Shape of Halo Bispectrum from Non-Gaussian Initial Conditions in Cosmological N-body Simulations

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special informal discussion @Berkeley 13 Oct. 2010

Local-type NG and Large Scale Structure

local-type primordial Non-Gaussianity

$$\Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\rm nl}[\phi^2(\mathbf{x}) - \langle\phi^2(\mathbf{x})\rangle]$$

Gaussian

$-10 < f_{\rm NL} < 74 \ \ (95\% \, \mathrm{CL})$ WMAP7(Komatsu+10)

We observe ``galaxy'',
not ``matter'' density fluctuations

biasing changes things dramatically!

- halo mass function
- halo power spectrum
- halo bispectrum

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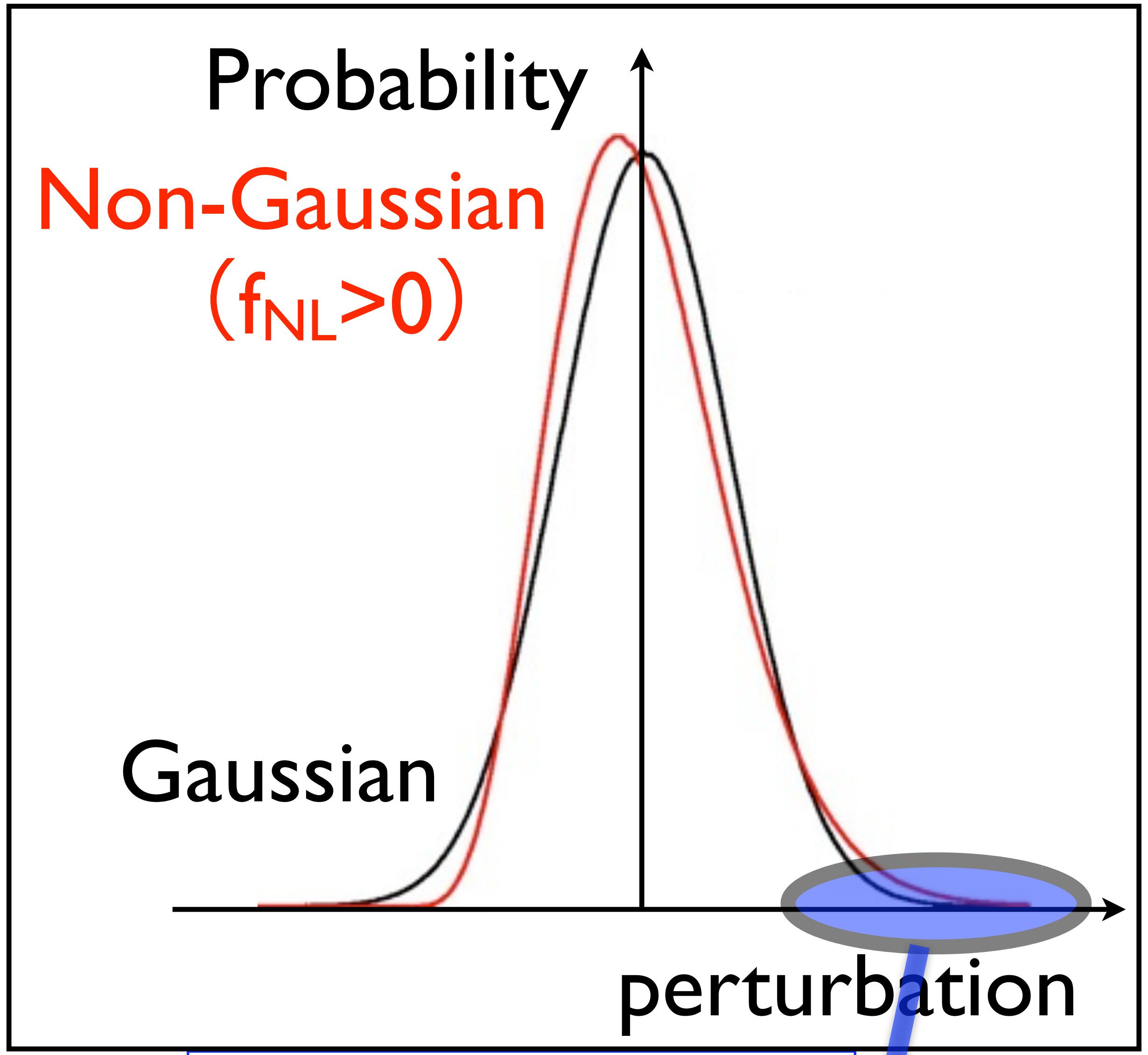
Understanding of the halo/galaxy biasing is the key!



change is relatively large at the high density tail!!
→ halos (galaxies)

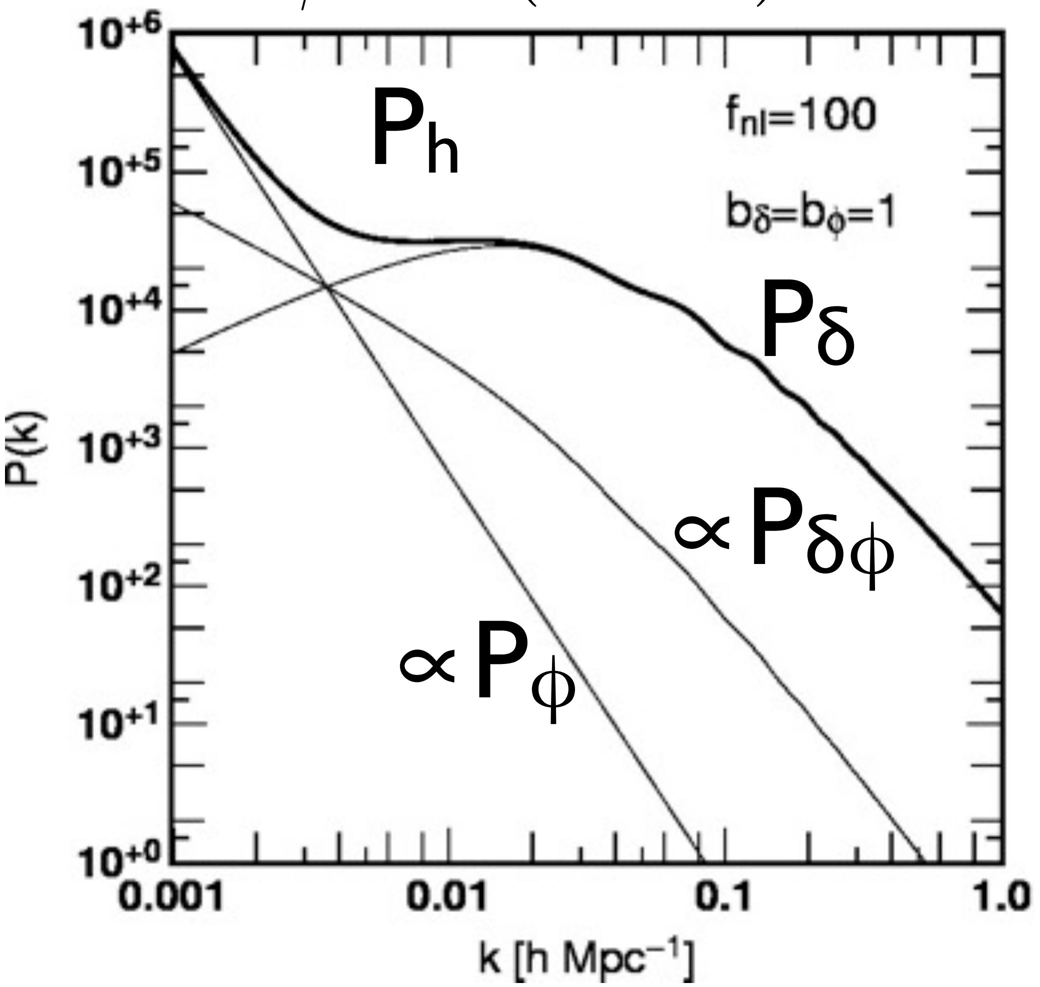
Scale-dependent bias

Theory

mass density curvature

$$\boxed{\delta^h_{\vec{x}} = b_\delta \underline{\delta_{\vec{x}}} + 2 f_{\rm nl} b_\phi \underline{\phi_{\vec{x}}}}$$

$$b_\phi = \delta_c (b_\delta - 1)$$



peak-background split
and/or peak(local) bias

Dalal+07
Slosar+08
Matarrese&Verde08
Afshordi&Tolley08
McDonald08
Taruya+09
Giannantonio&Porciani10
and more ...

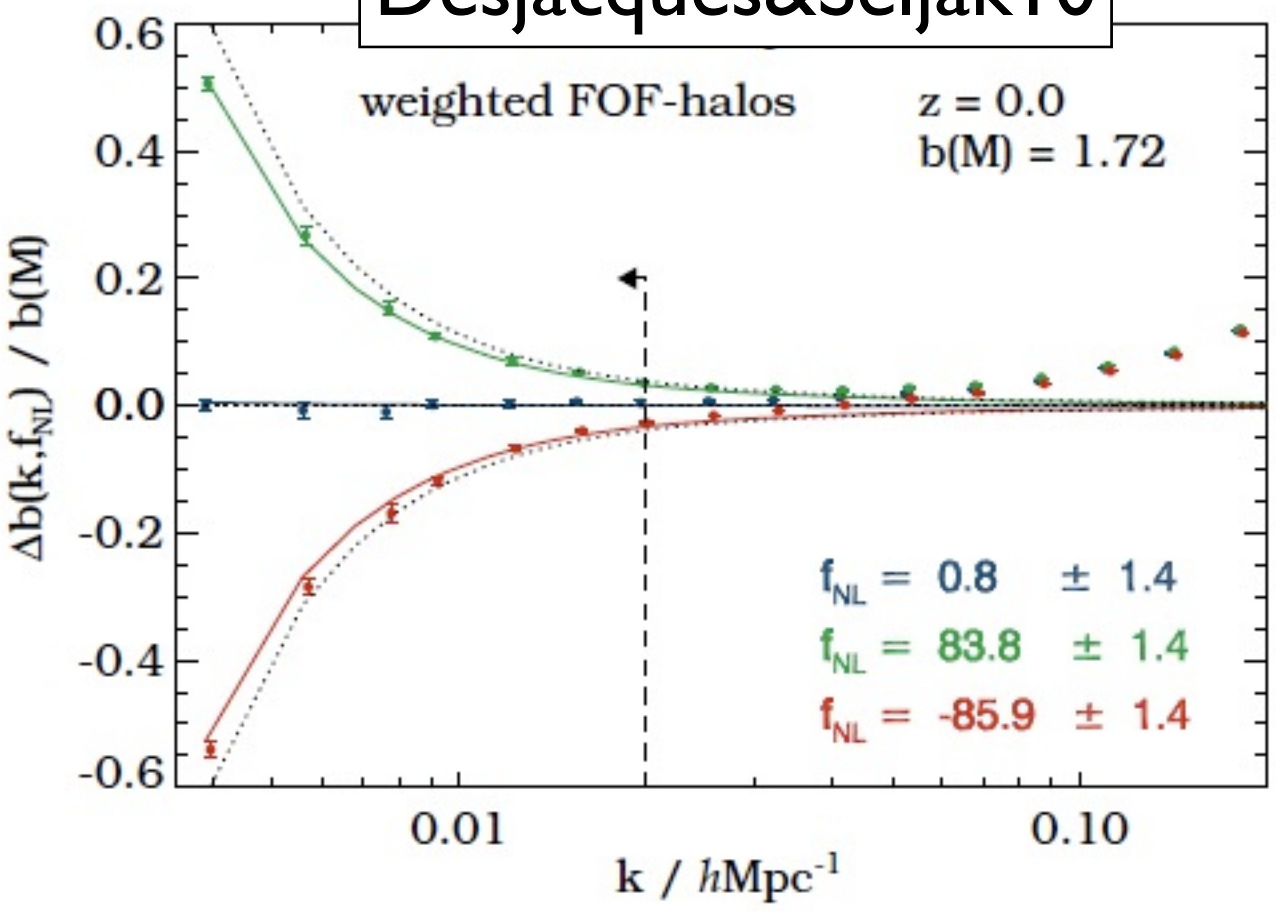
Slosar+08

-29 < f_{nl} < 69 (QSOs+more)

