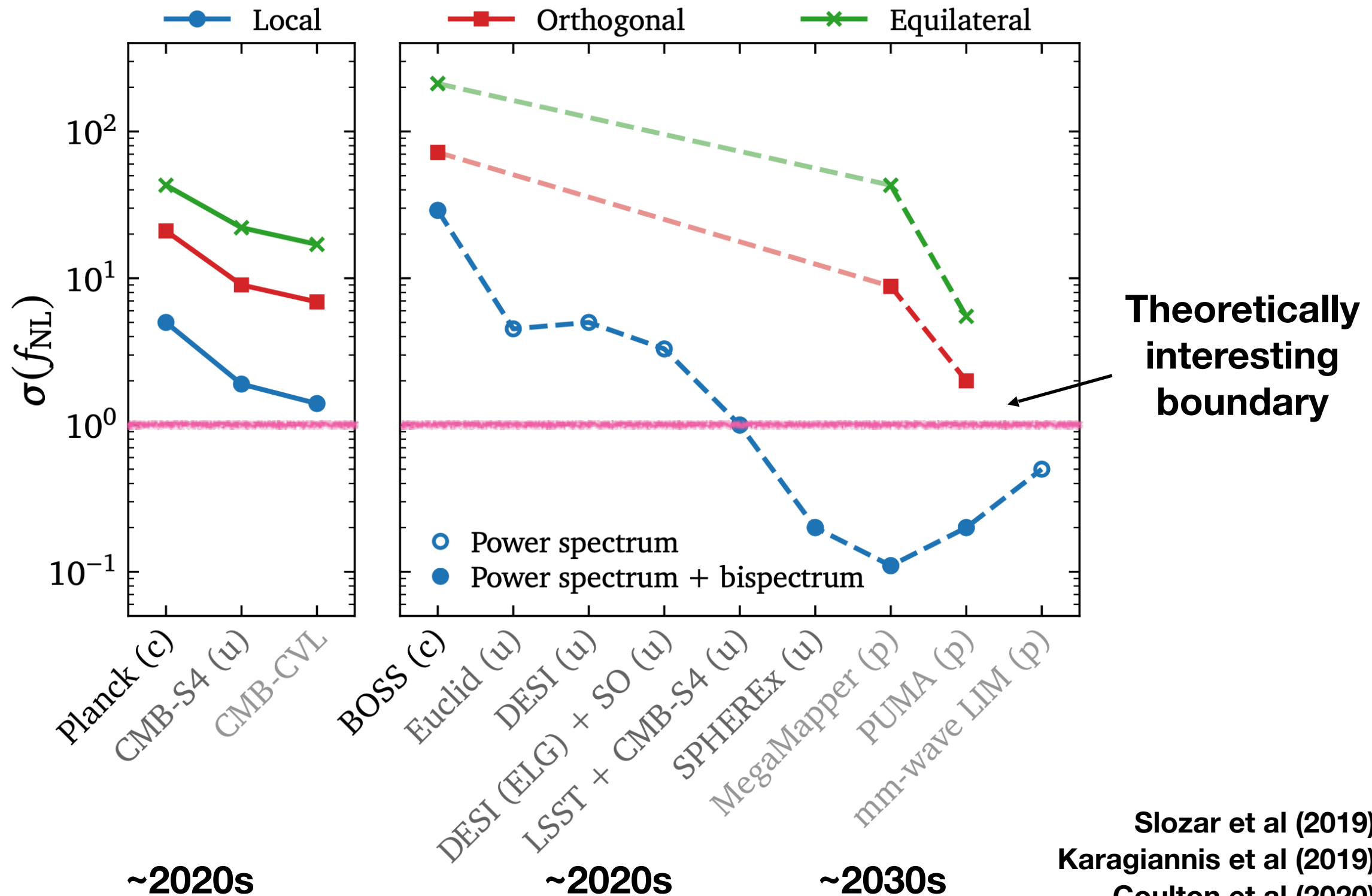


Exploring primordial physics through cosmological simulations

William Coulton in collaboration with Francisco Villaescusa-Navarro, Adrian Bayer, Lehman Garrison, Yong Sheng Yap and many more

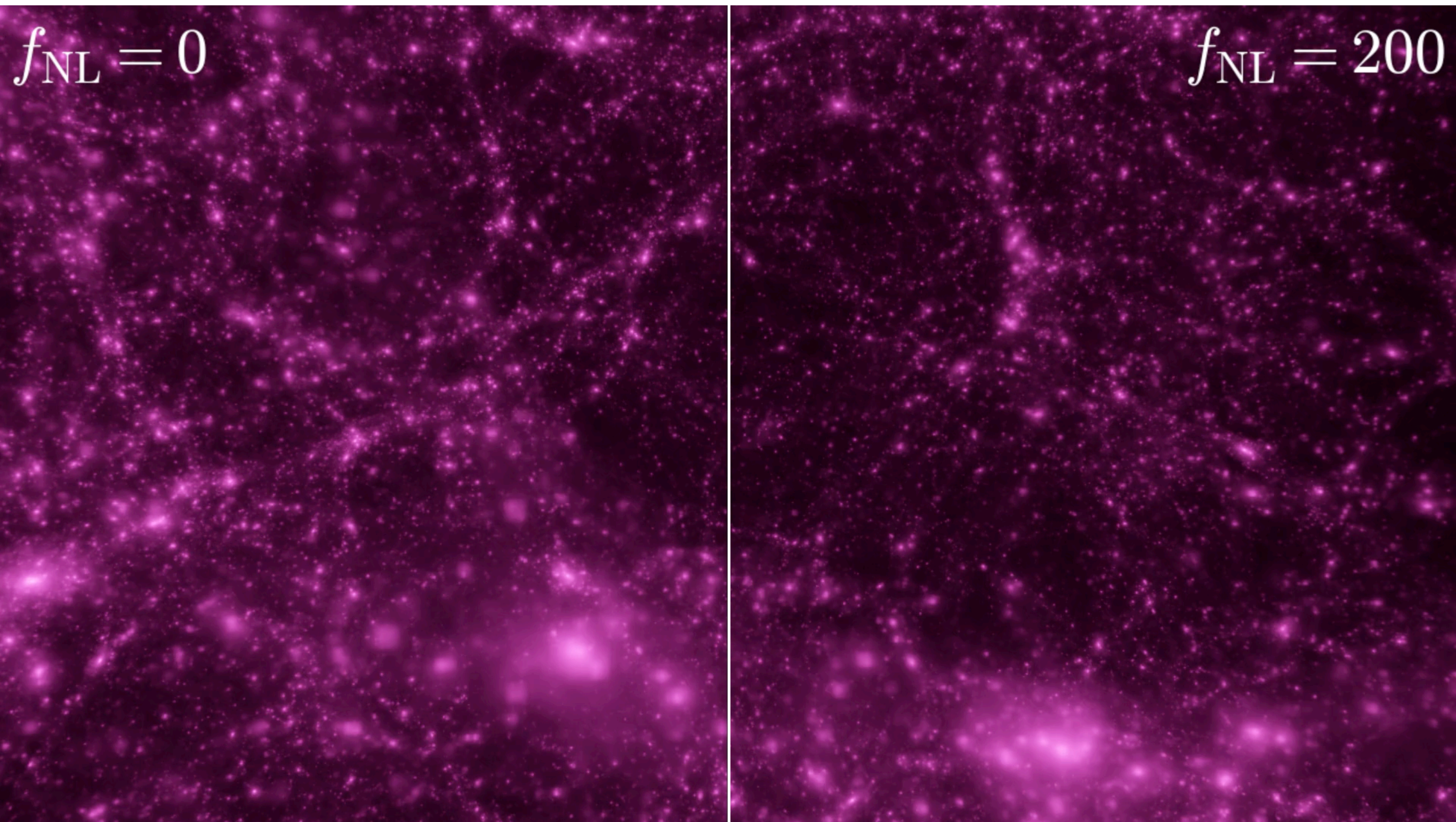
What can galaxies tell us about primordial non-Gaussianity?

