Effect of multi-field non-Gaussianities on the large-scale structure

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Outline

- brief review of single-field local-type nG on LSS
- effect of multi-field local-type nG on scale-dependent bias
  - bispectrum & trispectrum parametrized by (f_{nl}, g_{nl}, τ_{nl})
  - more general cases with scale dependence

single-field local-type nG

Local-type NG and Large Scale Structure

local-type primordial Non-Gaussianity

$$\zeta(\mathbf{x}) = \zeta_G(\mathbf{x}) + \frac{3}{5} f_{nl}[\zeta_G^2(\mathbf{x}) - \langle \zeta_G^2 \rangle]$$

Gaussian

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

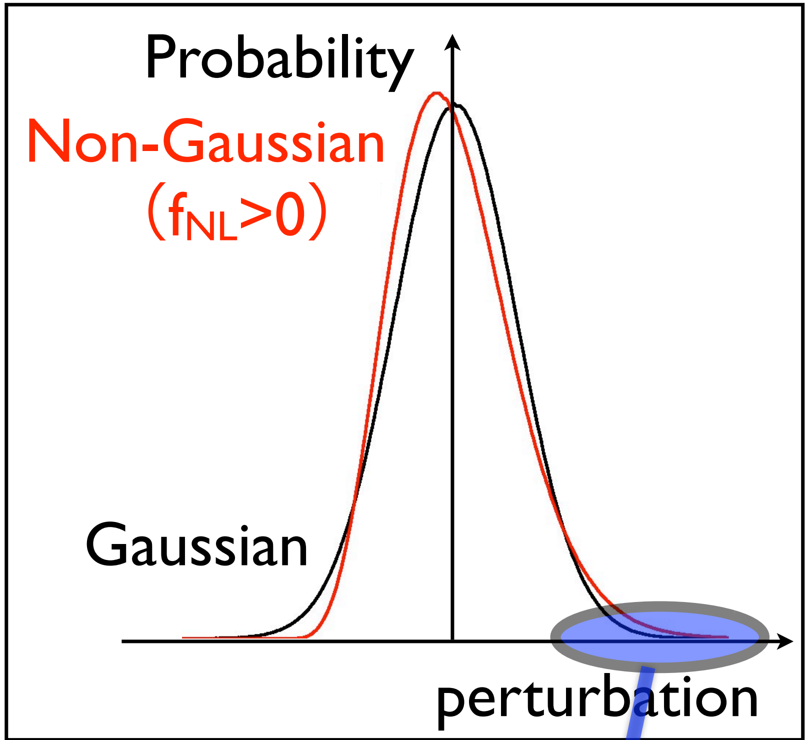
We observe ``galaxy'',
not ``matter'' density fluctuations

biasing changes things dramatically!

- halo mass function
- halo power spectrum
- halo bispectrum

:

Understanding of the halo/galaxy biasing is the key!



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

Scale-dependent bias

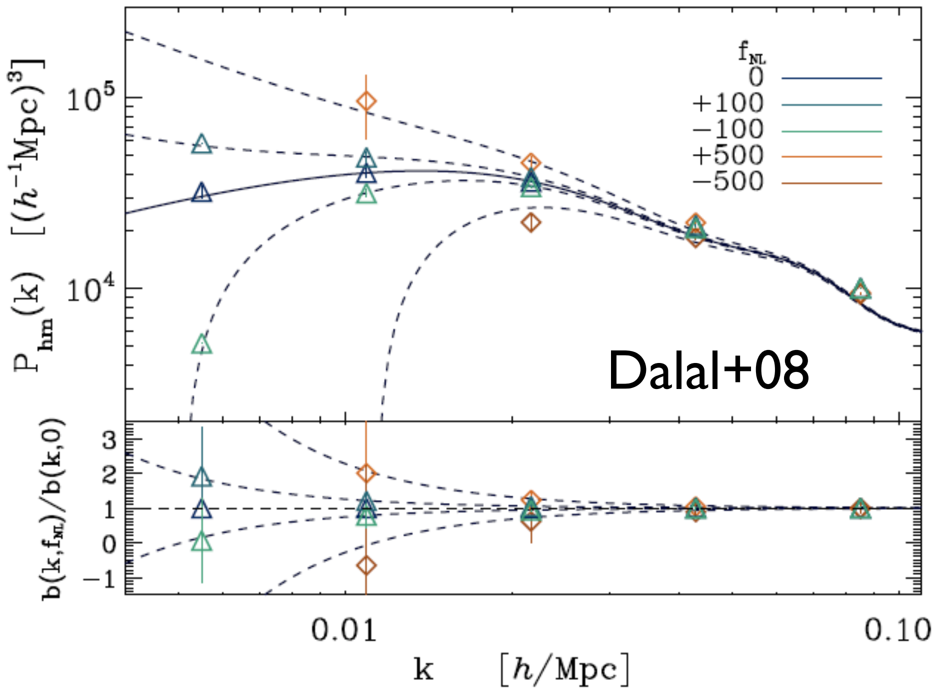
Theory

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

Dalal+08
Slosar+08
Matarrese, Verde08
Afshordi, Tolley08
McDonald08
Taruya+09
Giannantonio, Porciani10
Desjacques, Jeong, Schmidt11a,b
and more ...

calibration by simulations

Desjacques+09
Grossi+09
Pillepich+10

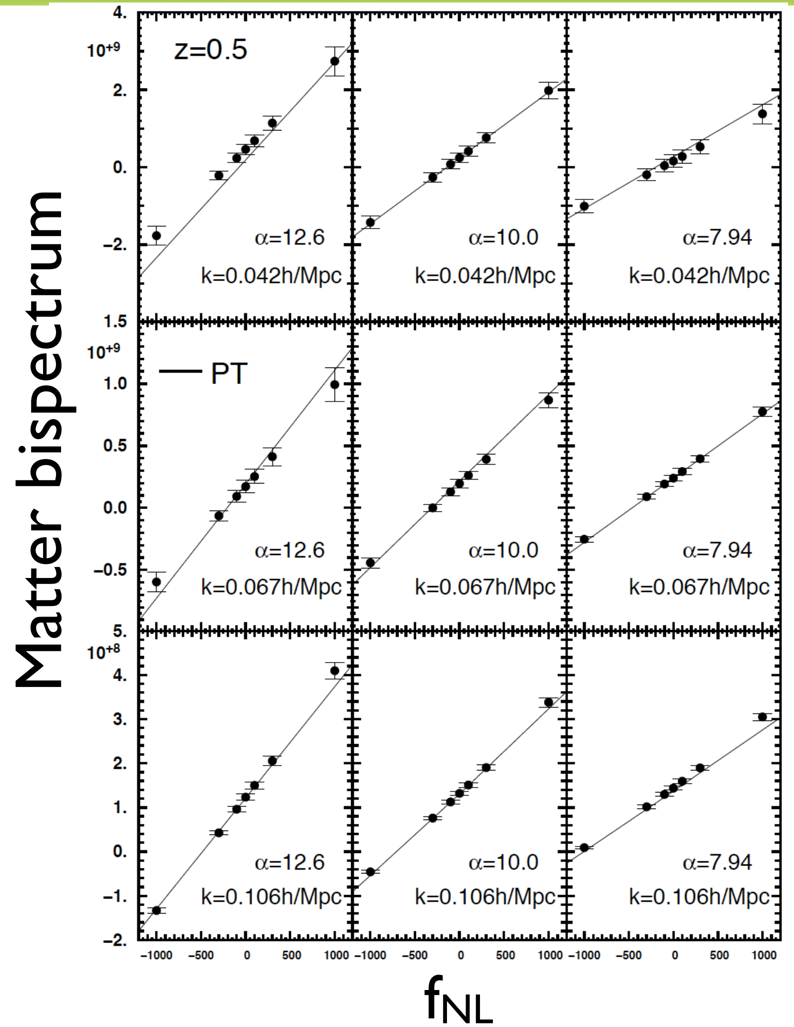


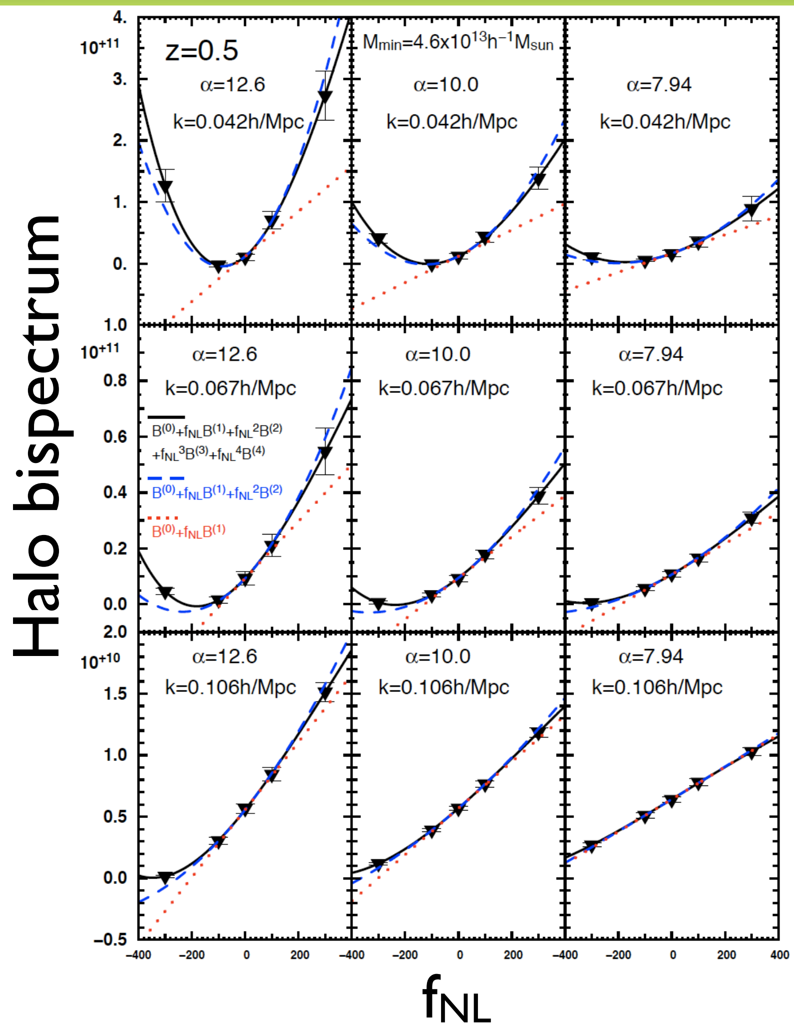
Slosar+08

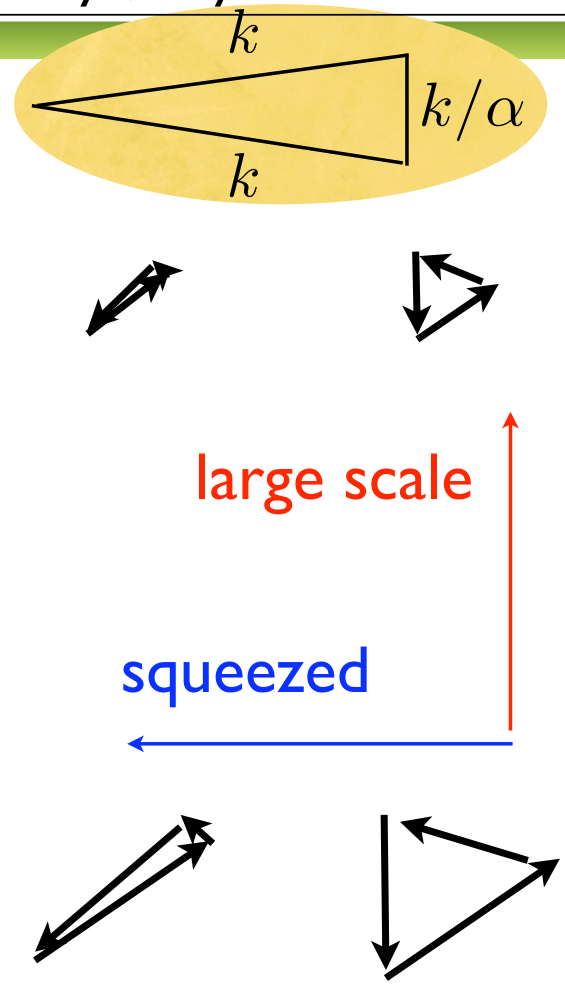
$-29 < f_{nl} < 69$ (QSOs+more)

