Enhancing Bispectrum Estimators for Photometric Galaxy Redshift Survey with Velocities

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In Collaboration with

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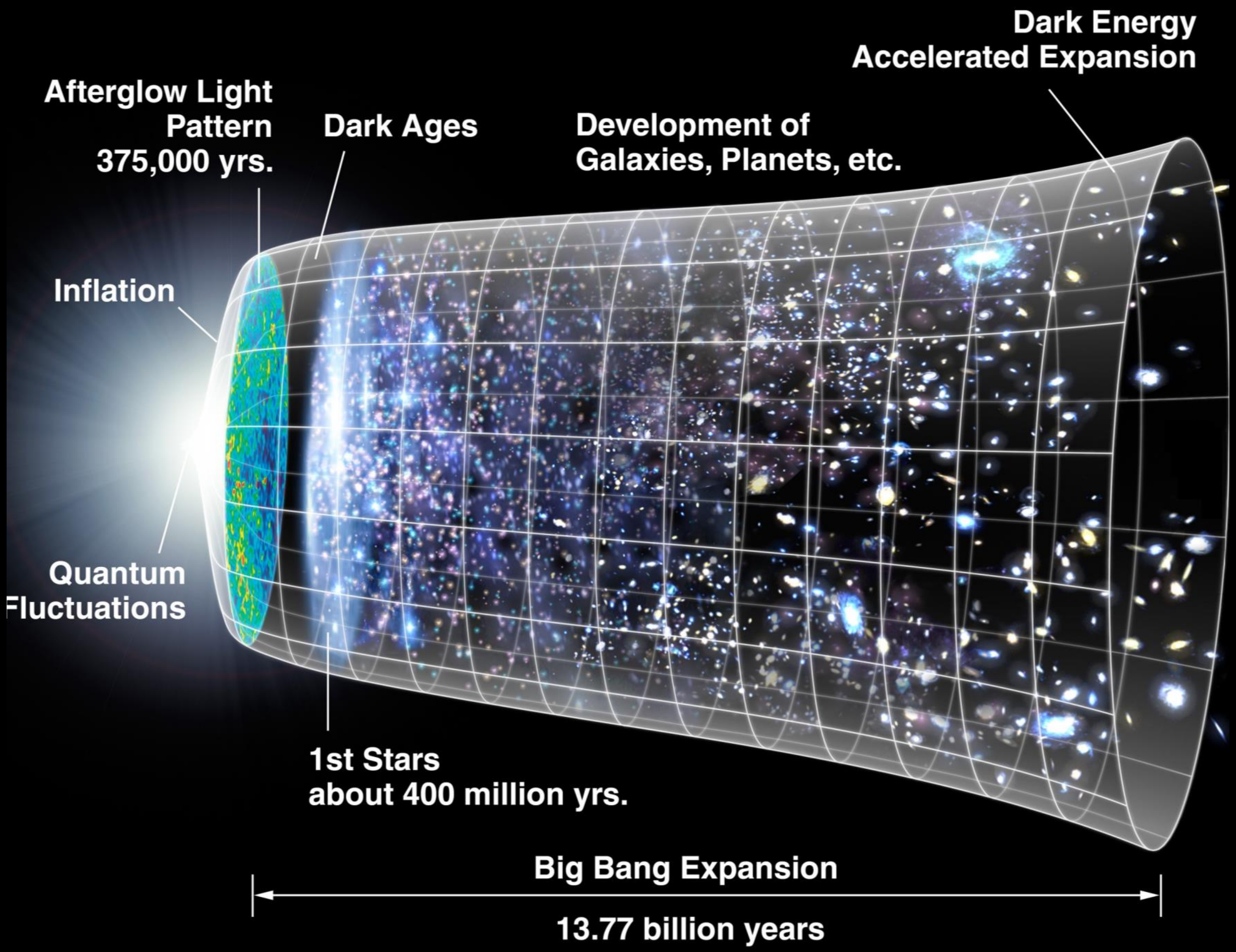


- Inflation solves initial value problems
- Quantum perturbations of inflaton create seeds for structure formation
- We want to learn more about primordial perturbations

Primordial Perturbation

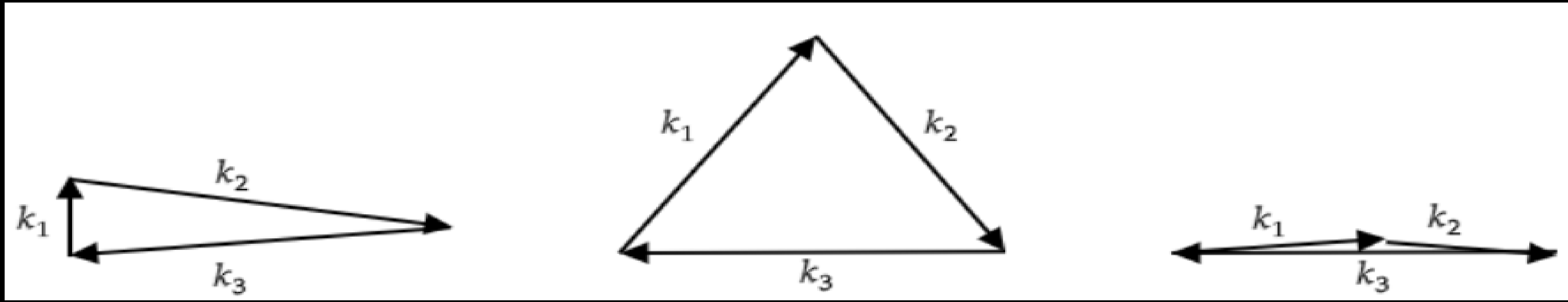
- Power Spectrum:

$$\left\langle \Phi(\vec{k}_1)\Phi(\vec{k}_2) \right\rangle = (2\pi)^3 \, P(k) \, \delta(\vec{k}_1 - \vec{k}_2)$$

