Columbia University
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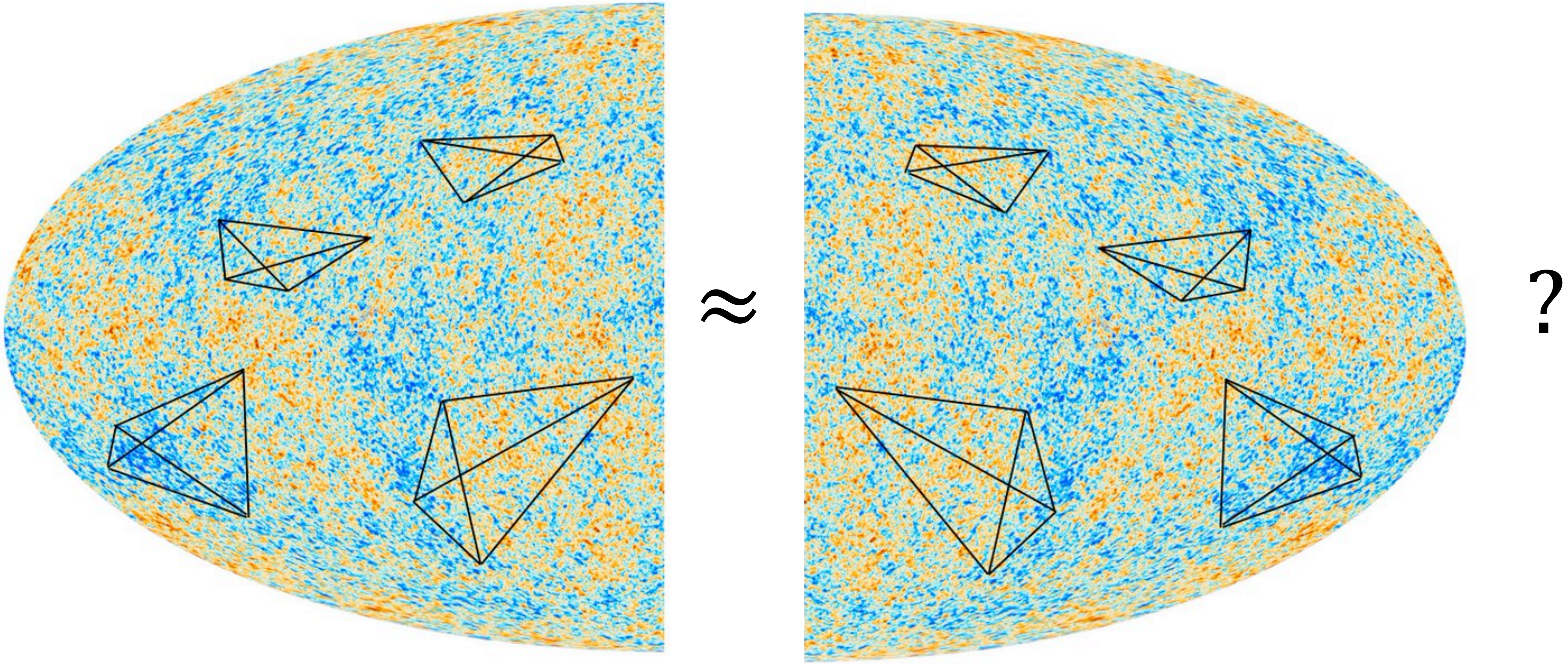


Undetecting Parity Violation

Oliver H. E. Philcox

Trieste, Nov. 2023

A BRIEF SUMMARY

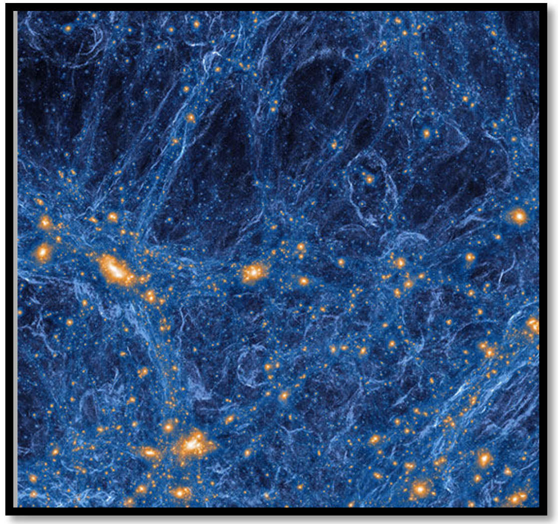
If cosmology is controlled by **gravity** it should be parity-symmetric.