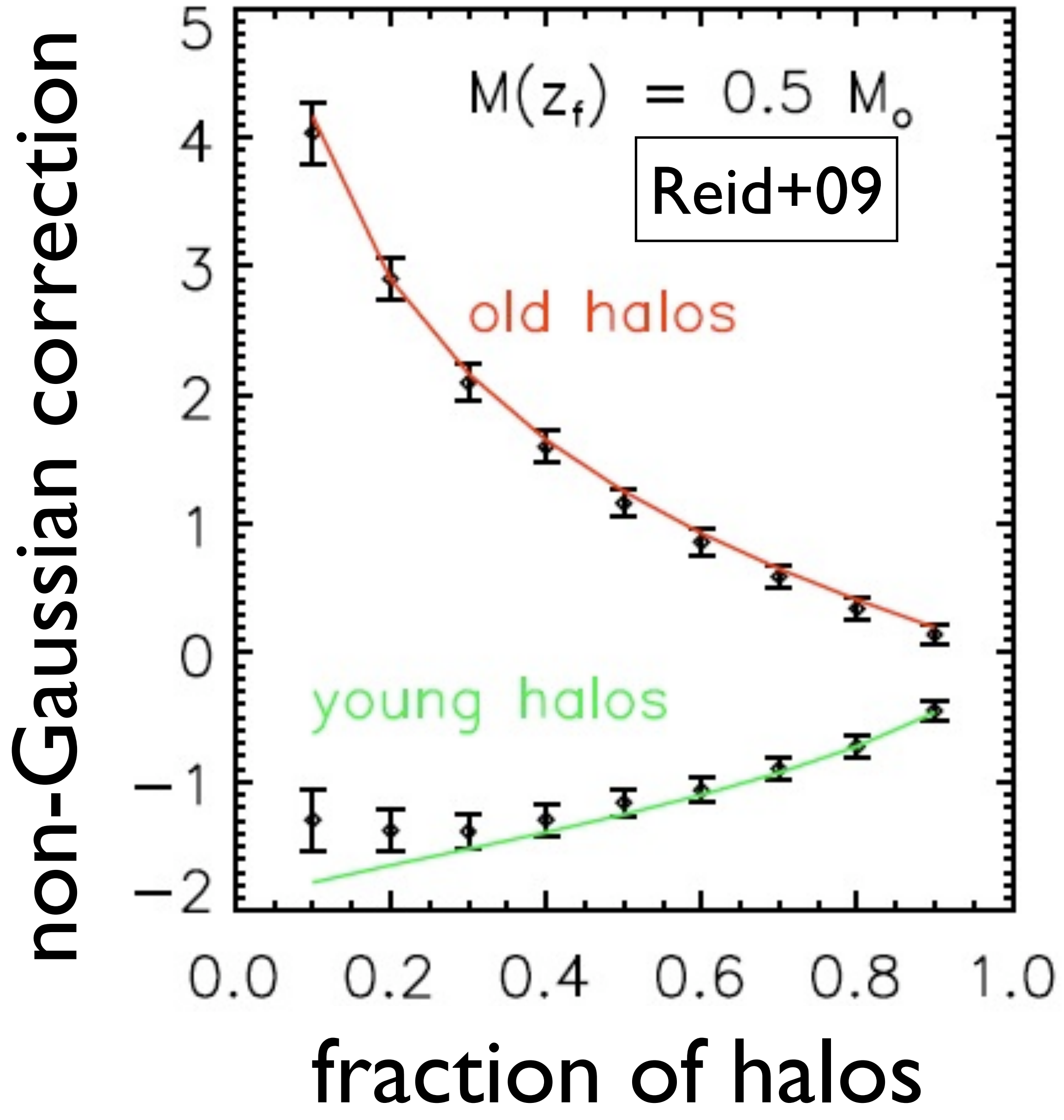
calibration by simulations

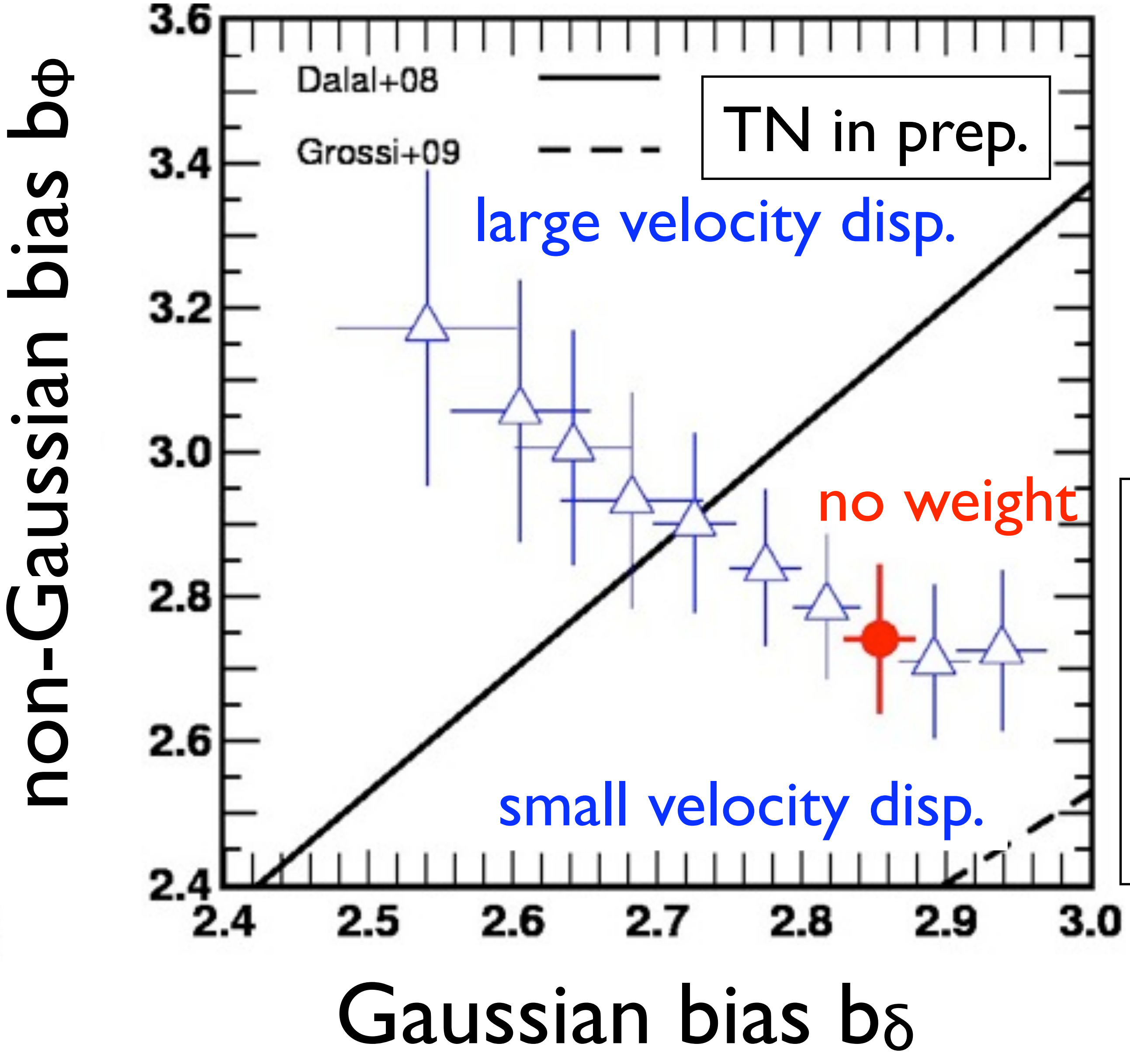
Desjacques+09
Grossi+09
Pillepich+10

Desjacques&Seljak10



Halo assembly bias





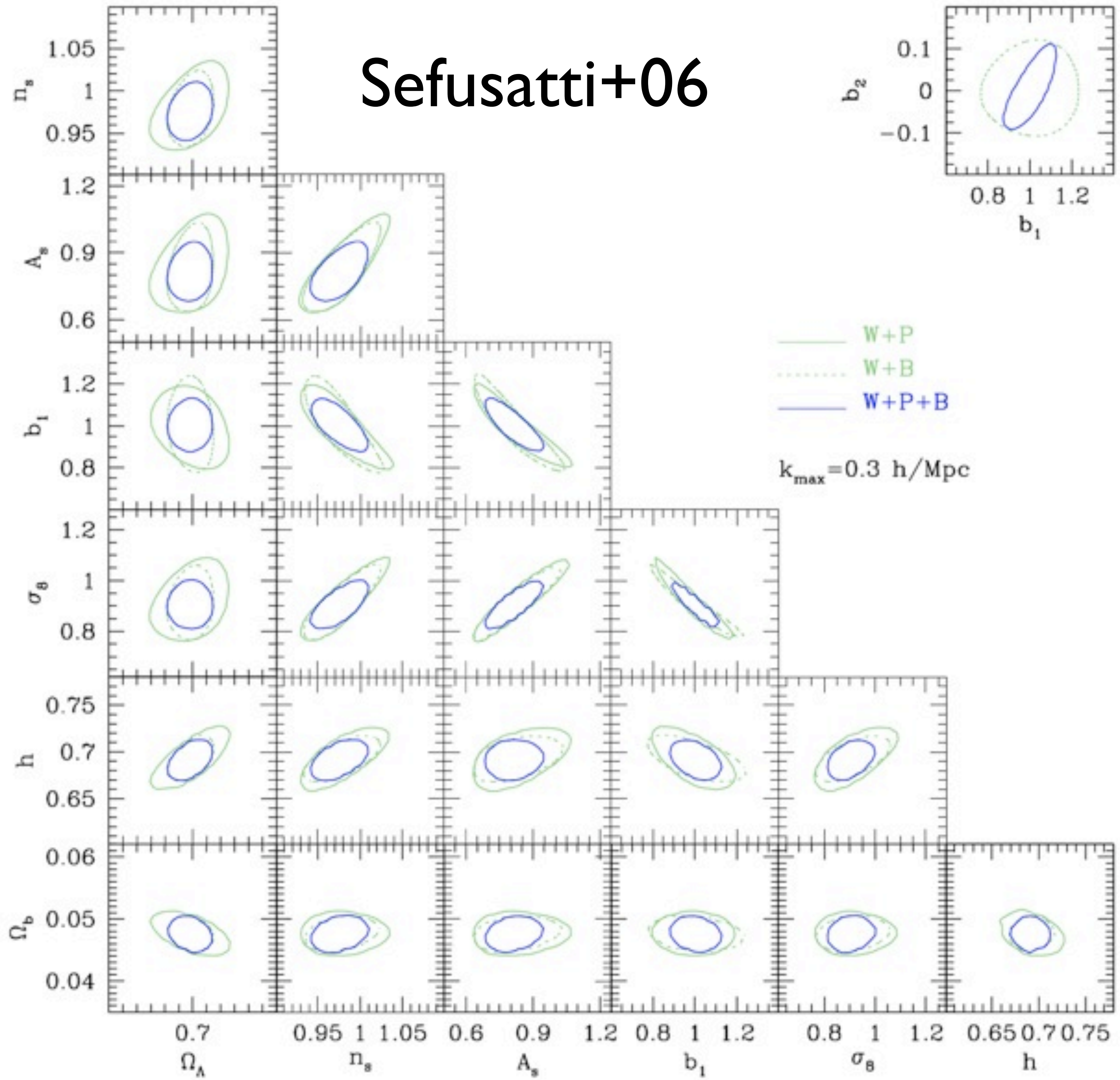
$$\delta^h_{\vec{x}} = b_\delta \delta_{\vec{x}} + 2 f_{\rm nl} b_\phi \phi_{\vec{x}}$$

usually $b_\phi = \delta_c (b_\delta - 1)$

assembly bias can change the amplitude of non-G correction for given Gaussian bias

Bispectrum?