Forecast constraints on PNG from LSS highlight challenges for non-local shapes



Slozar et al (2019)
Karagiannis et al (2019)
Coulton et al (2020)
Snowmass 2209.06854

Primordial non-Gaussianity in Quijote (Quijote-PNG)



Publicly available [here](#) - thousands of simulations with 9 types of PNG

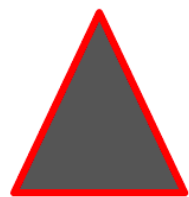
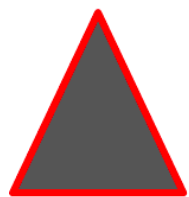
Probing symmetries of inflation?

Parity Violation in the Universe

What is parity symmetry?

$$\mathbf{P} : \begin{pmatrix} x \\ y \\ z \end{pmatrix} \mapsto \begin{pmatrix} -x \\ -y \\ -z \end{pmatrix}.$$

An analogy to mirror symmetry:



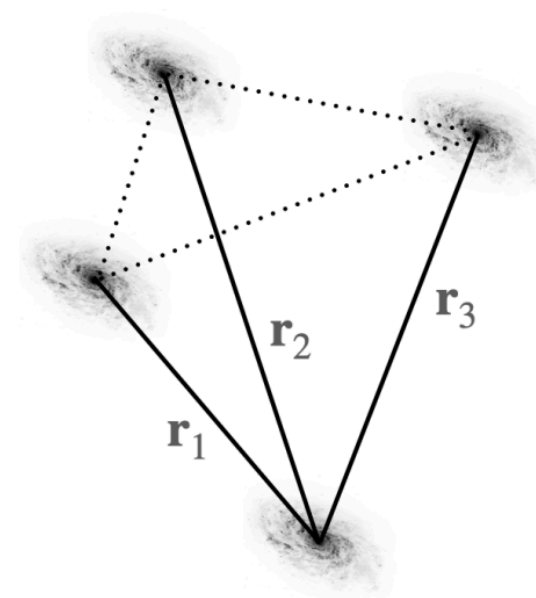
Parity-Symmetric



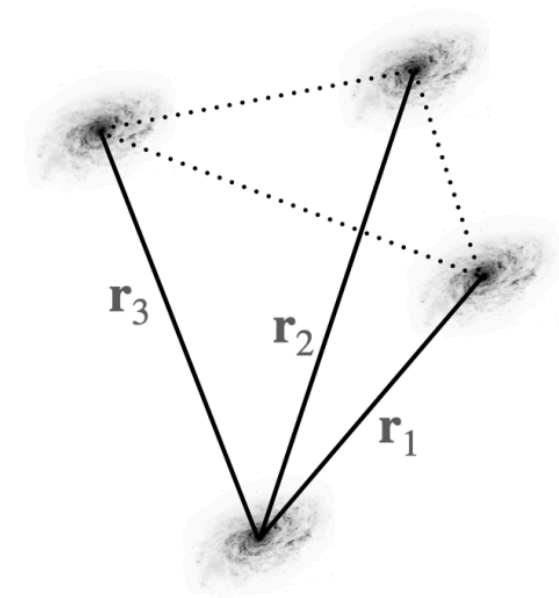
Parity-Asymmetric

M. Strassler 2013

Cosmic parity violation?