$$f(-\mathbf{x}, -\mathbf{y}, \dots) \stackrel{?}{=} f(\mathbf{x}, \mathbf{y}, \dots)$$

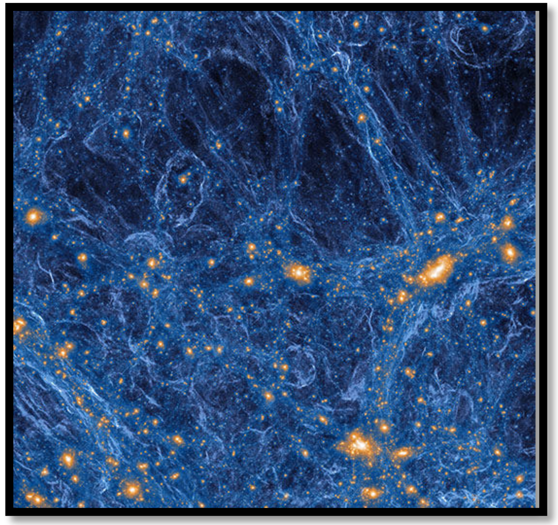
To search for parity-violation using **scalars** we need a triple product: $\mathbf{r}_1 \cdot \mathbf{r}_2 \times \mathbf{r}_3$

Simplest option: trispectra/4-point functions

The Universe



These should be **statistically indistinguishable!**

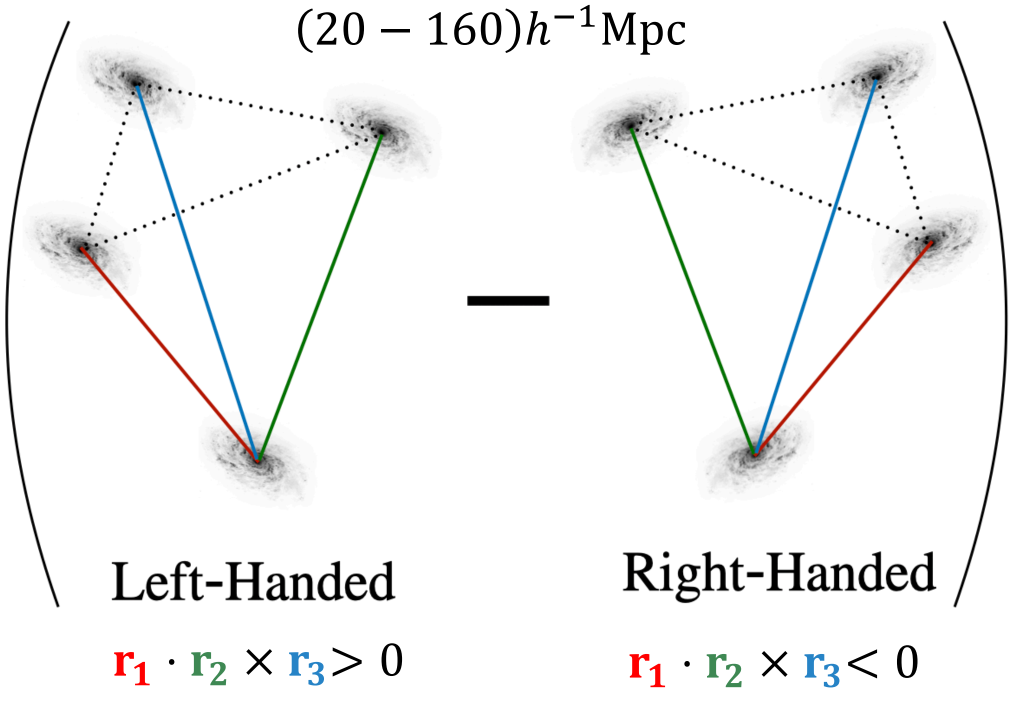


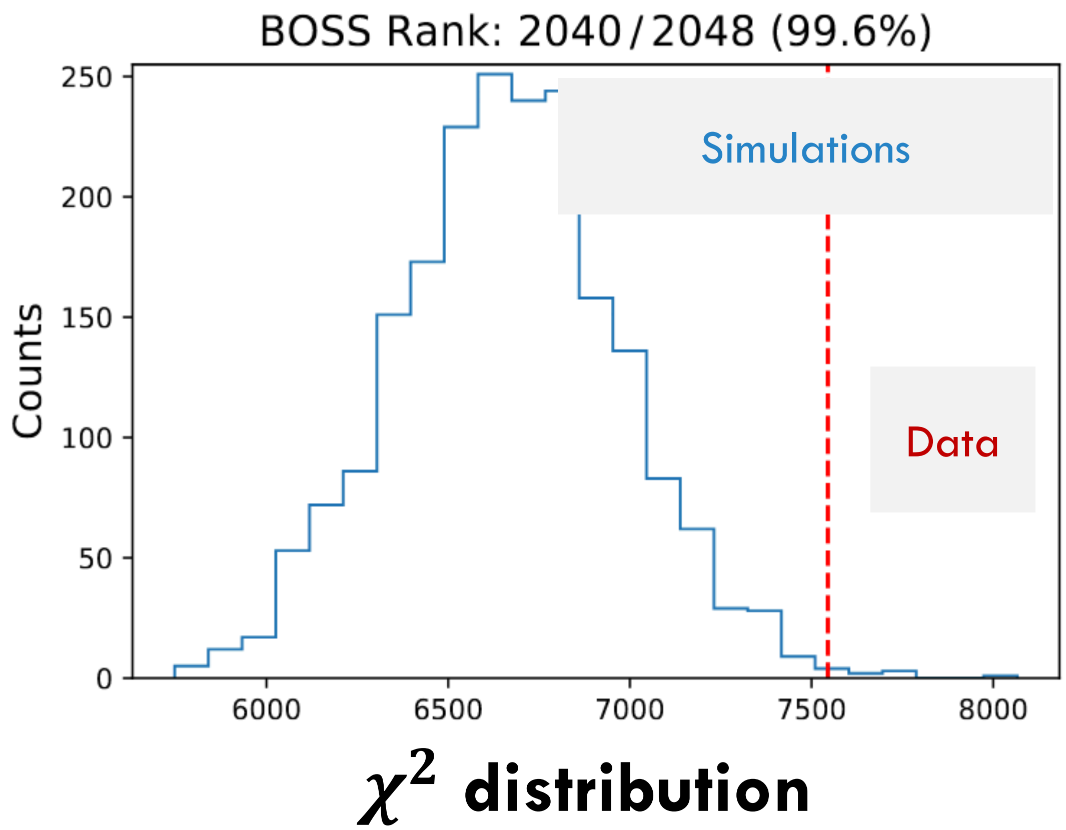
The Universe (flipped)

DETECTING PARITY VIOLATION?