signature of f_{nl} in bispectrum

TN, Taruya, Koyama & Sabiu '10





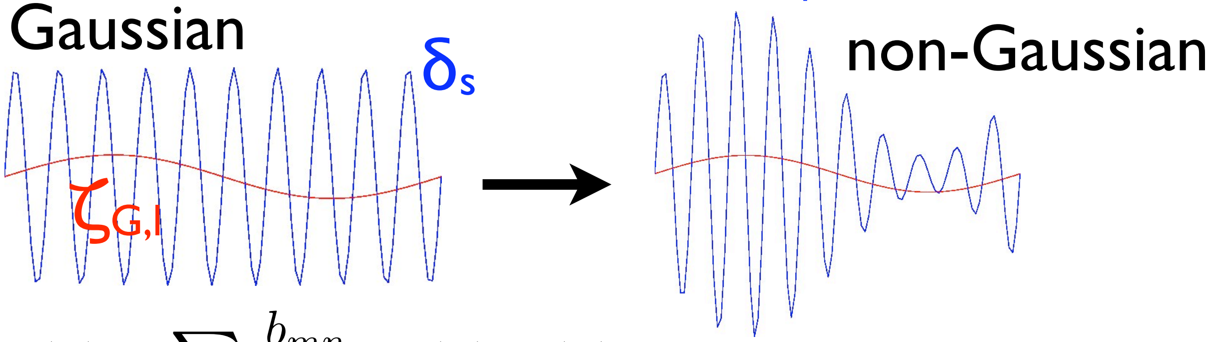


Peak-Background Split prediction

peak-background split

$$\zeta_G = \zeta_{G,\ell} + \zeta_{G,s} \qquad \delta = \delta_\ell + \delta_s$$

responsible for halo formation



$$\delta_h(\mathbf{x}) = \sum_{m,n} \frac{b_{mn}}{m!n!} \delta^m(\mathbf{x}) \zeta_G^n(\mathbf{x})$$

Giannantonio,Porciani10

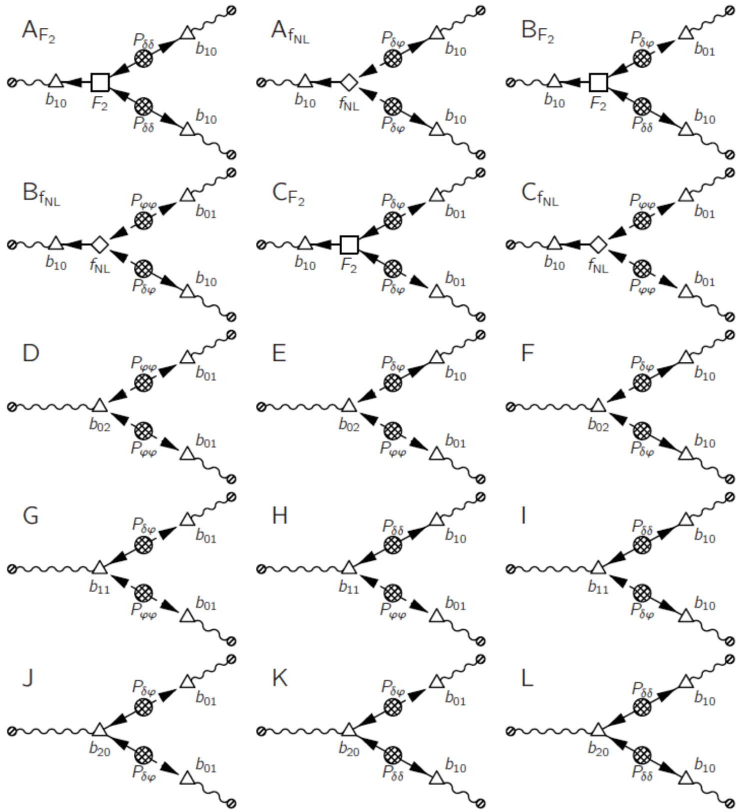
coefficients b_{mn} are given as derivatives of mass function

power spectrum

$$P_h(k) = b_{10}^2 P_\delta(k) + 2b_{10}b_{01}P_{\delta\zeta}(k) + b_{01}^2 P_\zeta(k)$$

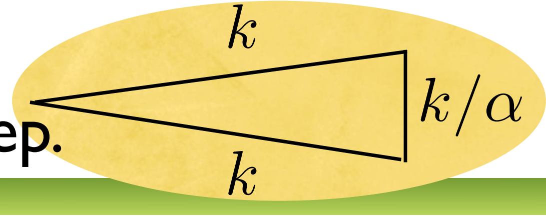
bispectrum

Baldauf, Seljak & Senatore'10

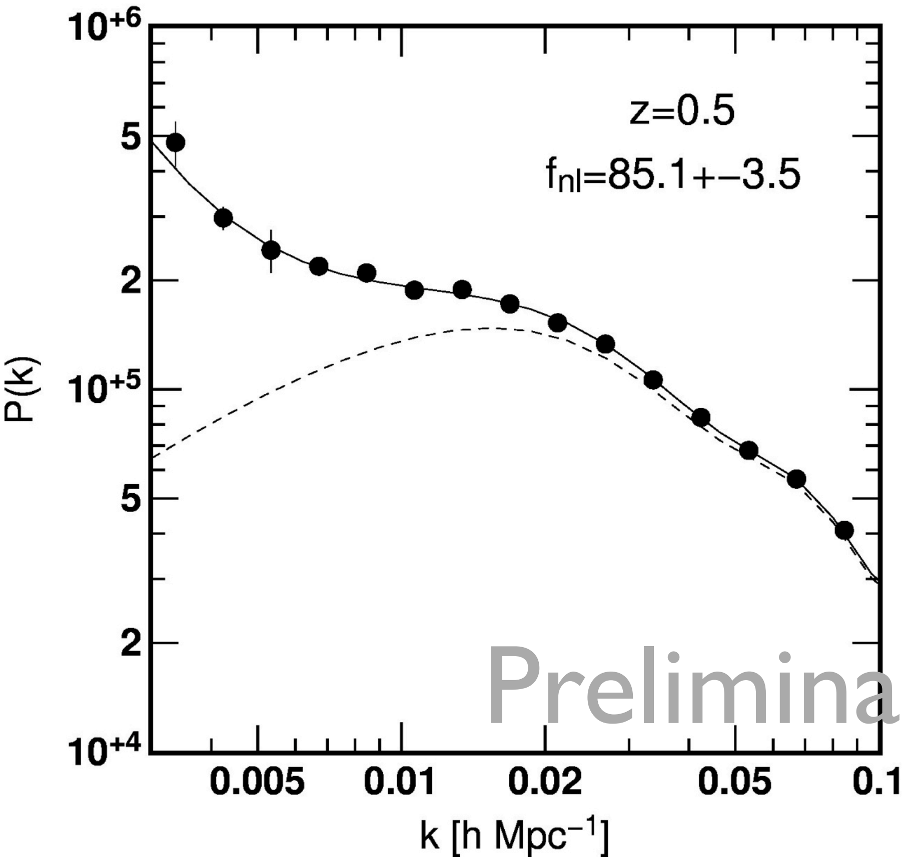


relevant bias parameters: $b_{10},\ b_{01},\ b_{20},\ b_{11},\ b_{02}$

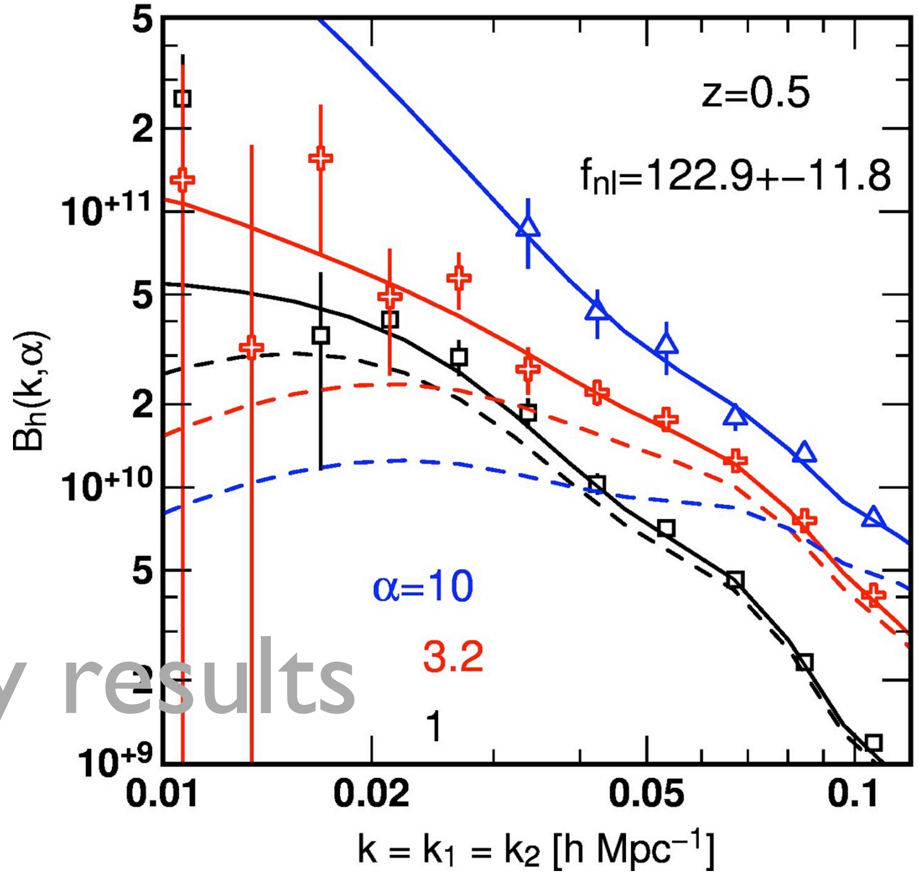
recovery of f_{nl} ? TN in prep.



power spectrum



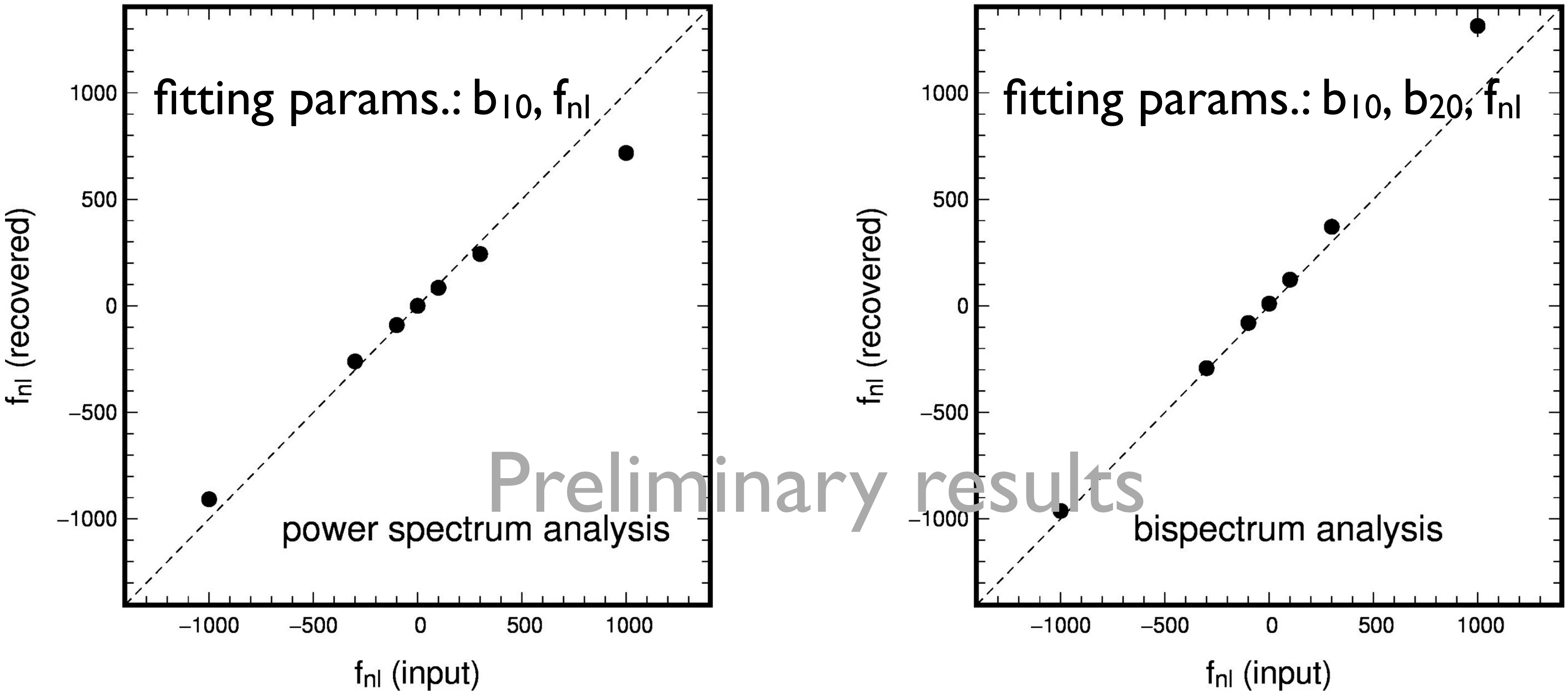
bispectrum



Preliminary results

recovery of f_{nl} ?

