

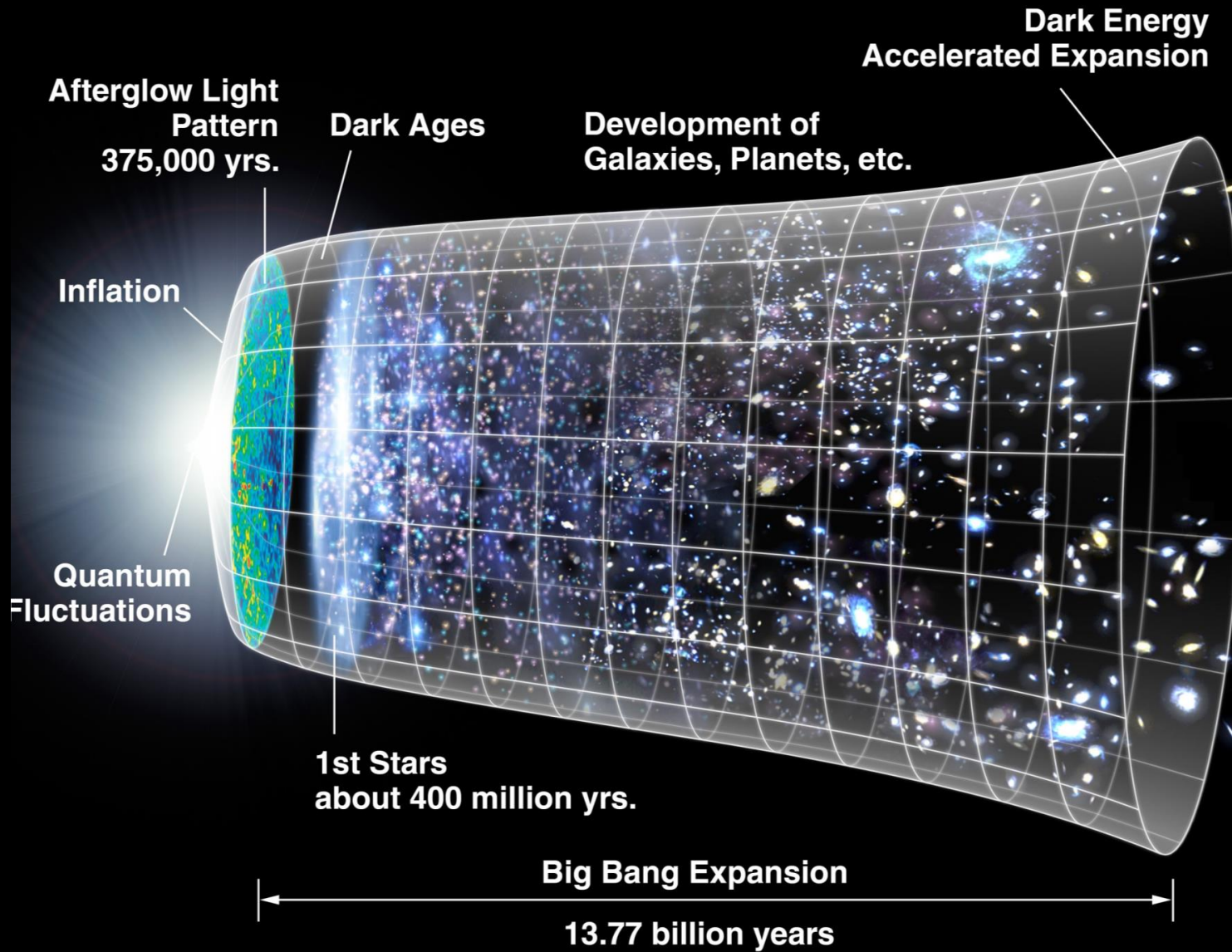
Enhancing Bispectrum Estimators for Photometric Galaxy Redshift Survey with Velocities

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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

