Testing the initial conditions with the Large-Scale Structure
the case for the galaxy bispectrum

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Primordial non-Gaussianity and the **Large-Scale Structure**

Inflation $\Rightarrow$ Initial curvature perturbations: $\langle\phi\phi\rangle$, $\langle\phi\phi\phi\rangle \neq 0$, $\langle\phi\phi\phi\phi\rangle \neq 0$?

What are the effects on the *Large-Scale Structure*?

- on the **matter higher-order correlation functions**

  $\langle\phi\phi\phi\rangle \Rightarrow \langle\delta\delta\delta\rangle$

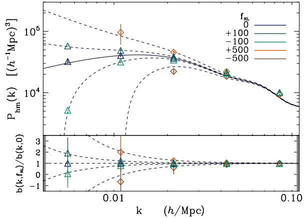
- on the **cluster abundance**

  $\langle\phi\phi\phi\rangle \Rightarrow s_3 \sim \langle\delta^3\rangle \Rightarrow n(M)$

- on the **halo and galaxy bias relation**

  $\langle\phi\phi\phi\rangle \Rightarrow [...] \Rightarrow b_{eff}(k, f_{NL})$, for *local* NG

This allowed contraints on the NG parameter f_{NL} *comparable to those from the CMB* bispectrum, already from current observations!



[Dalal *et al.*, 2008]

Primordial non-Gaussianity and the Large-Scale Structure

Inflation $\Rightarrow$ Initial curvature perturbations: $\langle\phi\phi\rangle$, $\langle\phi\phi\phi\rangle \neq 0$?

What are the effects of a non-vanishing initial 3-point function on the *Large-Scale Structure*?

- on the **matter higher-order correlation functions**

  $\langle\phi\phi\phi\rangle \Rightarrow \langle\delta\delta\delta\rangle$
- on the **cluster abundance**

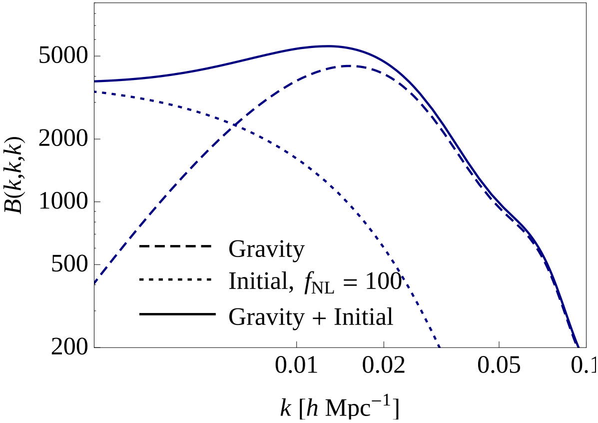
  $\langle\phi\phi\phi\rangle \Rightarrow s_3 \sim \langle\delta^3\rangle \Rightarrow n(M)$
- on the **halo and galaxy bias relation**

  $\langle\phi\phi\phi\rangle \Rightarrow [...] \Rightarrow b_{eff}(k, f_{NL})$, for *local* NG

Why bother with the galaxy bispectrum, then?

1. The effect of PNG is **larger** for the galaxy bispectrum
2. The bispectrum is sensitive to **any** *NG model*!

At large scales: PNG+ Gravity $\Rightarrow$ $B \simeq B_{Initial} + B^{tree}_{Gravity}$



$\Leftarrow$ Equilateral triangles

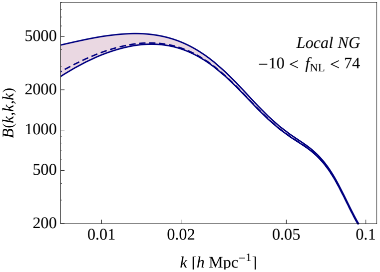
$B(k,k,k)$ *vs.* k

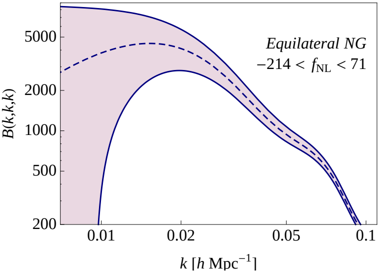
$$\frac{B_I}{B_G} \overset{k\to 0}{\sim} \frac{f_{NL}}{D(z)k^2}$$

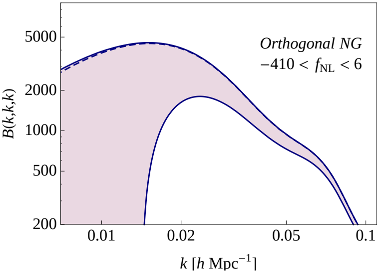
for a broad range of models

Current constraints
for different models
on equilateral configurations, $B(k, k, k)$