TN in prep.



multi-field nG?

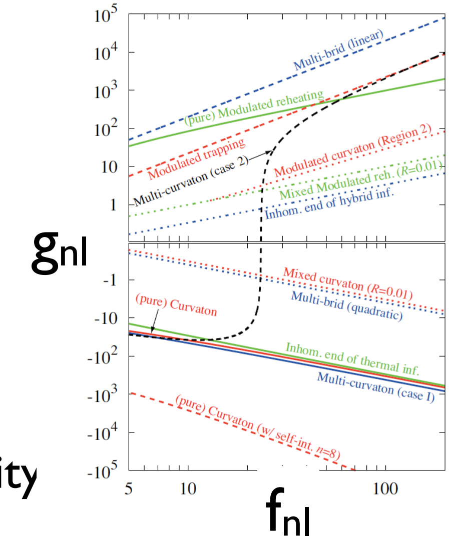
①local-type scale-independent nG TN in prep.

- What we observe in halo clustering when Bispectrum & Trispectrum exist at the beginning?
- We already have both B & T in $\Phi = \varphi + f_{nl}\,\varphi^2$ $\quad\tau_{nl} = (36/25)\, f_{nl}^2$
- (scale-independent) local models are parametrized by (f_{nl}, g_{nl}, τ_{nl}) in general

$$B_\zeta(k_1,k_2,k_3) = \frac{6}{5} f_{\rm nl} [P_\zeta(k_1)P_\zeta(k_2) + ({\rm perm.})]\,,$$

$$T_\zeta(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3,\mathbf{k}_4) = \tau_{\rm nl}[P_\zeta(k_{13})P_\zeta(k_3)P_\zeta(k_4) + ({\rm perm.})] + \frac{54}{25} g_{\rm nl} [P_\zeta(k_2)P_\zeta(k_3)P_\zeta(k_4) + ({\rm perm.})]\,.$$

$\tau_{nl} \geqq (36/25)\, f_{nl}^2$ Suyama-Yamaguchi inequality

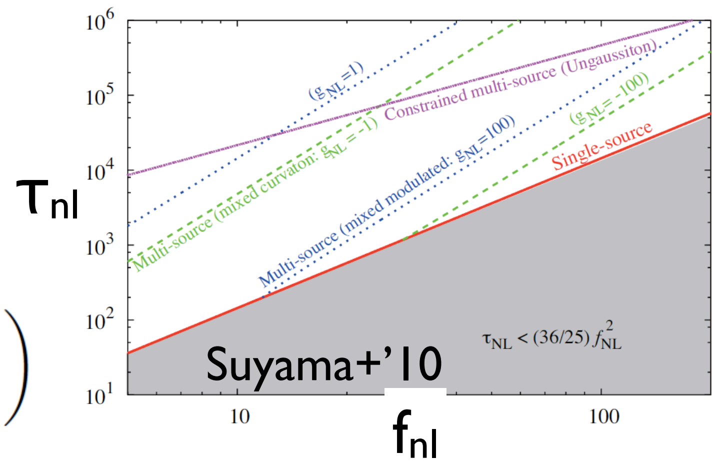


- This can be realized by employing 2 Gaussian fields:

$$\zeta(\mathbf{x}) = \chi_1(\mathbf{x}) + \chi_2(\mathbf{x}) + \widetilde{f_{\rm nl}}\left[{\chi_2}^2(\mathbf{x}) - \langle {\chi_2}^2\rangle\right] + \widetilde{g_{\rm nl}}\,{\chi_2}^3(\mathbf{x})$$

$$P_{\chi_1}(k) = (1-\alpha)P_\zeta(k) \qquad P_{\chi_2}(k) = \alpha\, P_\zeta(k)$$

$$\left(\widetilde{f_{\rm nl}}, \widetilde{g_{\rm nl}}, \alpha\right) = \left(\frac{125}{432}\frac{\tau_{\rm nl}^2}{f_{\rm nl}^3},\ \frac{625}{5184}\frac{\tau_{\rm nl}^3}{f_{\rm nl}^6} g_{\rm nl},\ \frac{36}{25}\frac{f_{\rm nl}^2}{\tau_{\rm nl}}\right)$$



PBS prediction

- "long mode", "short mode" decomposition for 2 Gaussian fields:

$$\chi_i = \chi_{i,\ell} + \chi_{i,s} \qquad \text{i = 1, 2}$$

$$\delta_h^{\mathrm{L}} = \frac{f(\mu_2, \mu_3, \cdots; \delta_{\mathrm{c}} - \delta_\ell)}{f(\bar{\mu}_2, \bar{\mu}_3, \cdots; \delta_{\mathrm{c}})} - 1$$

- "local" moments are modulated by long mode

$$\bar{\mu}_i(R) \equiv \langle \delta_s^i(R) \rangle_c \qquad \mu_i(\mathbf{x}; R) \equiv \langle \delta_s^i(\mathbf{x}; R) \rangle_{c|\chi_{i,\ell}(\mathbf{x})}$$

variance

$$\mu_2 \simeq \bar{\mu}_2 \left[1 + 4\,\widetilde{f_{\mathrm{nl}}}\,\alpha\,\chi_{2,\ell}\right] = \bar{\mu}_2 \left[1 + \frac{5}{3}\frac{\tau_{\mathrm{nl}}}{f_{\mathrm{nl}}}\,\underline{\chi_{2,\ell}}\right]$$

skewness

$$\mu_3 \simeq \bar{\mu}_3 + \Delta\mu_3,$$

$$\bar{\mu}_3 \equiv f_{\mathrm{nl}} \hat{\mu}_3,$$

See also Desjacques,Jeong,Schmidt'11

$$\Delta\mu_3 \equiv \frac{1}{60}\left(\frac{25\tau_{\mathrm{nl}}}{36 f_{\mathrm{nl}}^2}\right)(27 g_{\mathrm{nl}} + 25\tau_{\mathrm{nl}})\hat{\mu}_3 \underline{\chi_{2,\ell}}$$

$$b_\delta = 1 - \frac{\partial \ln f}{\partial \delta_{\mathrm{c}}}$$

$$\boxed{\delta_h = b_\delta\,\delta + b_{\chi_2}\,\chi_2}$$

$$b_{\chi_2} = \sum_{i=2}^{\infty} \frac{\partial \ln f}{\partial \mu_i}\frac{\partial \mu_i}{\partial \chi_{2,\ell}},$$

$$= \frac{5}{3}\frac{\tau_{\mathrm{nl}}}{f_{\mathrm{nl}}}\bar{\mu}_2 \frac{\partial \ln f}{\partial \mu_2} + \frac{1}{60}\left(\frac{25}{36}\frac{\tau_{\mathrm{nl}}}{f_{\mathrm{nl}}^2}\right)(27 g_{\mathrm{nl}} + 25\tau_{\mathrm{nl}})\hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3} + \cdots$$

final expression

$$P_h(k) = b_\delta^2 P_\delta(k) + \left[\frac{12}{5} f_{nl}\delta_c b_\delta (b_\delta - 1) + \frac{1}{30}(27 g_{nl} + 25\tau_{nl}) b_\delta \hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3}\right] P_{\delta\zeta}(k)$$

$$+ \left[\tau_{nl}\delta_c^2 (b_\delta - 1)^2 + \frac{\tau_{nl}}{f_{nl}}\left(\frac{27 g_{nl} + 25\tau_{nl}}{72}\hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3}\right)^2\right] P_\zeta(k)$$

N-body simulations and analysis

- $N=1024^3$ particles in a $L=4096$Mpc/h box
- 2LPT @ z=19 → output @ z=1
  - $f_{nl}=100$, $\tau_{nl}=(36/25)f_{nl}^2$
  - $f_{nl}=100$, $\tau_{nl}=2\mathrm{x}(36/25)f_{nl}^2$
  - $g_{nl}=1\mathrm{x}10^6$

$$\boxed{\delta_h = b_\delta\, \delta + b_{\chi_2}\, \chi_2}$$

$$\delta_h = b_\delta\, \mathcal{M}(k)\, \chi_1 + [b_\delta\, \mathcal{M}(k) + b_{\chi_2}]\chi_2$$

"propagator"

$$\langle \delta_h(\mathbf{k}) \chi_i(\mathbf{k}') \rangle = \mathcal{M}_{i\to\mathrm{h}}(k) \langle \chi_i(\mathbf{k}) \chi_i(\mathbf{k}') \rangle$$

