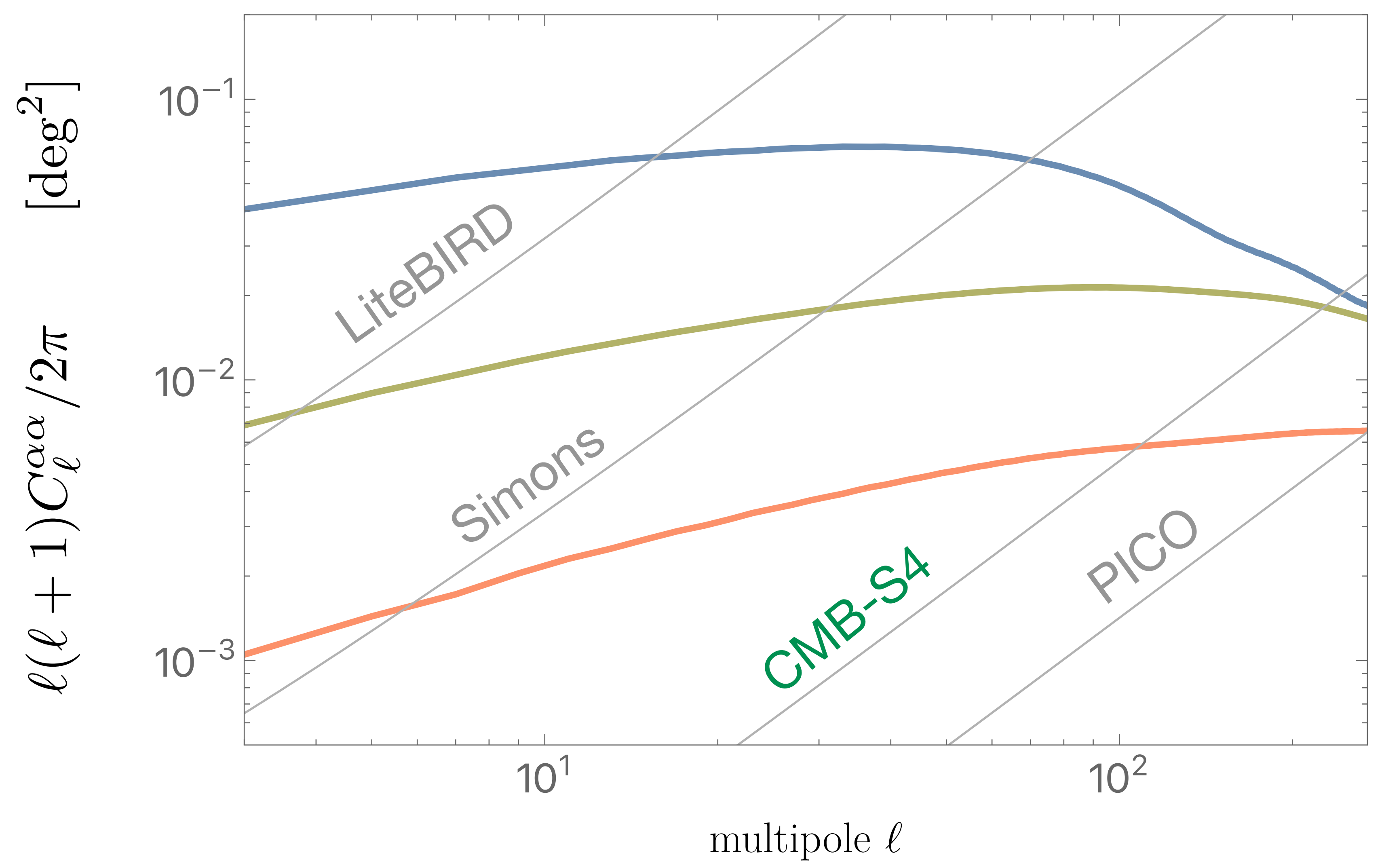
$(\mathcal{A}^2\xi_0 \geq 0)$

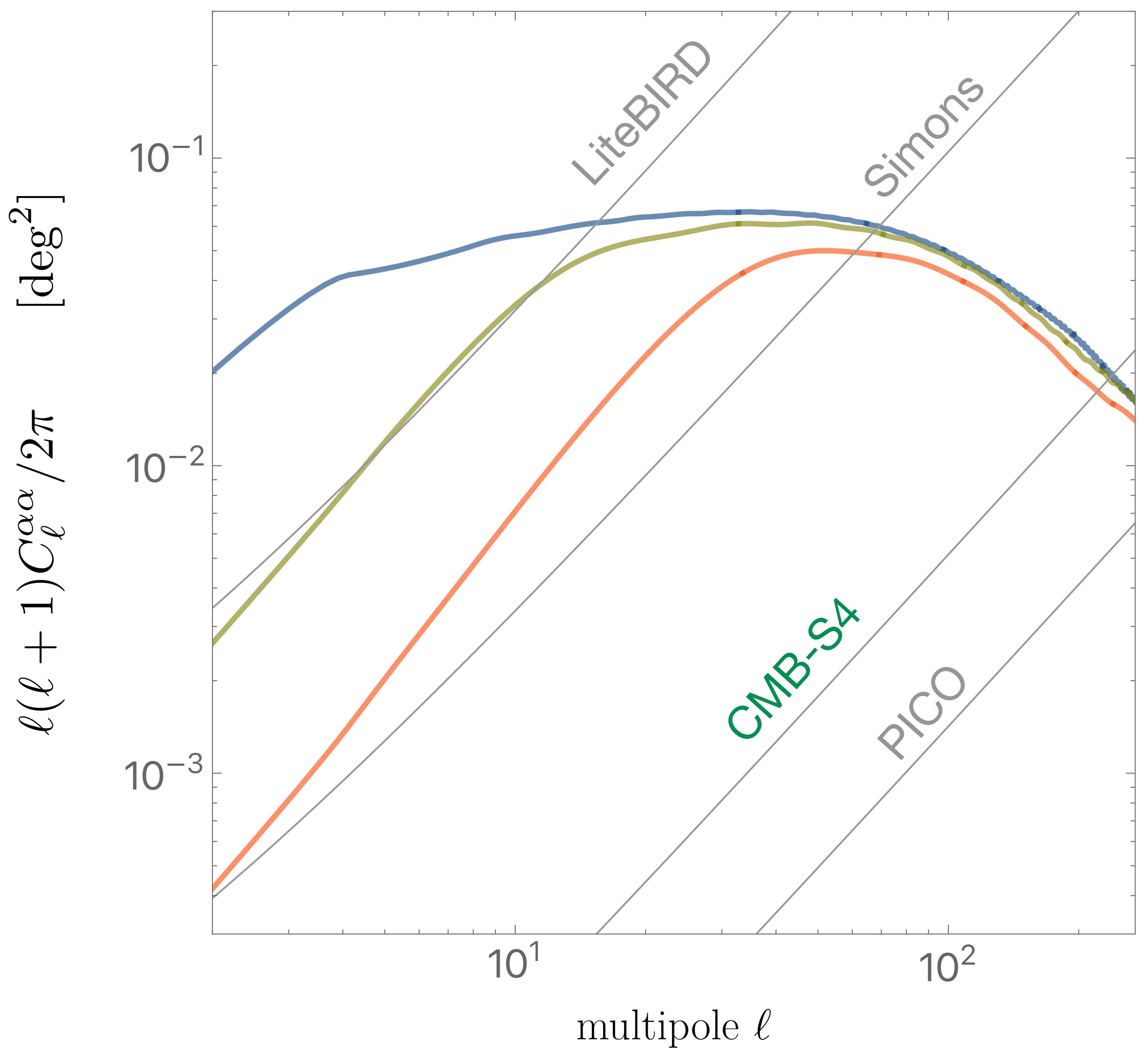
SUMMARY

- ALP defect networks can induce CMB birefringence and offer exciting new avenue to probe UV physics and learn about quantum gravity.

- Current data is consistent with no anisotropic signal.
  - $\mathcal{A}^2 \xi_0 < 3.7$ for non-collapsing string/wall networks (SPTpol); Meaningful constraints on the UV particles' charges already.

- Future surveys (like CMB-s4) can furnish a measurement (or provide constraints) on UV particles' charges $\mathcal{A}$, and/or m_a