- Bispectrum

$$\left\langle \Phi(\vec{k}_1)\Phi(\vec{k}_2)\Phi(\vec{k}_3) \right\rangle = (2\pi)^3 \, B(k) \, \delta\,(\vec{k}_1 + \vec{k}_2 + \vec{k}_3)$$

Bispectrum



Local

- Multiple fields

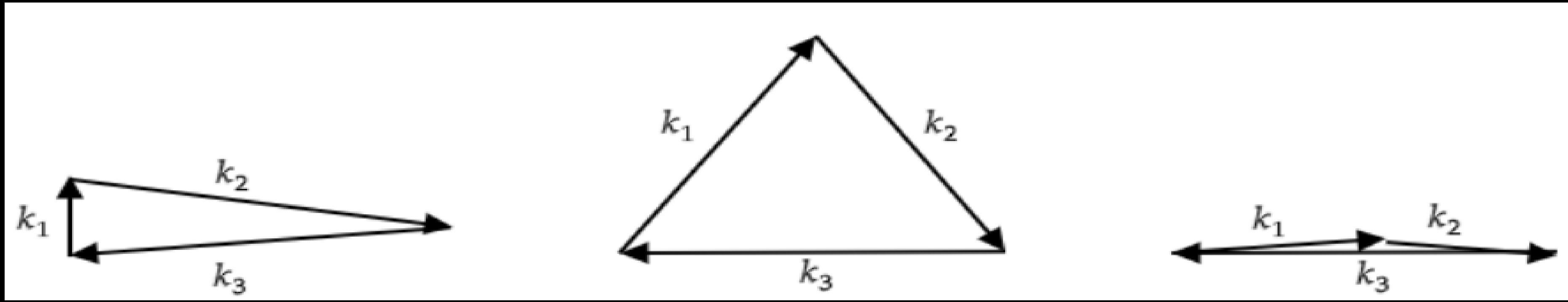
Equilateral

- Non-standard kinetic terms

Folded

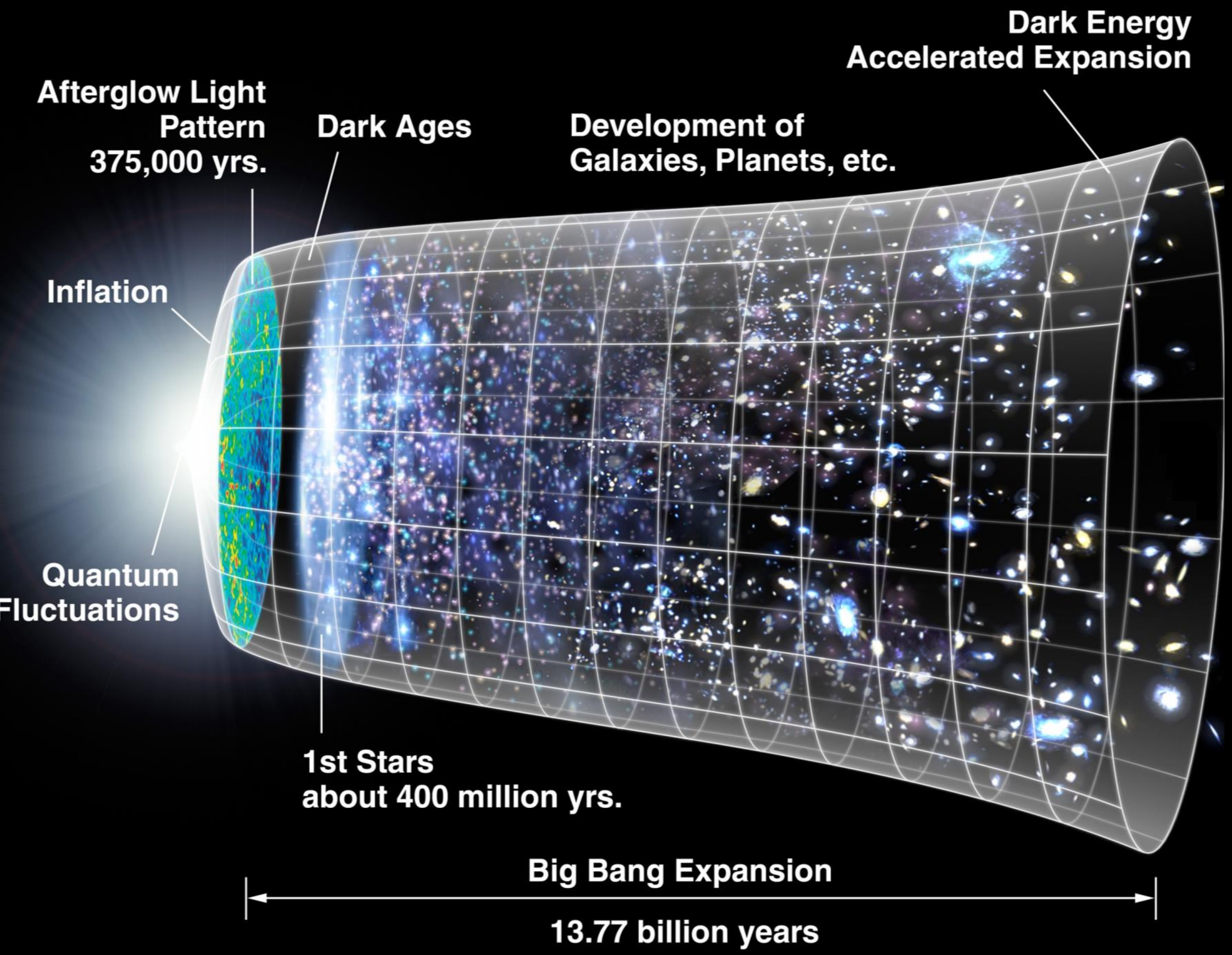
- Excited initial states

Bispectrum



Local	Equilateral	Folded
• Multiple fields	• Non-standard kinetic terms	• Excited initial states

Single Field Slow Roll Inflation predicts $f_{NL} < 1$



- Cosmic variance limits constraining power of CMB
- 2D Map of CMB
- 3D Map of galaxies

- CMB:

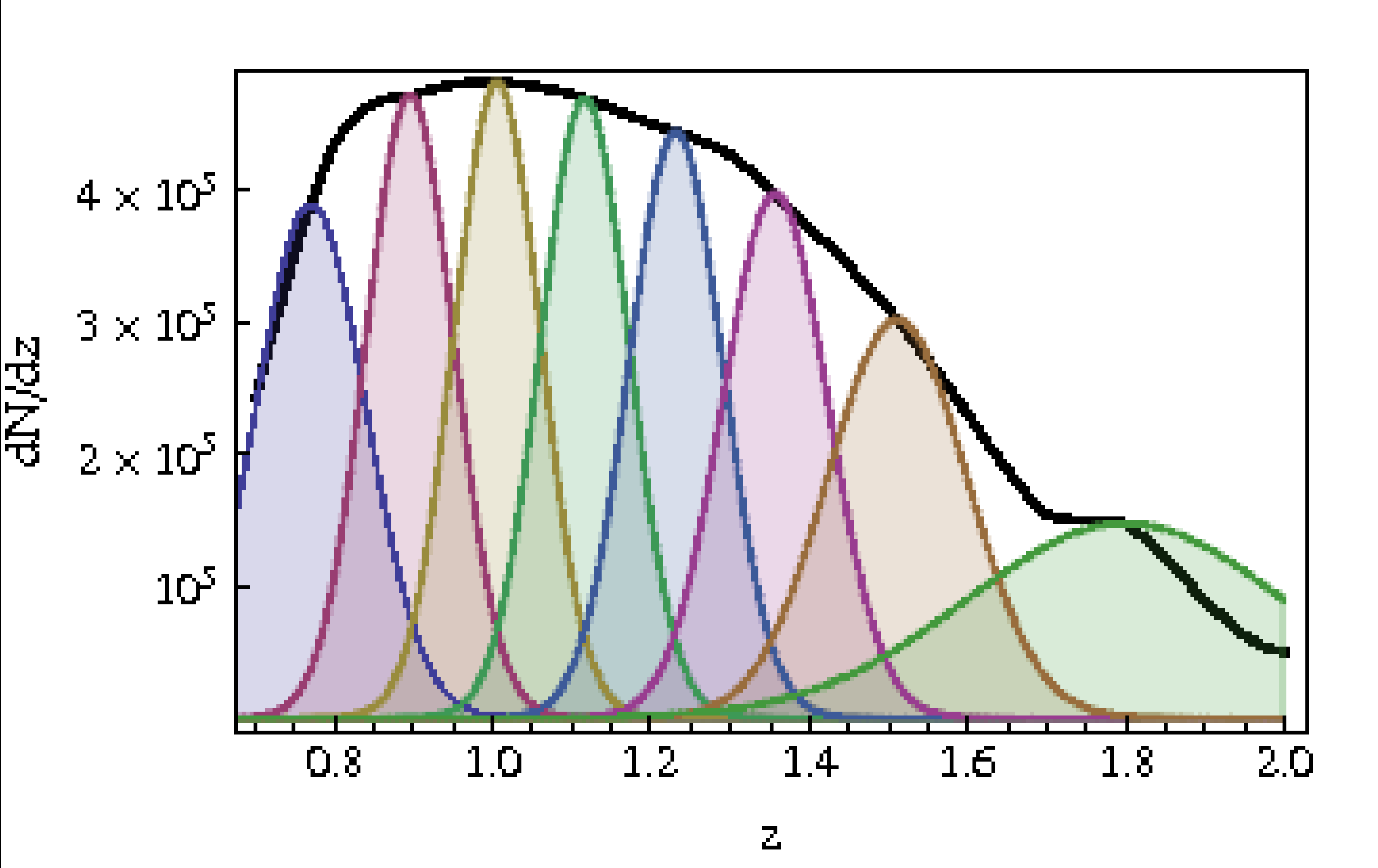
$$\Delta T_{CMB} \rightarrow \Phi$$

- LSS:
- Over densities $\rho = \frac{\bar{\delta} - \delta(x)}{\bar{\delta}}$

$$\rho_g \rightarrow \rho_m \rightarrow \Phi$$

Redshift Binning

- Range of z: 0-2
- Number of bins: 8



Bispectrum Estimator

$$\hat{f}_{\rm NL} = \frac{1}{6\sigma^2} \sum_{\{\ell_i, m_i, X_i\}} (B_1)^{\ell_1\ell_2\ell_3}_{m_1m_2m_3, X_1X_2X_3} \times \Big\{ \Big[(C^{-1}a)^{X_1}_{\ell_1 m_1} (C^{-1}a)^{X_2}_{\ell_2 m_2} (C^{-1}a)^{X_3}_{\ell_3 