$\zeta(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3)$

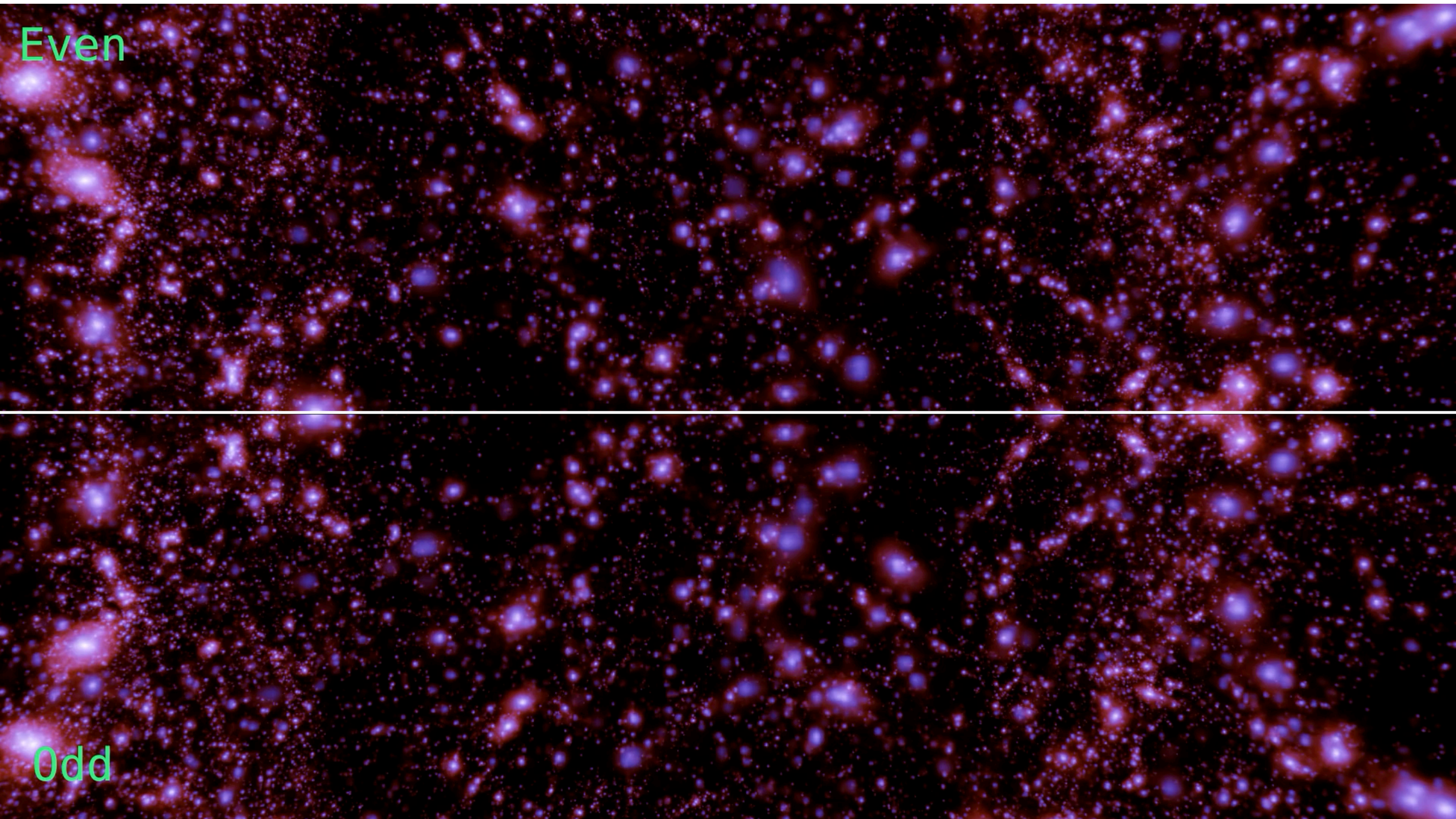


$\mathbb{P} [\zeta(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3)]$

Hints that galaxies are more likely
to be found in one configuration than the
other!

Philcox (2022), Hou et al (2022) ++
Minami and Komatsu (2021)

Simulations of parity violating physics

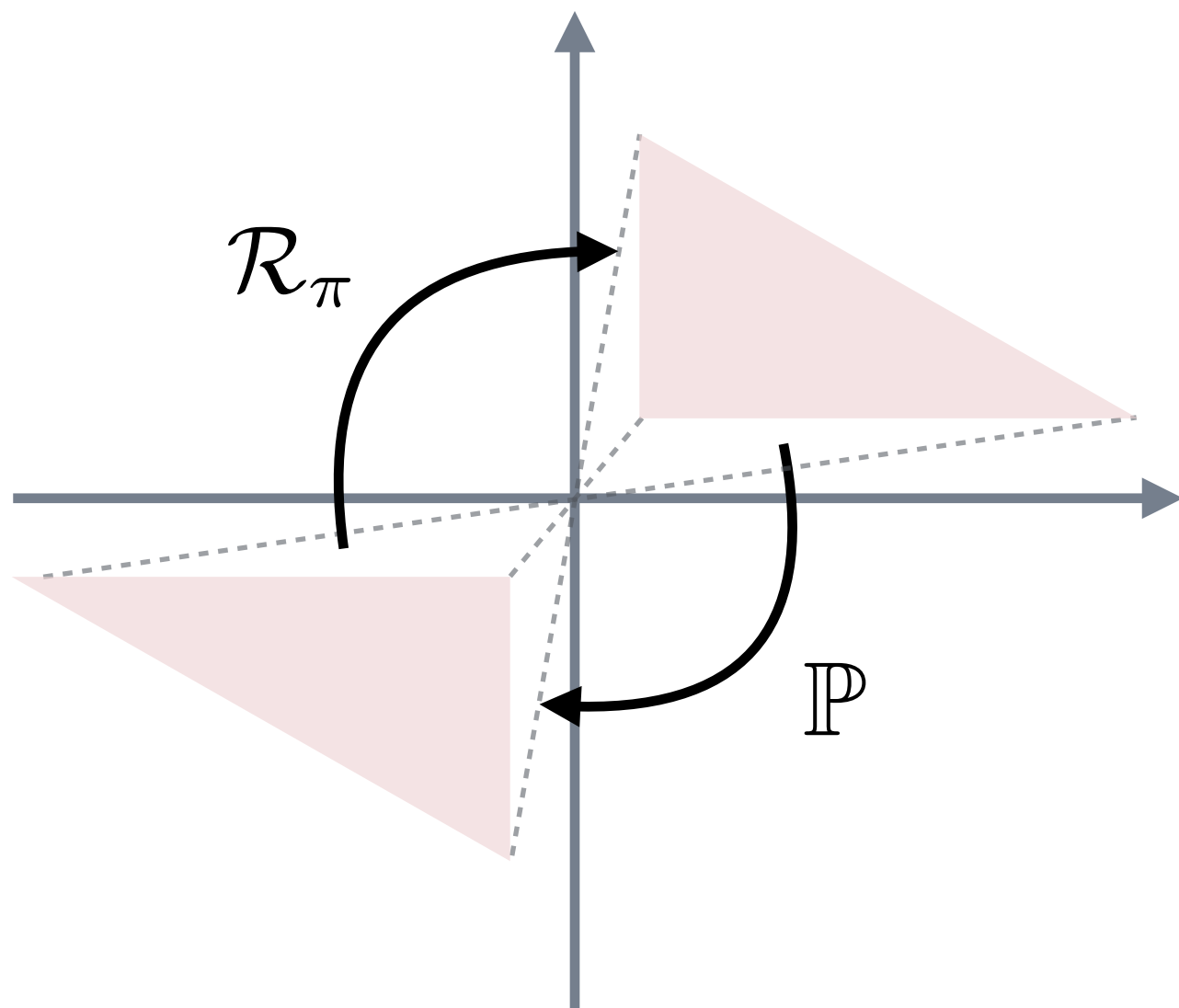


Probing parity violation through the bispectrum?



