

The Galaxy Bispectrum as a Probe of Primordial non-Gaussianity

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Only two things are infinite,
the universe and human stupidity,
and I'm not sure about the former.

Albert Einstein

Motivation to Study LSS Effects of non-Gaussianity

Goals

- exclude inflationary models
- learn about the dynamics of the inflaton field
- LSS provides constraints independent of CMB

Approach

- perturbation theory to derive shape and scale dependence
- bispectrum as a measure of interactions between short and long modes
- additional difficulties: biased tracers, non-linear clustering

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2 Perturbation Theory and Diagrammatics

3 The Galaxy Bispectrum

4 Discussion & Outlook

Primordial non-Gaussianity from Inflation

Models of Inflation

- slow-roll single-field Inflation - small non-Gaussianity
- non-standard single-field Inflation - equilateral and orthogonal non-Gaussianity
- multifield Inflation - local non-Gaussianity

Local shape non-Gaussianity

$$\Phi_{\text{nG}}(\mathbf{x}) = \varphi(\mathbf{x}) + \frac{f_{\text{NL}}}{c^2} (\varphi^2(\mathbf{x}) - \langle \varphi^2 \rangle) + \frac{g_{\text{NL}}}{c^4} \varphi(\mathbf{x})^3$$

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Statistics of LSS including non-Gaussianity

- local non-Gaussianity couples large and small scale modes

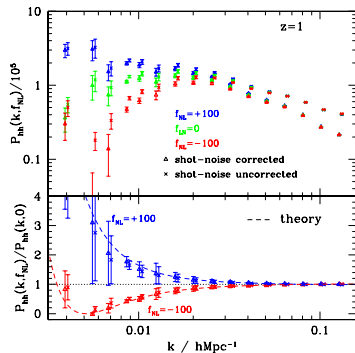
$$\Phi_{nG,s} = \varphi_s (1 + 2f_{NL}\varphi_1)$$

- modification of the distribution of galaxies on large scales

$$P_g(k) = P_0(k) \left(b_1 + \frac{4f_{NL}(b_1 - 1)}{\alpha(k)} \right)^2$$

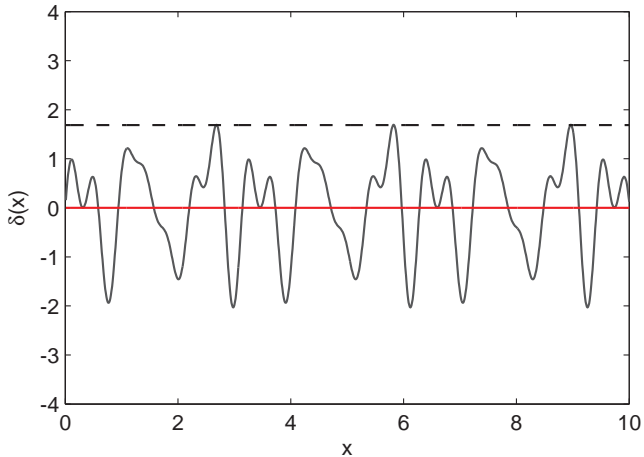
- constraints from a compilation of LSS data [Slosar *et. al* 2008]

