Towards accurate modelling of LSS

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Overview:

Model building 1:

Nonlinear evolution of coupled CDM+Baryon fluid from z=100 to z=0 using RPT...

(Somogyi & Smith 2010, PRD. arXiv: 0910.5220)

Model building 2:

LSS as a test for Primordial Non-Gaussianities (PNG)

(Smith et al. 2010, in prep.)

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Motivation:

End of the first Golden Age of cosmology:

LSS: PSCz + 2dFGRS + SDSS +...

CMB: COBE + Boomerang + WMAP + ...

SN Ia: HST + SDSS-II + ...

Shear: CTIO + Combo-17 + COSMOS(1/2) + CFHTLens + ...

Where do we go next?

Plenty of ideas:

DE + MOG + INFLATION+...?

PLANCK+... | LOFAR+ ALMA+... | Wigglez+ BOSS+... | DES+ Panstarrs1+...

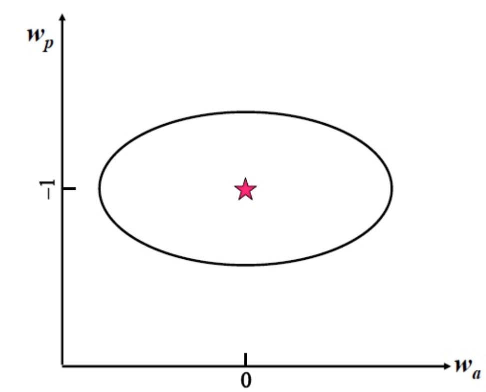
CMBPol+... | SKA+... | EUCLID+ JDEM+... | LSST+ Panstarrs4+...

Baryon P(k) accurate <1%

Matter P(k) accurate to <1%

Galaxy P(k) accurate to <1%

$$FoM = \frac{1}{\sigma_{w_0}\sigma_{w_a}} \rightarrow F^{-1}_{w_0 w_a}$$



The DETF figure of merit, which is defined to be the reciprocal of the area in the w_0–w_a plane that encloses the 95% C.L. region, is also proportional to $[\sigma(w_p)\times\sigma(w_a)]^{-1}$.

Simulating LSS with N-body method:

1: Pick cosmological model and generate the z=0 CDM/Matter transfer function

2: Generate the CDM/matter power spectrum:

$$P_{\bar{\delta}\bar{\delta}}(k, z=0) \approx [T^c(k, z=0)]^2 A k^n$$

$$P_{\bar{\delta}\bar{\delta}}(k, z=0) = \left[(1-f_b)T^c(k, z=0) + f_b T^b(k, z=0)\right]^2 A k^n$$

3: Scale back P(k) to z=z_start using linear growth factor for single fluid total matter

