# Constraining Primordial non-Gaussianities with Density and Velocity Map

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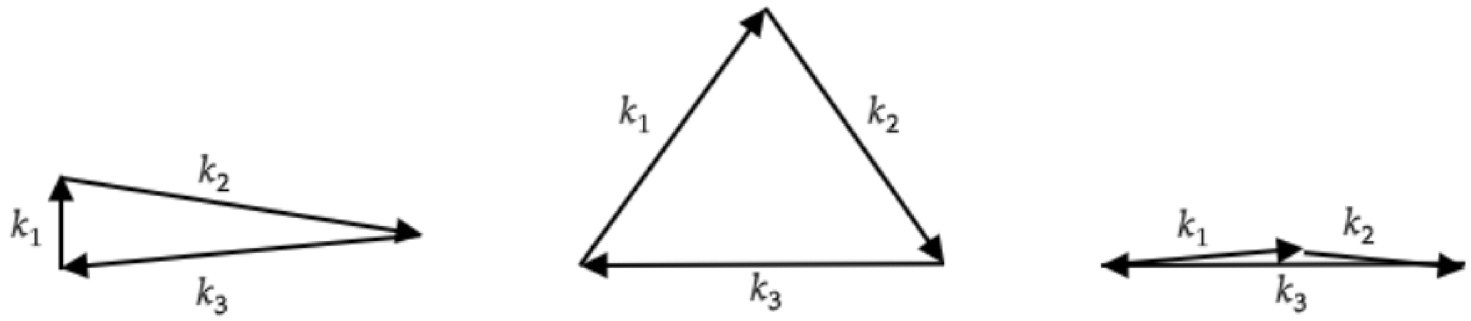
# The Bispectrum

Bispectrum: $$B^{\ell_1\ell_2\ell_3,TTT}_{m_1m_2m_3} = \langle a^T_{\ell_1 m_1} a^T_{\ell_2 m_2} a^T_{\ell_3 m_3} \rangle$$

Multipole: $$a^X_{\ell m} = \int \frac{d^3k}{(2\pi)^3} \mathcal{T}^X_\ell \mathcal{R}_k Y_{\ell m}(\hat{k})$$

Covariance: $$C^{XX'}_\ell = 4\pi \int d\ln(k) \mathcal{T}^X_\ell(k) \mathcal{T}^{X'}_\ell(k) P_{\mathcal{R}}(k)$$

# Primordial Non-Gaussianities (PNG)




Local/squeezed

Equilateral

Folded

$$B(k_1, k_2, k_3) = f_{\mathrm{NL}} F(k_1, k_2, k_3)$$

- Amplitude $f_{NL}$ and shape F
- Study / constrain $f_{NL}$

# KSW Estimator

$$\frac{1}{\sigma^2} = \sum_{\{X_i\}} \sum_{\ell_1 \le \ell_2 \le \ell_3} \frac{1}{\Delta_{\ell_1 \ell_2 \ell_3}} (B_1)^{X_1 X_2 X_3}_{\ell_1 \ell_2 \ell_3}$$
$$\times \left[ (C^{-1})^{X_1 X_4}_{\ell_1} (C^{-1})^{X_2 X_5}_{\ell_2} (C^{-1})^{X_3 X_6}_{\ell_3} \right]$$
$$\times (B_1^*)^{X_4 X_5 X_6}_{\ell_1 \ell_2 \ell_3} ,$$

B: Bispectrum

C: Covariance

$\Delta$: Geometric Factor

$T_l^X$: Transfer Function

$\Phi$: Primordial Potential

X: Polarisation

# The Idea

$$B^{\ell_1 \ell_2 \ell_3, X_1 X_2 X_3}_{m_1 m_2 m_3} \propto \mathcal{T}^{X_1}_{\ell_1} \mathcal{T}^{X_2}_{\ell_2} \mathcal{T}^{X_3}_{\ell_3} \langle \mathcal{R}_k \mathcal{R}_k \mathcal{R}_k \rangle$$

- Estimator requires transfer function to relate quantity to primordial perturbations
- CMB Temperature and E-Mode
- Transfer functions for **density** available

# Multipole Expansion of Density

Overdensity Field:
$$\delta(\mathbf{x}) \equiv \frac{\rho(\mathbf{x}) - \bar{\rho}}{\bar{\rho}}$$

Multipole Expansion:
$$a_{\ell m}^{X} = \int \frac{d^3k}{(2\pi)^3} \mathcal{T}_{\ell}^{X} \mathcal{R}_k Y_{\ell m}(\hat{k})$$

Transfer function:
$$\mathcal{T}_{\ell}^{\delta}(k,\chi) = 4\pi i^{\ell} j_{\ell}(k\chi) D_{\delta}(k,\chi)$$