m_3} \Big] - \Big[(C^{-1})^{X_1 X_2}_{\ell_1 m_1 \ell_2 m_2} (C^{-1}a)^{X_3}_{\ell_3 m_3} + \text{cyclic} \Big] \Big\}$$

$$\frac{1}{\sigma^2} = \sum_{\{X_i\}} \sum_{\ell_1, \ell_2, \ell_3} (B_1)^{X_1X_2X_3}_{\ell_1\ell_2\ell_3} (B_1^*)^{X_4X_5X_6}_{\ell_1\ell_2\ell_3} \times \Big[(C^{-1})^{X_1X_4}_{\ell_1} (C^{-1})^{X_2X_5}_{\ell_2} (C^{-1})^{X_3X_6}_{\ell_3} \Big]$$

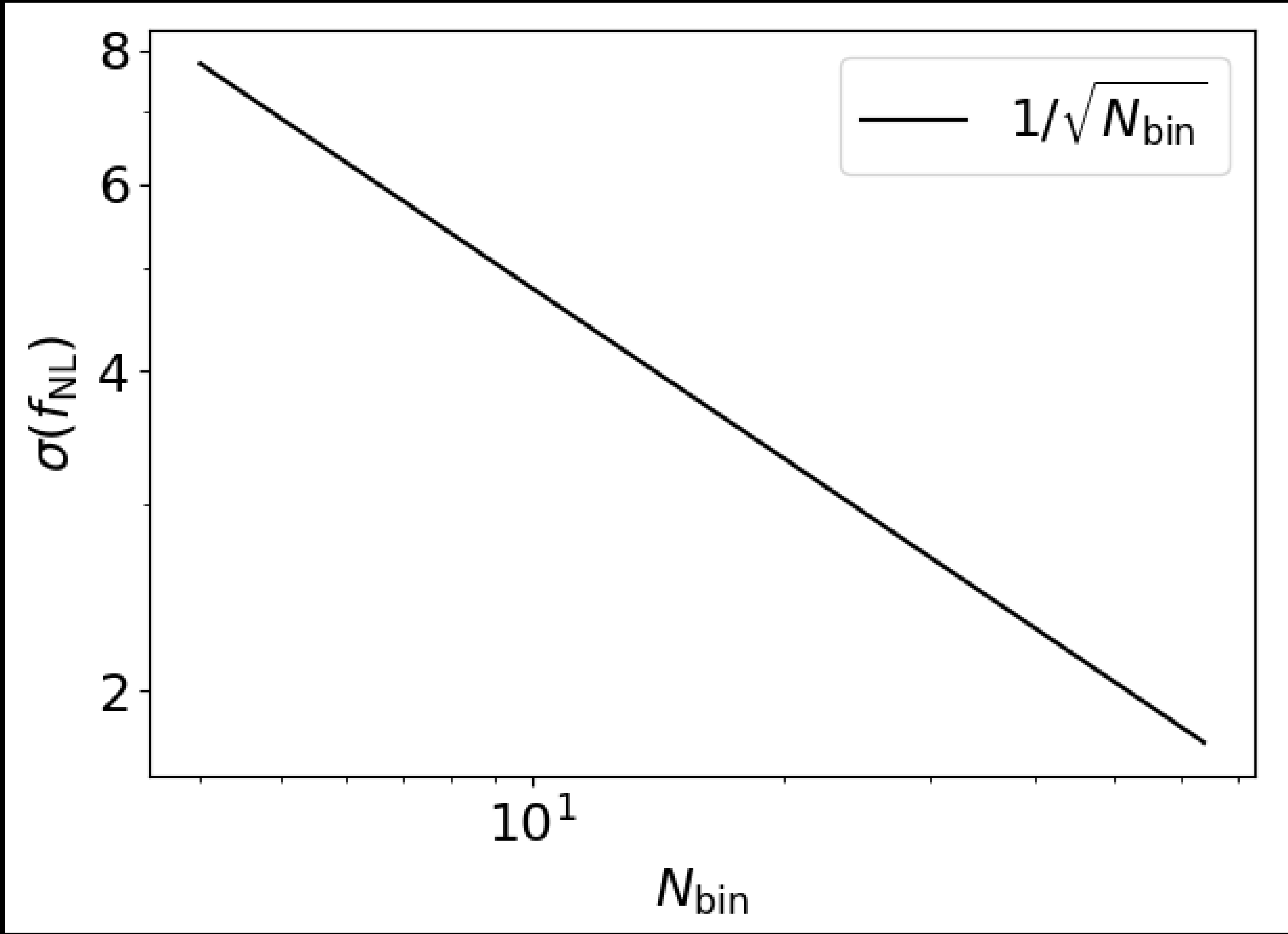
Forecast Setup

- Redshift Range: $0.2 < z < 2$
- Noise-free
- Maximal Multipole: Linear regime of matter power spectrum