Probe parity-violation with the chiral 4PCF: $[\zeta_{\mathrm{LH}} - \zeta_{\mathrm{RH}}](\mathbf{r}_1 \cdot \mathbf{r}_2 \times \mathbf{r}_3)$

3σ detection of parity-violation??





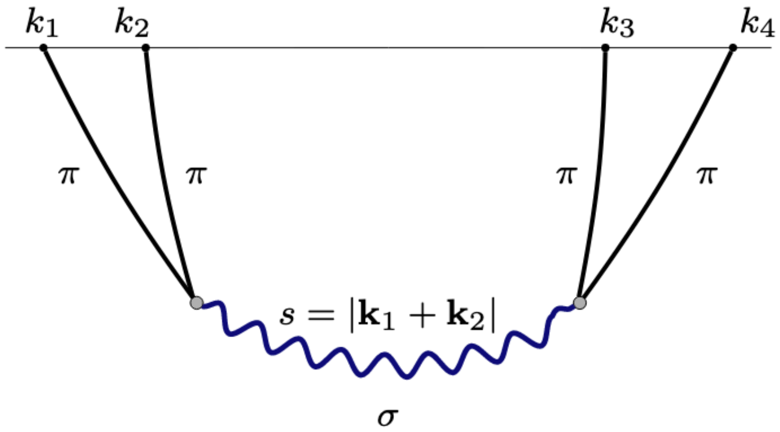
github.com/oliverphilcox/Parity-Odd-4PCF

Philcox 22, Hou+22

WHAT COULD SOURCE THIS?

1. **Early Sources**

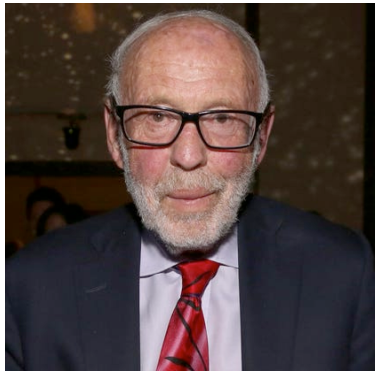
- ▷ New particles in inflation?
- ▷ Ghost condensates in inflation?
- ▷ Gravitational waves in inflation?



New particles!

Ghost inflation!