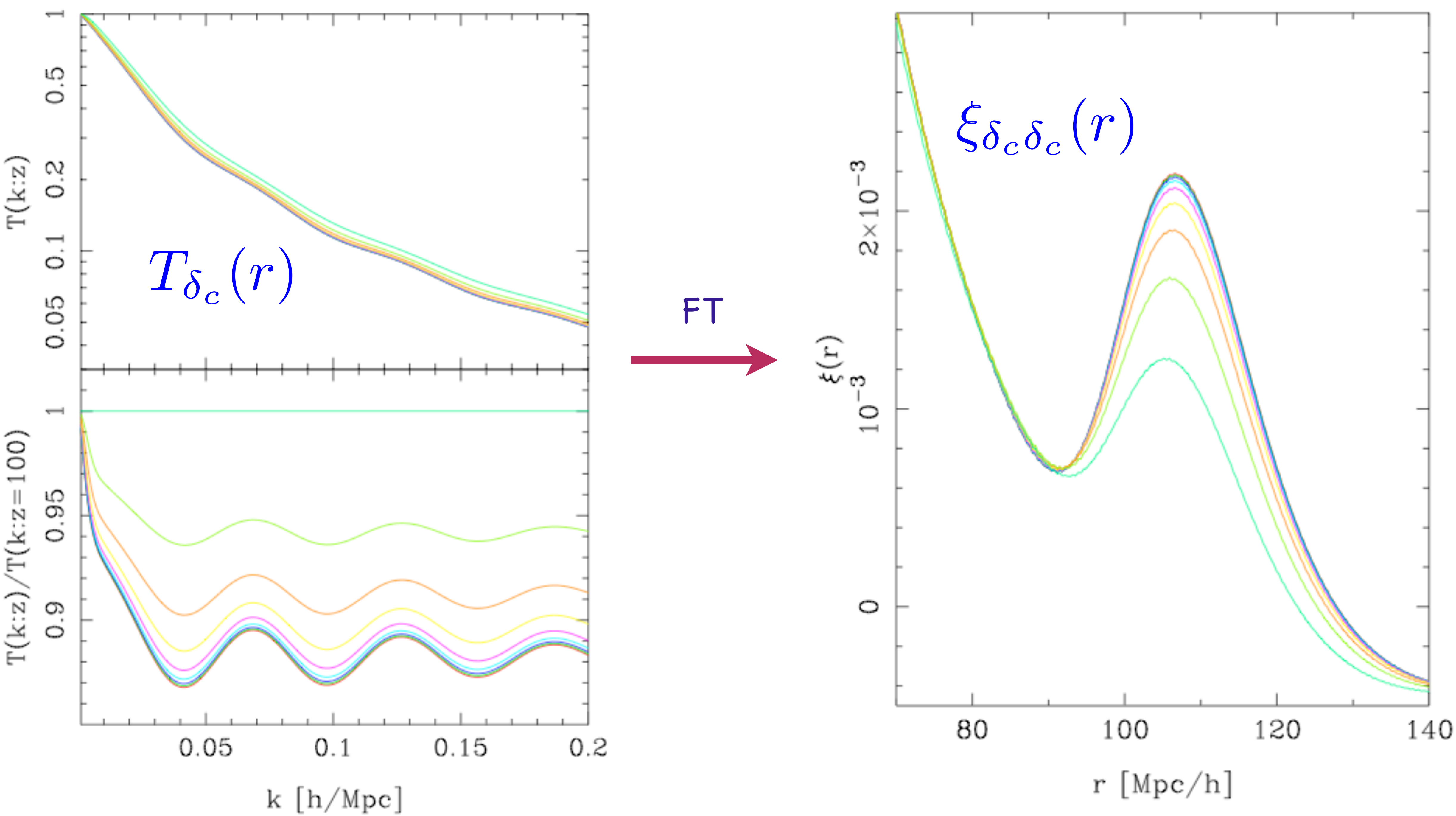
4: Generate the ICs assuming that baryons are perfect tracers of the CDM

5: Evolve effective CDM+baryon distribution using the nonlinear EOM

Why worry about baryons?

Consider evolution of CDM Transfer function in WMAP like cosmology

z = {100, 49, 25, 12.5, 6.0, 3.0, 1.5, 0.75, 0.0}



What are differences between P(k) for coupled baryon+CDM 2-Fluid and effective baryon+CDM 1-Fluid?

Evolution of coupled baryon+CDM fluid:

Extend standard PT approach:

Effective 1-Fluid of baryons+CDM => 2-Fluids interacting under gravity

$$\frac{\partial \delta_i(\mathbf{x},\tau)}{\partial \tau} + \nabla \cdot [(1+\delta_i(\mathbf{x},\tau))\mathbf{v}_i(\mathbf{x},\tau)] = 0\,,$$

Continuity

$$\frac{\partial \mathbf{v}_i(\mathbf{x},\tau)}{\partial \tau} + \mathcal{H}(\tau)\mathbf{v}_i(\mathbf{x},\tau) + (\mathbf{v}_i(\mathbf{x},\tau)\cdot\nabla)\mathbf{v}_i(\mathbf{x},\tau) = -\nabla\Phi(\mathbf{x},\tau)\,;$$

