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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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

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

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Statistics of LSS including non-Gaussianity

- local non-Gaussianity couples large and small scale modes

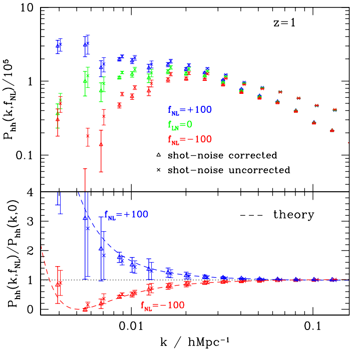
$$\Phi_{\mathrm{nG,s}} = \varphi_{\mathrm{s}} \left(1 + 2 f_{\mathrm{NL}} \varphi_{\mathrm{l}}\right)$$

- modification of the distribution of galaxies on large scales

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

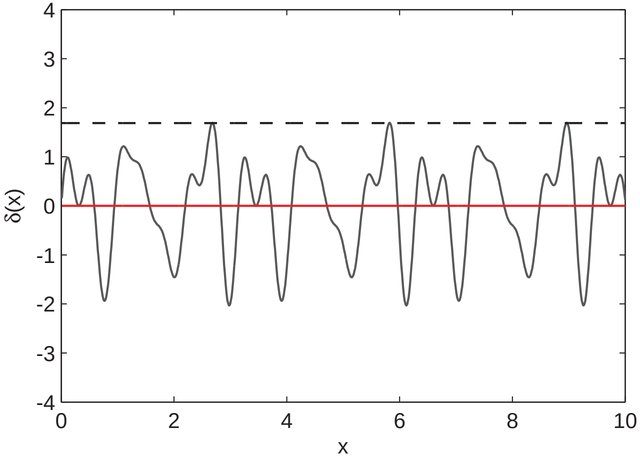
- constraints from a compilation of LSS data [Slosar *et. al* 2008]

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

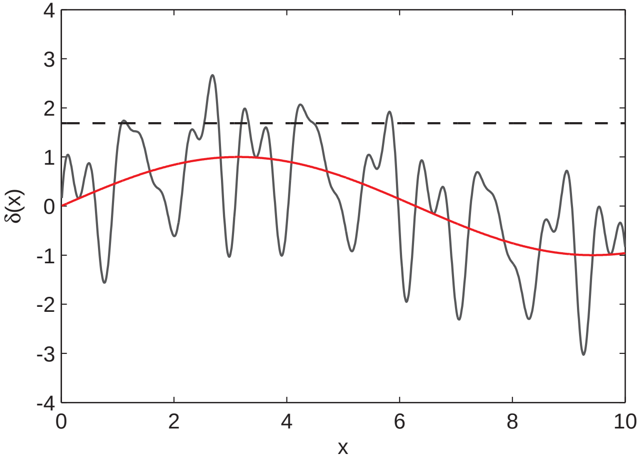


Desjacques, Seljak, Iliev 2009

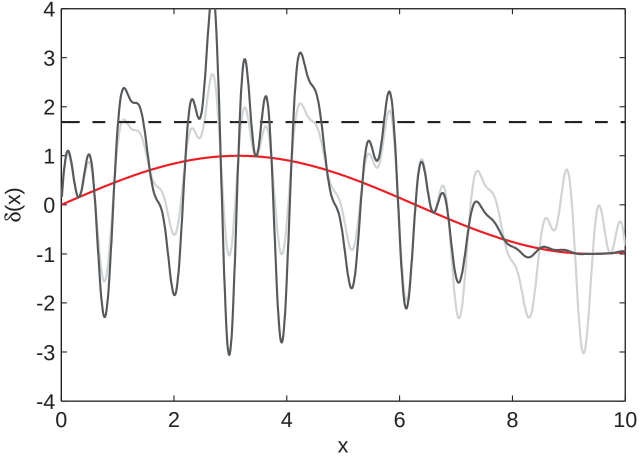
Clustering with local non-Gaussianity



Clustering with local non-Gaussianity



Clustering with local non-Gaussianity



Clustering with local non-Gaussianity

φ

Clustering with local non-Gaussianity

$$\varphi$$

$$\Phi_{nG}=\varphi+f_{NL}\varphi^2$$

Clustering with local non-Gaussianity

$$\varphi$$

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$$\sigma^2_{nG}=\sigma^2_G(1+4f_{NL}\varphi_l)$$