No evidence for an inflationary source from the 18 models we tried!



Chern-Simons inflation

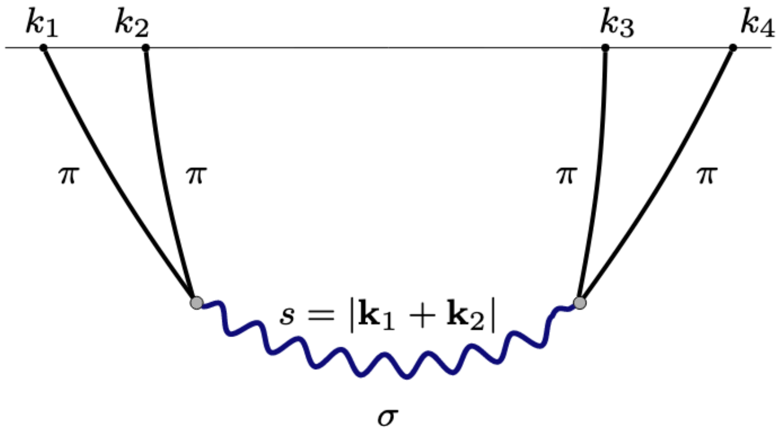
Cabass, **Philcox**+22, Creque-Sarbinowski, **Philcox**+22

WHAT COULD SOURCE THIS?

1. **Early Sources**
   - New particles in inflation?
   - Ghost condensates in inflation?
   - Gravitational waves in inflation?

2. **Late Sources**
   - Modified gravity?
   - Magnetic fields?

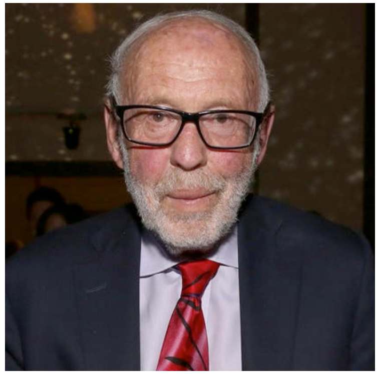
$$\delta_g \supset b_9^{(3)} R_*^9 \epsilon_{ijk} (\partial_i \delta)(\partial_j \partial^2 \delta)(\partial_k \partial^4 \delta)$$



New particles!

Ghost inflation!

Late-time physics has to happen on very large scales!



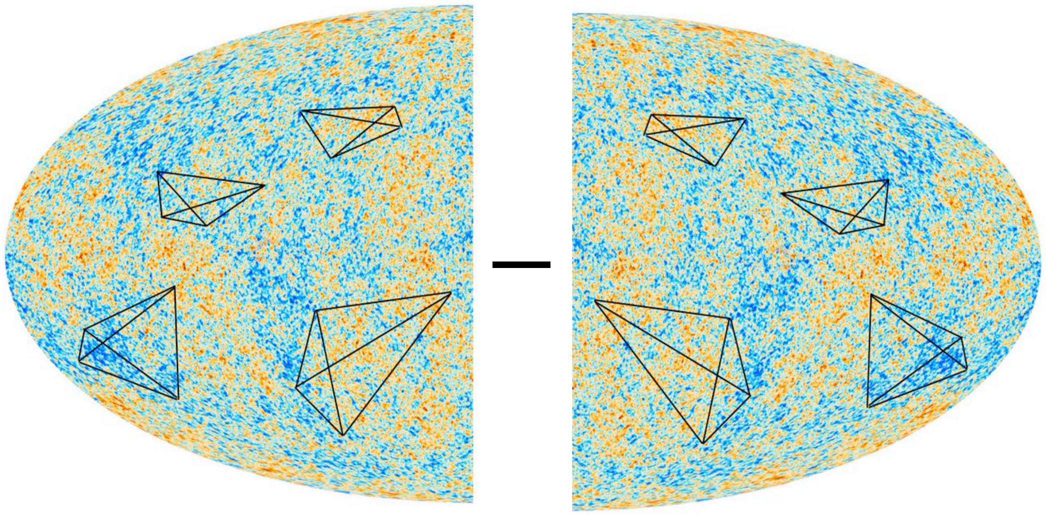
Chern-Simons inflation

Cabass, **Philcox**+22, Creque-Sarbinowski, **Philcox**+22

THE VIEW FROM THE CMB

PolyBin

Planck **T- and E-modes, e.g.** $t^{\ell_1\ell_2}_{\ell_3\ell_4}(L)_{\mathrm{TTEE}}$