Sefusatti+06



adds information

contains primordial non-G information by definition

B_h vs. B_m

"scale-dependent bias" should exist

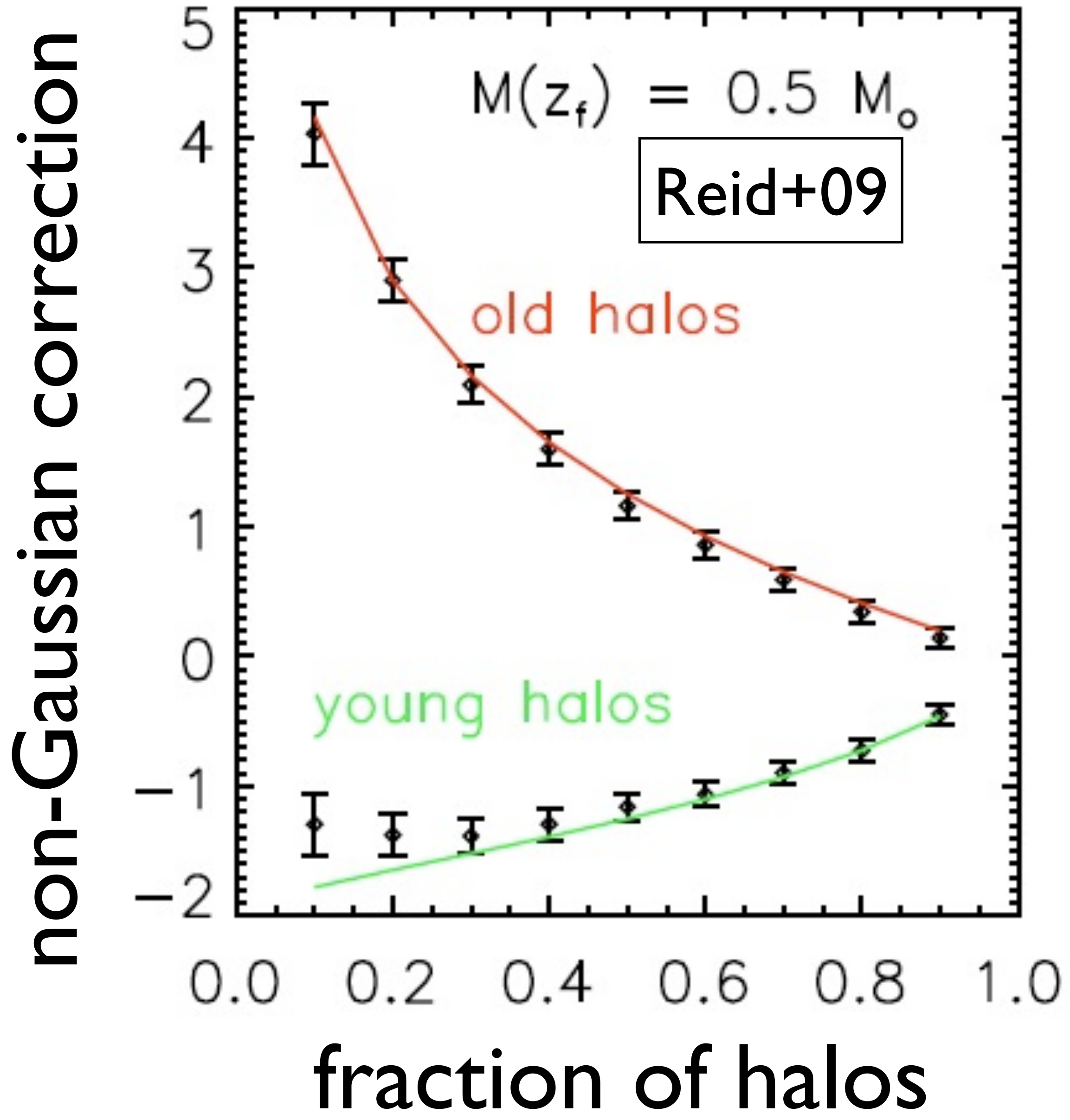
local bias

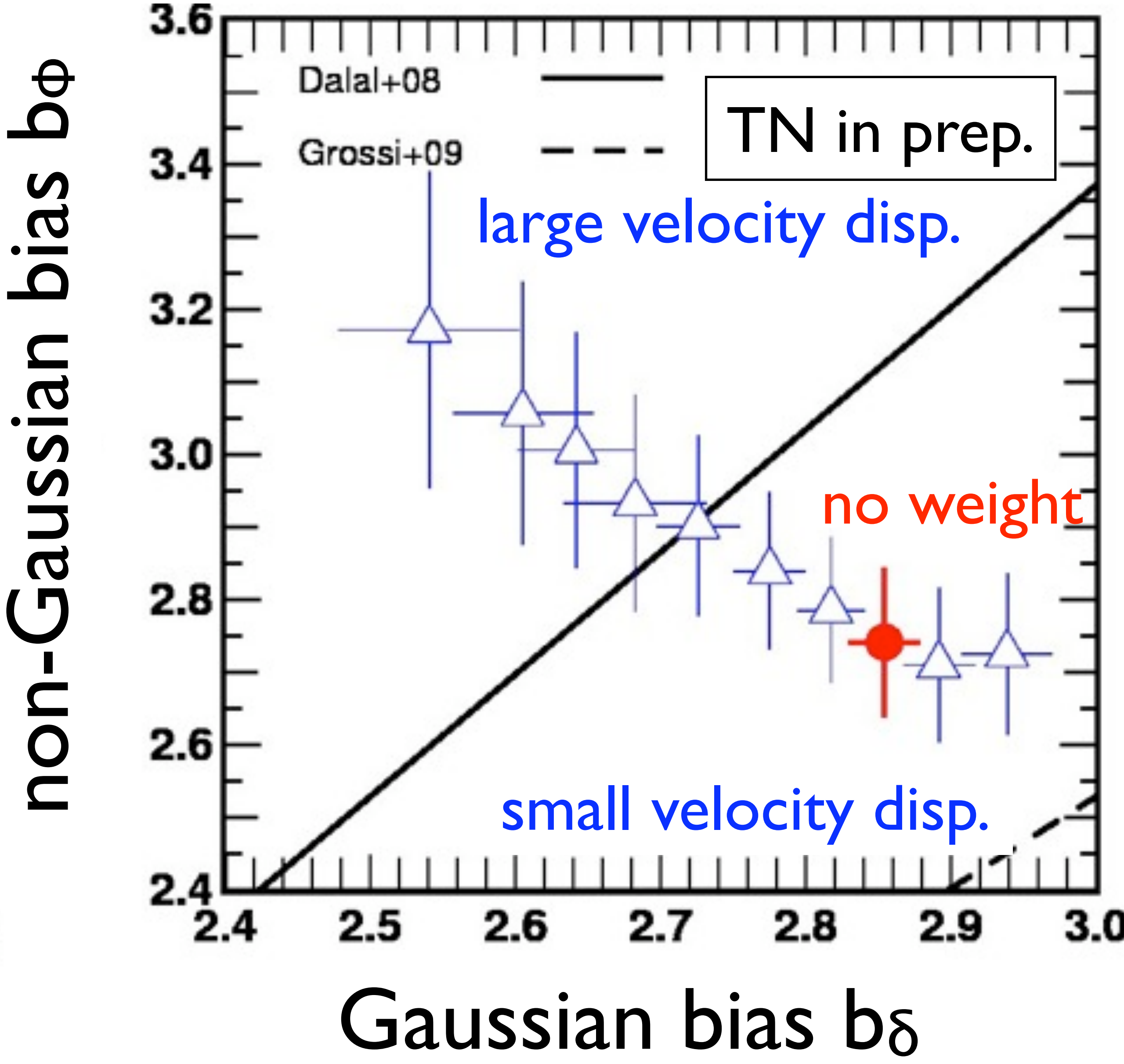
Jeong&Komatsu09

$$B_h(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3) = b_1^3\Big[B_R(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3) + \frac{b_2}{b_1}\{P_R(k_1)P_R(k_2) + (2\ \text{cyclic})\} + \frac{1}{2}\frac{b_2}{b_1}\int\frac{d^3q}{(2\pi)^3}T_R(\boldsymbol{q},\boldsymbol{k}_1-\boldsymbol{q},\boldsymbol{k}_2,\boldsymbol{k}_3) + (2\ \text{cyclic})\Big]. \quad (13)$$

but not investigated numerically

Halo assembly bias





$$\delta^h_{\vec{x}} = b_\delta \delta_{\vec{x}} + 2 f_{\rm nl} b_\phi \phi_{\vec{x}}$$

usually $b_\phi = \delta_c (b_\delta - 1)$

assembly bias can change the amplitude of non-G correction for given Gaussian bias

Bispectrum can break the degeneracy: $\Delta P \propto f_{nl}\, b_\Phi$, $\Delta B \propto f_{nl}^2\, b_\Phi$