  $\ell_{max}(z) \sim k_{NL}(z)\, \chi(z)$
- Photometric Redshift: $\frac{\sigma_z}{1+z} > 0.01$
- Full Sky Coverage

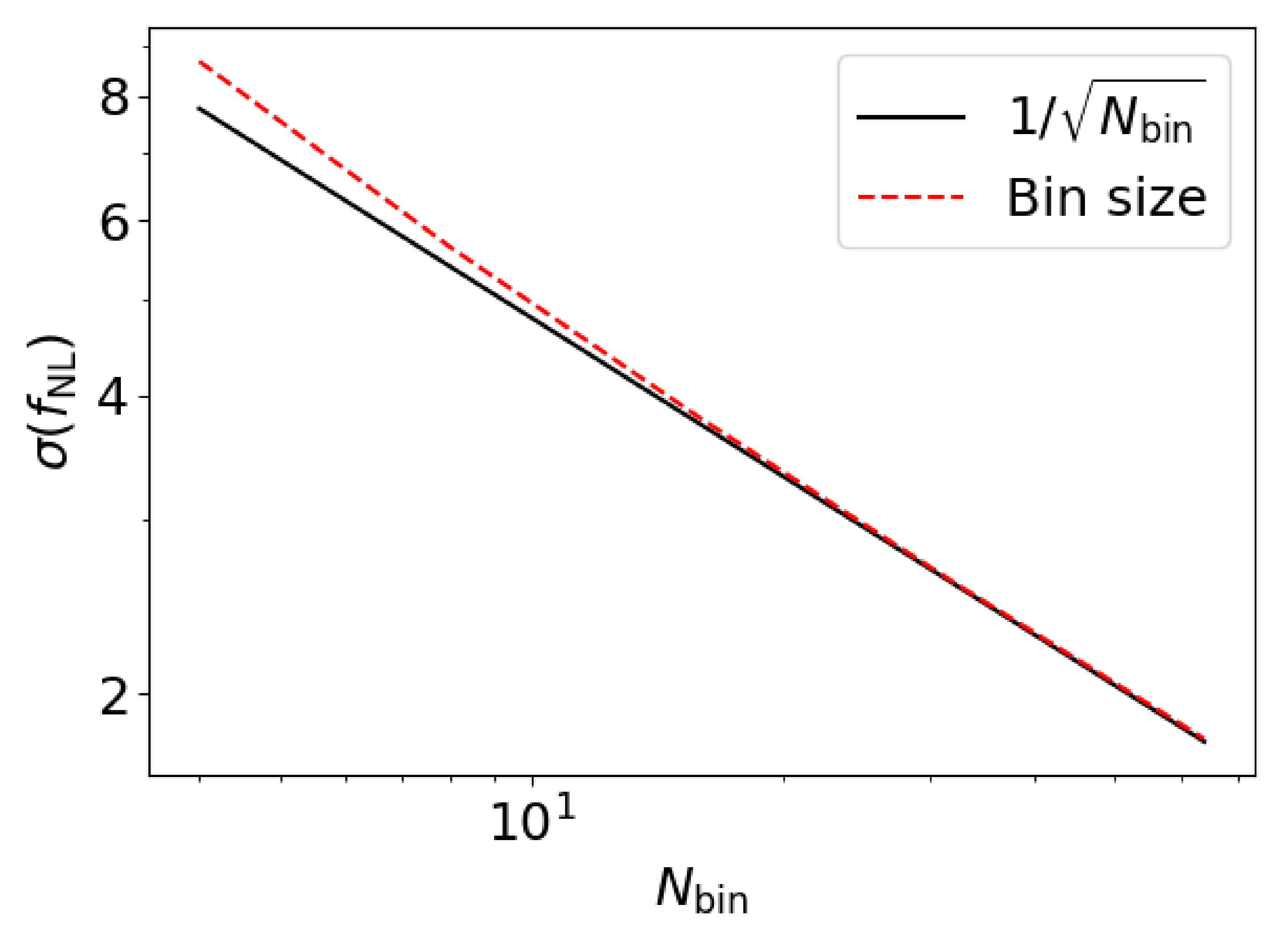
Scaling with Bins

- Uncorrelated maps give square-root scaling



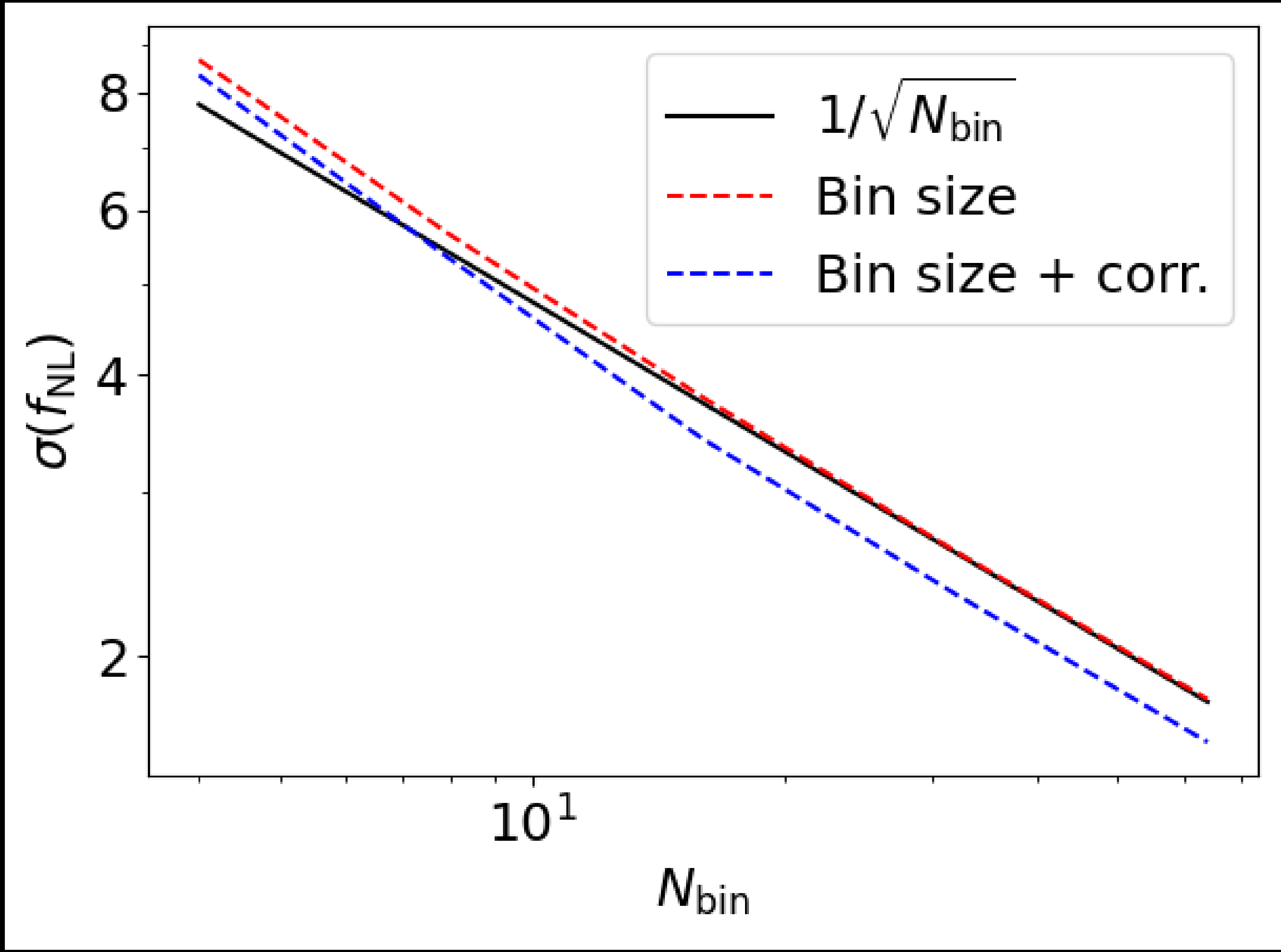
Scaling with Bins

- Uncorrelated maps give square-root scaling
