Non-linear Evolution of Primordial Parity Violation

Sha Azyzy - 30.06.2025

Based on work with E. Komatsu, D. Jamieson, T. Kurita

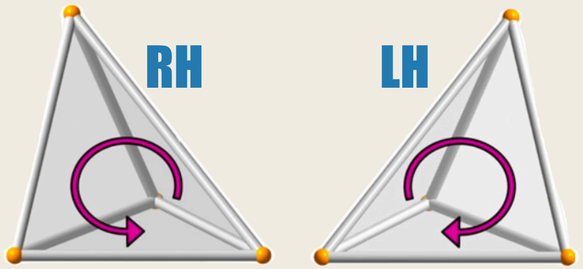
MAX PLANCK INSTITUTE
FOR ASTROPHYSICS

Summary

- A **violation of parity symmetry** is a **new probe of the primordial universe**!
- Parity violation in primordial density fluctuations is a generic prediction of **axion inflation**
- Observed **CMB anisotropies** and the **distribution of galaxies** also break parity
- To connect **theory** and **observation**, we need to model **non-linear evolution** from early to late times

Probe of Parity Violation in the LSS

- How to extract information about parity violation from the **scalar inflaton fluctuations** $\delta\phi$?
  - Evolve to **matter density perturbations** δ_m: $\delta\phi \to \zeta \to \delta_m = \delta\rho_m/\bar{\rho}_m$
  - Consider **correlation functions** of δ_m
- The **power spectrum** (2pcf) and **bispectrum** (3pcf) are not sensitive to parity violation
- The **trispectrum** (4pcf) is the lowest order statistics sensitive to parity violation [Shiraishi (2016), Cahn, Slepian, Hou (2023)]



[Figure: D. Yogev-Einot et al. 2007]

Parity Violating Matter Trispectrum

- The trispectrum can be split into the **parity-even** and **parity-odd** parts

$$< \delta_m(\vec{k}_1)\delta_m(\vec{k}_2)\delta_m(\vec{k}_3)\delta_m(\vec{k}_4) >_c = (2\pi)^3\delta_D(\vec{k}_{1234})(T_{m,+}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) + i\,T_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4))$$

- We compute the **non-linear** corrections at **1-loop** order in Eulerian perturbation theory

$$T_{m,-} = T^{lin}_{m,-} + T^{1-loop}_{m,-} + \dots$$

$$T^{1-loop}_{m,-} \propto \int T^{lin}_{m,-}\; P^{lin}_m \quad \text{x (SPT Kernel)}$$

[SA, Komatsu, Jamieson, Kurita in preparation]

Parity Violating Matter Trispectrum

$$T_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) = T^{lin}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) + \left(T^{1122}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) \ + 5\ Perm.\right) + \left(T^{1113}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) \ + 3\ Perm.\right) + \ \ldots$$

$$T^{lin}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) = \mathcal{T}(k_1)\mathcal{T}(k_2)\mathcal{T}(k_3)\mathcal{T}(k_4)\, T_{\zeta,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4)$$

PRIMORDIAL PARITY-ODD TRISPECTRUM

$$T^{1122}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) = \ 4\int_{\vec{q}} F^{(s)}_2(\vec{q},\vec{k}_3-\vec{q})\ F^{(s)}_2(-\vec{q},\vec{k}_4+\vec{q})\ P^{11}_m(q)\ T^{lin}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3-\vec{q},\vec{k}_4+\vec{q})$$