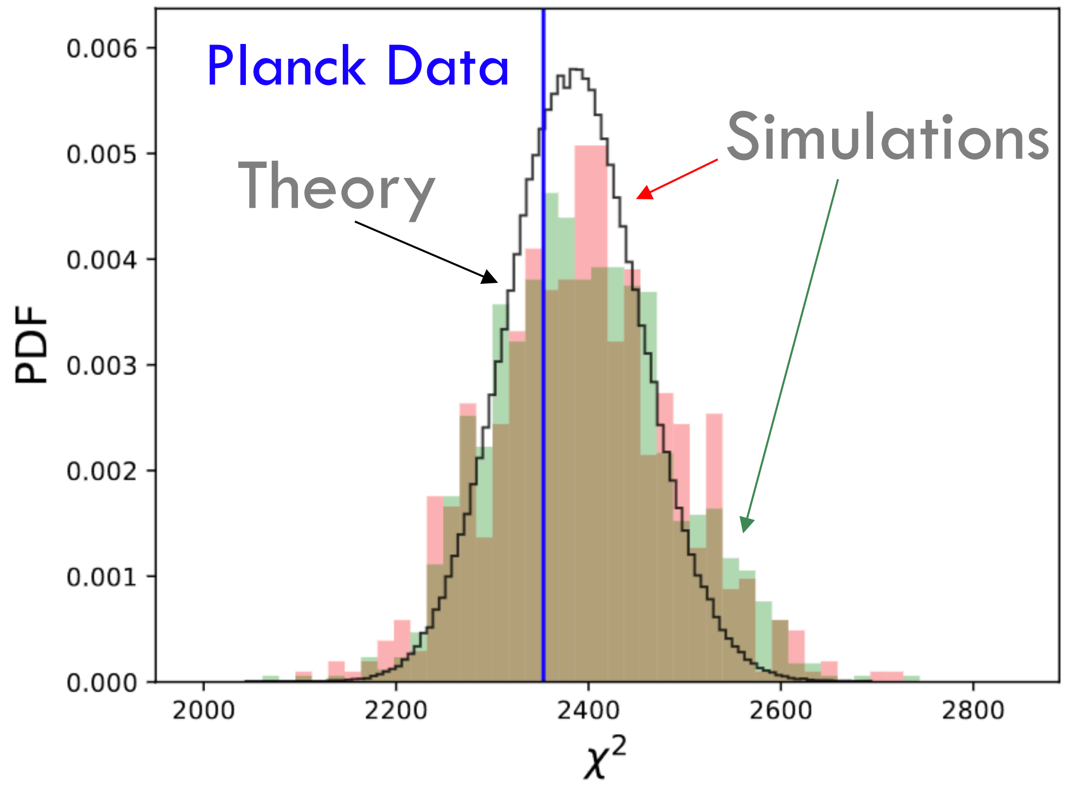


Left-Handed — Right-Handed

$2 \leq \ell_i \leq 500$

$\ell_1 + \ell_2 + \ell_3 + \ell_4 = \mathrm{odd}$

χ^2 Test



$< 0.4\sigma$ **detection!**

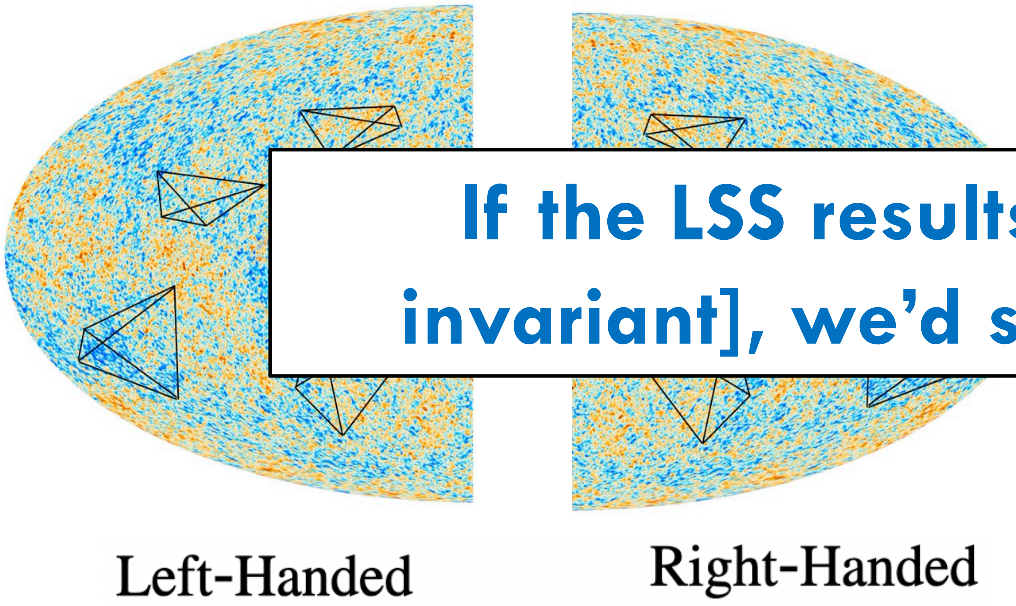
github.com/oliverphilcox/PolyBin

Philcox 23c, **Philcox** & Shiraishi 23

THE VIEW FROM THE CMB