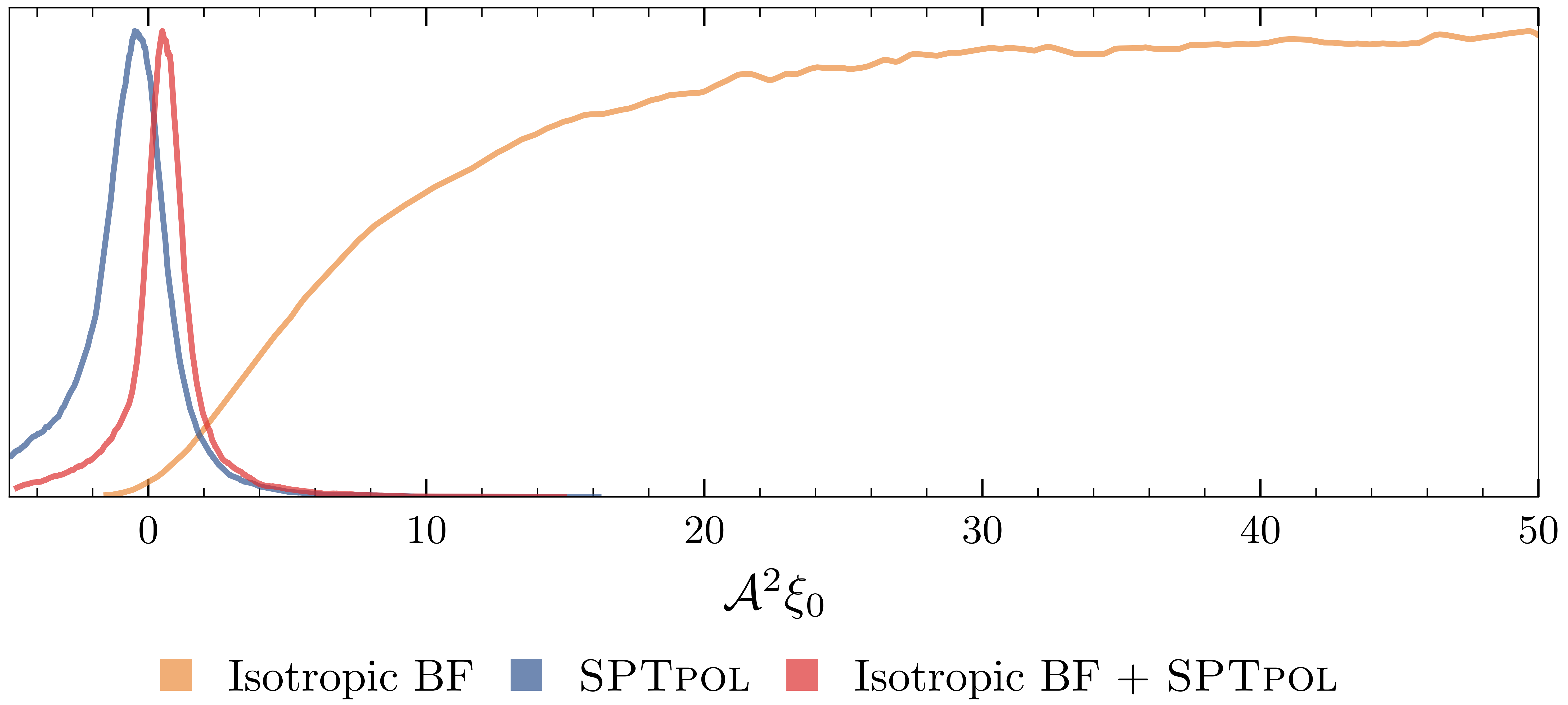


Back up / Extra

Isotropic + anisotropic birefringence

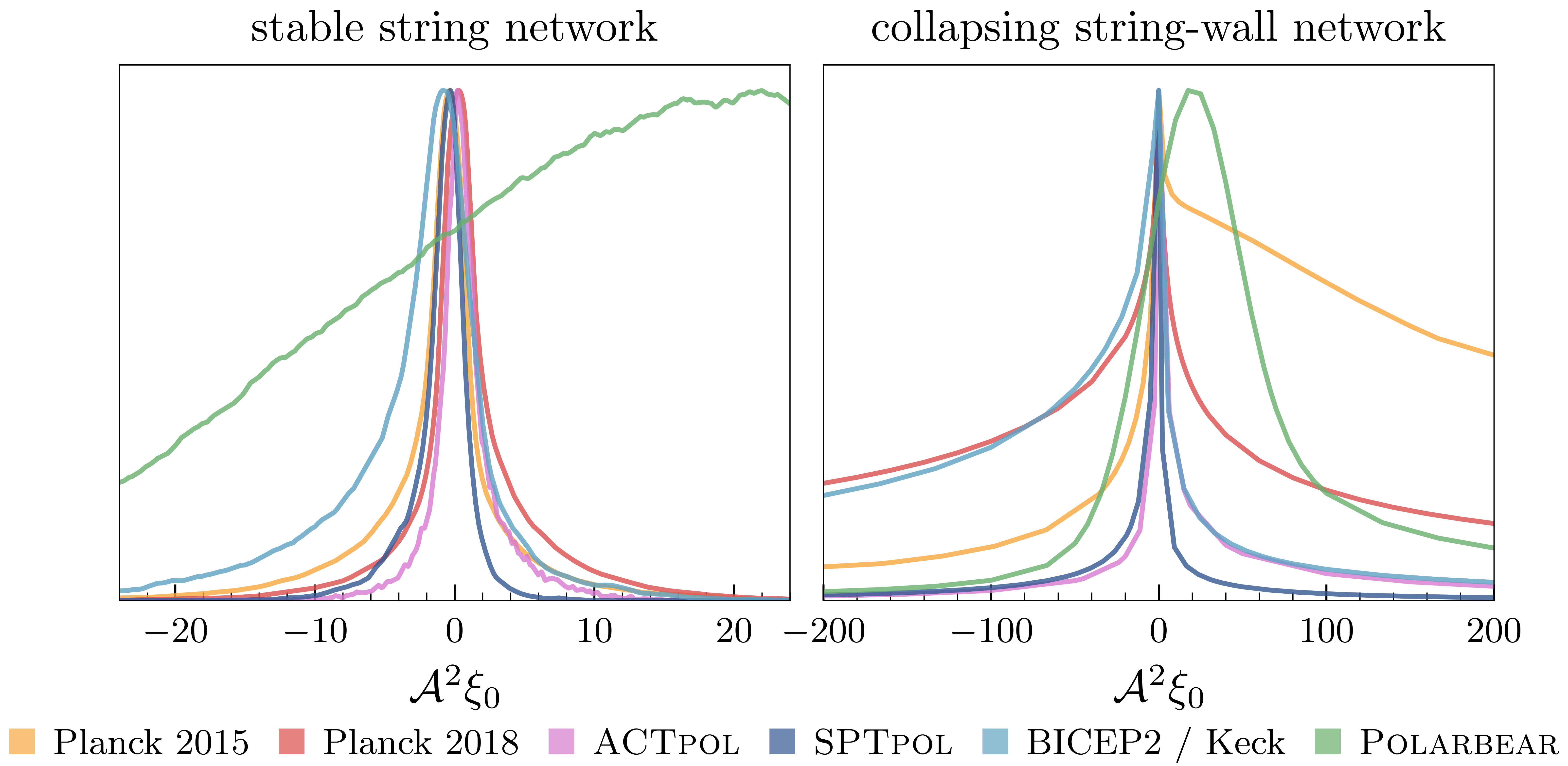
■ Isotropic BF + SPTpol

$$\mathcal{A}^2\xi_0 = 0.5 \pm 1 \text{ at } 68\% \text{ CL}$$



- With the current data, the anisotropic and isotropic birefringence measurements are difficult to reconcile in the context of axion-defect-induced birefringence