at lowest order: $\mathcal{M}_{1\to\mathrm{h}}(k) = b_\delta \mathcal{M}(k),$

$$\mathcal{M}_{2\to\mathrm{h}}(k) = b_\delta \mathcal{M}(k) + b_{\chi_2}$$

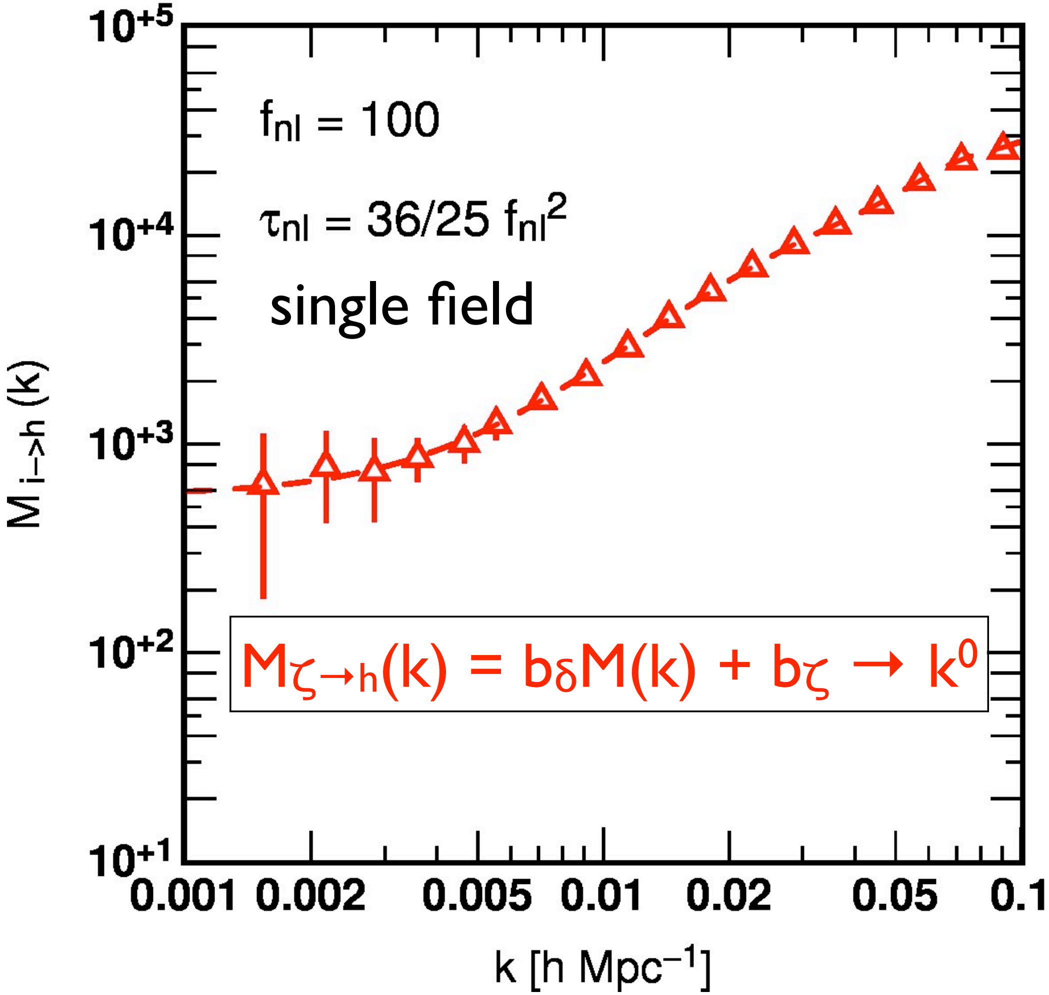
2 fitting params

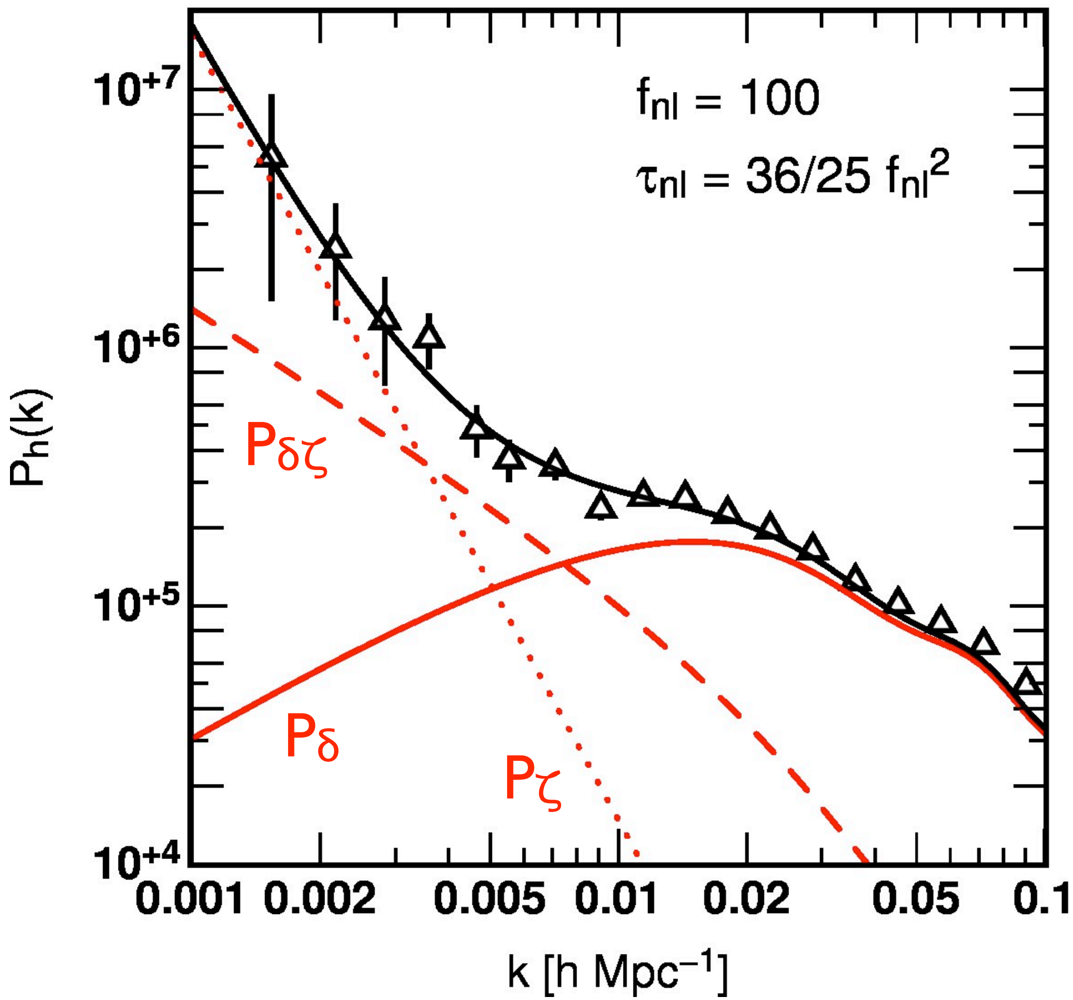
c.f., matter transfer function

$$\delta(\mathbf{k}) = \mathcal{M}(k)\zeta(\mathbf{k}) \propto k^2 T(k) \zeta(\mathbf{k})$$

f_{nl} + τ_{nl}

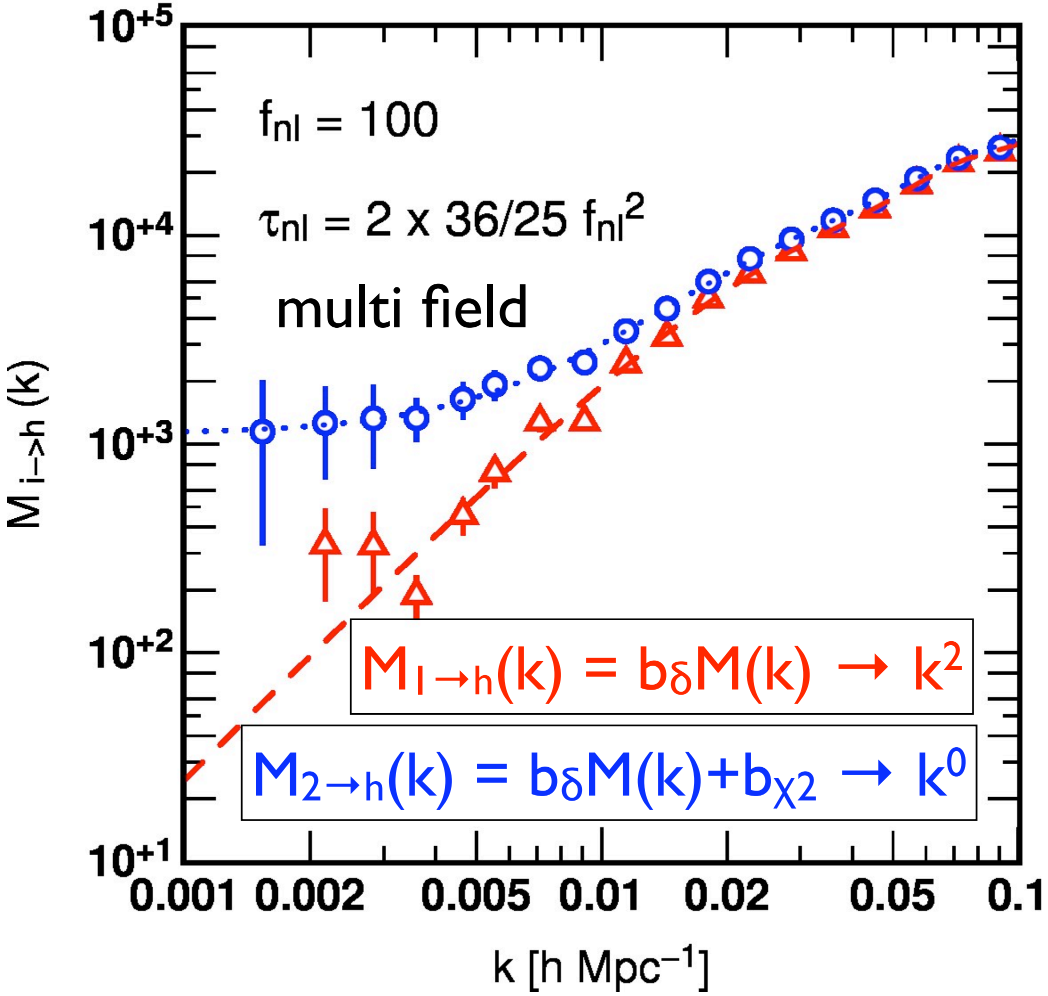
$$P_h(k) = b_\delta^2 P_\delta(k) + \frac{12}{5} f_{nl} \delta_c b_\delta (b_\delta - 1) P_{\delta\zeta}(k) + \tau_{nl} \delta_c^2 (b_\delta - 1)^2 P_\zeta(k)$$