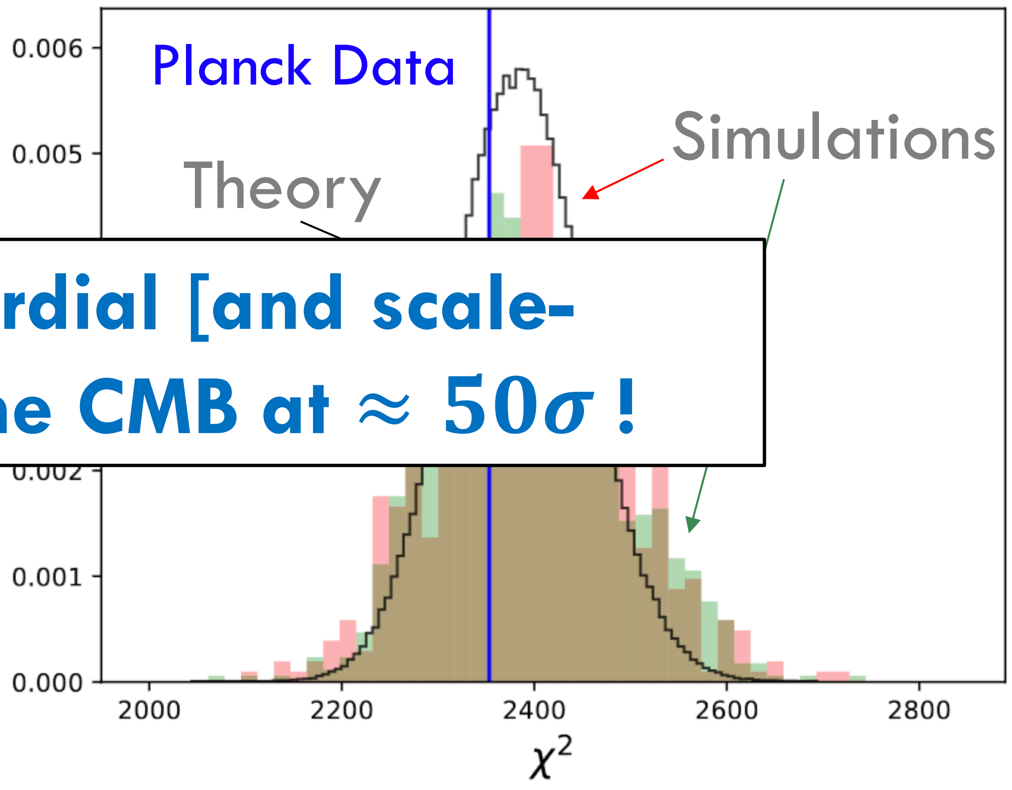
PolyBin

***Planck* T- and E-modes, e.g.** $t^{\ell_1\ell_2}_{\ell_3\ell_4}(L)_{\rm TTEE}$



$2 \leq \ell_i \leq 500$
$\ell_1 + \ell_2 + \ell_3 + \ell_4 = \text{odd}$

χ^2 Test



If the LSS results were primordial [and scale-invariant], we'd see them in the CMB at $\approx 50\sigma$!