- Smaller bins improve forecast (saturates)



Scaling with Bins

- Uncorrelated maps give square-root scaling
- Smaller bins improve forecast (saturates)
- Correlation will improve scaling further (grows)



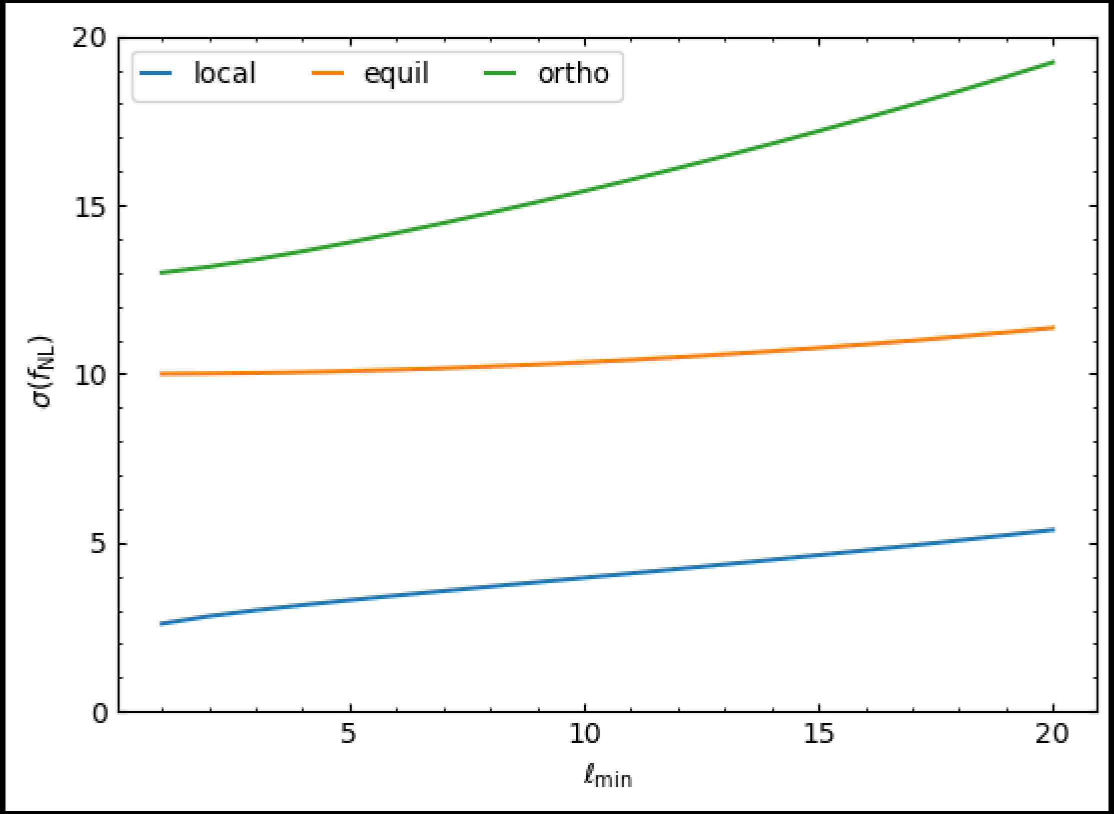
Forecast of $\sigma(f_{NL})$ using density field