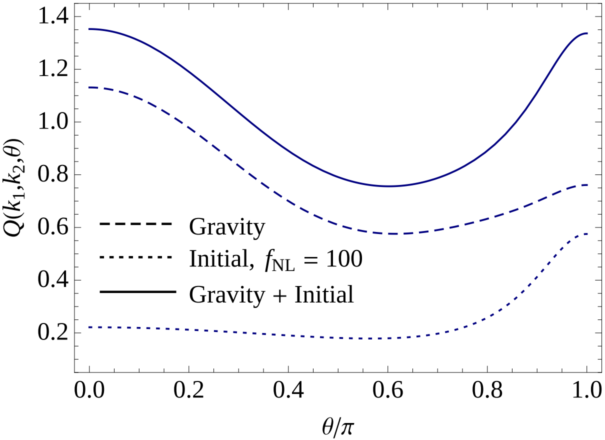
[Liguori, ES, Fergusson & Shellard (review, 2010)]





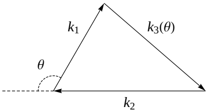


At large scales: PNG + Gravity $\Rightarrow$ $B \simeq B_{Initial} + B^{tree}_{Gravity}$



$\Leftarrow$ *Reduced* bispectrum:

$$Q \equiv \frac{B(k_1, k_2, k_3)}{P(k_1)P(k_2) + \mathrm{perm.}}$$



$k_1 = 0.01\, h\, \mathrm{Mpc}^{-1}$ and $k_2 = 1.5\, k_1$

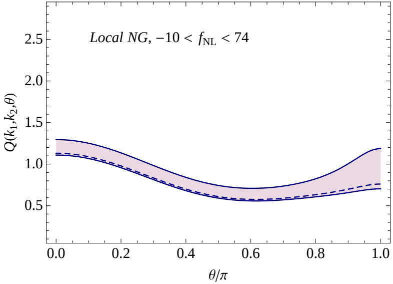
The **matter bispectrum** and **primordial non-Gaussianity**

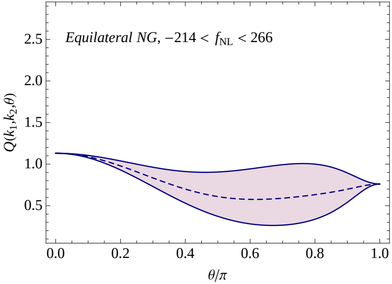
The **shape-dependence** of primordial non-Gaussianit*ies*

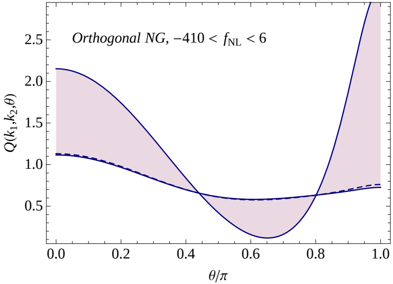
Current constraints
for different models
on generic configurations, $B(k_1, k_2, \theta)$

$k_1 = 0.01\, h\, \mathrm{Mpc}^{-1}$, $k_2 = 0.015\, h\, \mathrm{Mpc}^{-1}$
$z = 1$

[Liguori, ES, Fergusson & Shellard (review, 2010)]







At small scales, *non-linear evolution* is important!

In Perturbation Theory one studies *loop-corrections*:

$$B_m \stackrel{PT}{=} B_I + B_G^{tree} + B_m^{1-loop}(P_L, B_I, T_I) + \ldots$$

Loop corrections depend on the linear power spectrum as well as on *initial higher-order correlators*. For instance:

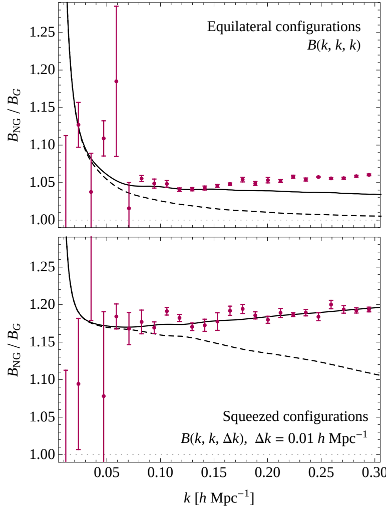
$$\begin{aligned} B_m^{1-loop} \supset & \int d^3q\ F_2(\mathbf{q}, \mathbf{k}_3 - \mathbf{q})\ T_I(\mathbf{k}_1, \mathbf{k}_2, \mathbf{q}, \mathbf{k}_3 - \mathbf{q}), \\ & 2\ P_L(k_1)\ F_2(\mathbf{k}_1, \mathbf{k}_3) \int d^3q\ F_2(\mathbf{q}, \mathbf{k}_3 - \mathbf{q})\ B_I(k_3, q, |\mathbf{k}_3 - \mathbf{q}|) + \mathrm{perm.}, \\ & 8 \int d^3q F_2(-\mathbf{q}, \mathbf{q} + \mathbf{k}_1) F_2(-\mathbf{q} - \mathbf{k}_1, \mathbf{q} - \mathbf{k}_2) F_2(\mathbf{k}_2 - \mathbf{q}, \mathbf{q}) P_L(q) P_L(|\mathbf{k}_1 + \mathbf{q}|) P_0(|\mathbf{k}_2 - \mathbf{q}|), \\ & \ldots \end{aligned}$$

$\Rightarrow$ Extra sensitivity to $B_{Initial}$ (and a mild one to $T_{Initial}$)

[Scoccimarro (1997); ES (2009)]

The same is true for the power spectrum ...

$$P_m \stackrel{PT}{=} P_L + P_m^{1-loop}(P_L, B_I) + \ldots$$



[ES, Crocce & Desjacques (2010)]

Relative effect of *Local* non-Gaussian I.C.

$$B(f_{NL} = 100)/B(f_{NL} = 0)$$

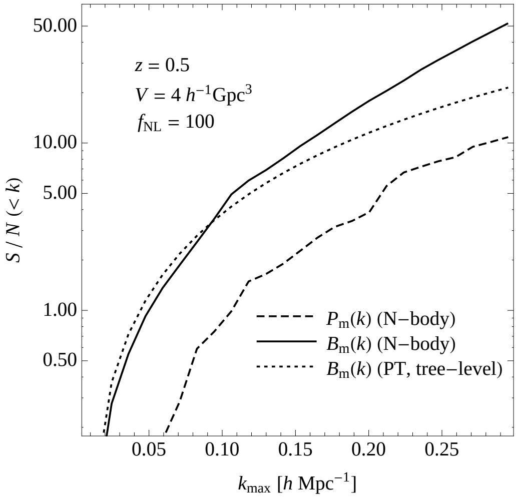
- There is a 5 - 20% effect of non-Gaussian Initial Conditions *for all triangles*, at small scales and at any redshift, for $f_{NL} = 100$
- The tree-level approximation breaks-down at relatively large scales, while 1-loop PT helps significantly to extend the validity of the theoretical predictions

We can do better: the **resummation** of infinite sub-sets of perturbative contributions in **RPT**, can be **extended to non-Gaussian initial conditions**

[Bernardeau, Crocce & ES (2010), see also Bartolo *et al.* (2010)]

The **matter bispectrum** and **primordial non-Gaussianity**

Cumulative, "**non-Gaussian**", signal-to-noise



$$\left(\frac{S}{N}\right)^2_P = \sum_{k}^{k_{\rm max}} \frac{(P_{NG} - P_G)^2}{\Delta P^2}$$

$$\left(\frac{S}{N}\right)^2_B = \sum_{\rm triangles}^{k_{\rm max}} \frac{(B_{NG} - B_G)^2}{\Delta B^2}$$

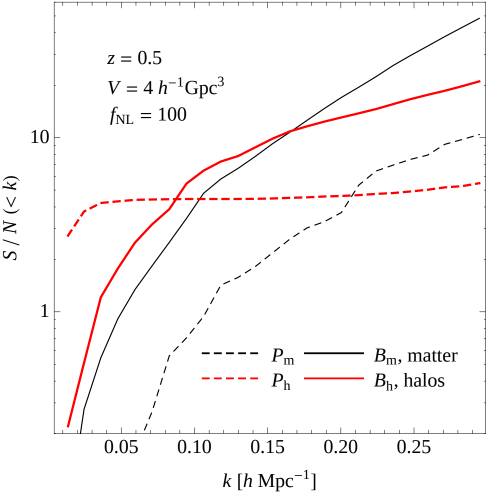
Sums over *all configurations* up to $k_{\rm max}$

Both the initial, non-Gaussian component *and* its effect on the nonlinear evolution are important

[ES, Crocce & Desjacques (*in preparation*)]

The **halo** **bispectrum** and **primordial non-Gaussianity**

Cumulative, "**non-Gaussian**", signal-to-noise



$$\left(\frac{S}{N}\right)^2_P = \sum_k^{k_{\rm max}} \frac{(P_{NG} - P_G)^2}{\Delta P^2}$$

$$\left(\frac{S}{N}\right)^2_B = \sum_{\rm triangles}^{k_{\rm max}} \frac{(B_{NG} - B_G)^2}{\Delta B^2}$$

Sums over *all configurations* up to $k_{\rm max}$

The *cumulative* "non-Gaussian" signal is larger for the bispectrum than for the power spectrum!