Results from other data sets



	stable strings	collapsing string-wall
Planck (2015):	$\mathcal{A}^2\xi_0 < 13$	$\mathcal{A}^2\xi_0 < 55,000$
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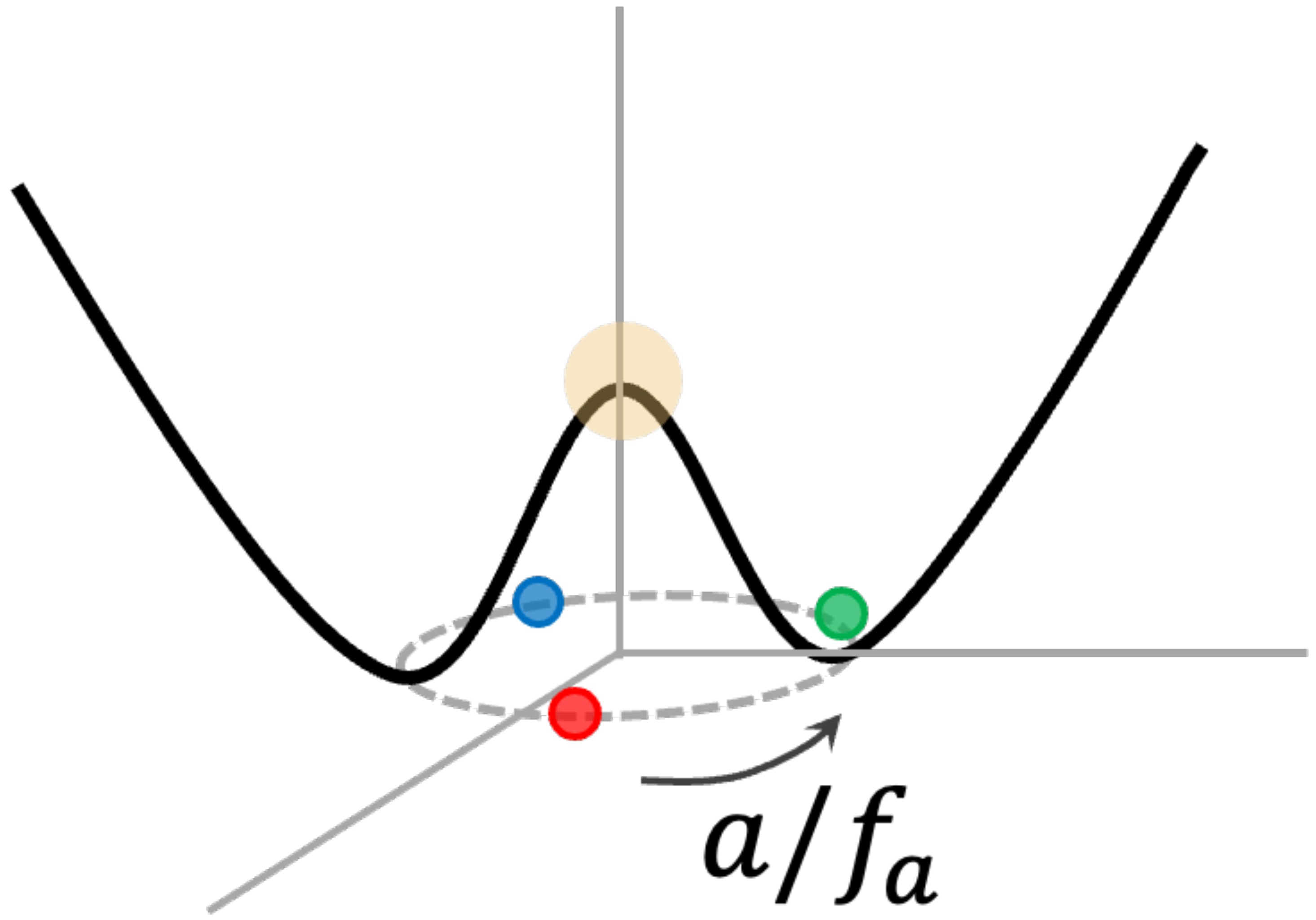
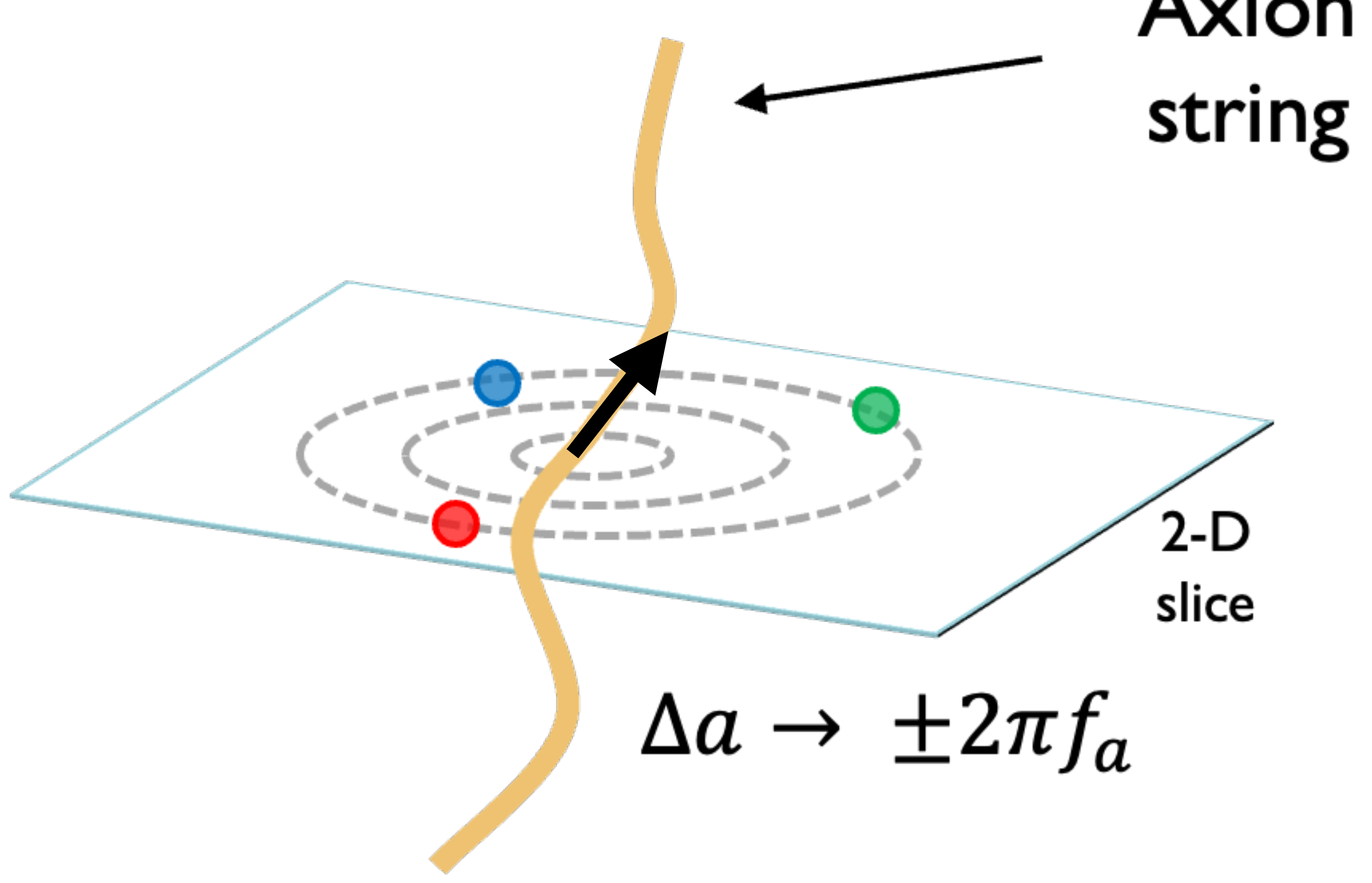
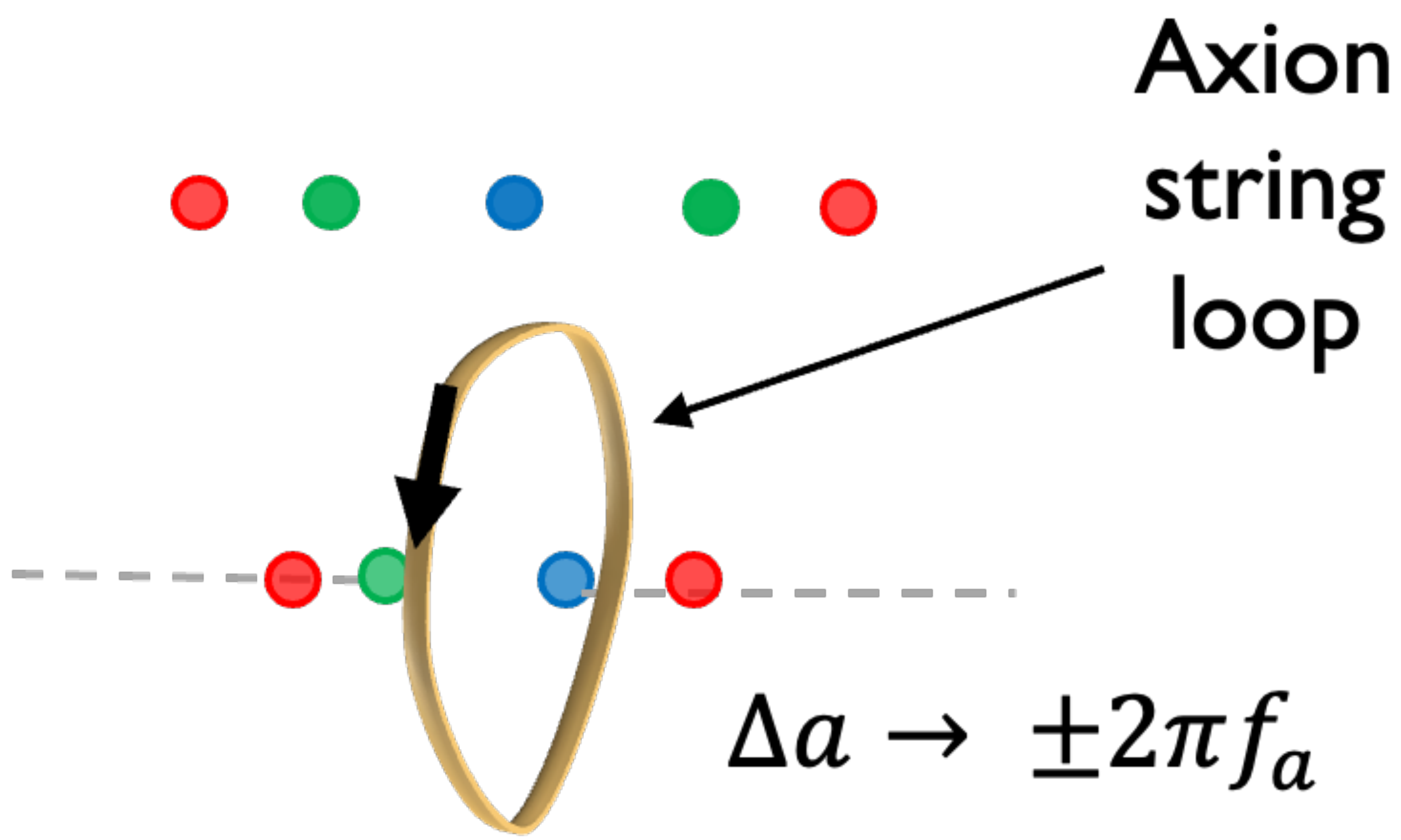
COSMIC STRINGS