Euler

$$\nabla^2\Phi(\mathbf{x},\tau) = 4\pi G a^2 \sum_{i=1}^{N} \bar{\rho}_i(\tau)\delta_i(\mathbf{x},\tau) = \frac{3}{2}\Omega_{\rm m}(\tau)\mathcal{H}^2(\tau)\sum_{i=1}^{N} w_i\delta_i(\mathbf{x},\tau)\,.$$

Poisson

I. Deal with 4-perturbation variables $\{\delta_c, \mathbf{v}_c, \delta_b, \mathbf{v}_b\}$

II. Assume baryons are cold, i.e. no significant thermal pressure after z=100

III. Switch to new time variables and consider divergence of velocities

$$\frac{\partial \tilde{\delta}_i(\mathbf{k},\eta)}{\partial \eta} - \tilde{\theta}_i(\mathbf{k},\eta) = \int {\rm d}^3\mathbf{k}_1\,{\rm d}^3\mathbf{k}_2\,\delta^D(\mathbf{k}-\mathbf{k}_1-\mathbf{k}_2)\alpha(\mathbf{k}_2,\mathbf{k}_1)\tilde{\delta}_i(\mathbf{k}_1,\eta)\tilde{\theta}_i(\mathbf{k}_2,\eta)\,;$$

$$\frac{\partial \tilde{\theta}_i(\mathbf{k},\eta)}{\partial \eta} + \tilde{\theta}_i(\mathbf{k},\eta)\left[1-\frac{\Omega_{\rm m}(\eta)}{2}+\Omega_\Lambda(\eta)\right] - \frac{3}{2}\Omega_{\rm m}(\eta)\sum_{j=1}^{N} w_j\tilde{\delta}_j(\mathbf{k},\eta) = \int {\rm d}^3\mathbf{k}_1\,{\rm d}^3\mathbf{k}_2\,\delta^D(\mathbf{k}-\mathbf{k}_1-\mathbf{k}_2)\beta(\mathbf{k}_1,\mathbf{k}_2)\tilde{\theta}_i(\mathbf{k}_1,\eta)\tilde{\theta}_i(\mathbf{k}_2,\eta)\,,$$

$$\nabla\cdot\mathbf{v}\equiv\theta$$

$$\eta\equiv\log a(t)$$

$$\alpha(\mathbf{k}_1,\mathbf{k}_2) = 1 + \frac{\mathbf{k}_1\cdot\mathbf{k}_2}{\mathbf{k}_1^2}$$

$$\beta(\mathbf{k}_1,\mathbf{k}_2) = \frac{(\mathbf{k}_1+\mathbf{k}_2)^2\mathbf{k}_1\cdot\mathbf{k}_2}{2\mathbf{k}_1^2\mathbf{k}_2^2}$$

Matrix form of EOM:

Introduce a 4-vector of fields:

$$\Psi_a^T(\mathbf{k},\eta) = \left[\tilde{\delta}_\mathbf{1}(\mathbf{k},\eta),\ \tilde{\theta}_\mathbf{1}(\mathbf{k},\eta),\ \tilde{\delta}_\mathbf{2}(\mathbf{k},\eta),\ \tilde{\theta}_\mathbf{2}(\mathbf{k},\eta)\right]$$

As in 1-Fluid case (c.f. Scoccimarro talk), the 2-Fluid EOM can be recast as

$$\partial_\eta \Psi_a(\mathbf{k},\eta) + \Omega_{ab}\Psi_b(\mathbf{k},\eta) = \int \mathrm{d}^3\mathbf{k}_1\, \mathrm{d}^3\mathbf{k}_2\, \gamma^{(\mathrm{s})}_{abc}(\mathbf{k},\mathbf{k}_1,\mathbf{k}_2)\Psi_b(\mathbf{k}_1,\eta)\Psi_c(\mathbf{k}_2,\eta)$$