Led by
Yong Sheng Yap

Consider a bispectrum such as $\langle \delta_m \delta_m \delta_m \rangle$.
This is not sensitive to parity



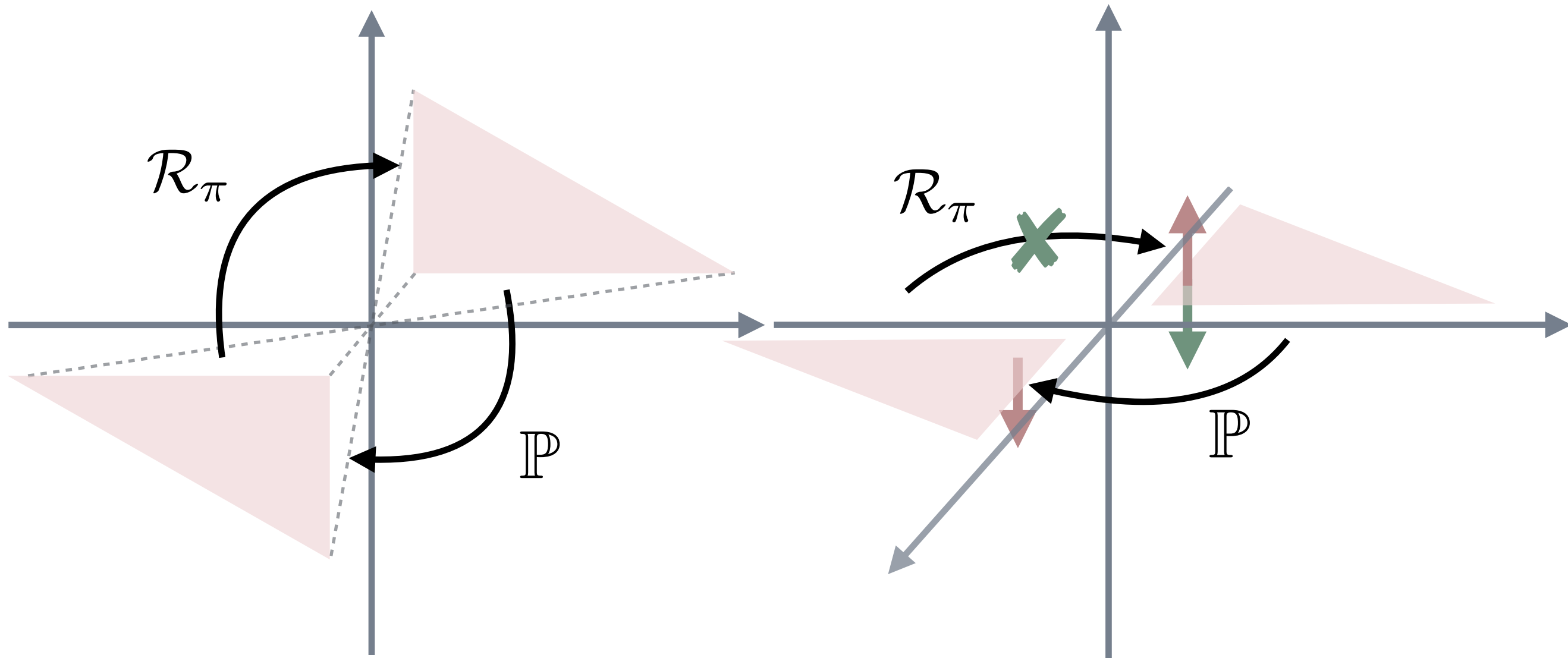
See Gao et al. (arXiv:2509.13207)
and Jamieson et al. (arXiv:2406.15683)

Probing parity violation through the bispectrum?



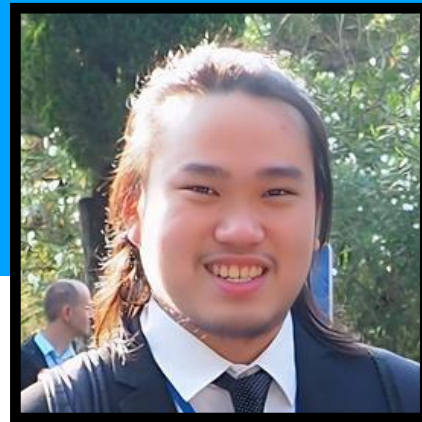
Consider a bispectrum such as $\langle \delta_m \delta_m \delta_m \rangle$.
This is not sensitive to parity

However, mixed bispectra $\langle v_i \delta_m \delta_m \rangle$.
are sensitive to parity