Field space



Physical space





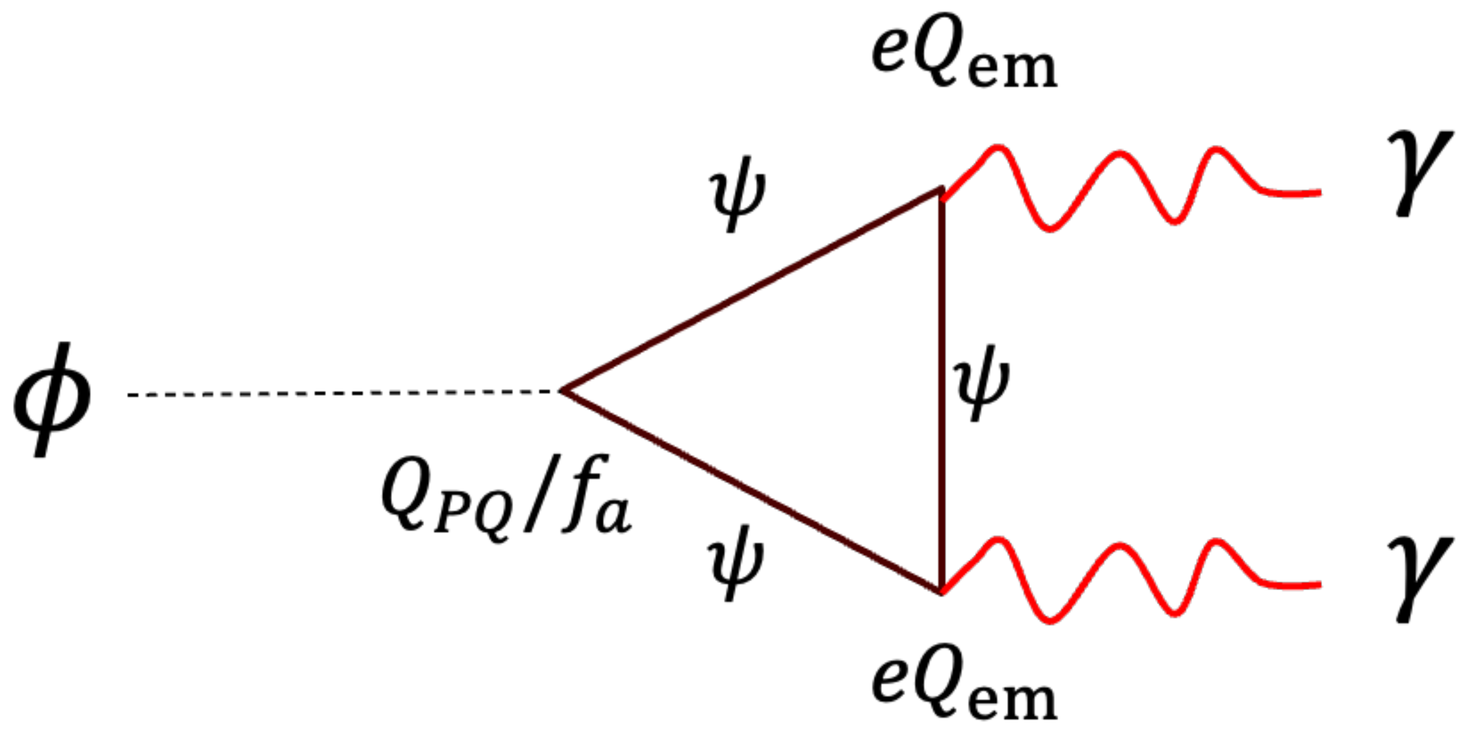
Anti-clockwise (+);
clockwise (-)