# Advantages of (Angular) Density Map

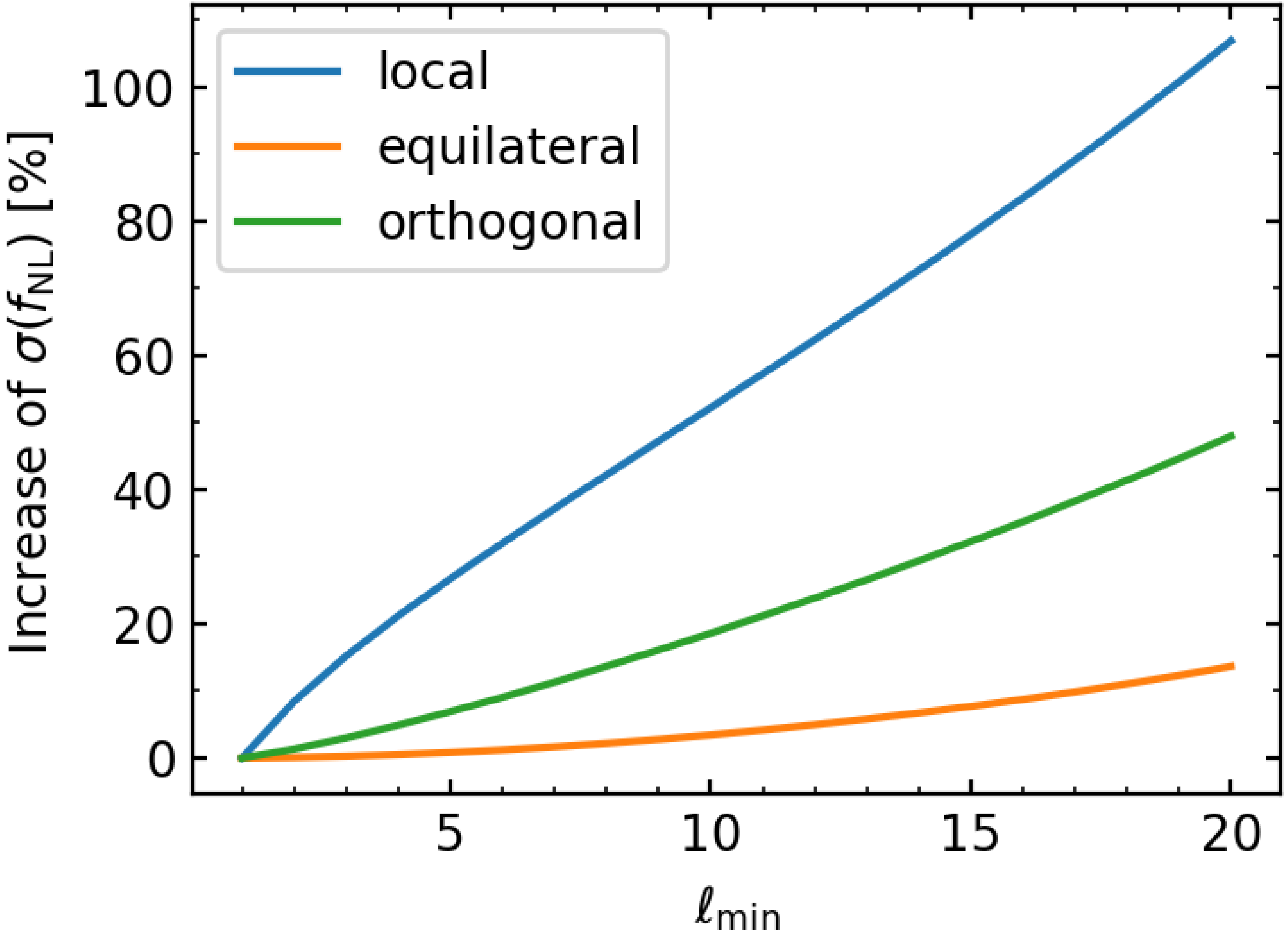
- 2D CMB map vs 3D density map
- Photometric Large-Scale Structure Surveys catalogues 3D map into multiple bins
- Estimator scales approximately (for weak correlation between bins):

$$\sigma^2(f_{NL}) \propto 1/N_{Bin}$$

# Our Setup

- Redshift range: 0.2 > z > 2 (avoid shot noise at large redshift)
- Number of bins: 26 (LSST-like) (32 with z<3)
- Noise free
- Only linear regime
- No skycut
- Large angular systematics