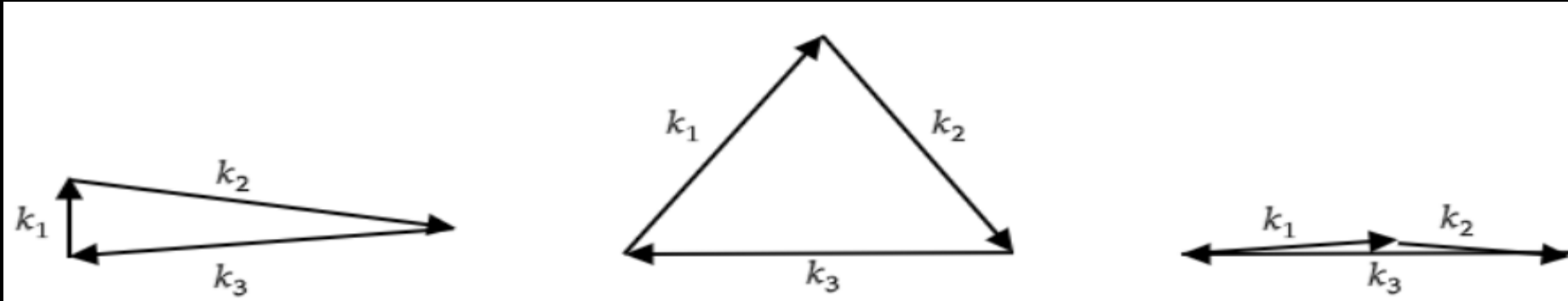
- Power Spectrum:

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

- Bispectrum

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

Bispectrum



Local

- Multiple fields

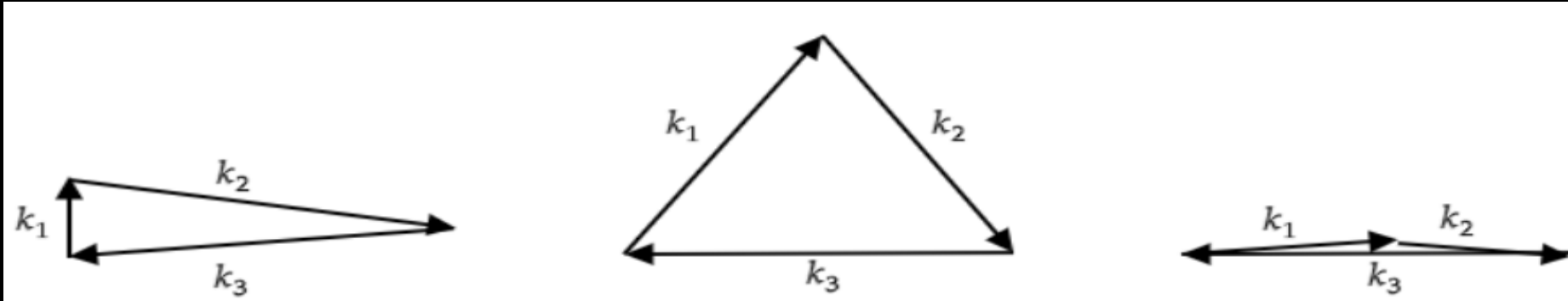
Equilateral

- Non-standard kinetic terms

Folded

- Excited initial states

Bispectrum



Local

- Multiple fields

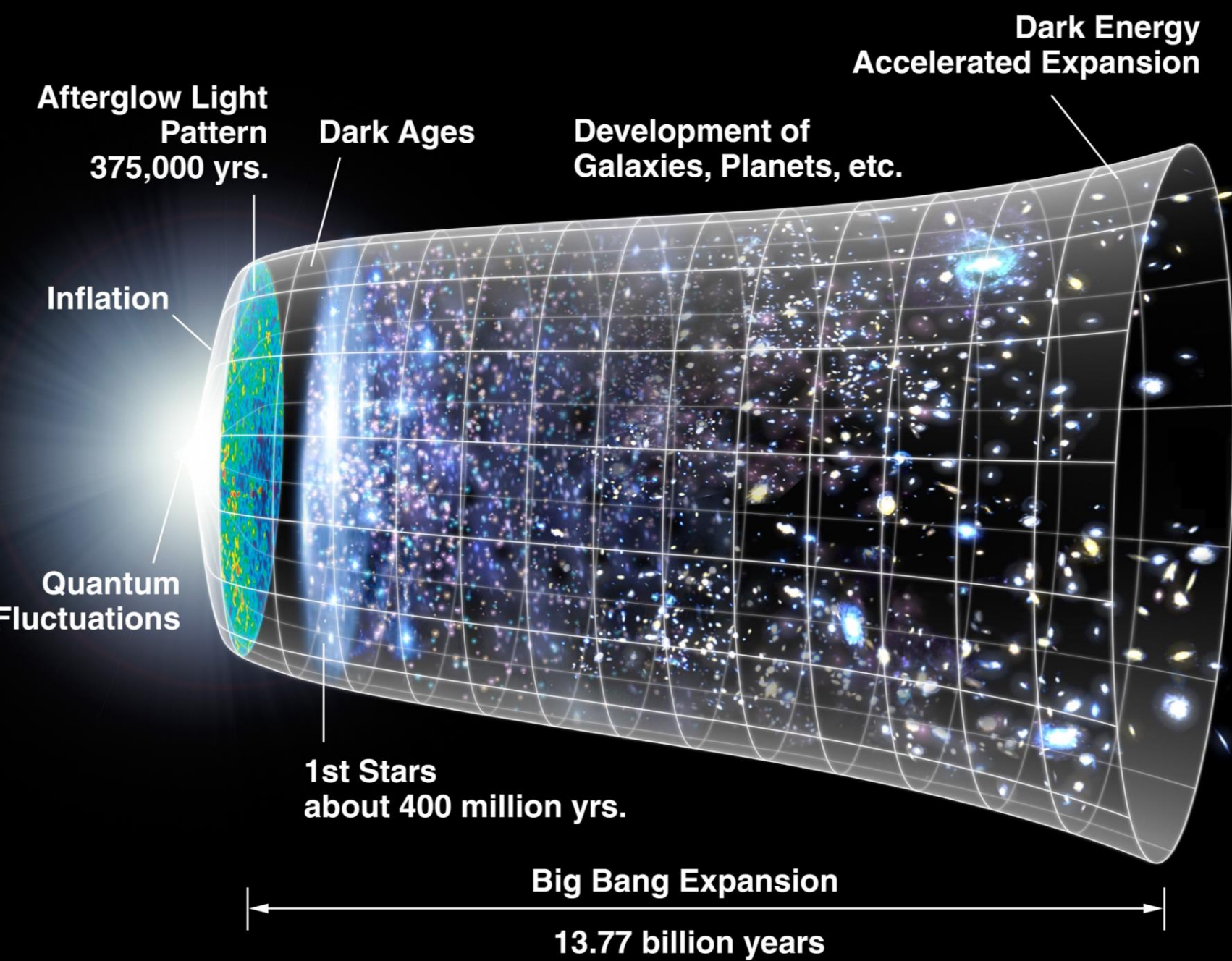
Equilateral

- Non-standard kinetic terms

Folded

- 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:

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

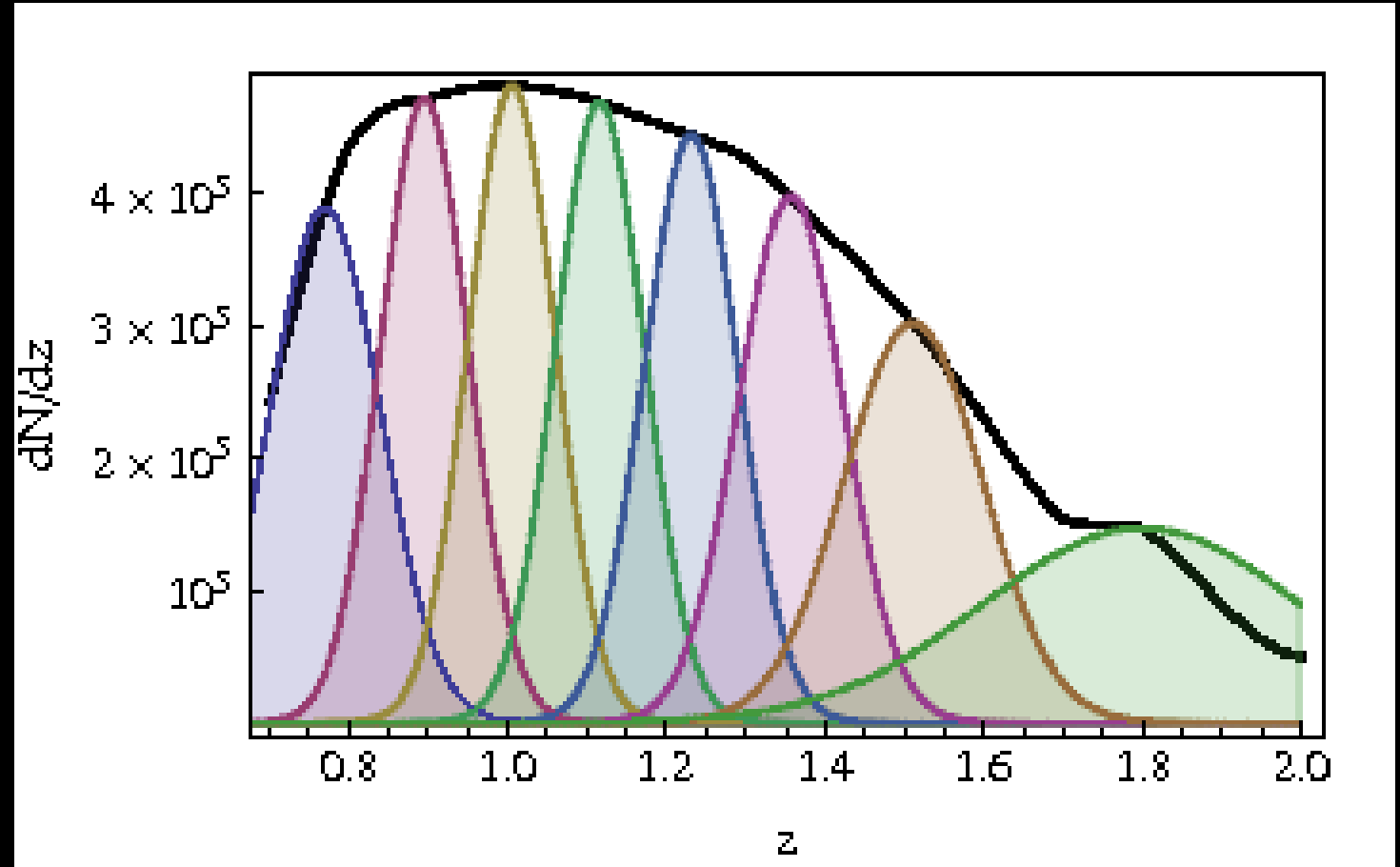
- LSS:

- 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

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

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

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

Forecast of $\sigma(f_{NL})$ using density field, full sky, ideal

$\sigma_z / 1 + z$	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

Scaling Relation

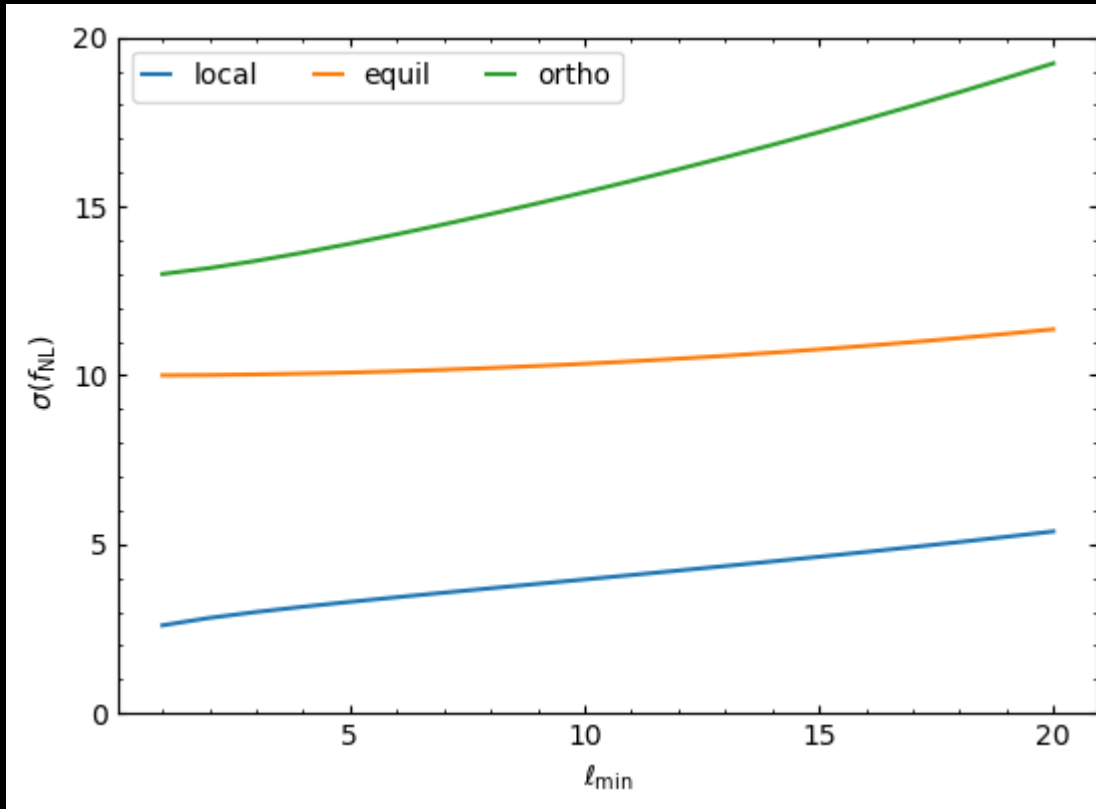
$$\sigma(f_{\text{NL}}) \approx 3.4 \sqrt{f_{\text{sky}}} \left(\frac{0.05}{\frac{\sigma_z}{1+z}} \right)^{\frac{1}{2}} \left(\frac{r(z=2)}{r(z_{\text{max}})} \right)^2 \frac{1}{\xi_{\text{NL}}}$$

- $\sqrt{f_{\text{sky}}}$: Sky coverage
- σ_z : Redshift resolution
- r : comoving distance
- ξ_{NL} : Nonlinear scale