$$-29 < f_{NL} < 69$$

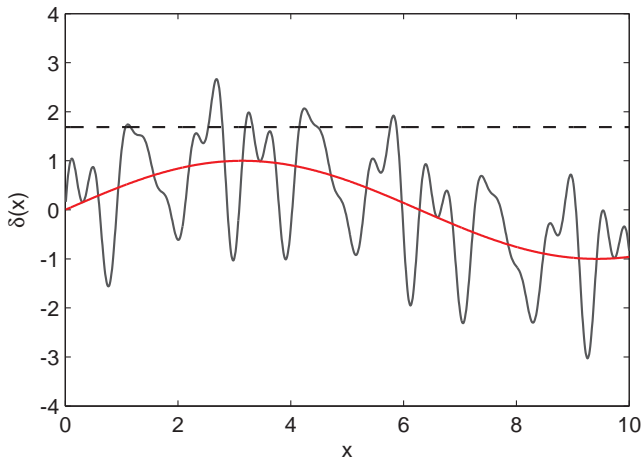


Desjacques, Seljak, Iliev 2009

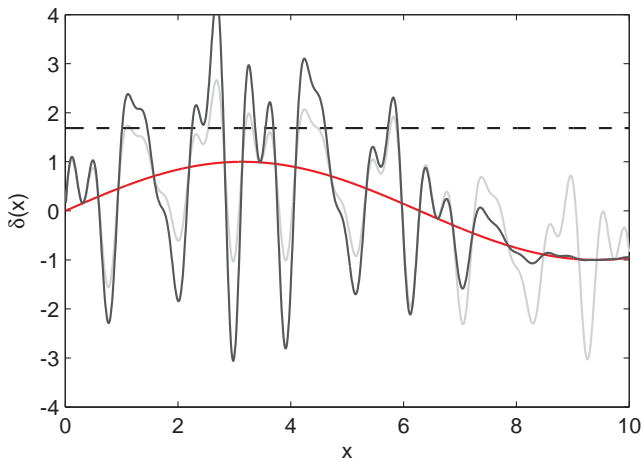
Clustering with local non-Gaussianity



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Clustering with local non-Gaussianity

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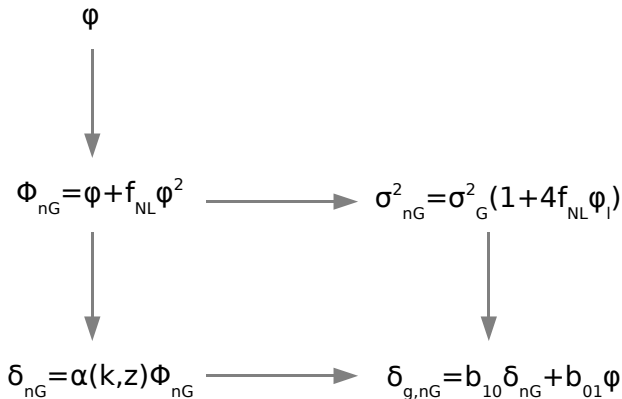
Clustering with local non-Gaussianity

$$\begin{array}{c} \phi \\ \downarrow \\ \Phi_{nG} = \phi + f_{NL} \phi^2 \end{array}$$

Clustering with local non-Gaussianity

$$\begin{array}{ccc}
 \varphi & & \\
 \downarrow & & \\
 \Phi_{\text{nG}} = \varphi + f_{\text{NL}} \varphi^2 & \longrightarrow & \sigma_{\text{nG}}^2 = \sigma_{\text{G}}^2 (1 + 4f_{\text{NL}} \varphi_{\text{I}}) \\
 \downarrow & & \\
 \delta_{\text{nG}} = \alpha(k, z) \Phi_{\text{nG}} & &
 \end{array}$$

Clustering with local non-Gaussianity



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Ingredients

- galaxy/halo density field δ_g
- matter density field δ_m
- primordial gravitational potential φ
- power spectrum $P_{\delta\delta}(k) = \alpha(k)P_{\delta\varphi}(k) = \alpha^2(k)P_{\varphi\varphi}$

○ φ

◐ δ_g

● δ_m

⊗ P_φ

Non-linear Clustering

Fluid equations

$$\frac{\partial \delta(\mathbf{x}, \tau)}{\partial \tau} + \theta(\mathbf{x}, \tau) = 0$$

$$\frac{\partial \theta(\mathbf{x}, \tau)}{\partial \tau} + \mathcal{H}(\tau)\theta(\mathbf{x}, \tau) + \frac{3}{2}\Omega_m \mathcal{H}^2(\tau)\delta(\mathbf{x}, \tau) = 0$$

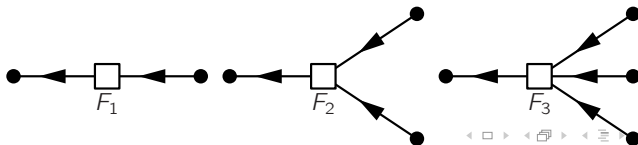
Non-linear Clustering

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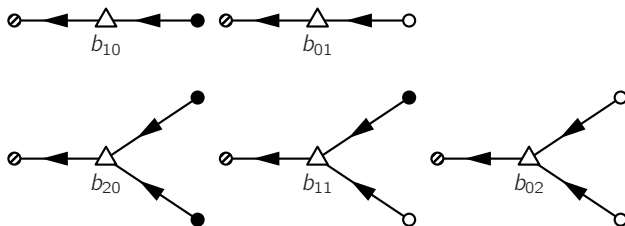
$$\delta_n(\mathbf{k}) = \int d^3 q_1 \dots \int d^3 q_n \delta^{(D)}\left(\mathbf{k} - \sum_s \mathbf{q}_s\right) F_n(\mathbf{q}_1, \dots, \mathbf{q}_n) \delta_0(\mathbf{q}_1) \dots \delta_0(\mathbf{q}_n)$$