Where the gravitational interaction matrices are:

$$\bar{\gamma}^{(\mathrm{s})}_{1bc}(\mathbf{k}_1,\mathbf{k}_2) = \begin{bmatrix} 0 & \alpha(\mathbf{k}_2,\mathbf{k}_1)/2 & 0 & 0 \\ \alpha(\mathbf{k}_1,\mathbf{k}_2)/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \qquad \bar{\gamma}^{(\mathrm{s})}_{2bc}(\mathbf{k}_1,\mathbf{k}_2) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \beta(\mathbf{k}_1,\mathbf{k}_2) & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\bar{\gamma}^{(\mathrm{s})}_{3bc}(\mathbf{k}_1,\mathbf{k}_2) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \alpha(\mathbf{k}_2,\mathbf{k}_1)/2 \\ 0 & 0 & \alpha(\mathbf{k}_1,\mathbf{k}_2)/2 & 0 \end{bmatrix}, \qquad \bar{\gamma}^{(\mathrm{s})}_{4bc}(\mathbf{k}_1,\mathbf{k}_2) = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta(\mathbf{k}_1,\mathbf{k}_2) \end{bmatrix}$$

and the time dependent auxiliary matrix is:

$$\Omega_{ab} = \begin{matrix} 0 & -1 & 0 & 0 \\ -\frac{3}{2}\Omega_{\mathrm{m}} w_1 & \left[1 - \frac{\Omega_m}{2} + \Omega_\Lambda\right] & -\frac{3}{2}\Omega_{\mathrm{m}} w_2 & 0 \\ 0 & 0 & 0 & -1 \\ -\frac{3}{2}\Omega_{\mathrm{m}} w_1 & 0 & -\frac{3}{2}\Omega_{\mathrm{m}} w_2 & \left[1 - \frac{\Omega_m}{2} + \Omega_\Lambda\right] \end{matrix}$$

Solution of EOM:

Assuming EdS universe EOM can be solved through Laplace Transforms

$$\Psi_a(\mathbf{k},a) = g_{ab}(\eta)\phi_b^{(0)}(\mathbf{k}) + \int_0^{\eta} \mathrm{d}\eta' g_{ab}(\eta-\eta')\gamma_{bcd}^{(s)}(\mathbf{k},\mathbf{k}_1\mathbf{k}_2)\Psi_c(\mathbf{k}_1,\eta')\Psi_d(\mathbf{k}_1,\eta')$$

For 1-Fluids the linear propagator takes the form (Scoccimarro 1998, Crocce & Scoccimarro 2006)

$$g_{ab}(\eta) = \frac{1}{5}\begin{bmatrix} 3\mathrm{e}^{\eta}+2\mathrm{e}^{-3\eta/2} & 2\mathrm{e}^{\eta}-2\mathrm{e}^{-3\eta/2} \\ 3\mathrm{e}^{\eta}-3\mathrm{e}^{-3\eta/2} & 2\mathrm{e}^{\eta}+3\mathrm{e}^{-3\eta/2} \end{bmatrix} = \frac{\mathrm{e}^{\eta}}{5}\begin{bmatrix} 3 & 2 \\ 3 & 2 \end{bmatrix} - \frac{\mathrm{e}^{-3\eta/2}}{5}\begin{bmatrix} -2 & 2 \\ 3 & -3 \end{bmatrix}$$

Growing mode   Decaying mode I

For 2-Fluids the linear propagator takes the form (Somogyi & Smith 2010)

$$g_{ab}(\eta) = \sum_l \mathrm{e}^{l\eta} g_{ab,l}\,; \quad l=\{1, 0, -0.5, -1.5\}$$

Growing mode

$$g_{ab,1} = \frac{1}{5}\begin{bmatrix} 3w_1 & 2w_1 & 3w_2 & 2w_2 \\ 3w_1 & 2w_1 & 3w_2 & 2w_2 \\ 3w_1 & 2w_1 & 3w_2 & 2w_2 \\ 3w_1 & 2w_1 & 3w_2 & 2w_2 \end{bmatrix},$$

Static mode

$$g_{ab,0} = \begin{bmatrix} 1-w_1 & 2(1-w_1) & -w_2 & -2w_2 \\ 0 & 0 & 0 & 0 \\ -w_1 & -2w_1 & 1-w_2 & 2(1-w_2) \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

$$g_{ab,-1/2} = \begin{bmatrix} 0 & -2(1-w_1) & 0 & 2w_2 \\ 0 & 1-w_1 & 0 & -w_2 \\ 0 & 2w_1 & 0 & -2(1-w_2) \\ 0 & -w_1 & 0 & 1-w_2 \end{bmatrix},$$