N-body simulations with f_{NL}

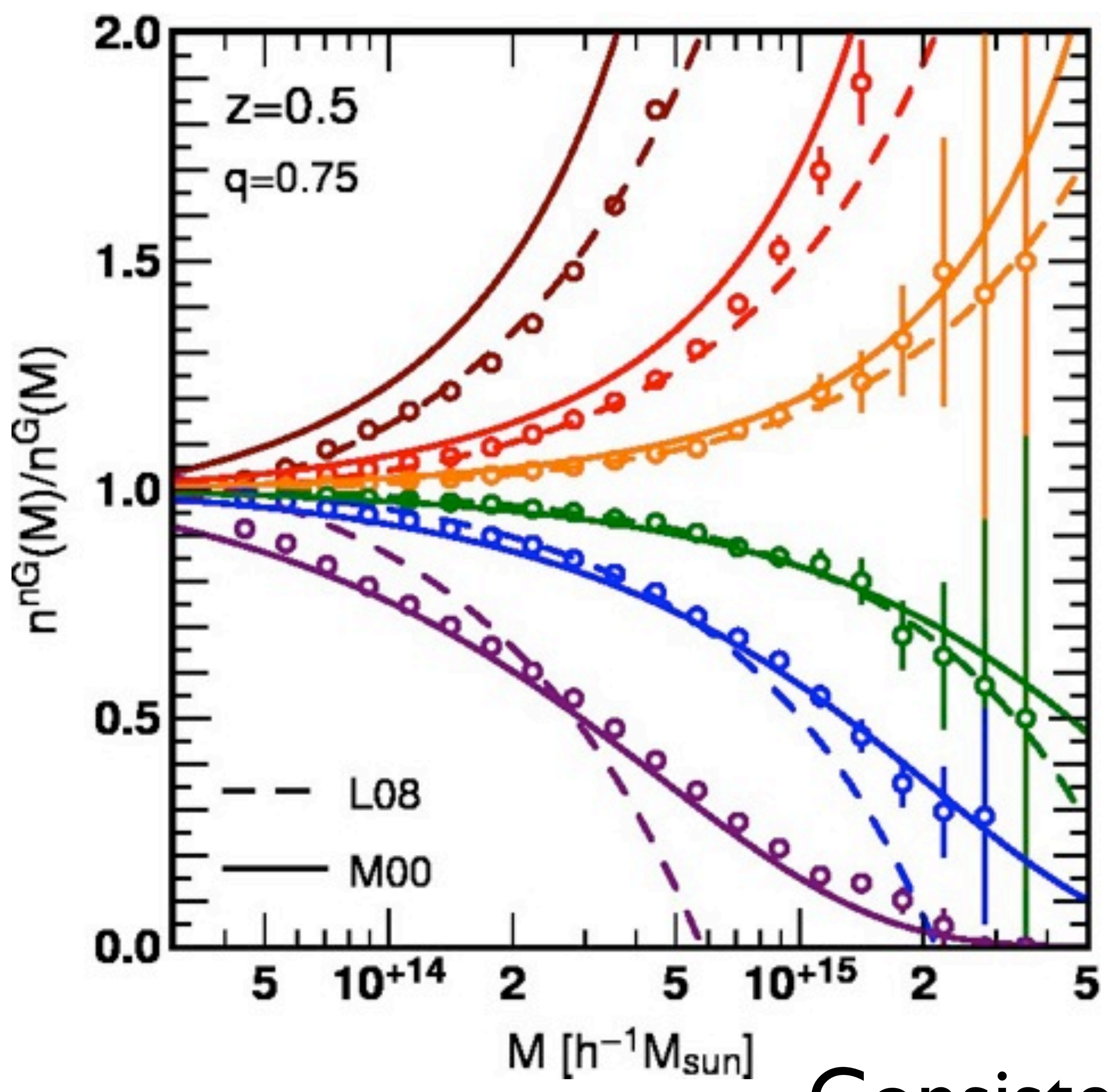
Author	f_{NL}	volume/run [$h^{-3}Gpc^3$]	run/model	particle/run	mass/particle [$h^{-1}M_{sun}$]
Kang+07	-580,134	0.027	1 (2)	128^3	$\sim 10^{12}$
Grossi+07	0,±100,±500,±1000	0.13	1	800^3	2.0×10^{10}
Dalal+08	0,±5,±50,±500 (±5000)	0.51	1	512^3	2.5×10^{11}
Pillepich+10	0,±27,±80,250,500,750	1.7	1 (2)	1024^3	1.2×10^{11}
Desjacques+09	0,±100 (±10,±30)	4.1	5 (2)	1024^3	3.0×10^{11}
Grossi+09	0,±100,±200	1.7	1	960^3	1.4×10^{11}
This work	0,±100,±300,±1000	8.0	20	512^3	4.6×10^{12}

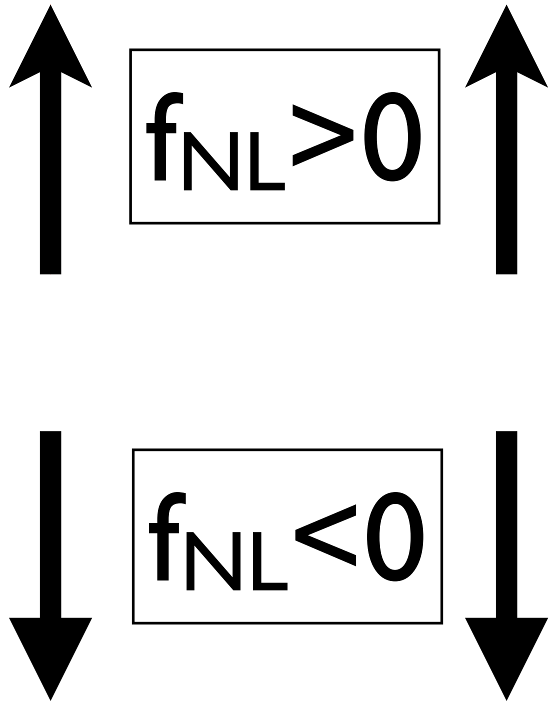
examine the clustering of massive haloes at large scale

We need a sufficient number of modes to see bispectrum!