$\sigma_z/1+z$	local	equilateral	orthogonal
0.05	3.4	15	17
0.02	2.1	8.5	10
Planck	5	43	21
CMB S4	1.8	21.2	9.1

Troubles in Paradise

- Photometric surveys showed strong systematic errors on the largest scales
- Photometric recalibration (atmospheric blurring, unaccounted-for Galactic dust, imperfect star-galaxy separation)

Truncated Density Forecast

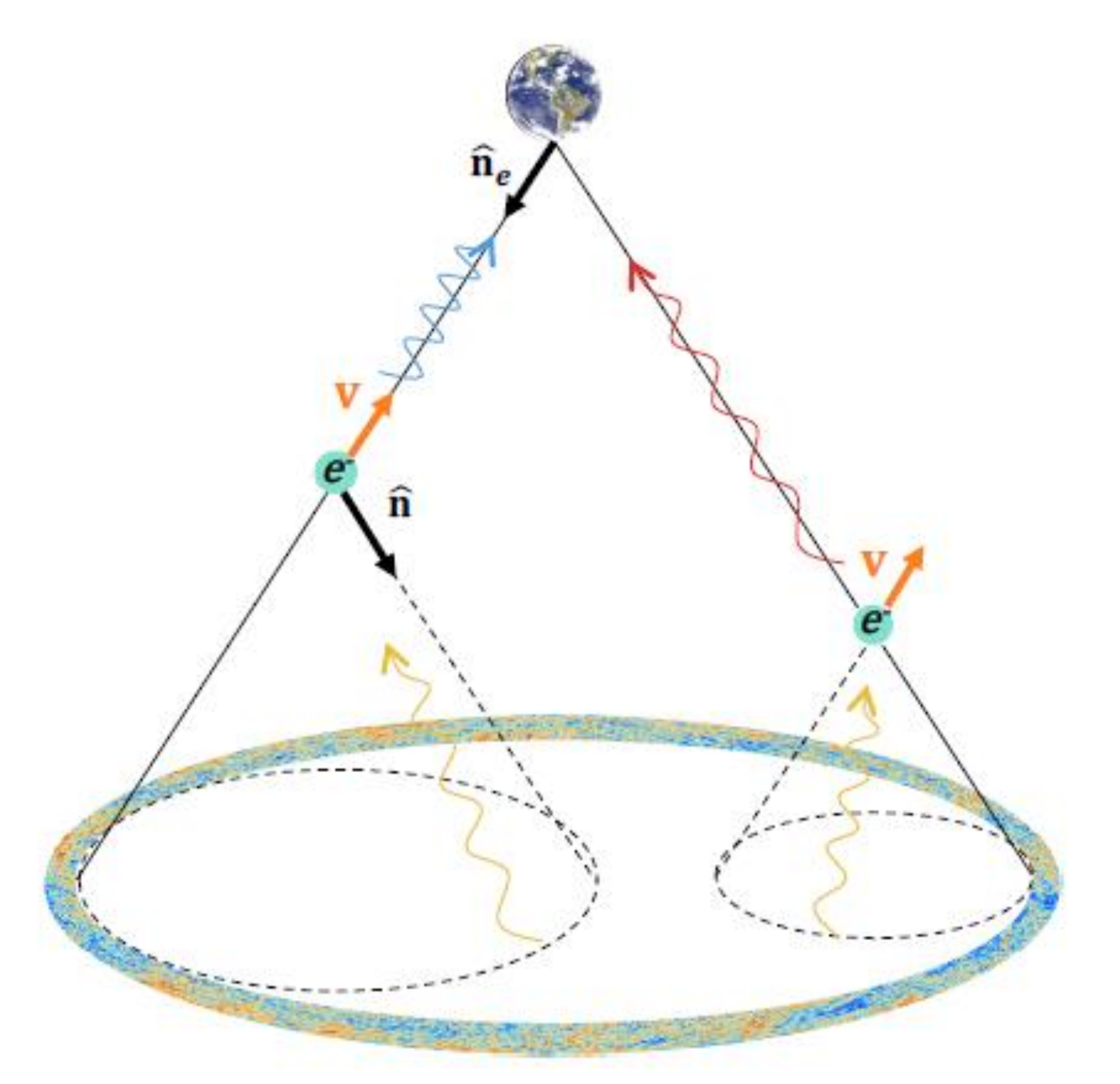


- Local and orthogonal shape strongly affected by large scale cutoff
- Local: 2.6 → 5.5
- Equilateral almost unaffected