Decaying mode II

$$g_{ab,-3/2} = \frac{1}{5}\begin{bmatrix} 2w_1 & -2w_1 & 2w_2 & -2w_2 \\ -3w_1 & 3w_1 & -3w_2 & 3w_2 \\ 2w_1 & -2w_1 & 2w_2 & -2w_2 \\ -3w_1 & 3w_1 & -3w_2 & 3w_2 \end{bmatrix}.$$

Decaying mode I

Linear Solution:

Initial conditions can in general be represented

$$\left[\phi_a^{(0)}(\mathbf{k})\right]^T = \left[u_1\delta_1^{(0)}(\mathbf{k}),\, u_2\theta_1^{(0)}(\mathbf{k}),\, u_3\delta_2^{(0)}(\mathbf{k}),\, u_4\theta_2^{(0)}(\mathbf{k}),\,\right]$$

We make the simplifying approximation that: $\delta_i^{(0)}(\mathbf{k}) = \theta_i^{(0)}(\mathbf{k})$. Thus we may write

=> $$\left[\phi_a^{(0)}(\mathbf{k})\right]^T = \left[u_1T_1(k),\, u_2T_1(k),\, u_3T_2(k),\, u_4T_2(k),\,\right]\delta^{(0)}(\mathbf{k})$$

Eigenvector decomposition of linear propagator gives us the choices

$$u_a^{(1)} = \begin{pmatrix}1\\1\\1\\1\end{pmatrix} \; ; \; u_a^{(2)} = \begin{pmatrix}2/3\\-1\\2/3\\-1\end{pmatrix} \; ; \; u_a^{(3,1)} = \begin{pmatrix}w_2\\0\\-w_1\\0\end{pmatrix} \; ; \; u_a^{(4,1)} = \begin{pmatrix}2w_2\\-w_2\\-2w_1\\w_1\end{pmatrix}$$

Choosing U(1) gives large-scale growing mode solutions -- but not pure on small scales!

$$\begin{aligned}
\delta_{\rm lin}^{\rm c}(\mathbf{k},\eta)/\delta_0(k) = \Psi_1^{(0)}(\mathbf{k},\eta)/\delta_0(k) &= [g_{11}(\eta)+g_{12}(\eta)]\,T^{\rm c}(k) + [g_{13}(\eta)+g_{14}(\eta)]\,T^{\rm b}(k)\;;\\
&= \left[(1-f^{\rm b}){\rm e}^{\eta} + 3f^{\rm b}(1-2{\rm e}^{-\eta/2})\right]T^{\rm c}(k) + f^{\rm b}\left[{\rm e}^{\eta}-3+2{\rm e}^{-\eta/2}\right]T^{\rm b}(k)\;;\\
\delta_{\rm lin}^{\rm b}(\mathbf{k},\eta)/\delta_0(k) = \Psi_3^{(0)}(\mathbf{k},\eta)/\delta_0(k) &= [g_{31}(\eta)+g_{32}(\eta)]\,T^{\rm c}(k) + [g_{33}(\eta)+g_{34}(\eta)]\,T^{\rm b}(k)\;;\\
&= (1-f^{\rm b})\left[{\rm e}^{\eta}-3+2{\rm e}^{-\eta/2}\right]T^{\rm c}(k) + \left[f^{\rm b}{\rm e}^{\eta} + (1-f^{\rm b})(3-2{\rm e}^{-\eta/2})\right]T^{\rm b}(k)
\end{aligned}$$

$$\delta_{\rm lin}^{\rm c}(\mathbf{k},\eta)/\delta_0(k) \approx \begin{cases} T^{\rm c}(k) & (\eta \ll 1)\\ {\rm e}^{\eta}\left[(1-f^{\rm b})T^{\rm c}(k) + f^{\rm b}T^{\rm b}(k)\right] & (\eta \gg 1)\end{cases}$$