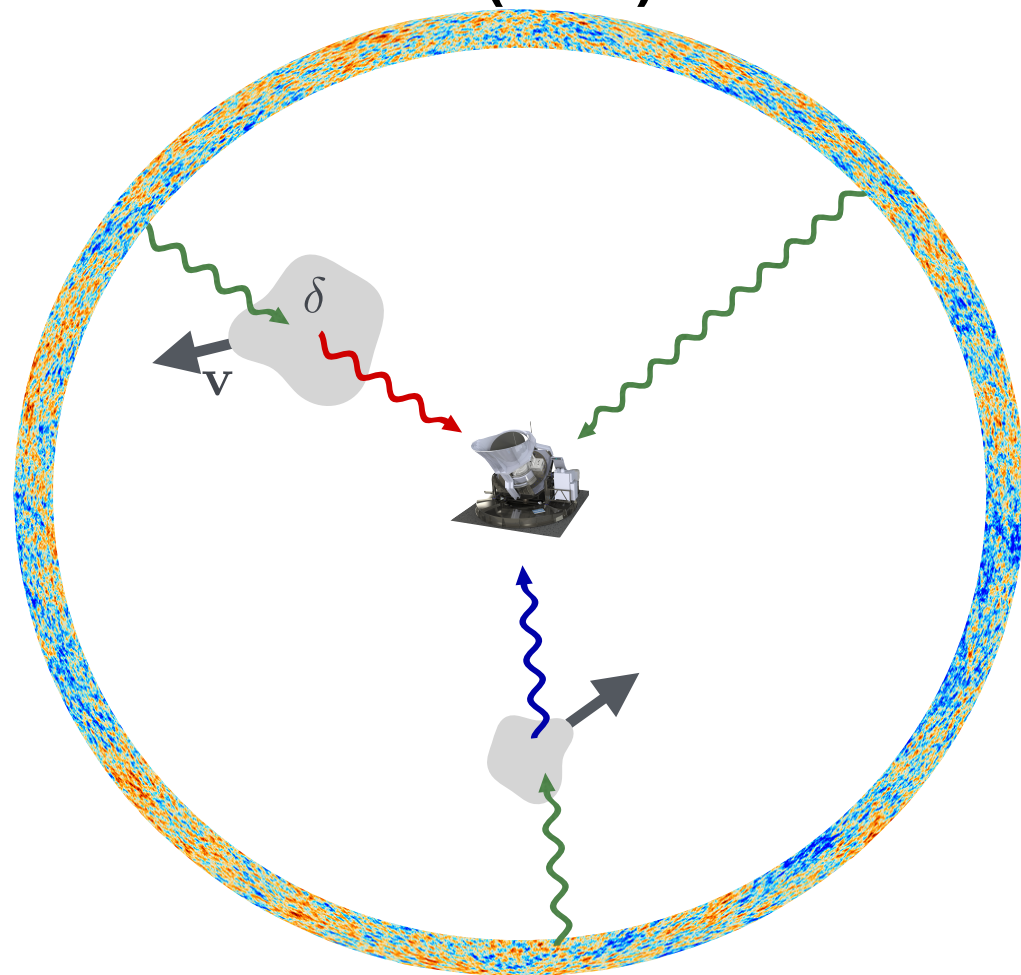


See Gao et al. (arXiv:2509.13207)
and Jamieson et al. (arXiv:2406.15683)

Probing parity violation with the kSZ bispectrum?



What is the kinetic Sunyaev Zeldovich (kSZ) effect?



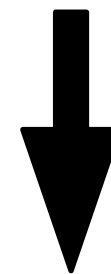
Gas density

$$\delta T_{kSZ} \propto \int n_e \mathbf{n} \cdot \mathbf{v}$$

Velocity

How do we measure it?

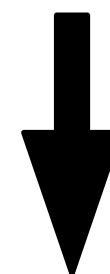
$$\langle \delta_g \delta T_{kSZ} \rangle = 0$$



Measure it with the bispectrum

$$\langle \delta_g \delta_g \delta T_{kSZ} \rangle$$

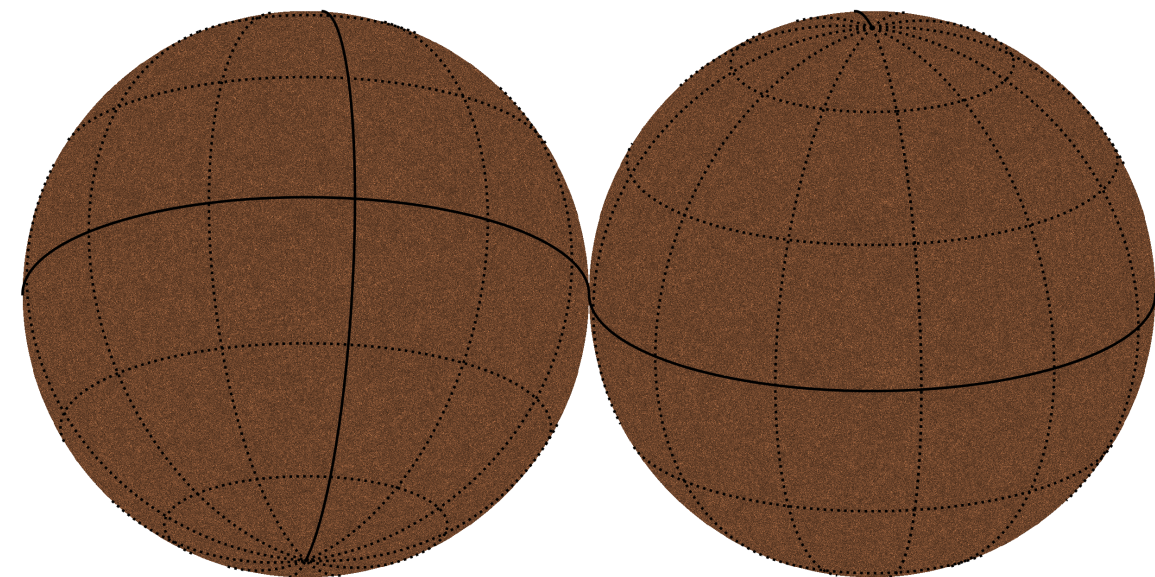
Bloch et al (2024), McCarthy et al (2024)
Hotinli et al (2025) Lai et al (2025) +++