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

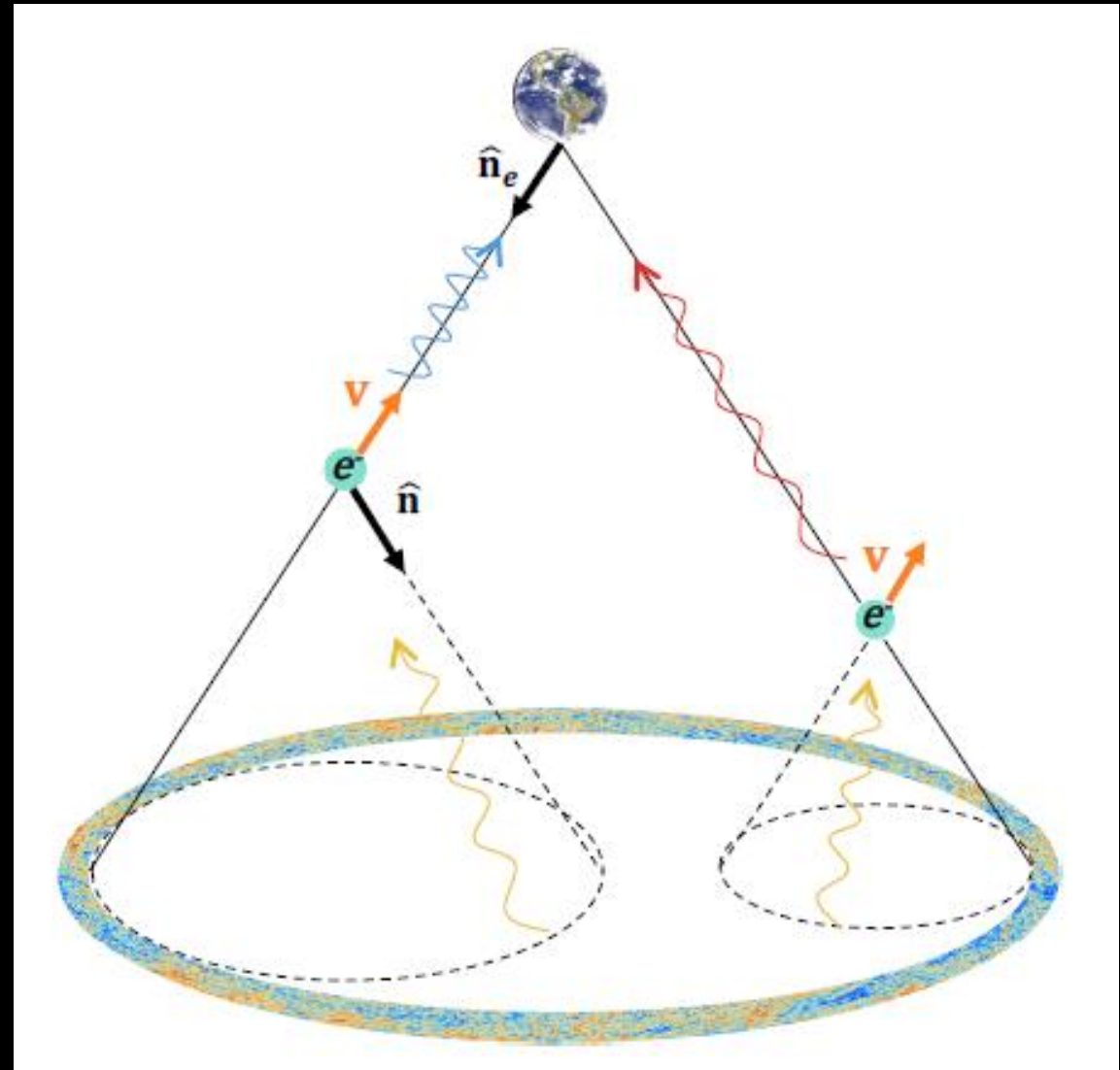


- Local and orthogonal shape strongly affected by large scale cutoff
- Local: 2.6 \rightarrow 5.5
- Equilateral almost unaffected