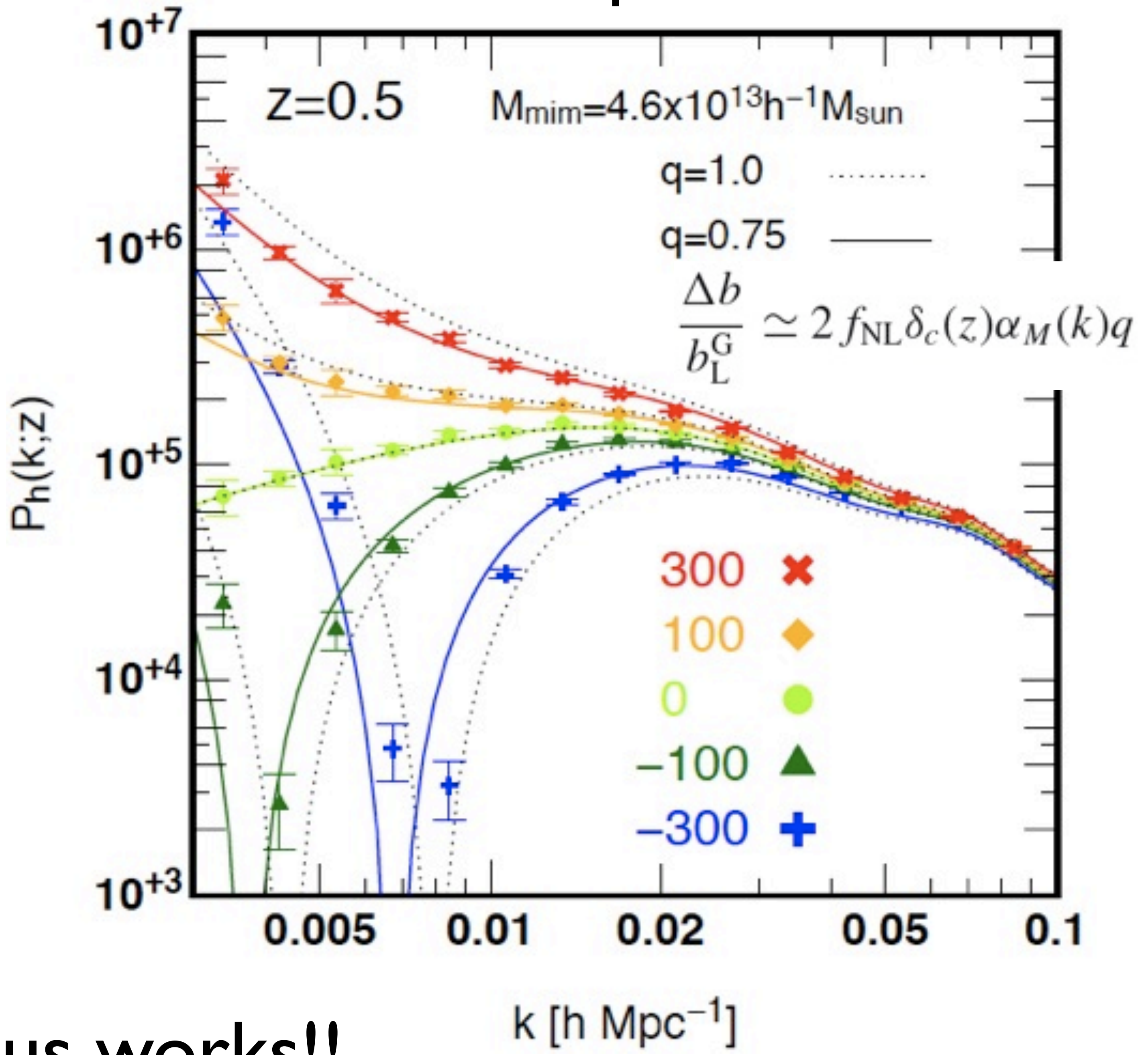
Our halo catalog

Mass function



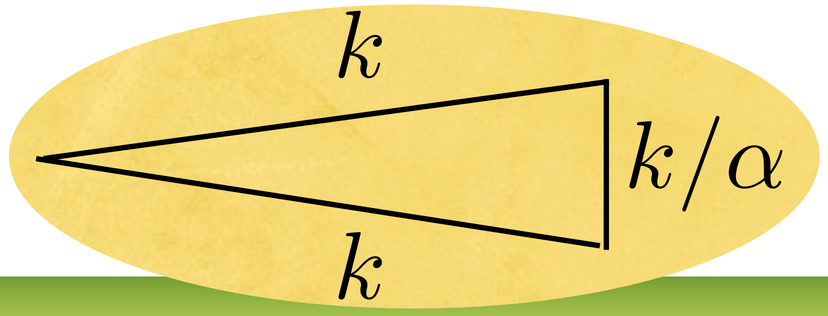


Power spectrum

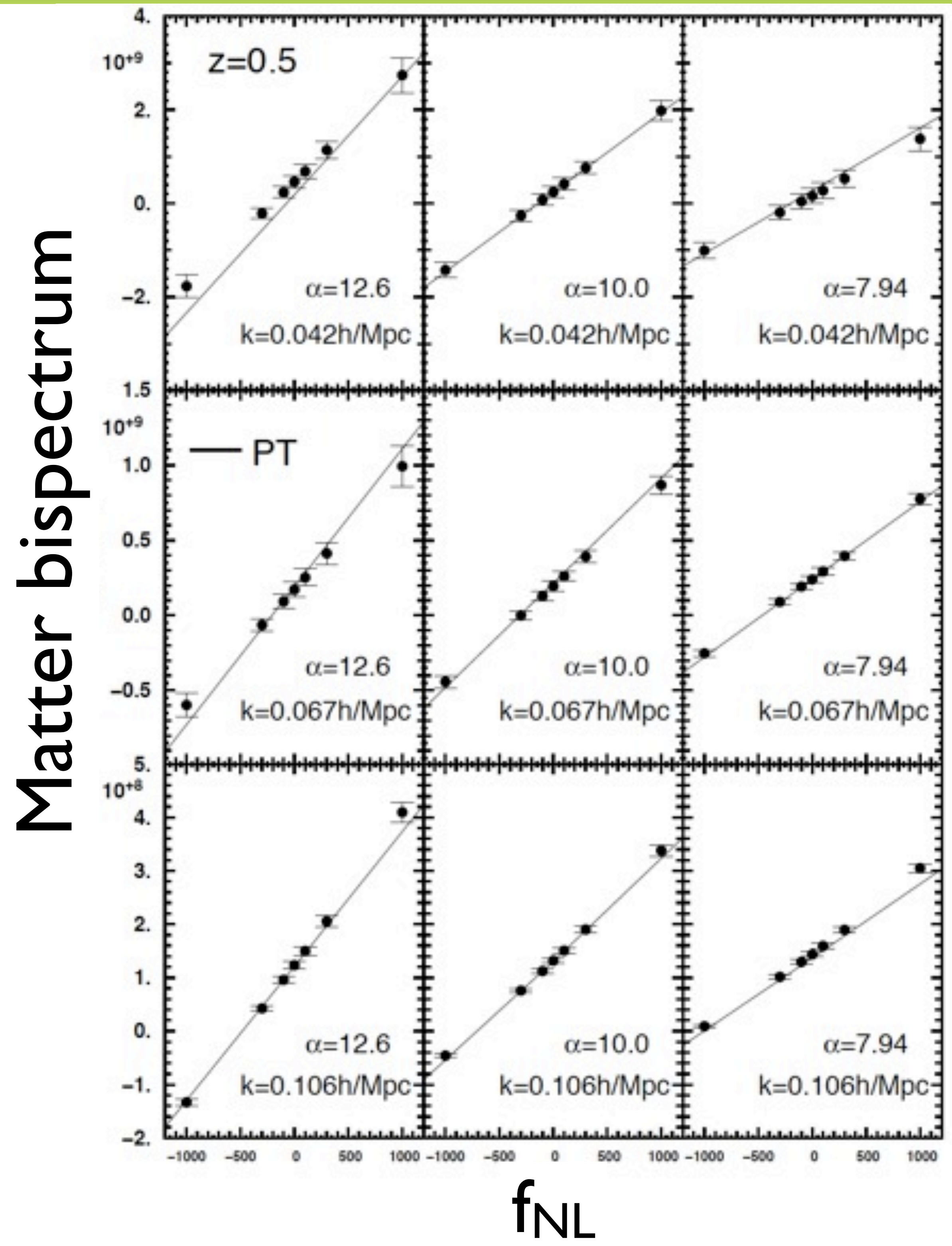


Consistent with previous works!!

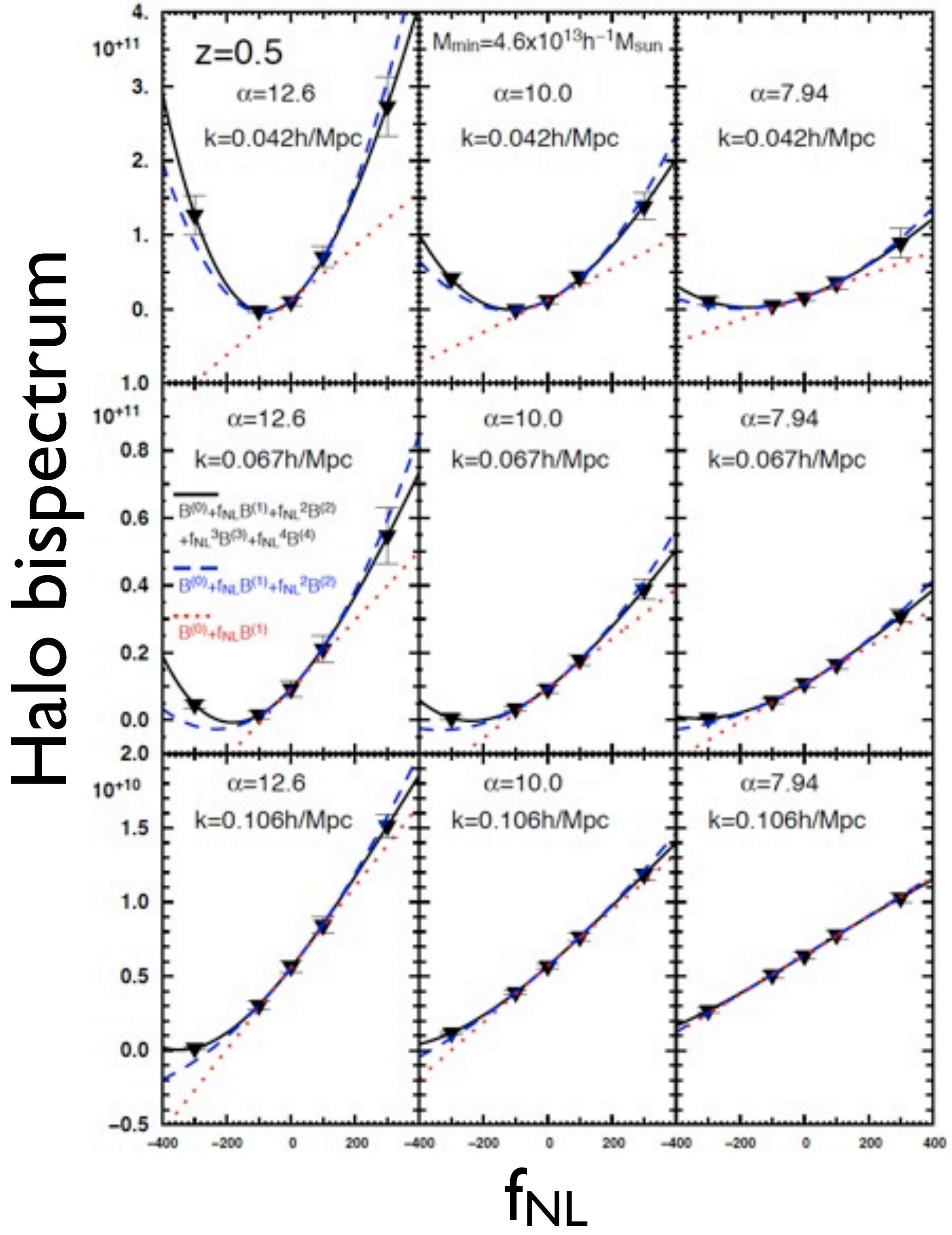
Result



k
k/α
k



Matter bispectrum
z=0.5
— PT
α=12.6
α=10.0
α=7.94
k=0.042h/Mpc
k=0.067h/Mpc
k=0.106h/Mpc
10+9
10+9
10+8
fNL



Halo bispectrum
z=0.5
Mmin=4.6x10^13h^-1Msun
α=12.6
α=10.0
α=7.94
k=0.042h/Mpc
k=0.067h/Mpc
k=0.106h/Mpc
10+11
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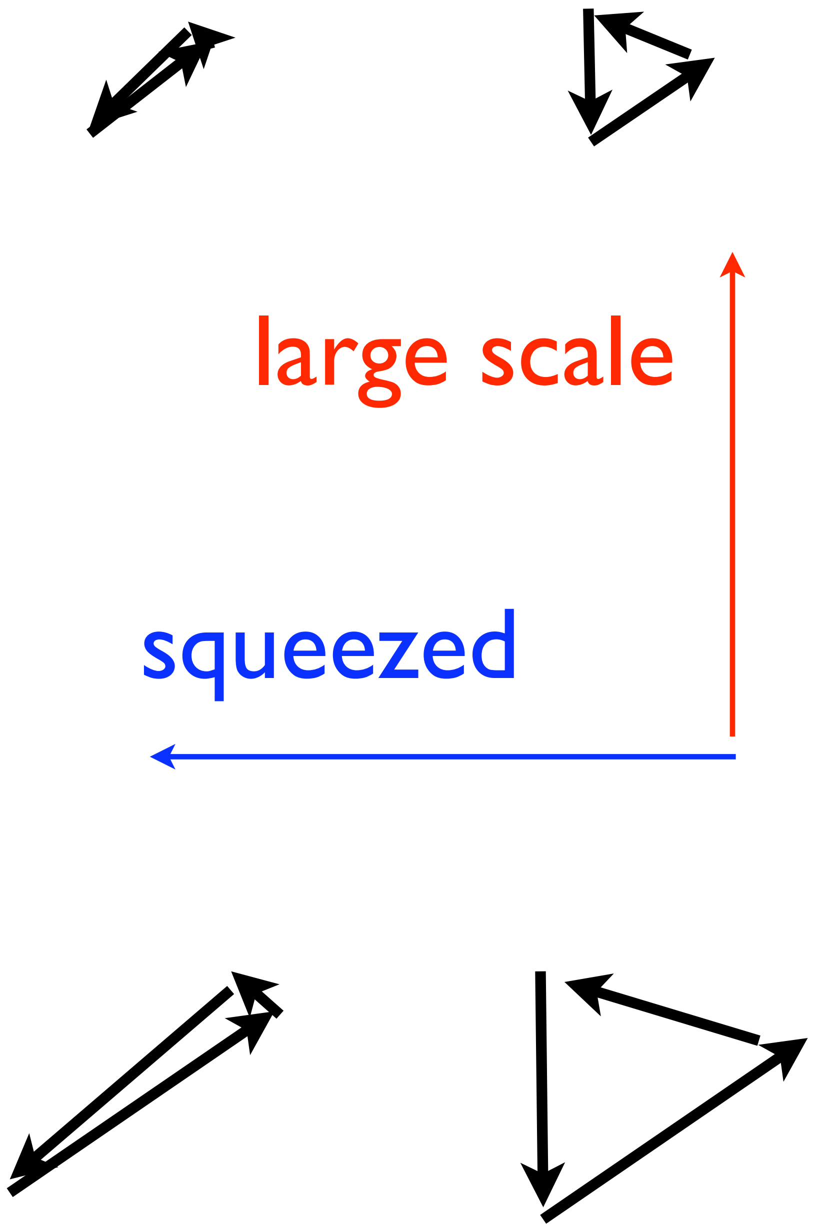
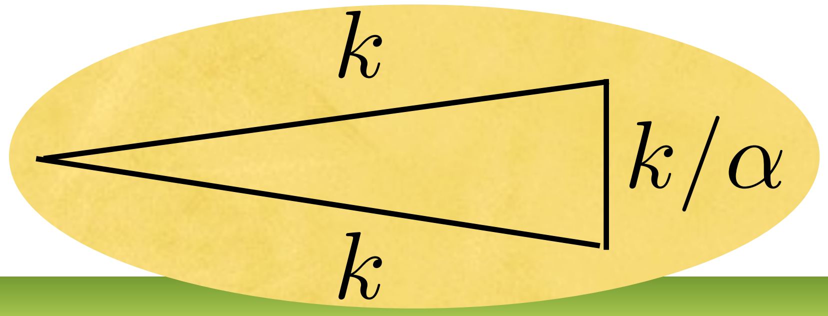
fNL