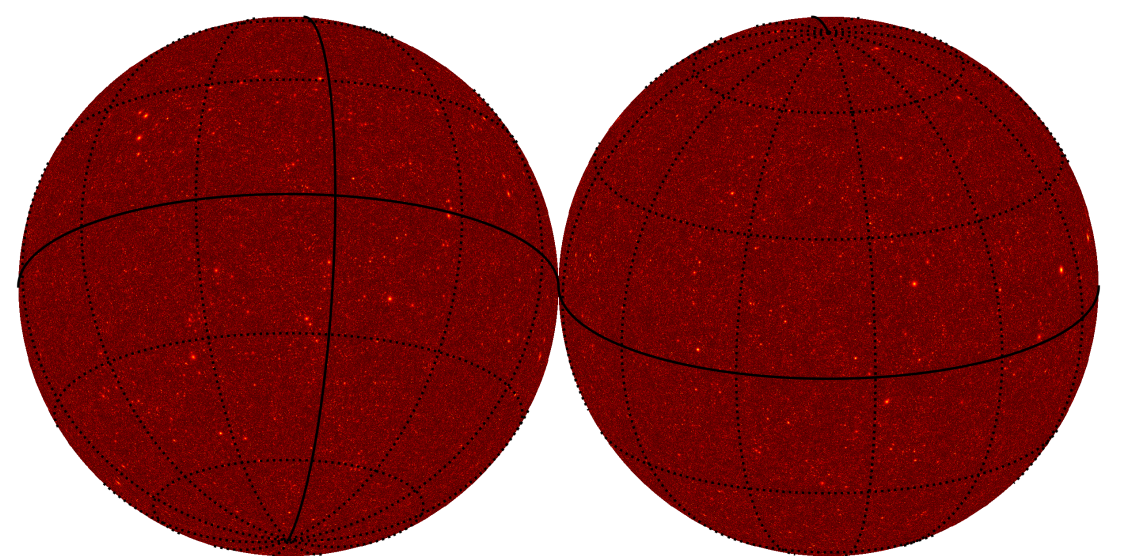
Exploit this machinery
to constrain parity violation!

What's next in this program?

Galaxies

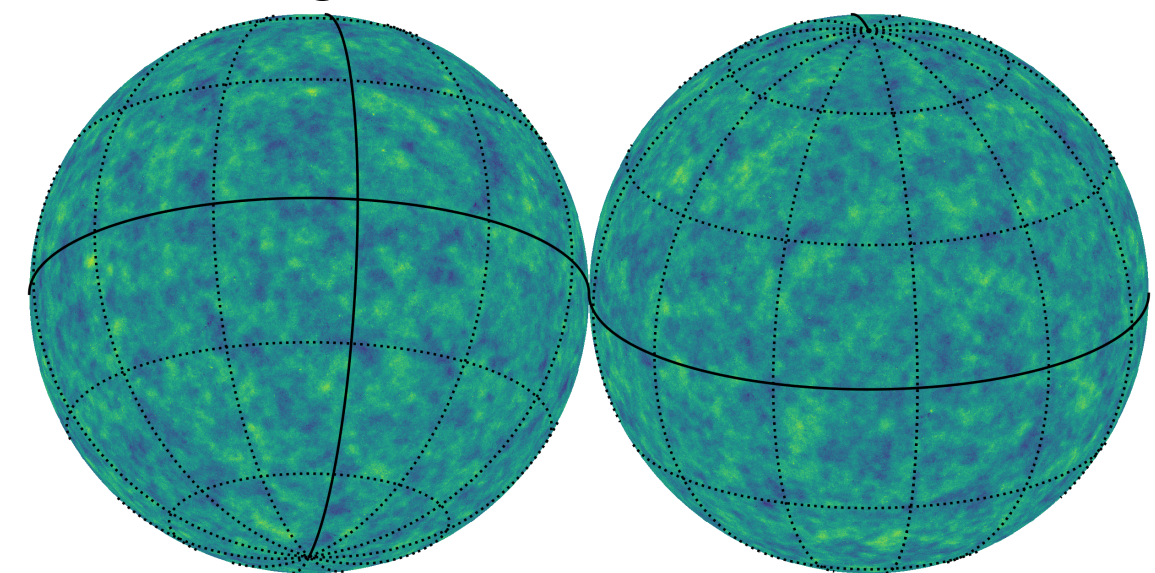


Integrated Pressure

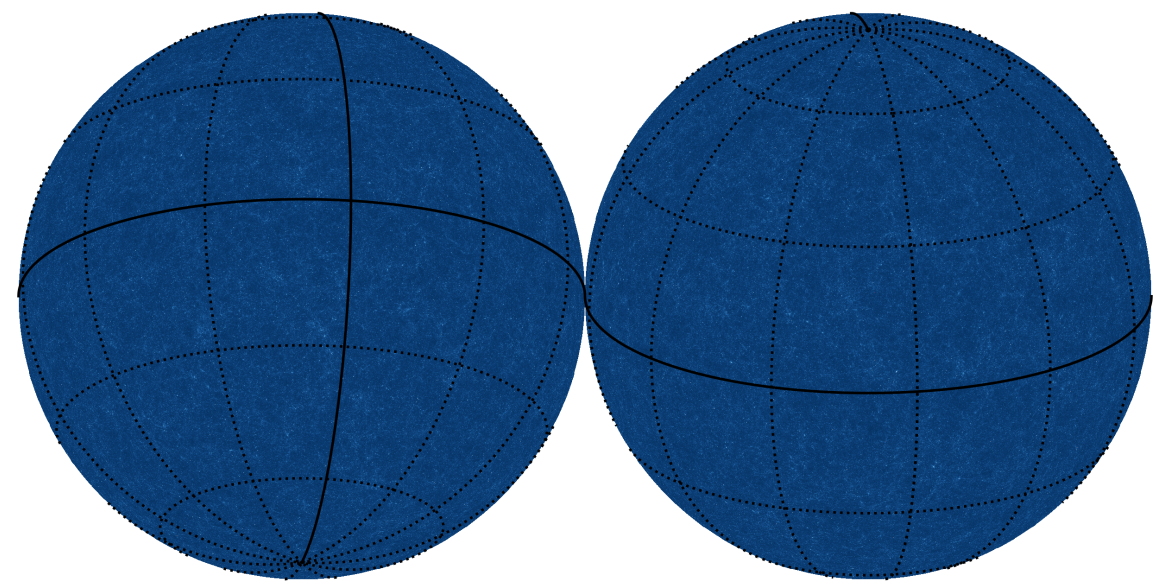


What's next in this program?