$$\delta_{nG}=\alpha(k,z)\Phi_{nG}$$

Clustering with local non-Gaussianity

$$\varphi$$

$$\Phi_{nG} = \varphi + f_{NL}\varphi^2 \quad \longrightarrow \quad \sigma^2_{nG} = \sigma^2_{G}(1 + 4 f_{NL} \varphi_l)$$

$$\delta_{nG} = \alpha(k,z)\Phi_{nG} \quad \longrightarrow \quad \delta_{g,nG} = b_{10}\delta_{nG} + b_{01}\varphi$$

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

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

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

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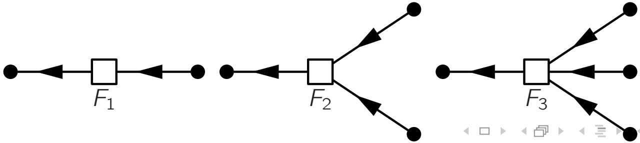
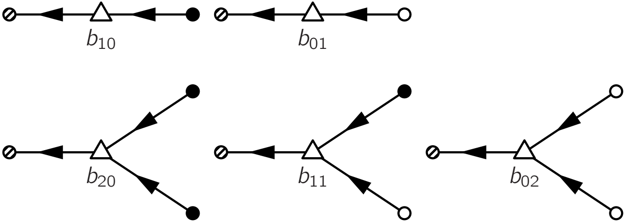
$$\delta_n(\mathbf{k}) = \int d^3q_1 \ldots \int d^3q_n\, \delta^{(\mathrm{D})}\left(\mathbf{k} - \sum_s \mathbf{q}_s\right) F_n(\mathbf{q}_1, \ldots, \mathbf{q}_n)\delta_0(\mathbf{q}_1)\ldots\delta_0(\mathbf{q}_n)$$



Multivariate Biasing[1]

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

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

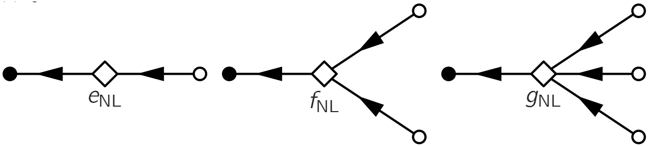


1 [Giannantonio & Porciani 2010]

Local non-Gaussianity

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

$$\begin{aligned}\delta(\mathbf{k}) =& \alpha(k)\Phi_{nG}(\mathbf{k})\\ =& \alpha(k)\varphi(\mathbf{k}) + \alpha(k) f_{NL}\int d^3q\,\delta^{(D)}(\mathbf{k}-\mathbf{q}_1-\mathbf{q}_2)\varphi(\mathbf{q}_1)\varphi(\mathbf{q}_2) + \dots\end{aligned}$$

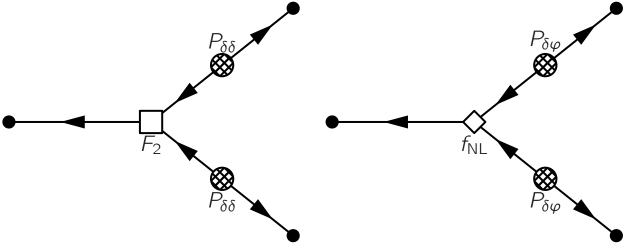


Feynman Rules

1. Draw all diagrams up to the desired order in φ
2. For each vertex with ingoing momenta $\mathbf{q}_i$ and outgoing momenta $\mathbf{p}_i$ write a delta function $\delta^{(\mathrm{D})}\left(\sum_i \mathbf{q}_i - \sum_j \mathbf{p}_j\right)$
3. For the outer momenta $\mathbf{k}_i$ write a delta function $\delta^{(\mathrm{D})}\left(\sum_i \mathbf{k}_i\right)$
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 $\alpha(\mathbf{q})G_{\mathrm{NL}}$
6. Integrate over all inner momenta $\mathbf{q}_i$