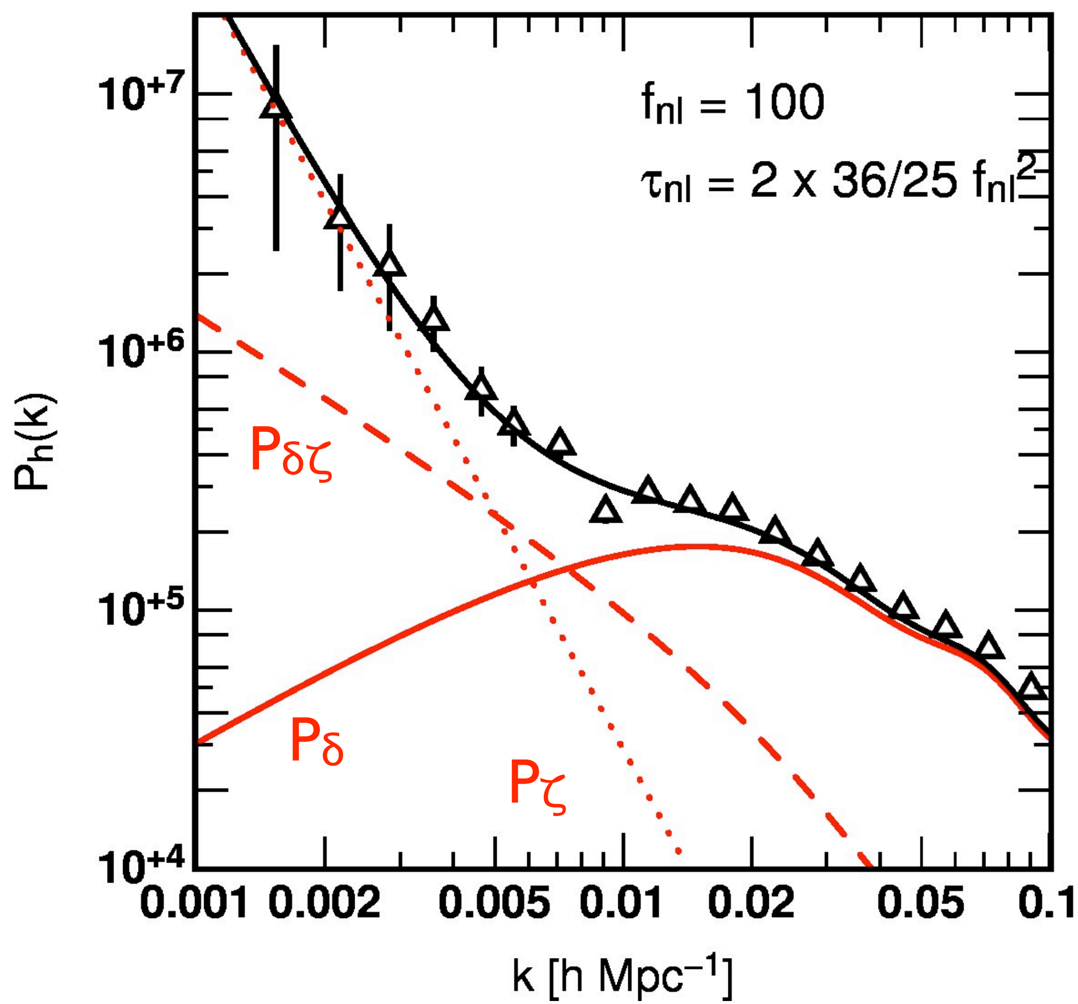




f_{nl} + τ_{nl}

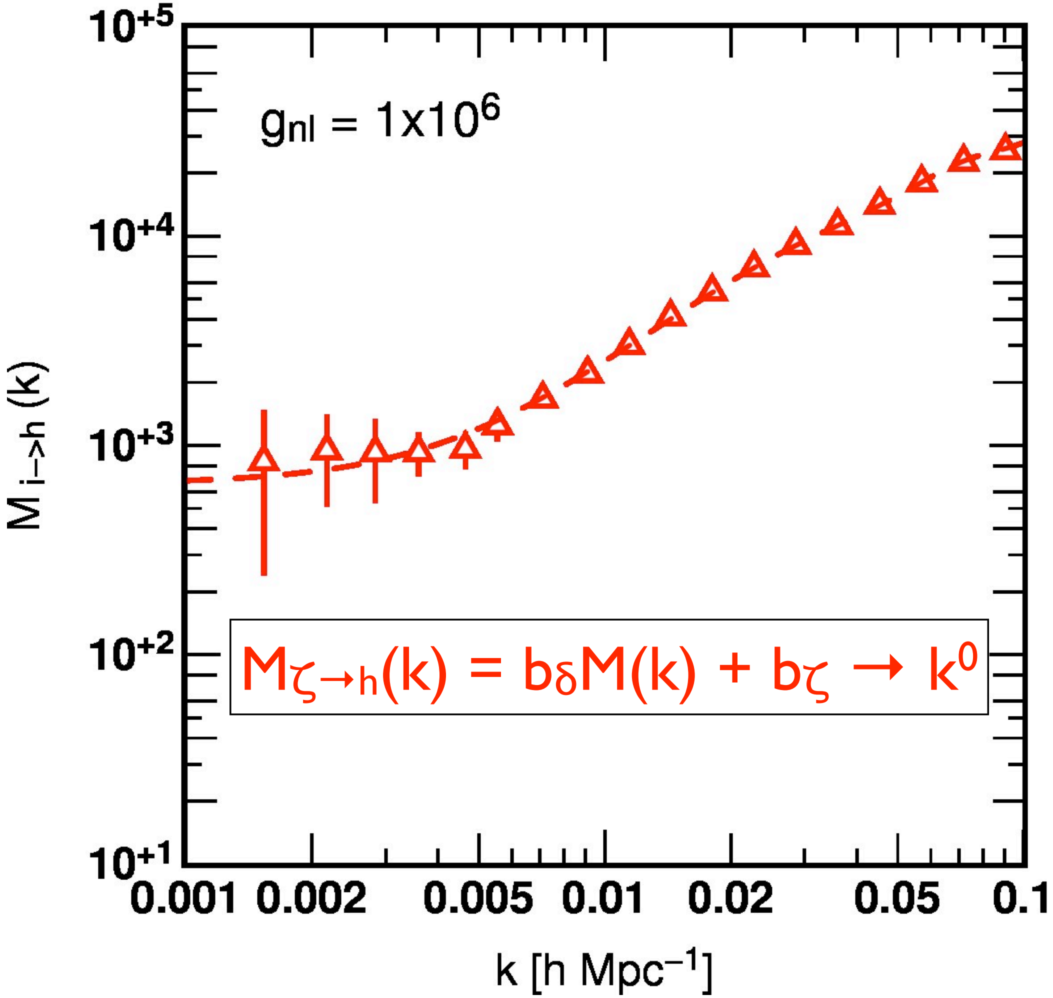
$$P_h(k) = b_\delta^2 P_\delta(k) + \frac{12}{5} f_{nl}\delta_c b_\delta(b_\delta - 1)P_{\delta\zeta}(k) + \tau_{nl}\delta_c^2(b_\delta - 1)^2 P_\zeta(k)$$

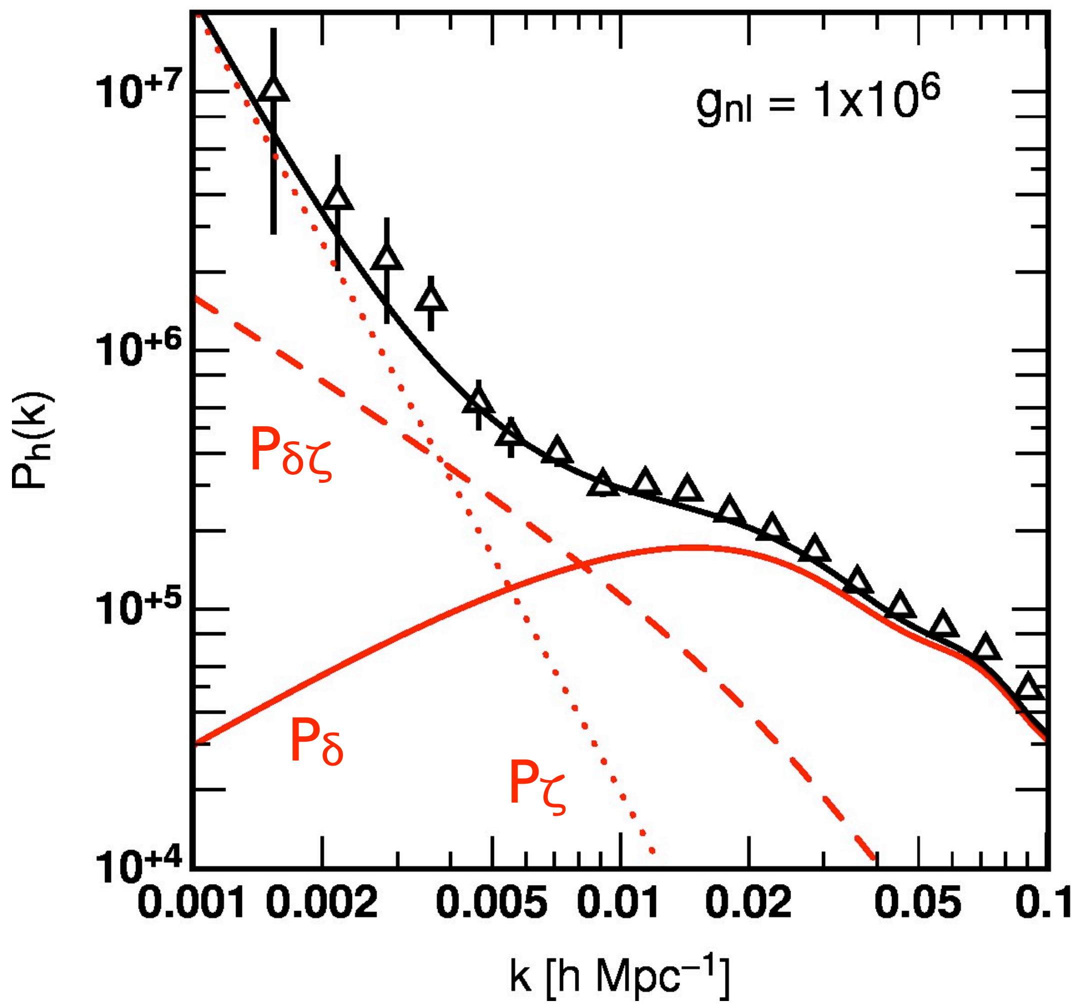




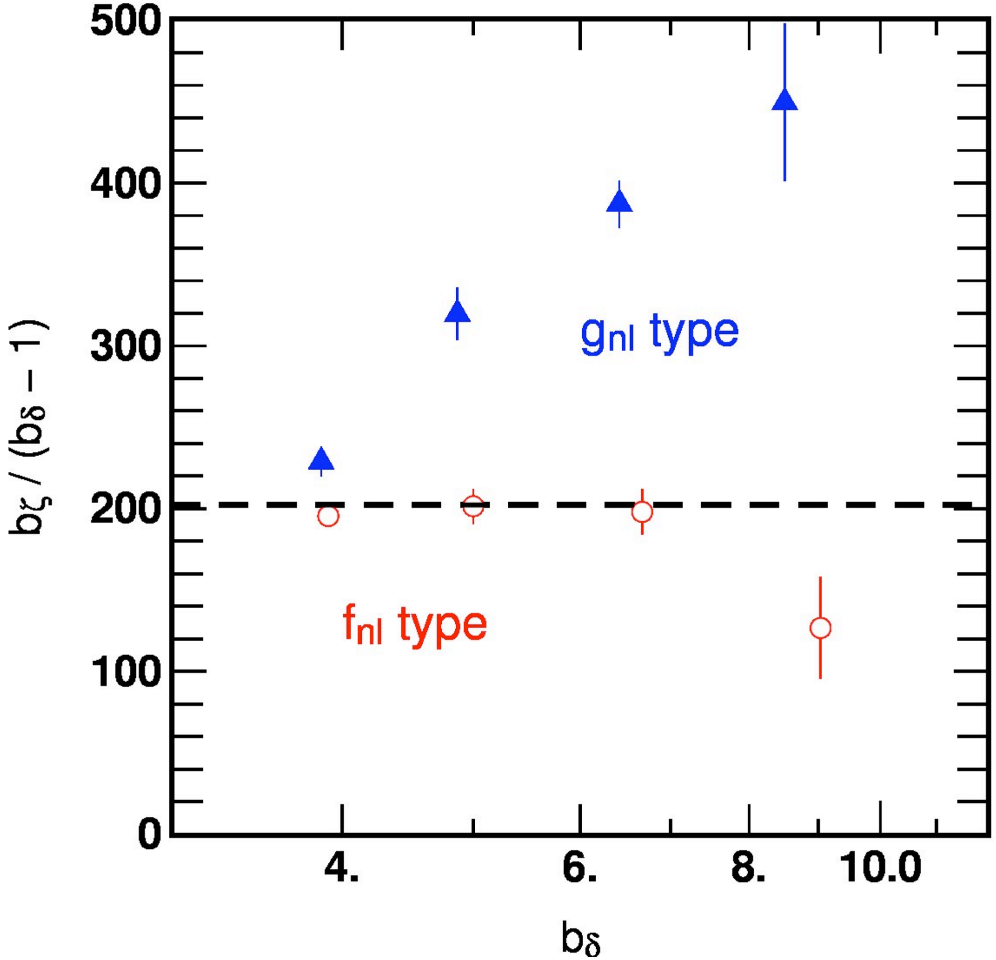
g_{nl}

$$P_h(k) = b_\delta^2 P_\delta(k) + \frac{9}{10} g_{nl} b_\delta \hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3} P_{\delta\zeta}(k) + \left[\frac{9}{20} g_{nl} \hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3}\right]^2 P_\zeta(k)$$





f_{nl}? g_{nl}? Mass dependence



- halo P(k) shows the same k-dependence in f_{nl} model and g_{nl} model.

- the nG correction comes from different origins
  - f_{nl}: modulation in the *local variance*

$$b_\zeta = \frac{12}{5} f_{nl} \bar{\mu}_2 \frac{\partial \ln f}{\partial \mu_2} = \frac{6}{5} f_{nl} \delta_c (b_\delta - 1)$$

assume universal mass function

  - g_{nl}: modulation in the *local skewness*

$$b_\zeta = \frac{9}{20} g_{nl} \hat{\mu}_3 \frac{\partial \ln f}{\partial \mu_3}$$

- Detection of nG signal from different tracers is a key to distinguish the 2 models

②local-type scale-dependent nG

TN Taruya Koyama in prep.

- Observation indicates an almost Gaussian almost adiabatic initial condition

→ (Perfectly) Gaussian adiabatic field + (strongly) non-Gaussian non-adiabatic field ?