Multivariate Biasing¹

$$\delta_{\mathbf{g}}(\mathbf{x}) = \sum_{i,j} b_{ij} \delta^i(\mathbf{x}) \varphi^j(\mathbf{x})$$

$$\delta_{\mathbf{g},ij}(\mathbf{k}) = b_{ij} \int d^3 q_1 \dots \int d^3 q_{i+j} \delta^{(D)}\left(\mathbf{k} - \sum_s \mathbf{q}_s\right) \delta_1(\mathbf{q}_1) \dots \varphi_j(\mathbf{q}_{i+j})$$



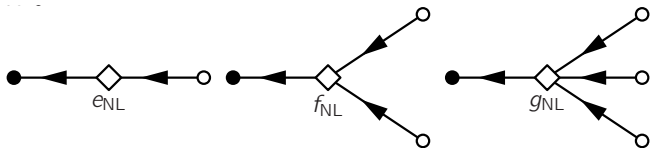
¹[Giannantonio & Porciani 2010]

Local non-Gaussianity

$$\Phi_{\text{nG}}(\mathbf{x}) = \varphi(\mathbf{x}) + \frac{f_{\text{NL}}}{c^2} (\varphi^2(\mathbf{x}) - \langle \varphi^2 \rangle) + \frac{g_{\text{NL}}}{c^4} \varphi(\mathbf{x})^3,$$

$$\delta(\mathbf{k}) = \alpha(k) \Phi_{\text{nG}}(\mathbf{k})$$

$$= \alpha(k) \varphi(\mathbf{k}) + \alpha(k) f_{\text{NL}} \int d^3 q \delta^{(D)}(\mathbf{k} - \mathbf{q}_1 - \mathbf{q}_2) \varphi(\mathbf{q}_1) \varphi(\mathbf{q}_2) + \dots$$

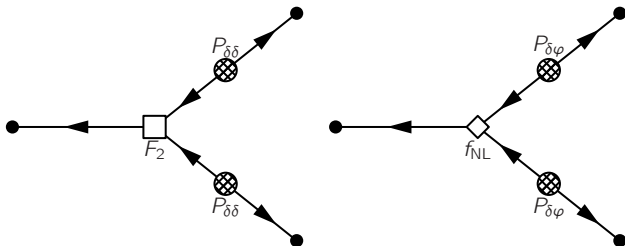


Feynman Rules

- 1 Draw all diagrams up to the desired order in φ
- 2 For each vertex with ingoing momenta \mathbf{q}_i and outgoing momenta \mathbf{p}_j write a delta function $\delta^{(D)}\left(\sum_i \mathbf{q}_i - \sum_j \mathbf{p}_j\right)$
- 3 For the outer momenta \mathbf{k}_i write a delta function $\delta^{(D)}\left(\sum_i \mathbf{k}_i\right)$
- 4 For each square shaped vertex F_n with ingoing momenta \mathbf{q}_i write a mode coupling kernel $F_n(\mathbf{q}_1, \dots, \mathbf{q}_n)$
- 5 For each diamond shaped vertex G_{NL} with outgoing momentum \mathbf{q} write $\alpha(\mathbf{q})G_{\text{NL}}$
- 6 Integrate over all inner momenta \mathbf{q}_i

Example: Matter Bispectrum

$$\begin{aligned}
 B_{\text{mmm}}(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3) &= \left(2P(k_1)P(k_2)F_2(\mathbf{k}_1, \mathbf{k}_2) + 2 \text{ cyc.} \right) + \\
 &\quad \left(2f_{\text{NL}} \frac{P(k_1)P(k_2)\alpha(k_3)}{\alpha(k_1)\alpha(k_2)} + 2 \text{ cyc.} \right) \\
 &= B_{F_2}(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3) + B_{f_{\text{NL}}}(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3)
 \end{aligned}$$