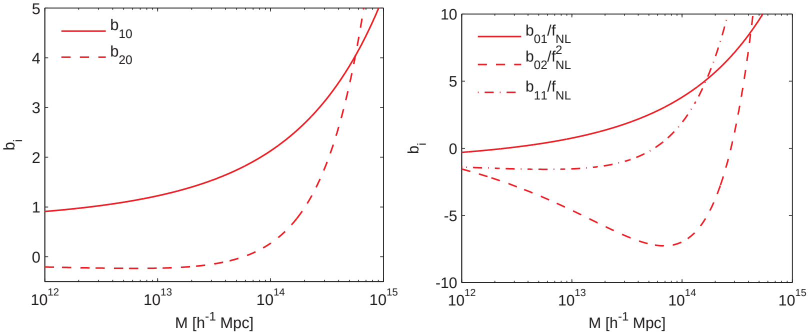
Example: Matter Bispectrum

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

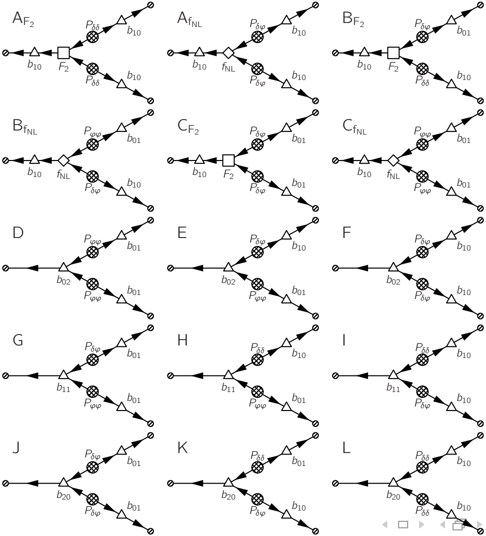


Bias functions

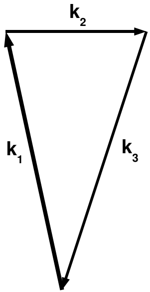
$$b_{ij} = \frac{1}{\bar{n}} \frac{\partial^{i+j} n}{\partial \delta^i \partial \varphi^j}$$

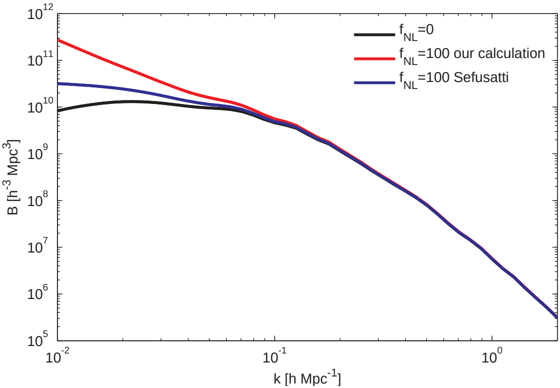


Galaxy Bispectrum



Galaxy Bispectrum - Squeezed Configuration





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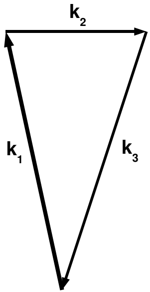

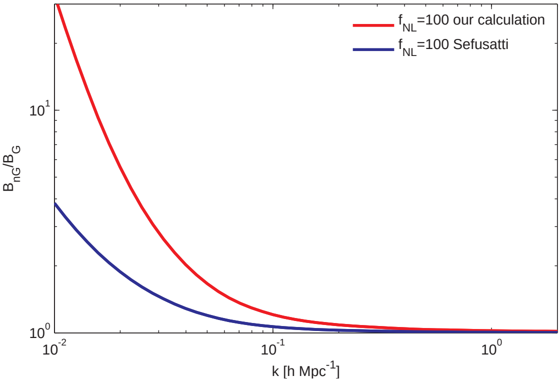

Discussion

Achievements

- diagramatic 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!