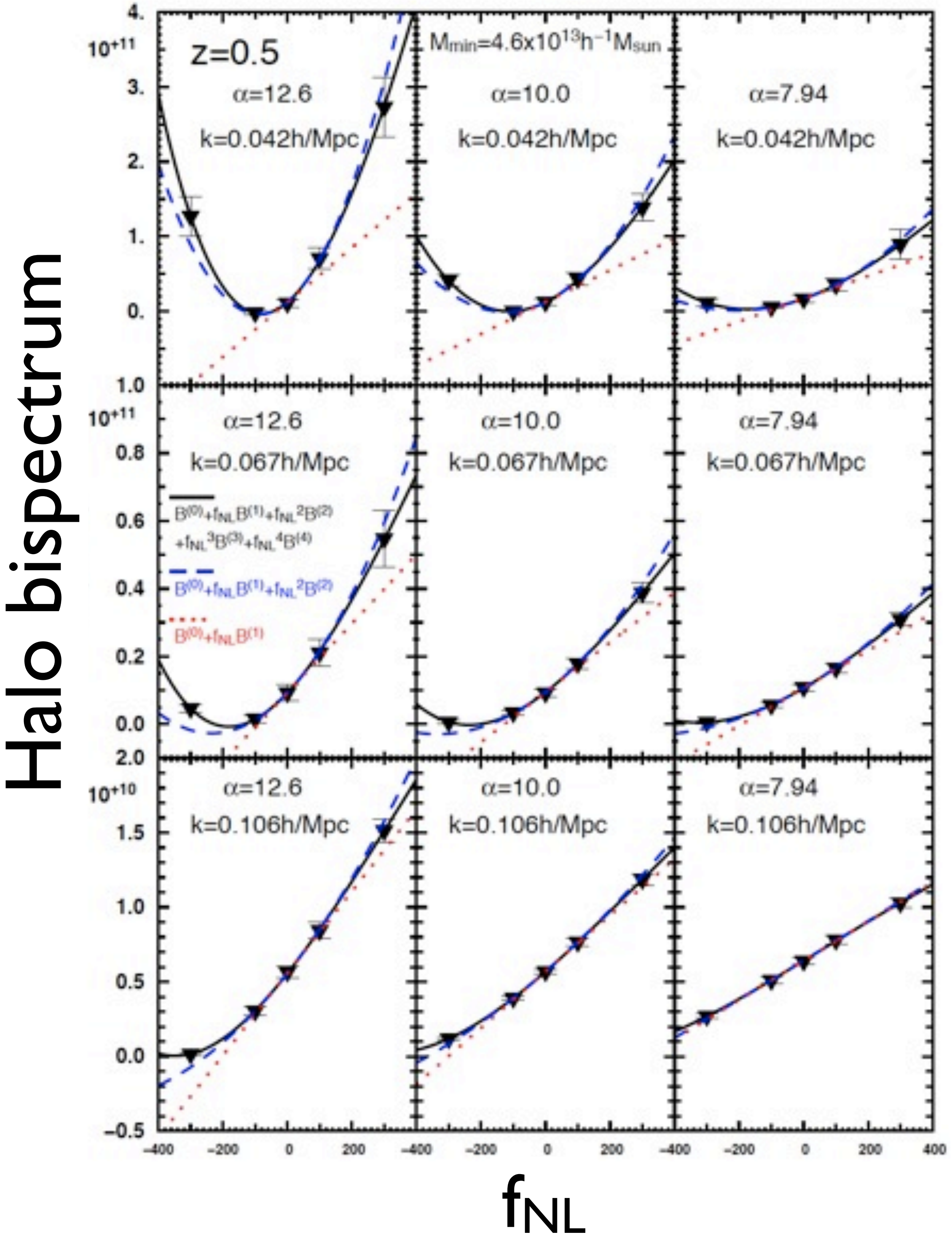


large scale
squeezed

Result



Halo bispectra at z=0.5 for isosceles triangles



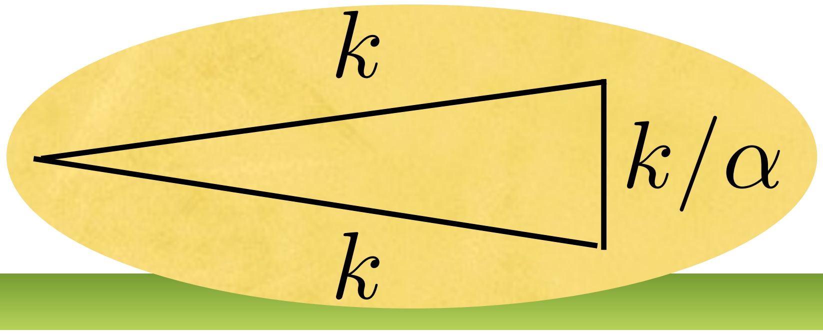
Fitted by 4th-order polynomial:

$$B^h(k,\alpha;f_{\mathrm{NL}}) = B_0(k,\alpha) + f_{\mathrm{NL}}B_1(k,\alpha) + f_{\mathrm{NL}}^2 B_2(k,\alpha) + f_{\mathrm{NL}}^3 B_3(k,\alpha) + f_{\mathrm{NL}}^4 B_4(k,\alpha)$$

For reasonable values of f_{NL},

- B_0, B_1 & B_2 are enough to describe N-body data
- The new term (B_2) is important for squeezed triangles (small k & large α)

Comparison with theory



Assuming local bias model

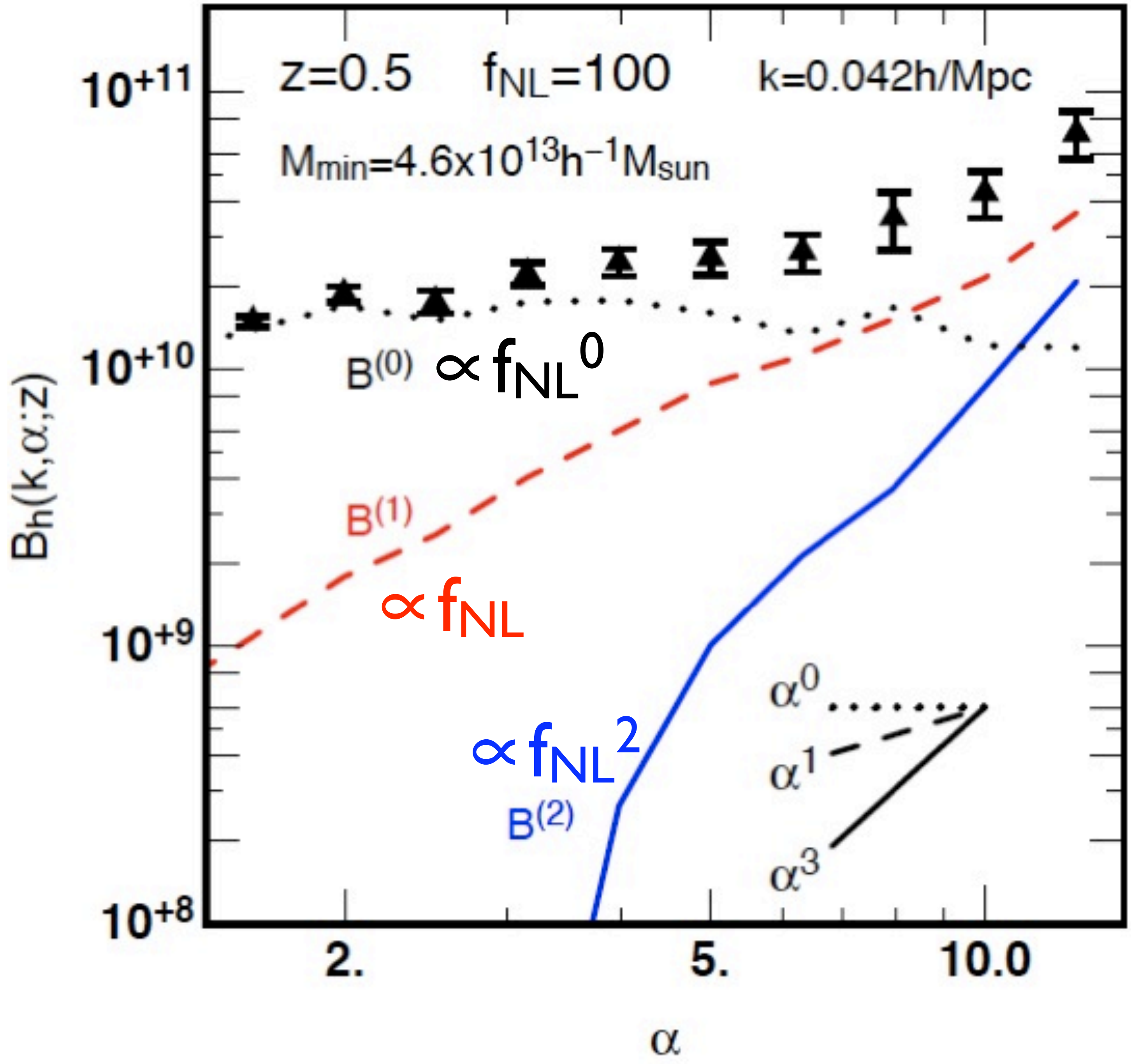
Jeong,Komatsu09

$$
\begin{aligned}
&B_h(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3)\\
&= b_1^3\Big[B_R(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3)+\frac{b_2}{b_1}\{P_R(k_1)P_R(k_2)+(2\text{ cyclic})\}\\
&+\frac{1}{2}\frac{b_2}{b_1}\int\frac{d^3q}{(2\pi)^3}T_R(\boldsymbol{q},\boldsymbol{k}_1-\boldsymbol{q},\boldsymbol{k}_2,\boldsymbol{k}_3)+(2\text{ cyclic})\Big].(13)
\end{aligned}
$$

Asymptotic behavior of halo bispectrum at ``squeezed limit'' (α→∞)