[ES, Crocce & Desjacques (*in preparation*)]

Halo bias and the bispectrum

Dalal *et al.*, (2008): the bias of halos receives a large correction (at large scales!) for **local** primordial non-Gaussianity

⇒ a **non-local bias** relation [Giannantonio & Porciani, 2010]:

$$\delta_g(x) = f[\delta(x), \phi(x)] = b_1\delta(x) + c_1(f_{NL})\phi(x) + \frac{b_2}{2}\delta^2(x) + c_2(f_{NL})\delta(x)\phi(x) + \ldots$$

The simplest model for the galaxy bispectrum is then "tree-level"

$$\begin{aligned} B_g(k_1,k_2,k_3) &= b_1^3 B(k_1,k_2,k_3) + b_1^2 c_1 B_{\delta\delta\phi}(k_1,k_2,k_3) \\ &+ b_1^2 b_2 P(k_1)P(k_2) + \text{perm.} + b_1^2 c_2 P(k_1) P_{\delta\phi}(k_2) + \text{perm.} \end{aligned}$$

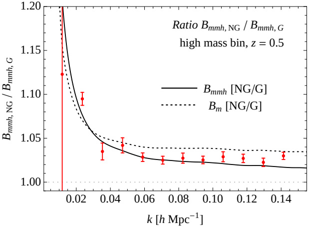
(but we keep the matter and matter-potential correlators at 1-loop)

Relative effect (B_{NG}/B_G) on the matter-matter-halo bispectrum, B_{mmh}

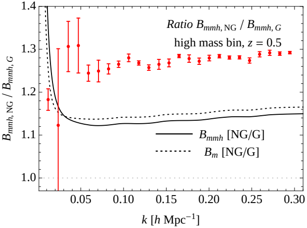
Work in progress!

[ES, Crocce & Desjacques (*in preparation*)]

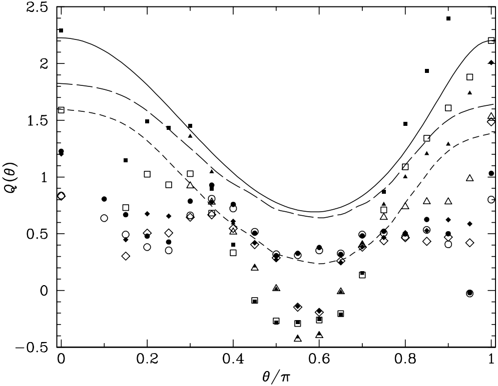
Isosceles triangles $B(2k,2k,k)$ *vs* k



Squeezed triangles $B(k,k,\Delta k)$ *vs* k



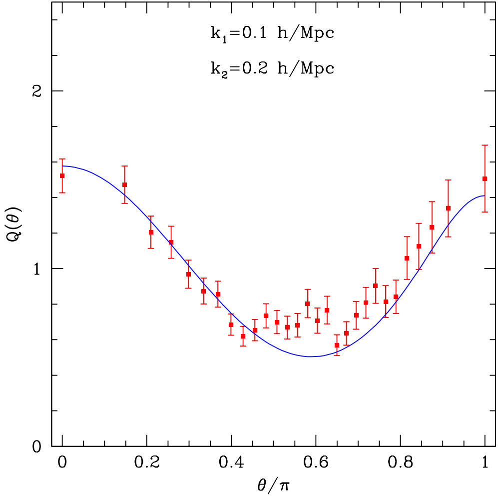
The **galaxy** bispectrum: the past



PSCz catalogue

[Scoccimarro *et al.*, 2001]

The **galaxy** bispectrum: SDSS DATA are coming!



[Scoccimarro *et al.*, *in preparation*]

In principle, constraints on primordial non-Gaussianity from the galaxy **bispectrum** are expected to be better than those from other LSS probes, both

- *quantitatively* (smaller errors on f_{NL}'s)

and

- *qualitatively* (larger sensitivity to the shape of non-Gaussianities)

In practice, more work is needed:
we need an accurate description of the galaxy bispectrum at mildly nonlinear scales