Velocity Distribution comes to the Rescue

Kinetic Sunyaev Zel'dovich Effect

- Scattering between CMB photons and electrons
- Imprint of dipole moment of electrons onto photons
- Cross-correlation between LSS and CMB
- Reconstruct dipole moment

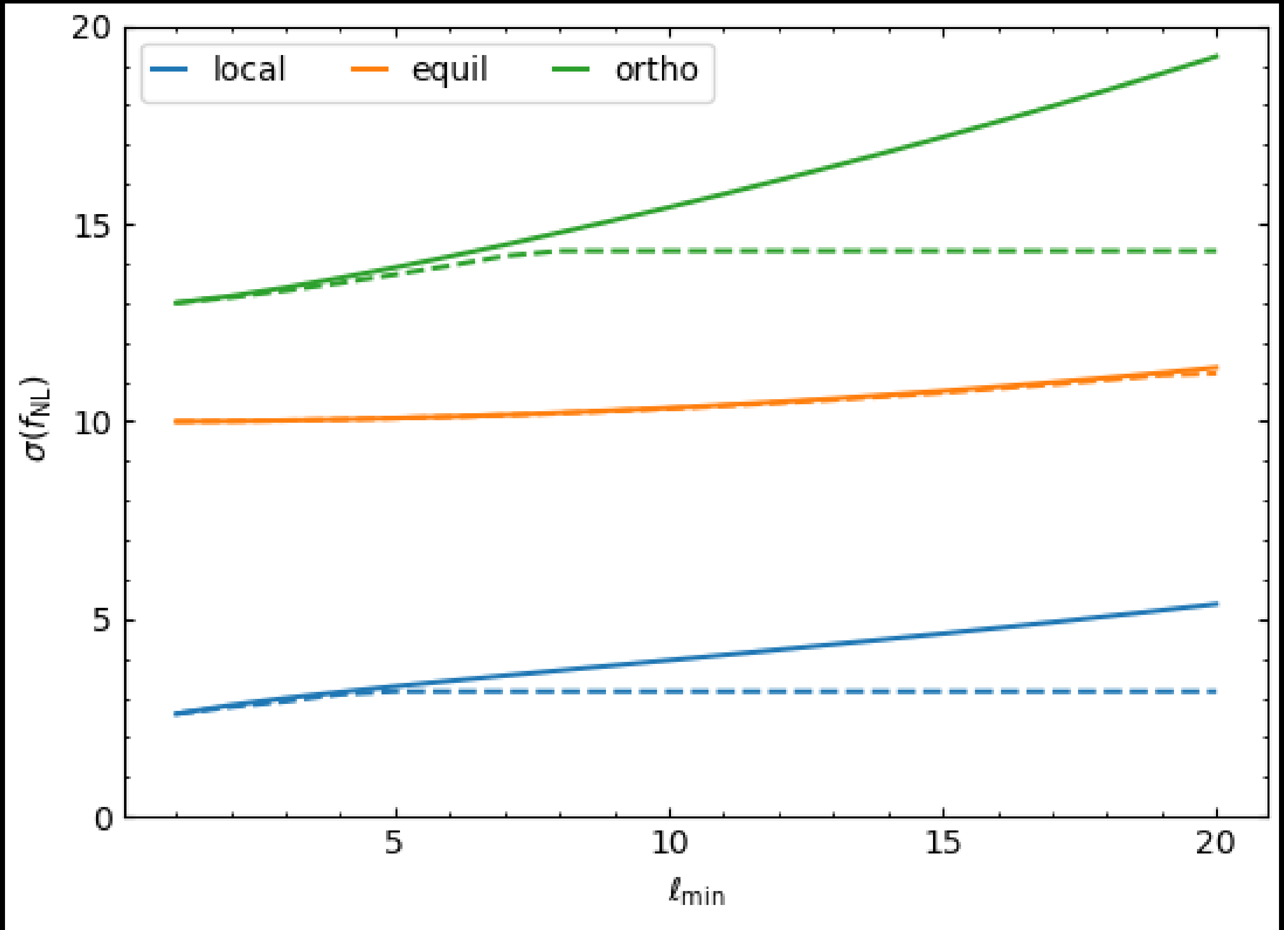


Velocity Distribution comes to the Rescue

- Velocity map of the Universe can help on the largest scale
- Reconstructed velocity map has highest signal-to-noise ratio on largest scales
- Excellent complimentary map to density map

[Matt Johnson et al, 1610.06919 ,*JCAP* 02 (2017) 040]

Density + Velocity



- Velocity until $\ell = 20$
- Velocity modes substituted density modes
- Adding velocity reduces the error
- Up to 80% of information restored for local shape

Summary & Outlook

- Upcoming LSS surveys will increase sensitivity to non-Gaussanities
- Photometric surveys could surpass CMB constraints

- More detailed forecast for LSST or SPHEREx
  - Including noise
  - Extending the redshift beyond z=2