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



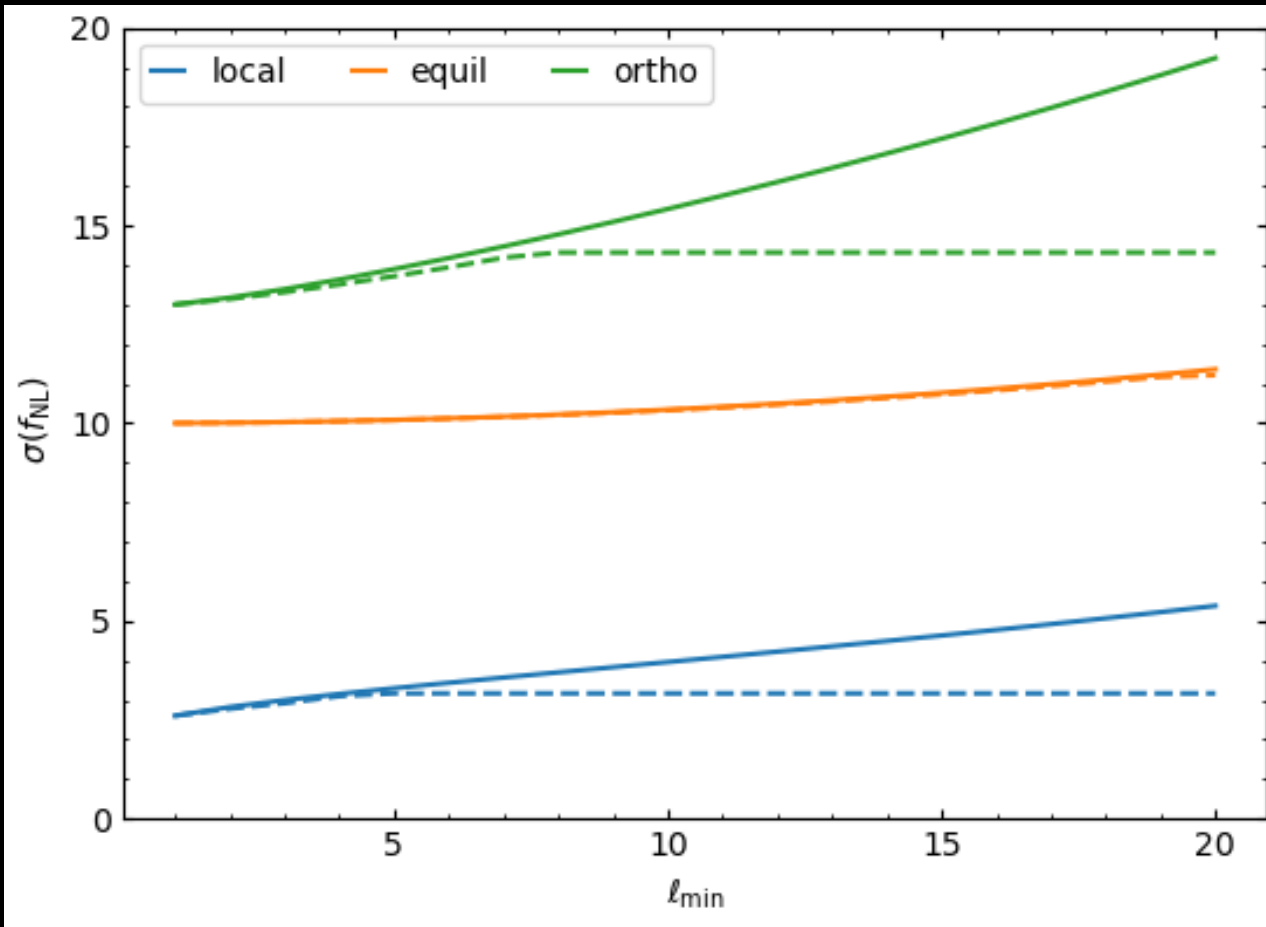
Velocity Distribution comes to the Rescue

- 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-Gaussianities
- Photometric surveys could surpass CMB constraints
- Nonlinear scales required for $\sigma(f_{NL}) < 1$
- More detailed forecast for LSST or SPHEREx
 - Including noise
 - Extending the redshift beyond $z=2$
 - Nonlinear scale
- Estimation for Photometric Survey