$$\propto f_{\rm NL}^2\alpha^3k^{-2}$$

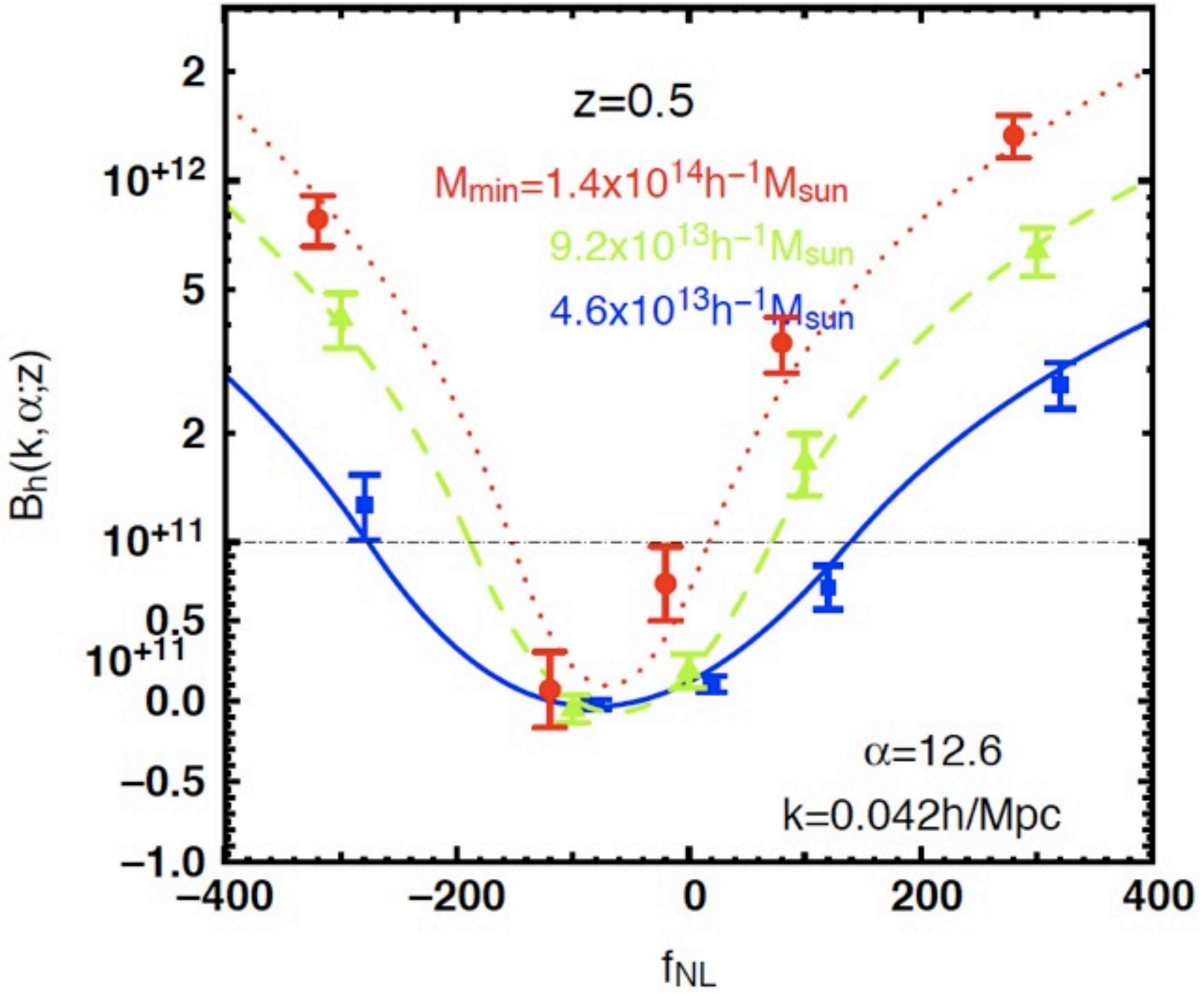
c.f. matter bispectrum: $\propto f_{\rm NL}^1\alpha^1k^0$



Dependence on the halo mass

Halo bispectrum for different minimum halo masses

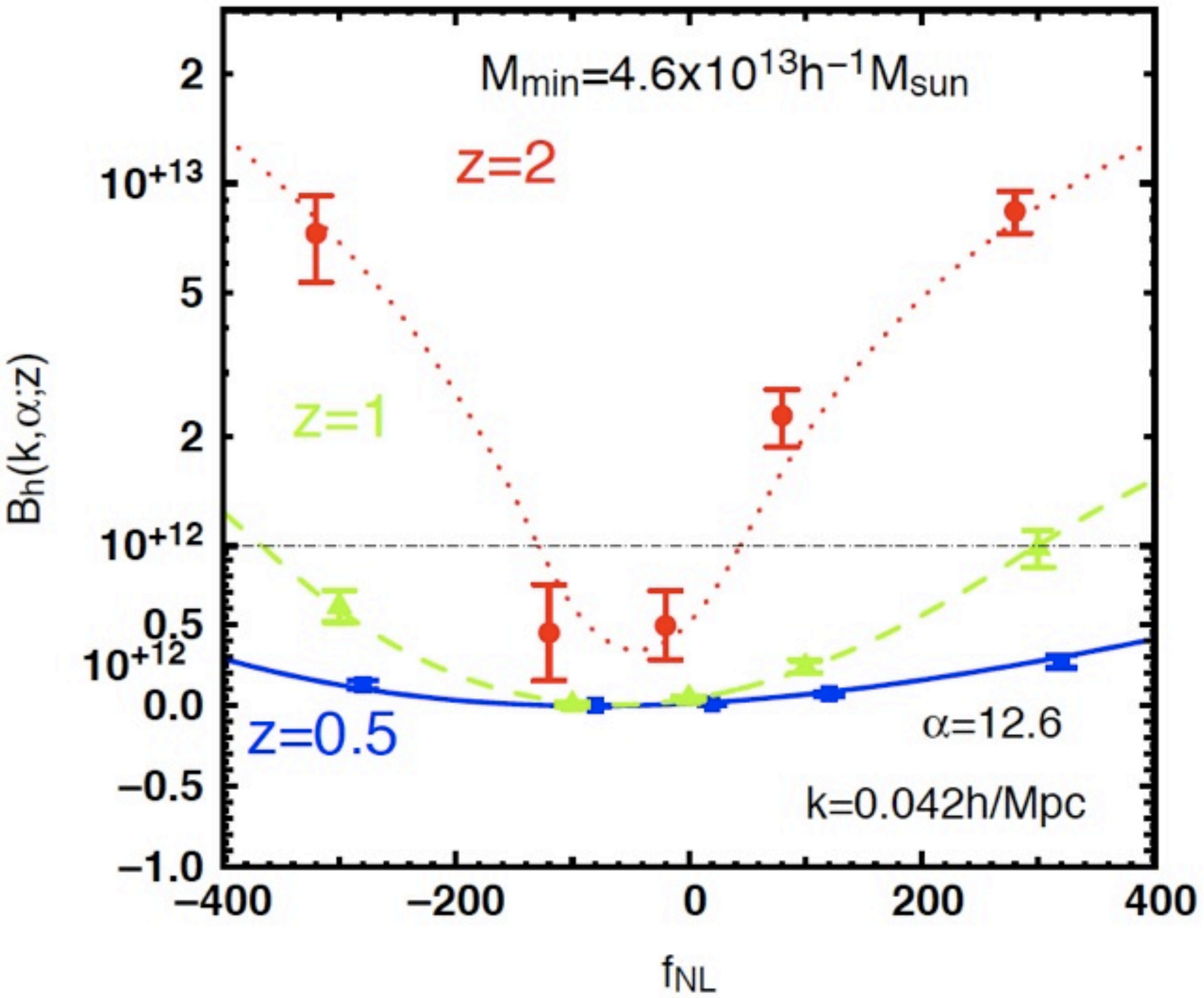
f_{NL}^2 term is more important for more massive haloes



Dependence on redshift

halo bispectrum at different epochs

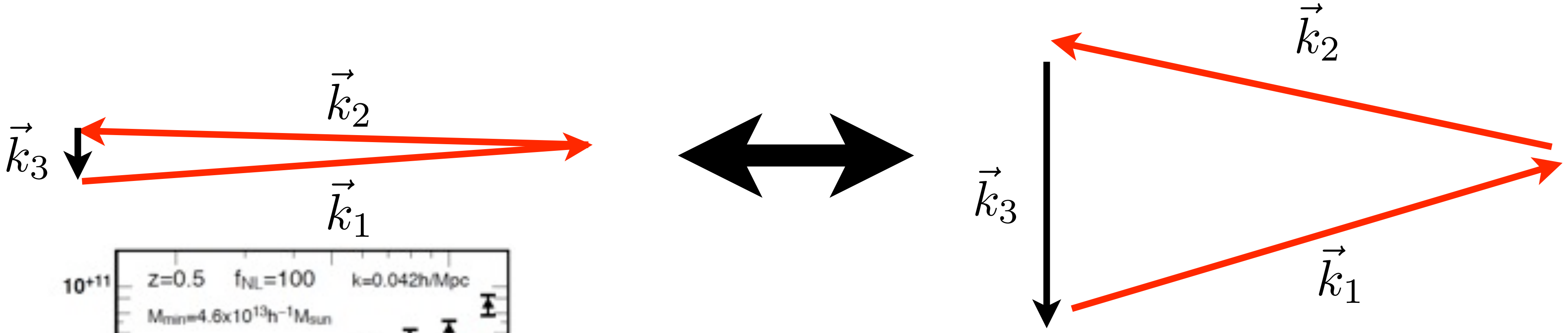
f_{NL}^2 term is more important at higher redshift

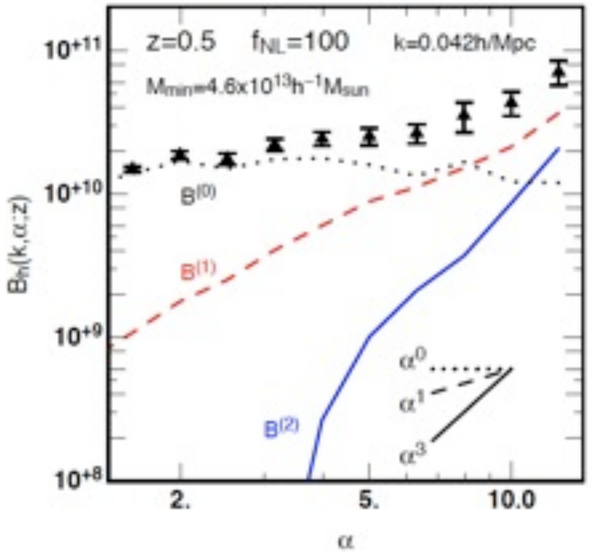


Detectability

detectability when using only limited configurations of $k_1 = k_2 = 0.042 h/\mathrm{Mpc}$

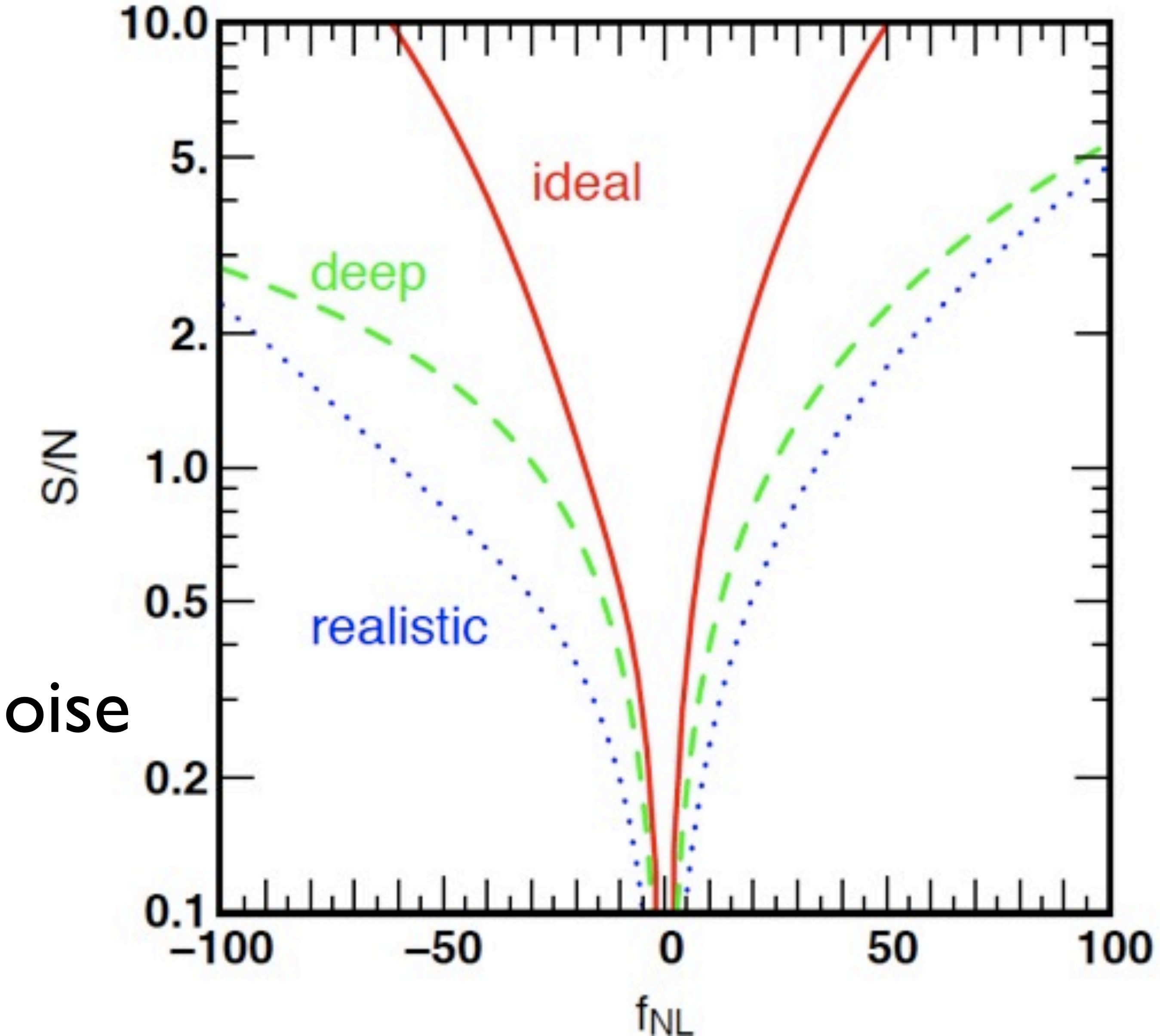
survey	z	$V\ [h^{-3}\mathrm{Gpc}^3]$	$n_g\ [h^3\mathrm{Mpc}^{-3}]$	$M_{\min}\ [h^{-1}M_\odot]$	b_1
IDEAL	1.0	100	1×10^{-3}	2.8×10^{12}	1.9
REALISTIC	1.0	10	5×10^{-4}	5.0×10^{12}	2.2
DEEP	2.0	3	3×10^{-4}	3.4×10^{12}	3.3