# Lost Information on Largest Scales



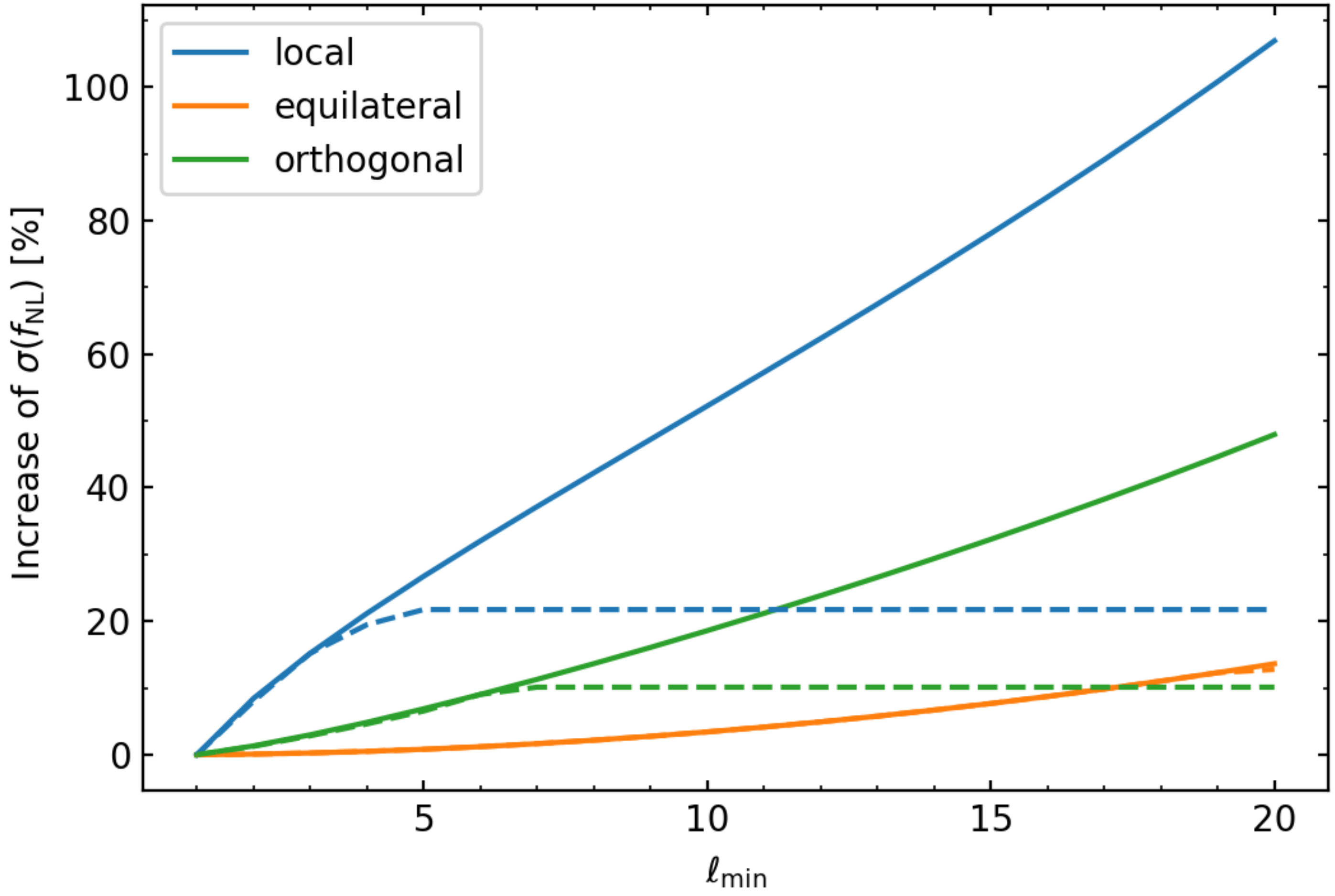

- Large losses for local shape
  - 10% just from dipole
- Small losses for equilateral shape

# Velocity Maps

- Kinetic Sunyaev Zel'dovich Effect (kSZ) can reconstruct velocity map on largest scales
- Up to $\ell$=20-30 signal of future surveys is forecasted to have high signal-to-noise ratio
- Low number of multipoles limits constraining power
- Access to largest scales can restore information for density

Deutsch et al., 1707.08129

# Restored Information by Velocity




- Velocity + density independent of $\ell_{min}$
- Information restored for local and orthogonal shape
- Equilateral only at large $\ell_{min}$

# Non-Gaussanities in Density Map

- Expected level of NG of different shapes in density map due cosmic variance
- How much NG is expected in our realization of the Universe assuming f_nl=0

| Shape | This work | Planck | CMB-S4 |
|---|---|---|---|
| local | 3.5* | 5 | 1.8 |
| equilateral | 14* | 43 | 21.2 |
| orthogonal | 8.3* | 21 | 9.1 |

* “semi“ - ideal experiment
* No Skycut   $(\sigma \sim \frac{1}{\sqrt{f_{sky}}})$
* Noise-free measurement
* Neglect other effects producing NGs

# Future Work

- How do we get the density map
- Contaminations in the map
- Include systematics and errors
- Consider skycuts
- Include reconstruction noise for velocity reconstruction

# Conclusion

- Density map thanks to 3D nature reduces cosmic variance on PNG
- Low-$\ell$ velocity modes via kSZ tomography provide valuable Large-Scale Information
- Non-Gaussian effects from non-primordial contributions have to be considered
- Full forecast for an upcoming experiment required (skycut, bias, shot noise, and other systematics, …)