- More general 2 field local-type nG: $\delta(\mathbf{k}) = \mathcal{M}_1(k)X_1(\mathbf{k}) + \mathcal{M}_2(k)X_2(\mathbf{k})$

field 1

$$X_1 = \chi_1$$
$$\mathcal{M}_1(k) = \mathcal{M}_{\rm adi}(k)$$
$$\frac{k^3}{2\pi^2}P_{\chi_1}(k) = A_{\chi_1}\left(\frac{k}{k_0}\right)^{n_{\chi_1}-1}$$

field 2

$$X_2(\mathbf{x}) = \chi_2(\mathbf{x}) + \widetilde{f_{\rm nl}}\left[\chi_2^2(\mathbf{x}) - \langle\chi_2^2\rangle\right]$$
$$\mathcal{M}_2 = \mathcal{M}_{\rm adi} \text{ or } \mathcal{M}_2 = \mathcal{M}_{\rm iso}$$
$$\frac{k^3}{2\pi^2}P_{\chi_2}(k) = A_{\chi_2}\left(\frac{k}{k_0}\right)^{n_{\chi_2}-1}$$

cross correlation

$$\beta \equiv -\frac{P_{\chi_1\chi_2}(k)}{P_{\chi_1}(k)P_{\chi_2}(k)}$$

- parameters: $A_{\chi 1}$, $n_{\chi 1}$, $A_{\chi 2}$, $n_{\chi 2}$, $\widetilde{f_{\rm nl}}$, β, transfer function of X_2

PBS prediction

- "long mode", "short mode" decomposition for 2 Gaussian fields:

$$\chi_i = \chi_{i,\ell} + \chi_{i,s} \qquad \text{i = 1, 2}$$

- "local" moments are modulated by long mode

$$\bar{\mu}_i \equiv \langle \delta^i(R) \rangle_c \qquad \mu_i(\mathbf{x}) \equiv \langle \delta^i(\mathbf{x}; R) \rangle_c$$

$\boxed{\text{variance}}$ $$\mu_2 \simeq \bar{\mu}_2 \left[1 + 4 \frac{\sigma_{12}^2 + \sigma_2^2}{\sigma^2} \underline{\chi_{2,\ell}} \right]$$

$$\sigma^2 \equiv \bar{\mu}_2 \equiv \sigma_1^2 + 2\sigma_{12}^2 + \sigma_2^2$$

$$\sigma_i^2 \equiv \langle (\mathcal{M}_i * \chi_{i,s})^2 \rangle,$$

$$\sigma_{12}^2 \equiv \langle (\mathcal{M}_1 * \chi_{1,s})(\mathcal{M}_2 * \chi_{2,s}) \rangle$$

$$\delta_h^{\mathrm{L}} = \frac{f(\mu_2, \cancel{\mu_3, \cdots}; \delta_c - \delta_\ell)}{f(\bar{\mu}_2, \cancel{\bar{\mu}_3, \cdots}; \delta_c)} - 1$$

$$\boxed{\delta_h = b_\delta\, \delta + b_{\chi_2}\, \chi_2}$$

$$b_\delta = 1 - \frac{\partial \ln f}{\partial \delta_c}$$

$$b_{\chi_2} = 2\, \tilde{f}_{nl}\, \frac{\sigma_{12}^2 + \sigma_2^2}{\sigma^2}\, \delta_c\, [b_\delta - 1]$$

final expression

$$P_h(k) = b_\delta^2\, M_1^2(k) P_{\chi_1}(k) + 2\, b_\delta\, M_1(k)\, [b_\delta\, M_2(k) + b_{\chi_2}]\, P_{\chi_1\chi_2}(k) + [b_\delta\, M_2(k) + b_{\chi_2}]^2\, P_{\chi_2}(k),$$

N-body simulations and analysis

- $N=1024^3$ particles in a L=4096Mpc/h box
- 2LPT @ z=19 → output @ z=1
  - $n_{\chi 2} = 1.5$
  - $M_2(k) = M_{iso}(k)$ (CDM isocurvature)
  - $\beta = -1$

$$\boxed{\delta_h = b_\delta\,\delta + b_{\chi_2}\,\chi_2}$$

$$\delta_h = b_\delta\,\mathcal{M}(k)\,\chi_1 + [b_\delta\,\mathcal{M}(k) + b_{\chi_2}]\chi_2$$

"propagator"

$$\langle \delta_h(\mathbf{k})\chi_i(\mathbf{k}')\rangle = \mathcal{M}_{i\to\mathrm{h}}(k)\langle\chi_i(\mathbf{k})\chi_i(\mathbf{k}')\rangle$$

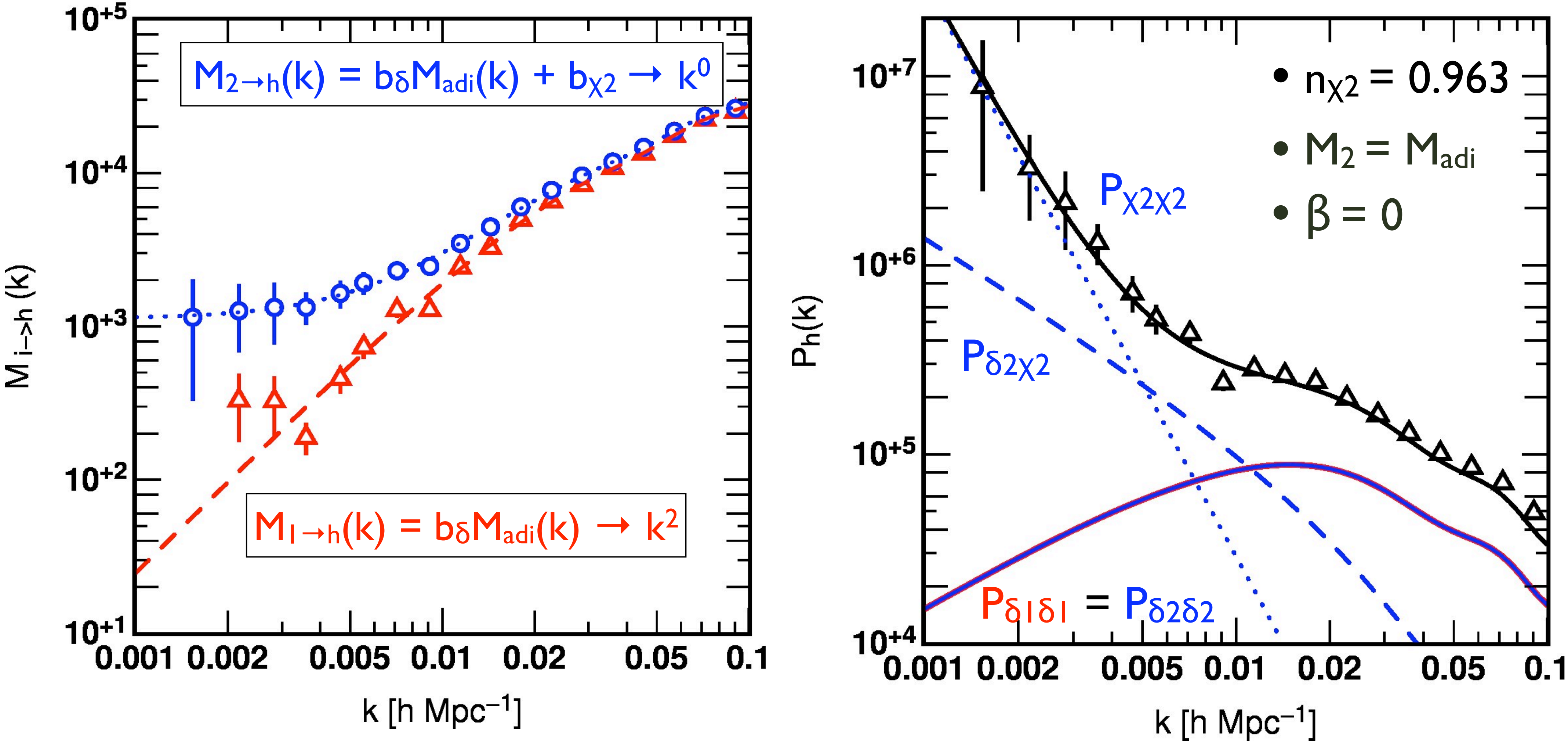
at lowest order: $\mathcal{M}_{1\to\mathrm{h}}(k) = b_\delta\mathcal{M}(k),$

$$\mathcal{M}_{2\to\mathrm{h}}(k) = b_\delta\mathcal{M}(k) + b_{\chi_2}$$

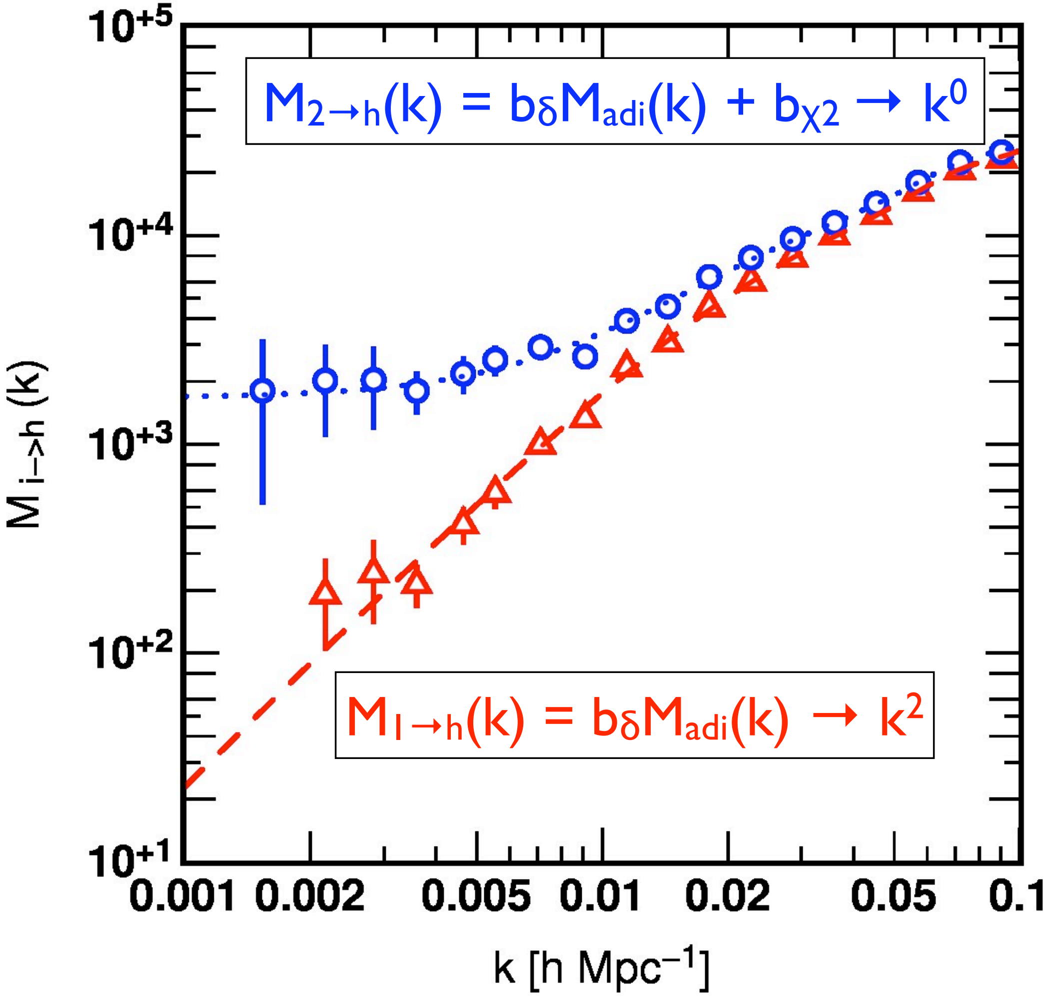
c.f., matter transfer function

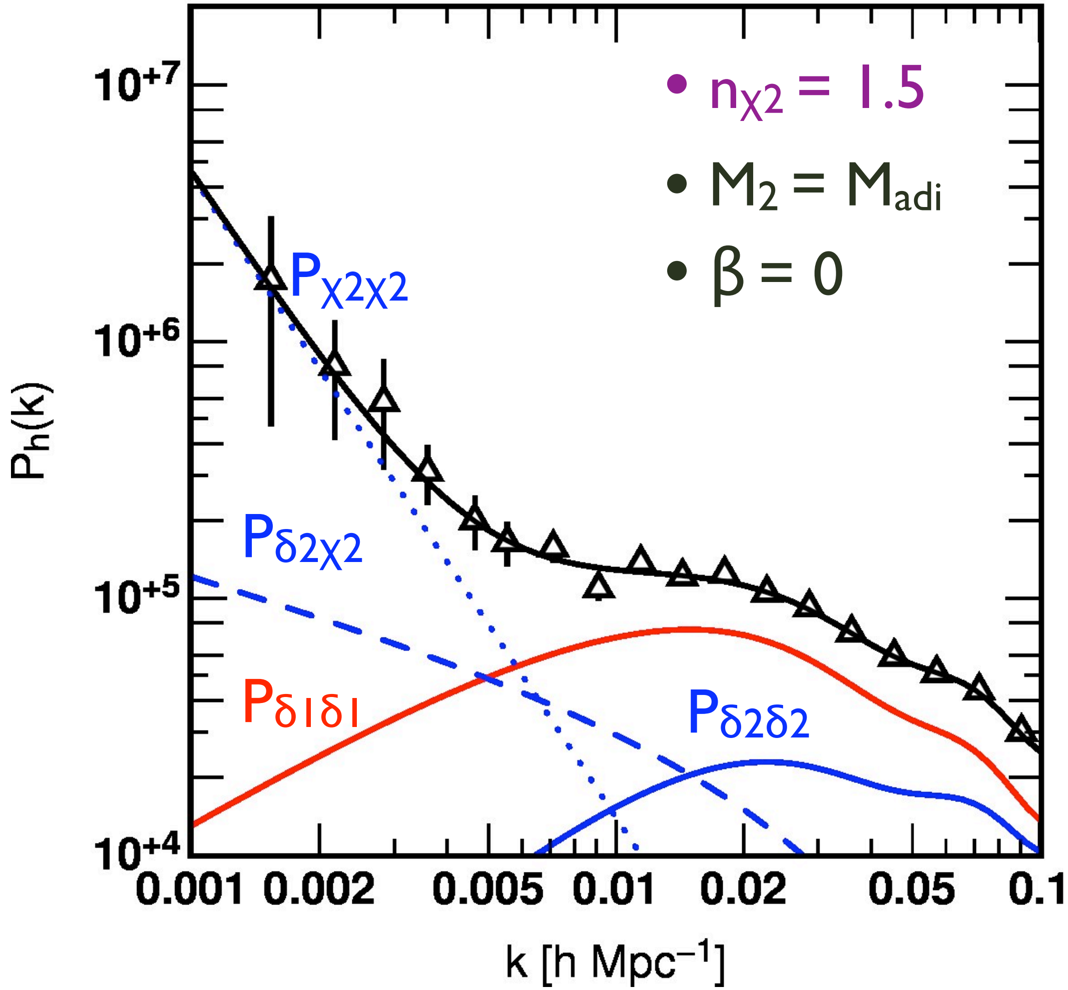
$$\delta(\mathbf{k}) = \mathcal{M}(k)\zeta(\mathbf{k}) \propto k^2 T(k)\zeta(\mathbf{k})$$