$< 0.4\sigma$ **detection!**

github.com/oliverphilcox/PolyBin

Philcox 23c, **Philcox** & Shiraishi 23

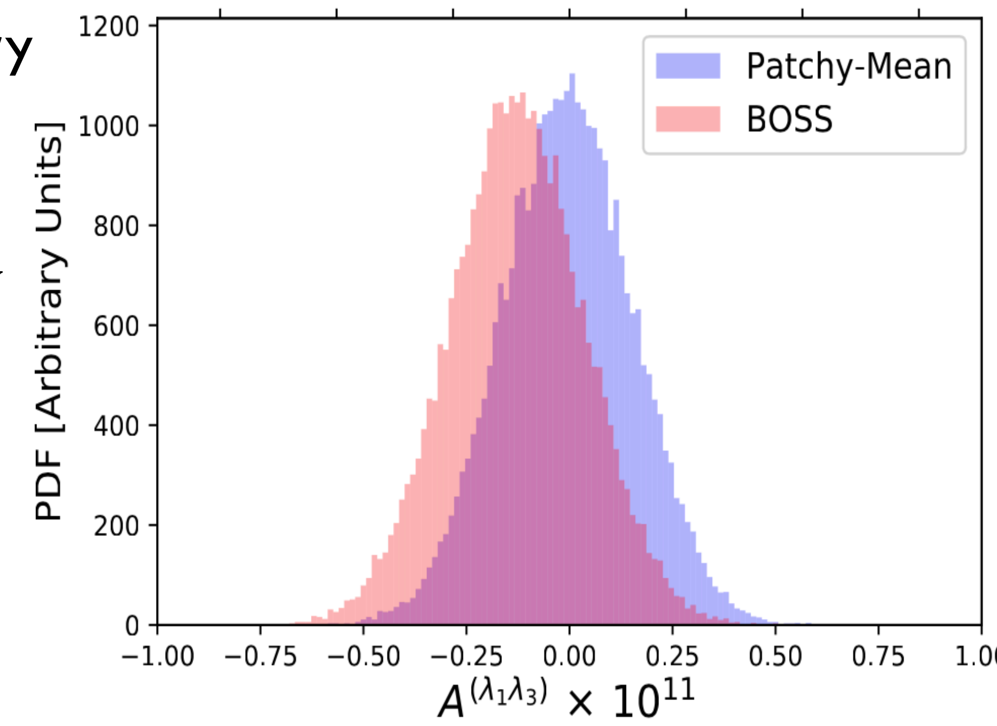
LESSONS LEARNT FROM LSS

- Four-point analyses are great probes of inflationary physics *and* their analysis is not too far off

$$T_g(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4) \sim T_\zeta(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3, \mathbf{k}_4) + \text{gravity}$$

But

- **Gravity** must be carefully modeled (less if $\mathbb{P}$-odd)
- We should use the **trispectrum** not the **4PCF**
- Controlling covariances gets difficult: $\mathrm{cov}[\zeta^N] \sim \sigma_8^{2N}$



Some spin-1 collider constraints from BOSS

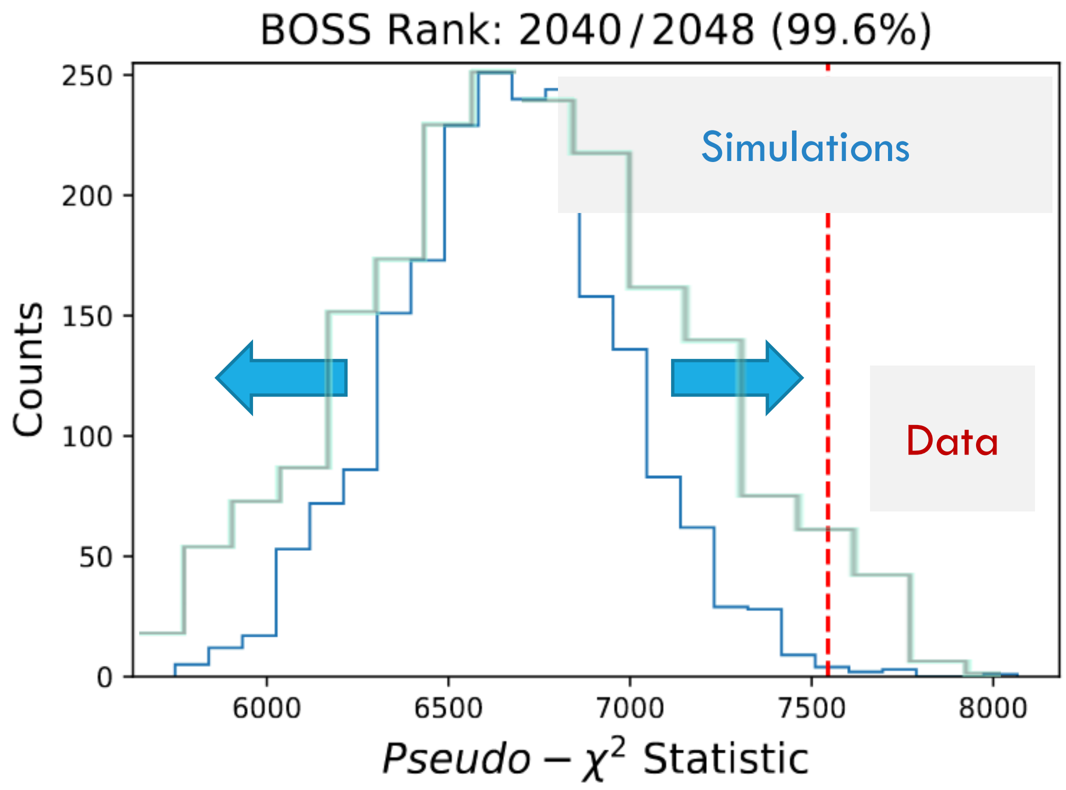
Philcox 23abc, **Philcox** & Shiraishi 23