Integrated Gas Momentum



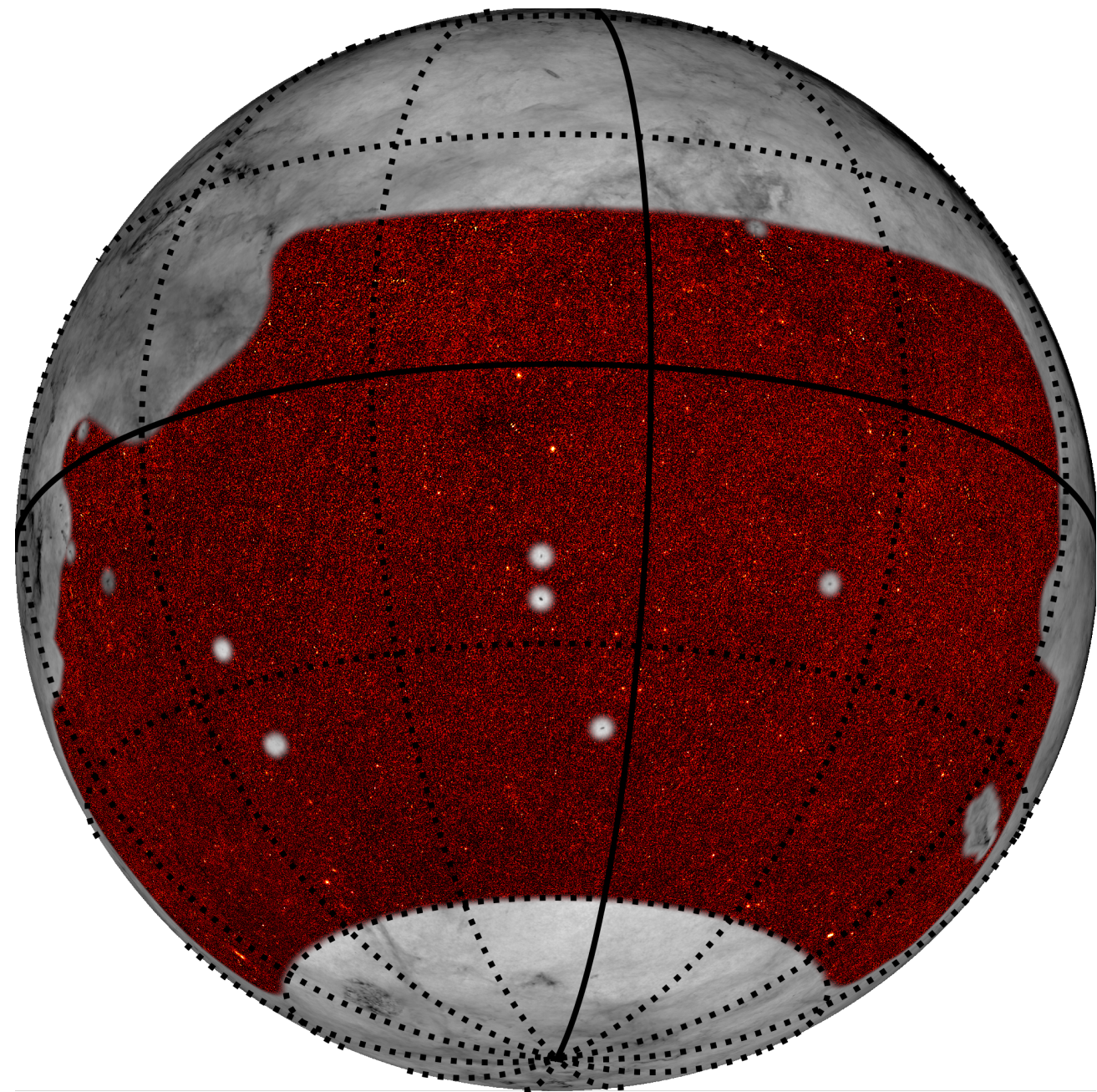
Integrated Matter



Quijote on the sphere -> SBI for CMB and galaxies!

- CMB secondaries are inherently non-Gaussian!
- Much of the information is encoded in statistics beyond the 2pnt!
- Presents a strong case for SBI & field level inference
 - Already doing this for CMB lensing!

Extract of ACT-Planck Compton-y map

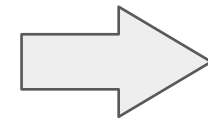
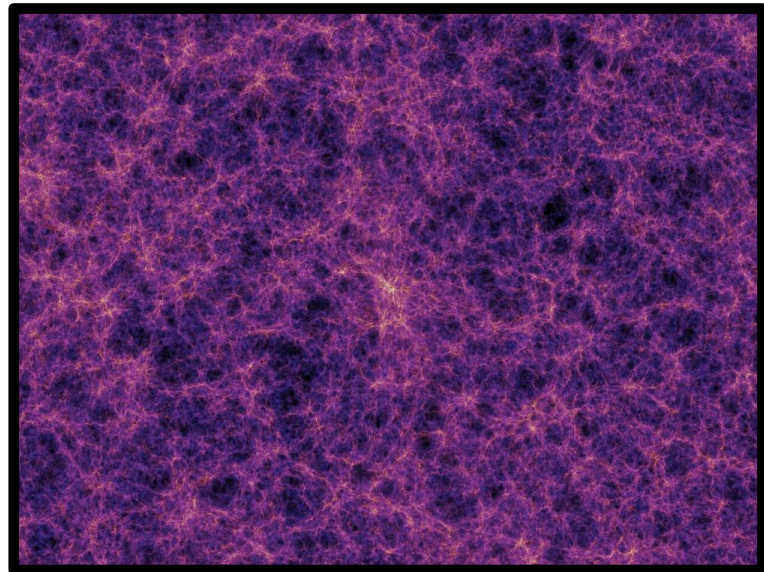


What is the backlight simulations project?