scale-independent nG

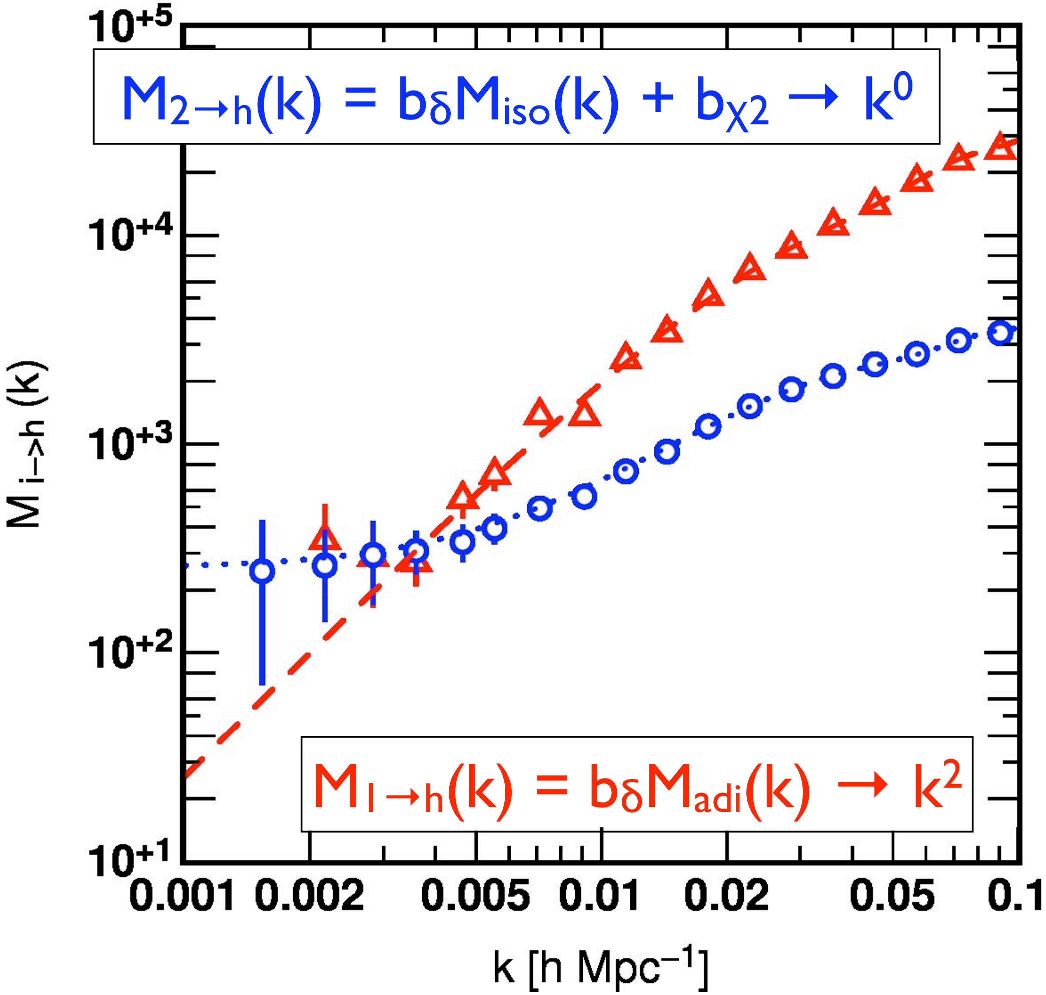


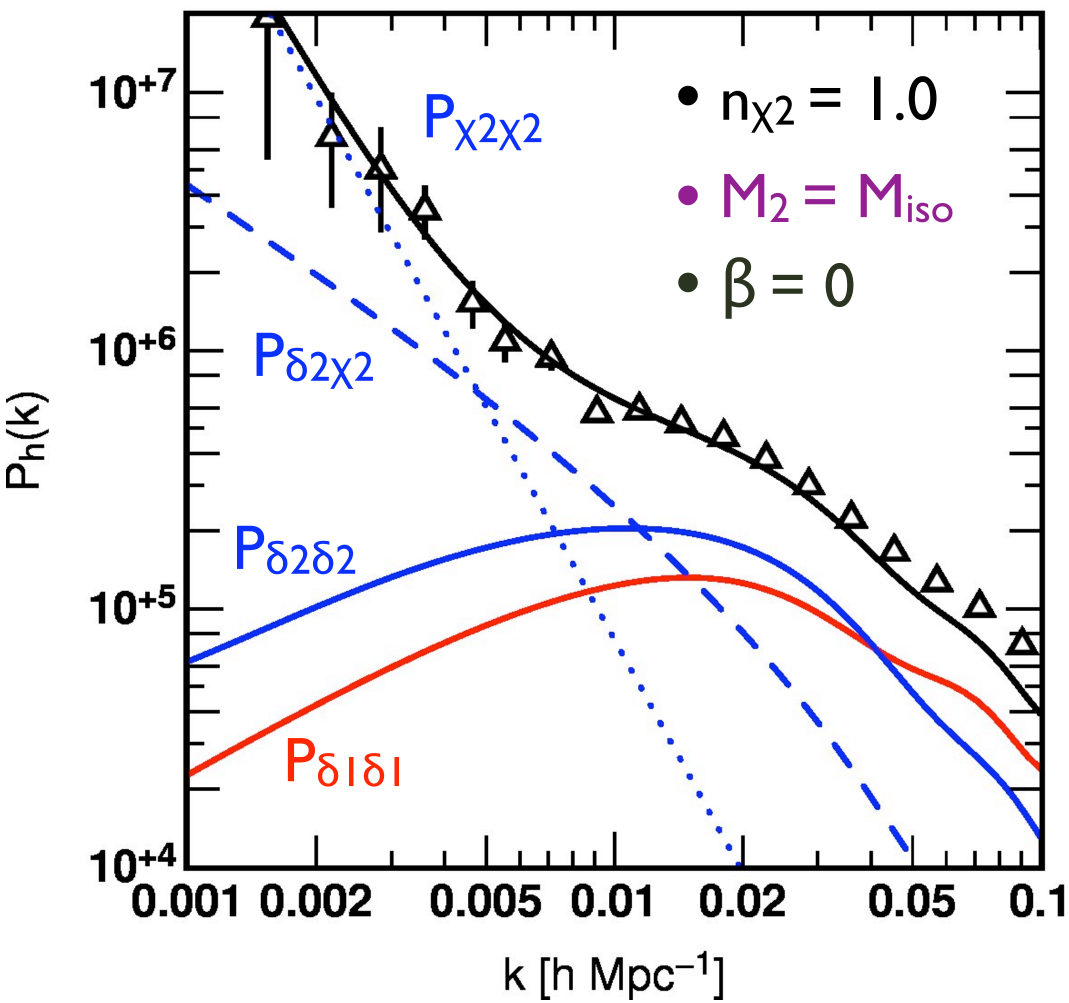
Effect of scalar spectral index



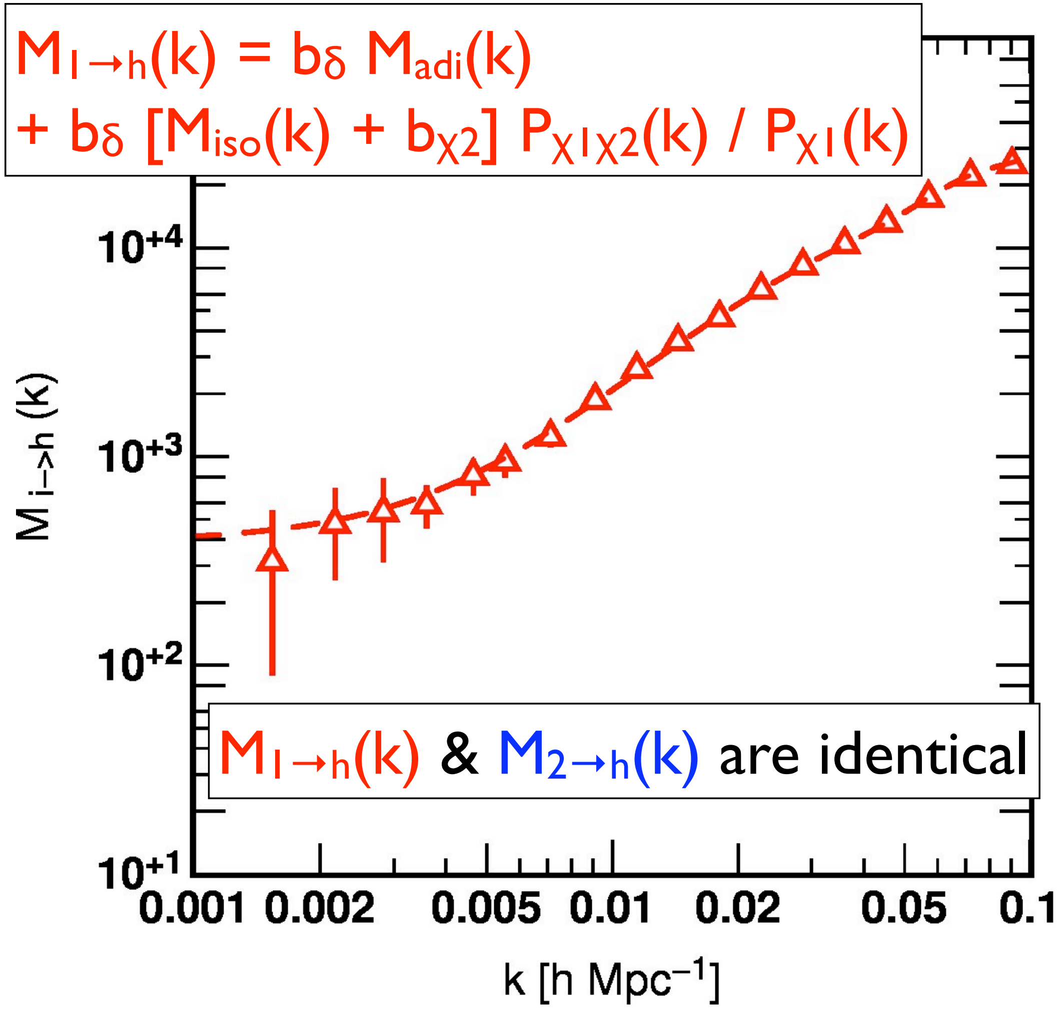


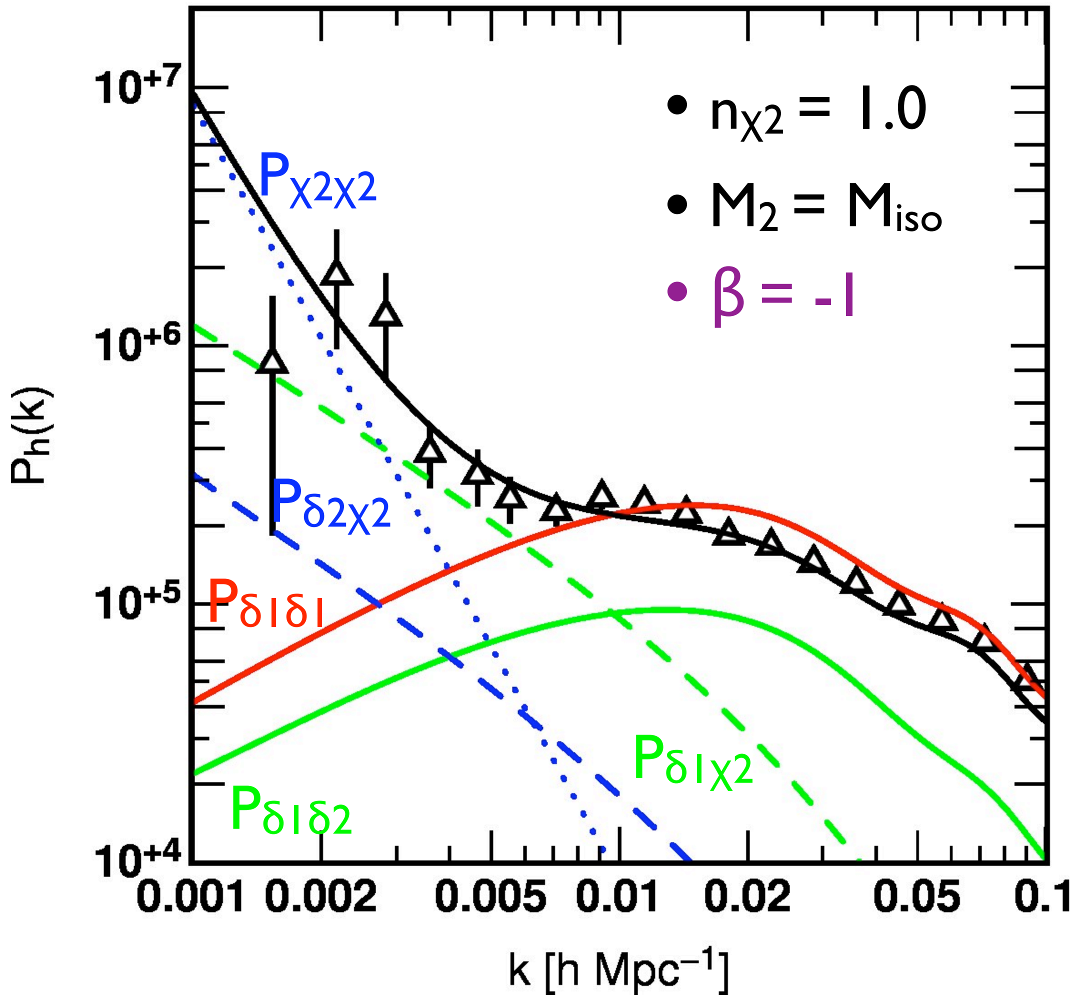
Effect of transfer function





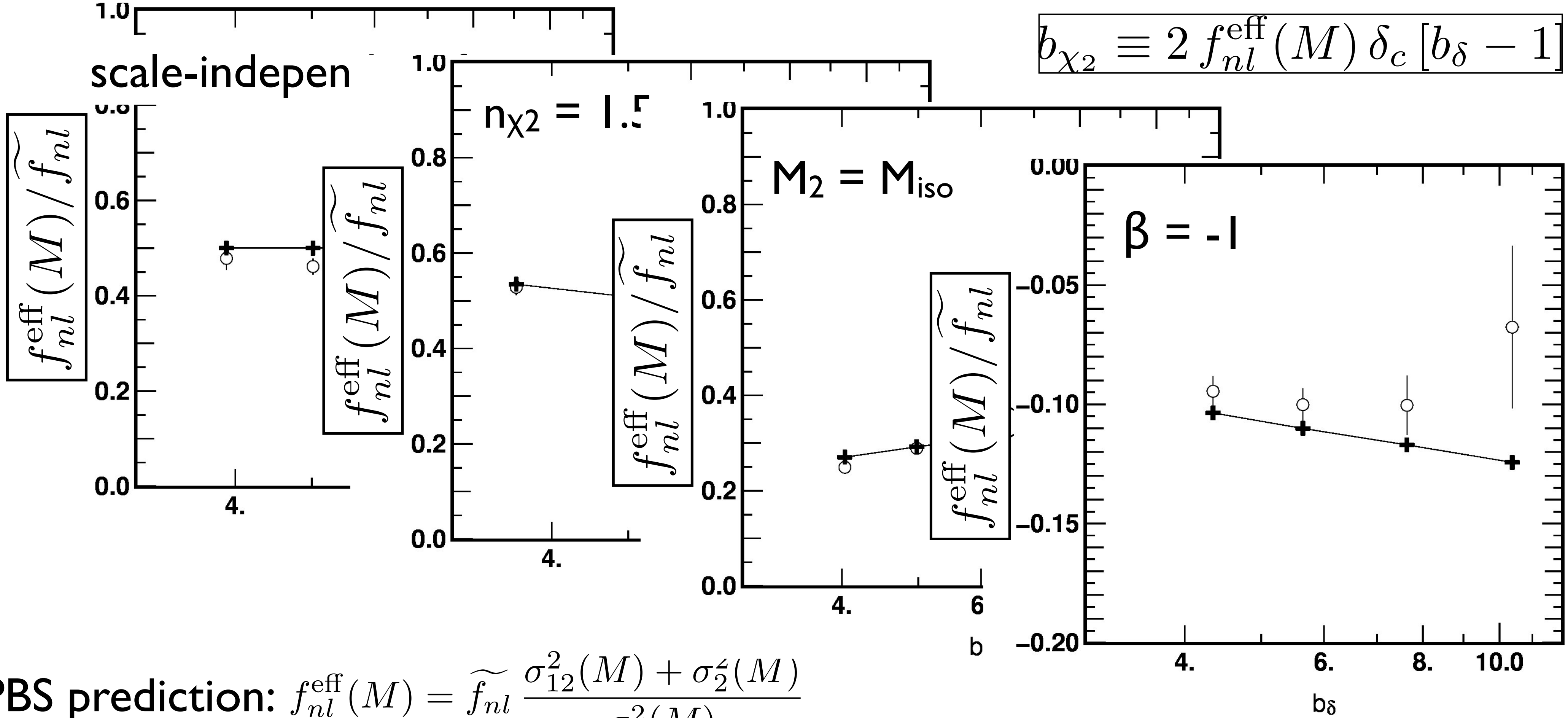
Effect of cross correlation





mass dependence of nG correction

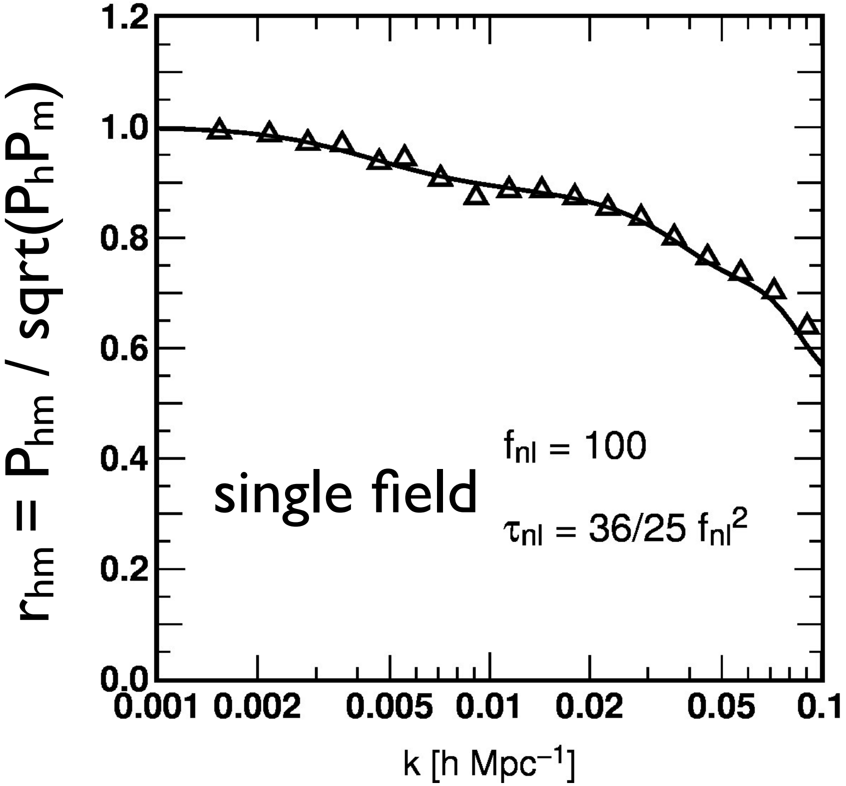
$\boxed{b_{\chi_2} \equiv 2\, f_{nl}^{\rm eff}(M)\, \delta_c\, [b_\delta - 1]}$

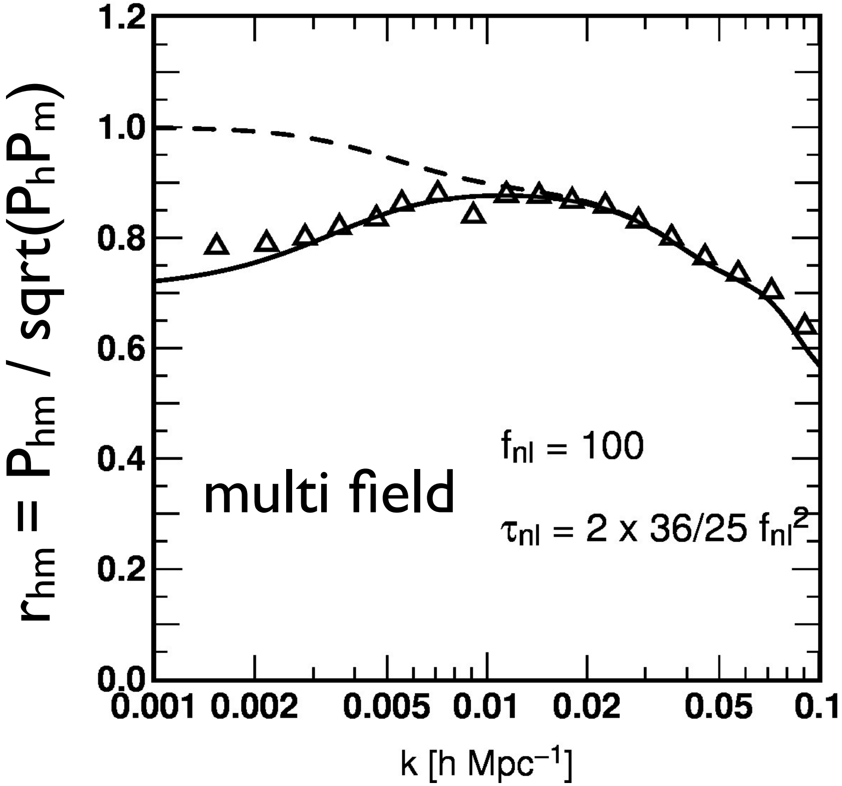


PBS prediction: $f_{nl}^{\rm eff}(M) = \widetilde{f_{nl}}\, \dfrac{\sigma_{12}^2(M) + \sigma_2^4(M)}{\sigma^2(M)}$

See also Shandera, Dalal & Huterer '11

discussion: stochasticity btwn halo/matter





- Can we get info from the cross-correlation of galaxies and cosmic shear?

See also Tseliakhovich, Hirata & Slosar'10, Smith & LoVerde'10

Summary and future directions

We have examined the effects of multi-field local-type primordial non-Gaussianities on the halo clustering:

- $\delta_h = b_\delta \, \delta + b_{\chi_2} \, \chi_2$ is a quite general consequence
- the 2nd term yields the scale dependence in bias
- f_{nl} controls the amplitude of $P_{\delta\zeta}(k)$
- τ_{nl} controls the amplitude of $P_\zeta(k)$
- g_{nl} gives a similar correction as f_{nl}, but it has a different mass dependence
- the nG correction becomes halo mass-dependent when 2 fields have different power spectra/transfer functions