WHAT'S THE SOLUTION?

1. **Early Sources**
   - ▷ New particles in inflation?
   - ▷ Ghost condensates in inflation?
   - ▷ Gravitational waves in inflation?

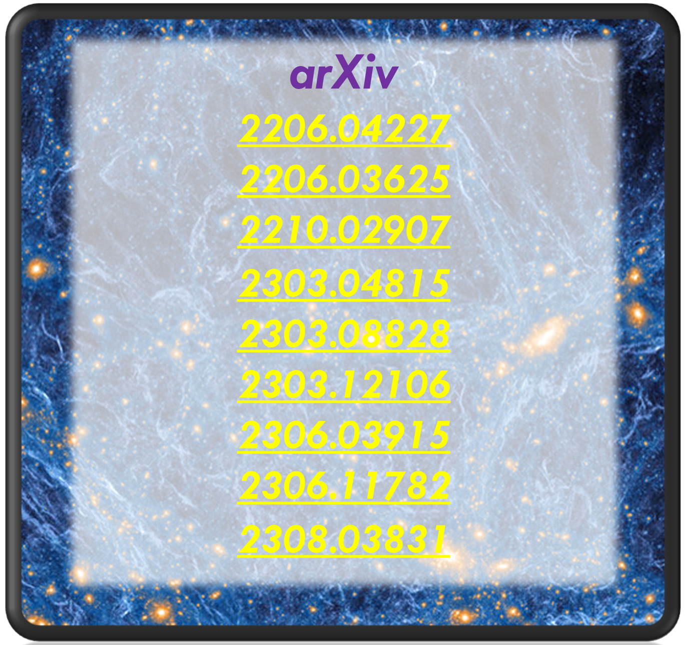
2. **Late Sources**
   - ▷ Modified gravity?
   - ▷ Magnetic fields?

3. **Systematics**
   - ▷ Do we understand the noise properties of the data?

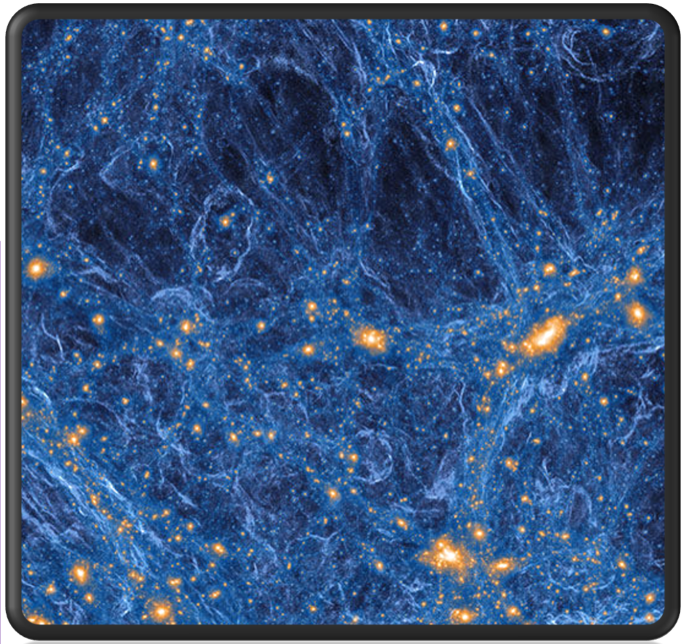


Simulations may not adequately represent experimental noise!

Cabass, **Philcox**+22, Creque-Sarbinowski, **Philcox**+22



CONCLUSIONS



Is the Universe symmetric under **reflections?**

- **Galaxies:** No! [~3σ]
- **CMB:** Yes! [<0.4σ]

Though new physics is unlikely, we learnt:

- Four-point analyses are possible!
- Configuration-space is hard!
- Gravity can sometimes be tempered!