$$\left(\frac{\mathrm{S}}{\mathrm{N}}\right)^2 \equiv \sum_i \frac{[B(k,\alpha_i; f_{\mathrm{NL}}) - B(k,\alpha_i; f_{\mathrm{NL}}=0)]^2}{\Delta B(k,\alpha_i; f_{\mathrm{NL}}=0)^2}.$$

cosmic variance + shot noise



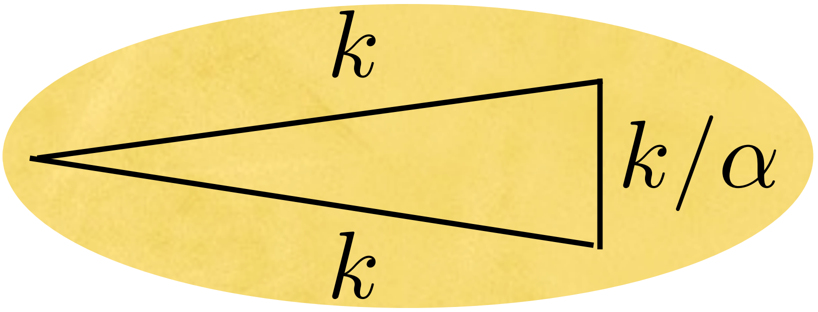
$|f_{NL}| < 10$ from ultimate future surveys!
($|f_{NL}| < 1$ if we use full information!)

Summary

We have examined the effects of local-type primordial non-Gaussianity on the halo bispectrum:

- Big difference between the matter and halo bispectra
- f_{NL}^2 term is important for squeezed configurations at large scale
- Especially for massive haloes at high z
- The trend can be explained by analytical model assuming local bias

$$\textbf{new term} \propto f_{\rm NL}^2 \alpha^3 k^{-2}$$



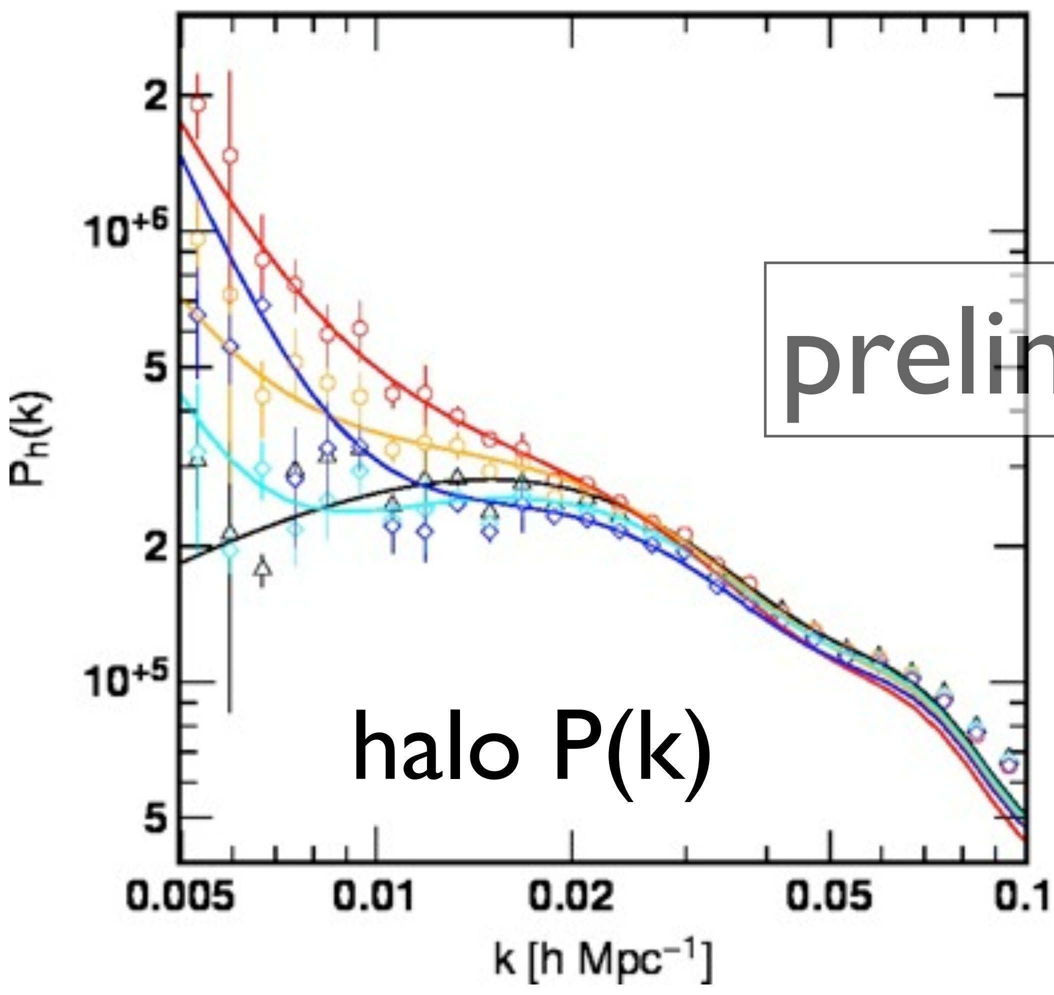
On going project

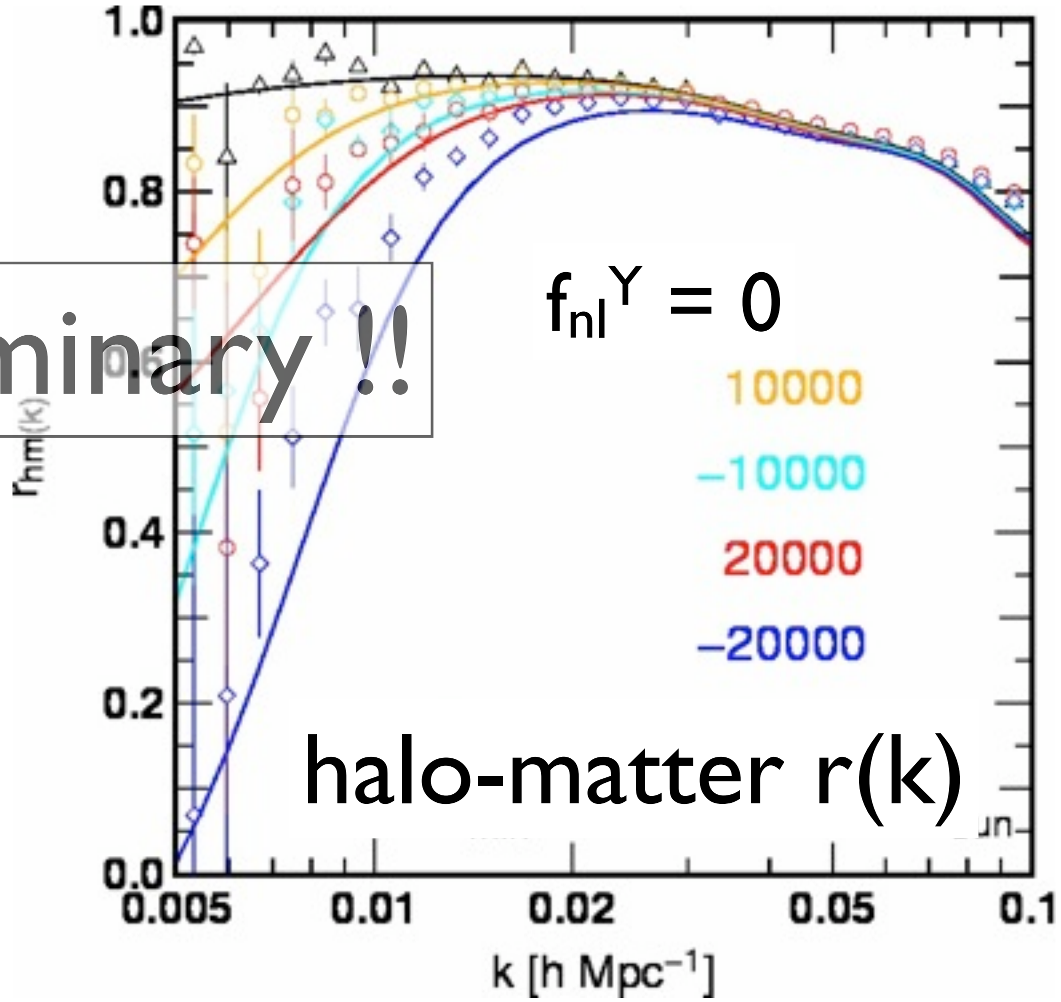
2 field non-Gaussian models

$$\delta(k) = M_X(k)\, X(k) + M_Y(k)\, Y(k)$$

Gaussian (X) — non-Gaussian (Y)

$$Y = \left\{ \begin{array}{l} \eta + f_{\rm nl}^{Y}(\eta^2 - \langle \eta^2 \rangle) \\ \eta^2 - \langle \eta^2 \rangle \end{array} \right. \times \left\{ \begin{array}{l} \zeta \\ s \end{array} \right. \times \text{correlation}$$





preliminary !!

c.f., inflaton+curvaton model

Tseliakhovich+10: theory

Smith&LoVerde10: simulation