1 Introduction

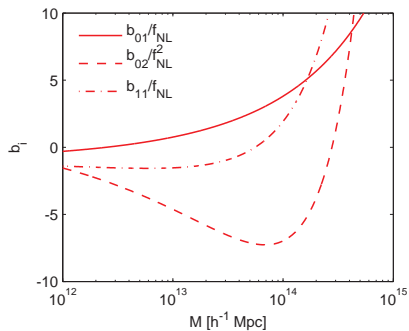
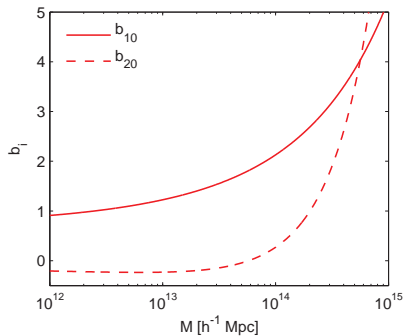
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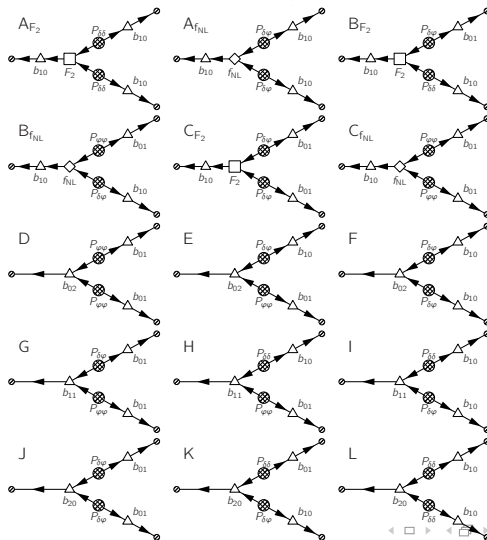
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Bias functions

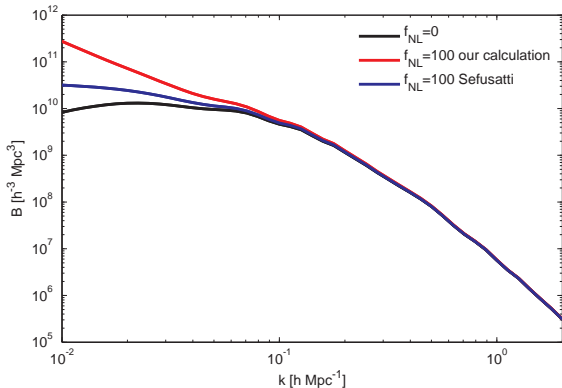
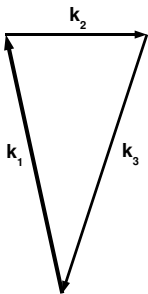
$$b_{ij} = \frac{1}{\bar{n}} \frac{\partial^{i+j} n}{\partial \delta^i \partial \varphi^j}$$



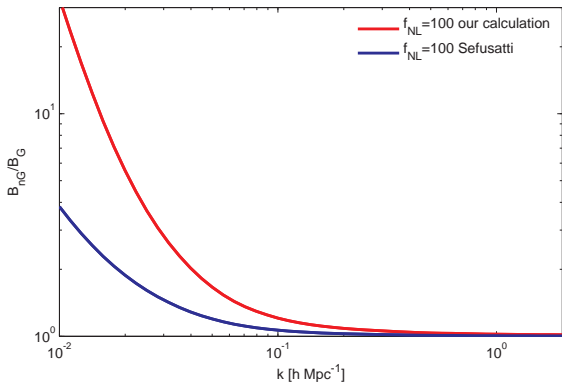
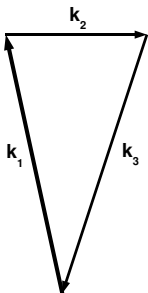
Galaxy Bispectrum



Galaxy Bispectrum - Squeezed Configuration



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Discussion

Achievements

- diagrammatic prescription including effects of
 - clustering
 - biasing
 - non-Gaussianity
- corrections to existing calculations at tree level

To Do

- calculation of the 1-loop corrections
- comparison with N-body simulations

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Thank you for your attention!