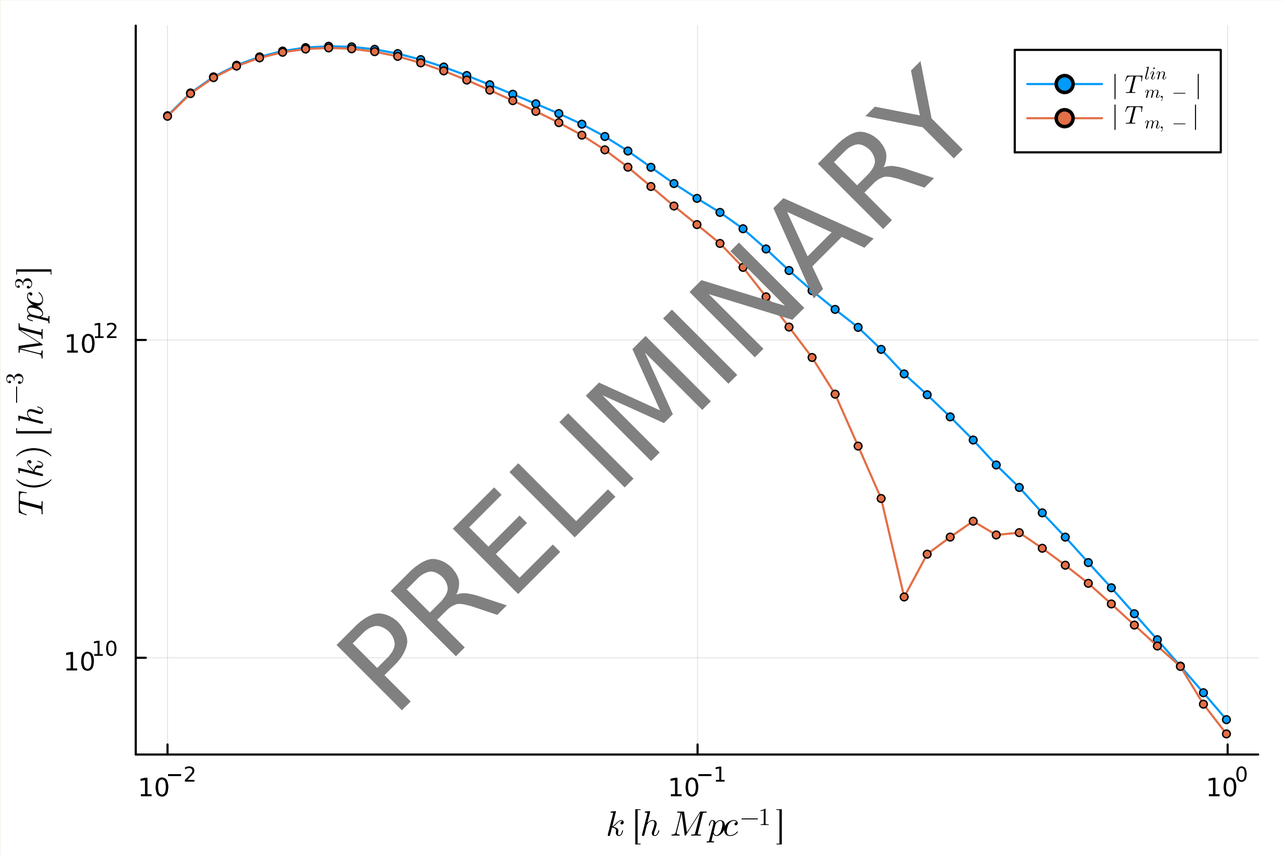
$$T^{1113}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) = T^{lin}_{m,-}(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4)\ \frac{P^{13}_m(k_4)}{P^{lin}_m(k_4)}$$

$$+3\ P^{11}_m(k_1)\int_{\vec{q}} F^{(s)}_3(\vec{q},-\vec{k}_1,\vec{k}_1+\vec{k}_4-\vec{q})\ T^{lin}_{m,-}(\vec{k}_2,\vec{k}_3,\vec{q},\vec{k}_1+\vec{k}_4-\vec{q}) \ + \ (\vec{k}_1\leftrightarrow\vec{k}_2) + \ (\vec{k}_1\leftrightarrow\vec{k}_3)$$

[SA, Komatsu, Jamieson, Kurita in preparation]

Parity Violating Matter Trispectrum

With primordial parity-odd template



Squeezed configuration
k1<< k2 ~k3 ~k4

[SA, Komatsu, Jamieson, Kurita in preparation]

Summary

- A **violation of parity symmetry** is a **new probe of the primordial universe**!
- Parity violation in primordial density fluctuations is a generic prediction of **axion inflation**
- Observed **CMB anisotropies** and the **distribution of galaxies** also break parity
- To connect **theory** and **observation**, we need to model **non-linear evolution** from early to late times


Thank you for your attention!