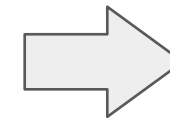
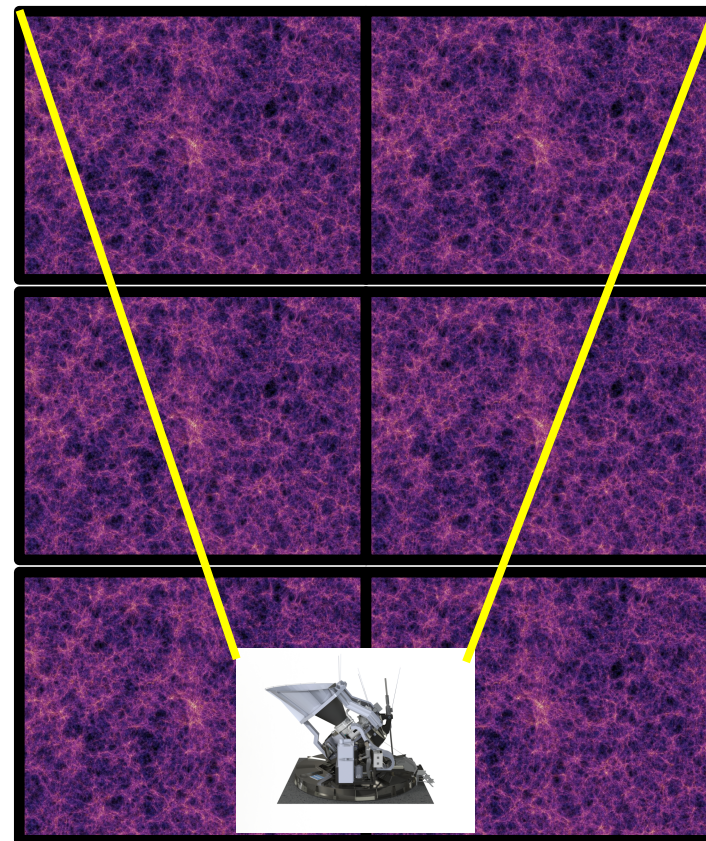
- Goal: A suite of **~1000 mock, non-Gaussian mocks**
 - Varying cosmology, astrophysical models ++
 - Multiple observables (CMB, optical galaxies, lensing +++)
- Designed to test pipeline biases, compute cov. mats, develop new analysis methods
- Current status:
 - **~150** covariance matrix simulation and Fisher simulations
 - Latin Hypercube of simulations (~200/1000 done, **next ~6 months**)

Our approach

High resolution, high fidelity dark matter simulations



Tile box to cover the Universe and construct a light cone

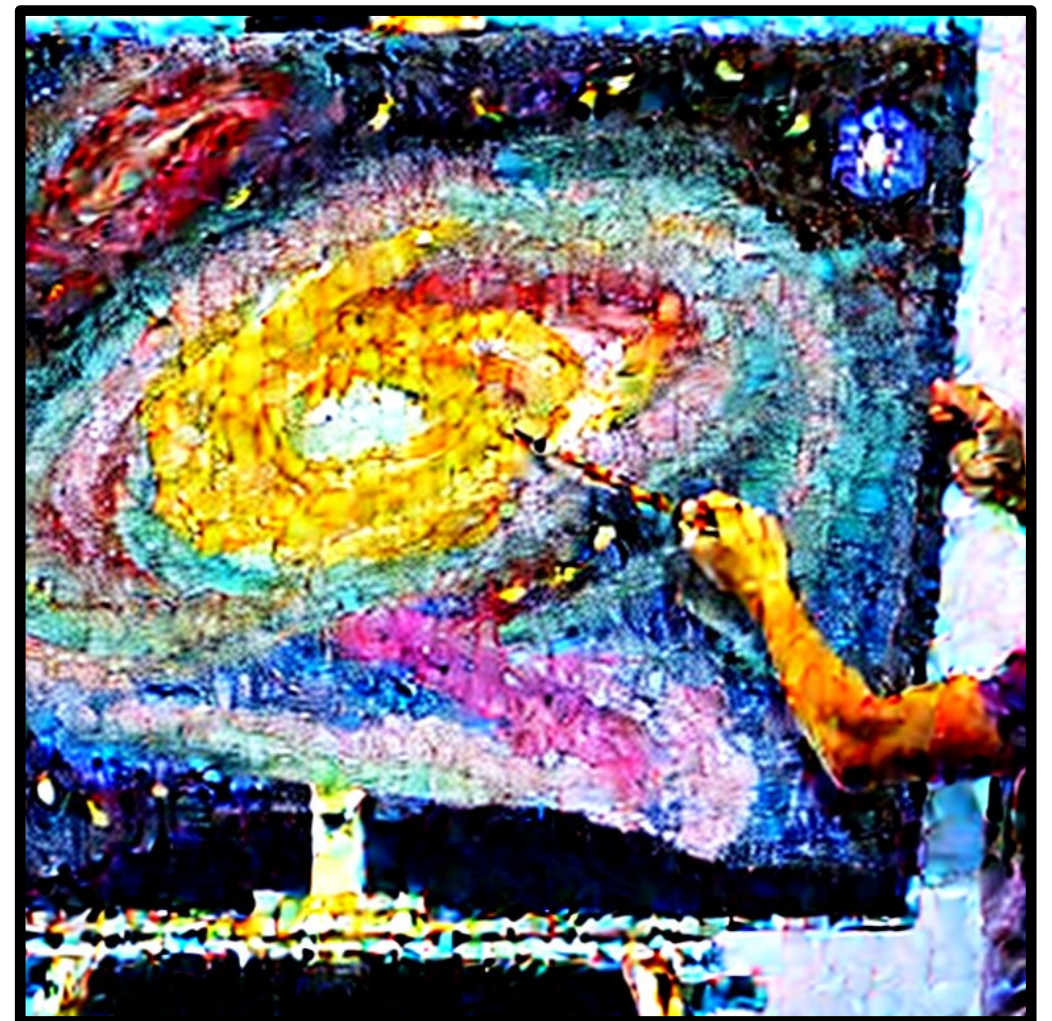


“Paint” observables onto simulations



“Painting” on the observables

Goal: a variety of different “painting” methods with different assumptions



Conclusions

- Simulations provide path to connection primordial physics to observations
- Large number of simulations
 - Currently have ~250
Goal: >1000
- Large range of observables (CMB, galaxy clustering, lensing++)
 - Talk to us about adding other observables
- Goal multiple “painting” methods
 - Currently a halo-based approach and a particle based approach

A slice through the simulated observables from one of our simulations