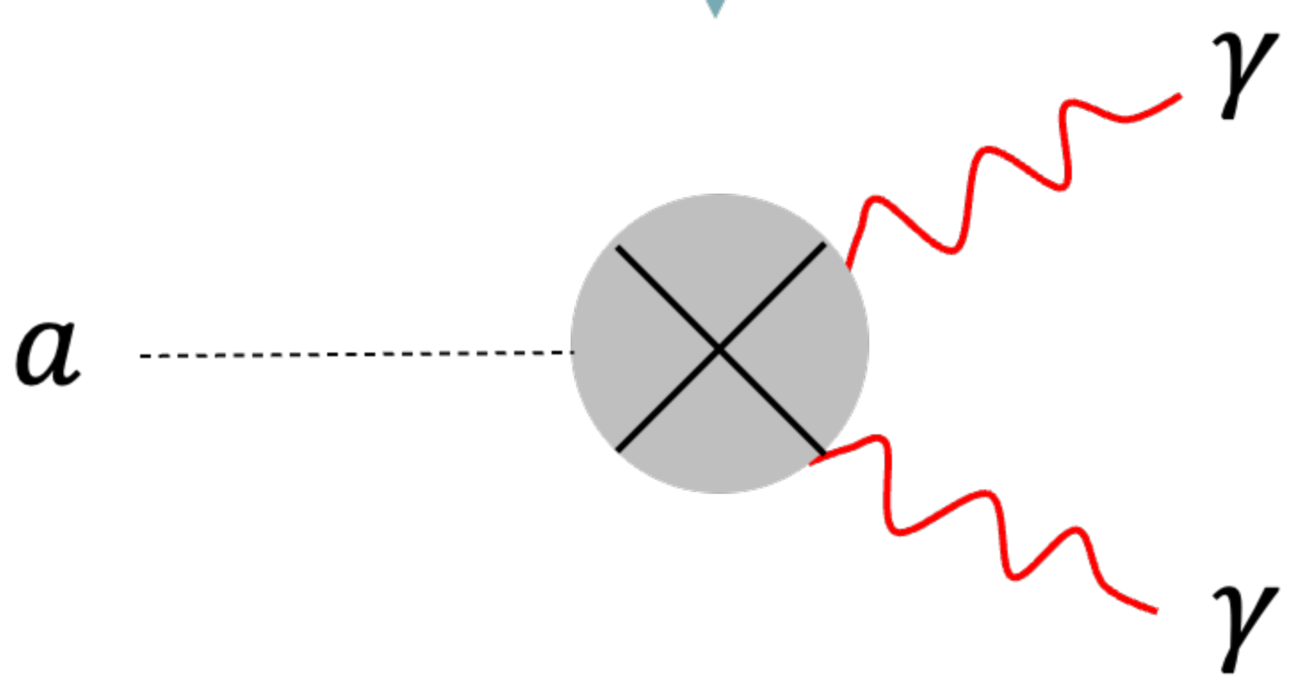
UV to IR

$$i\bar{\psi}\,(\gamma^{\mu}\partial_{\mu} + m)\psi \;+ i\,\frac{Q_{PQ}}{f_a}\bar{\psi}\,\gamma^5\gamma^{\mu}\partial_{\mu}\phi\,\psi \;+\; \mathcal{L}_{\text{em}}$$

Heavy fermion

$\phi = \rho\, e^{i\theta}$ ← a/f_a





$$\frac{\mathcal{A}\,\alpha_{\text{em}}}{4\pi f_a}\,a\,\tilde{F}F$$

Loop $= \dfrac{1}{16\pi^2}\,\dfrac{Q_{PQ}}{f_a}\,(eQ_{\text{em}})^2$

↓

$$\underbrace{Q_{PQ}\;Q_{\text{em}}^2}_{\mathcal{A}}\;\frac{1}{4\pi f_a}\;\alpha_{\text{em}}$$

$\mathcal{A}$: Anomaly coefficient

For multiple-fermions

$$\mathcal{A} = \sum_f Q_{PQ,f}\;Q_{\text{em},f}^2$$