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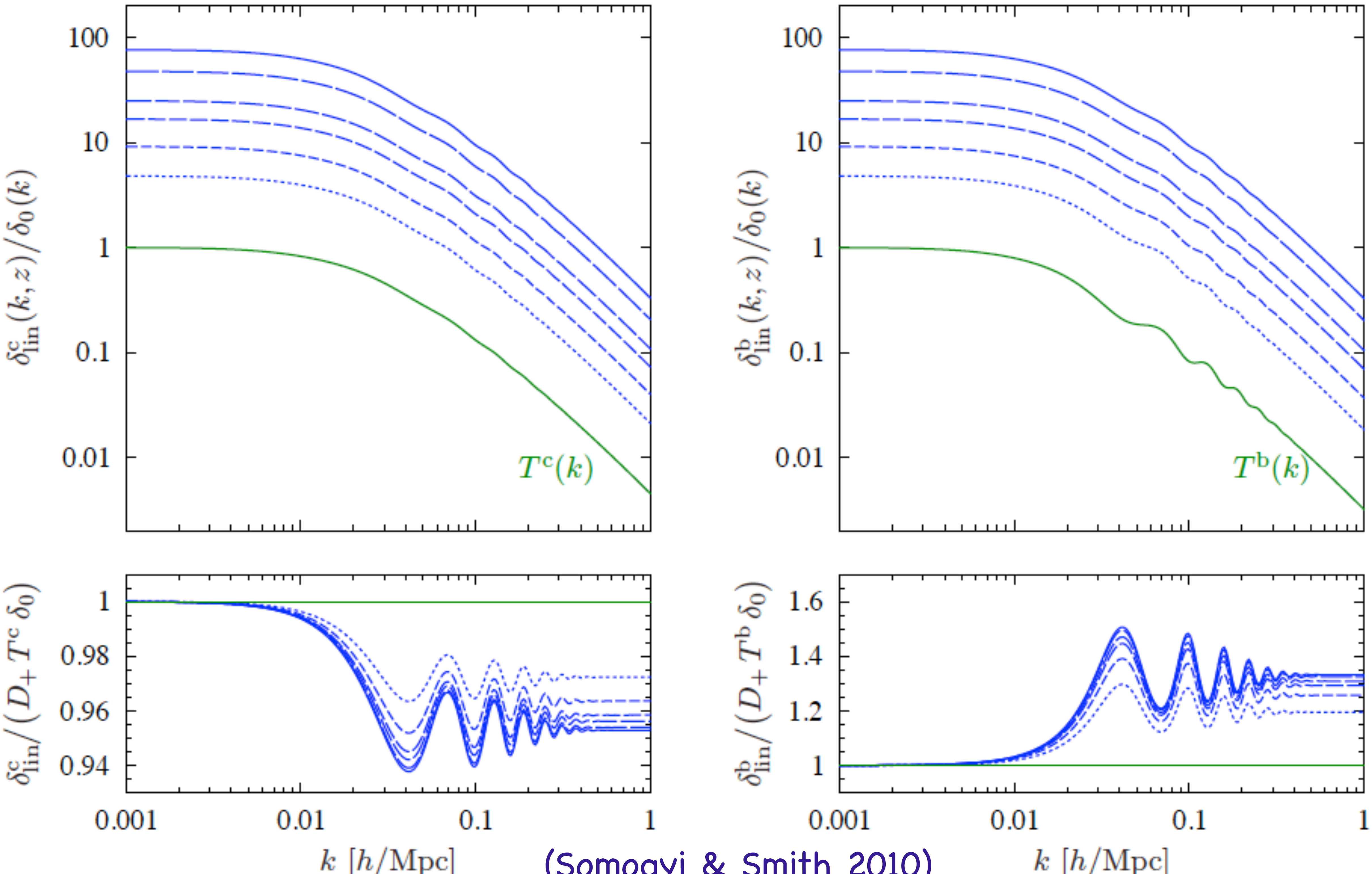
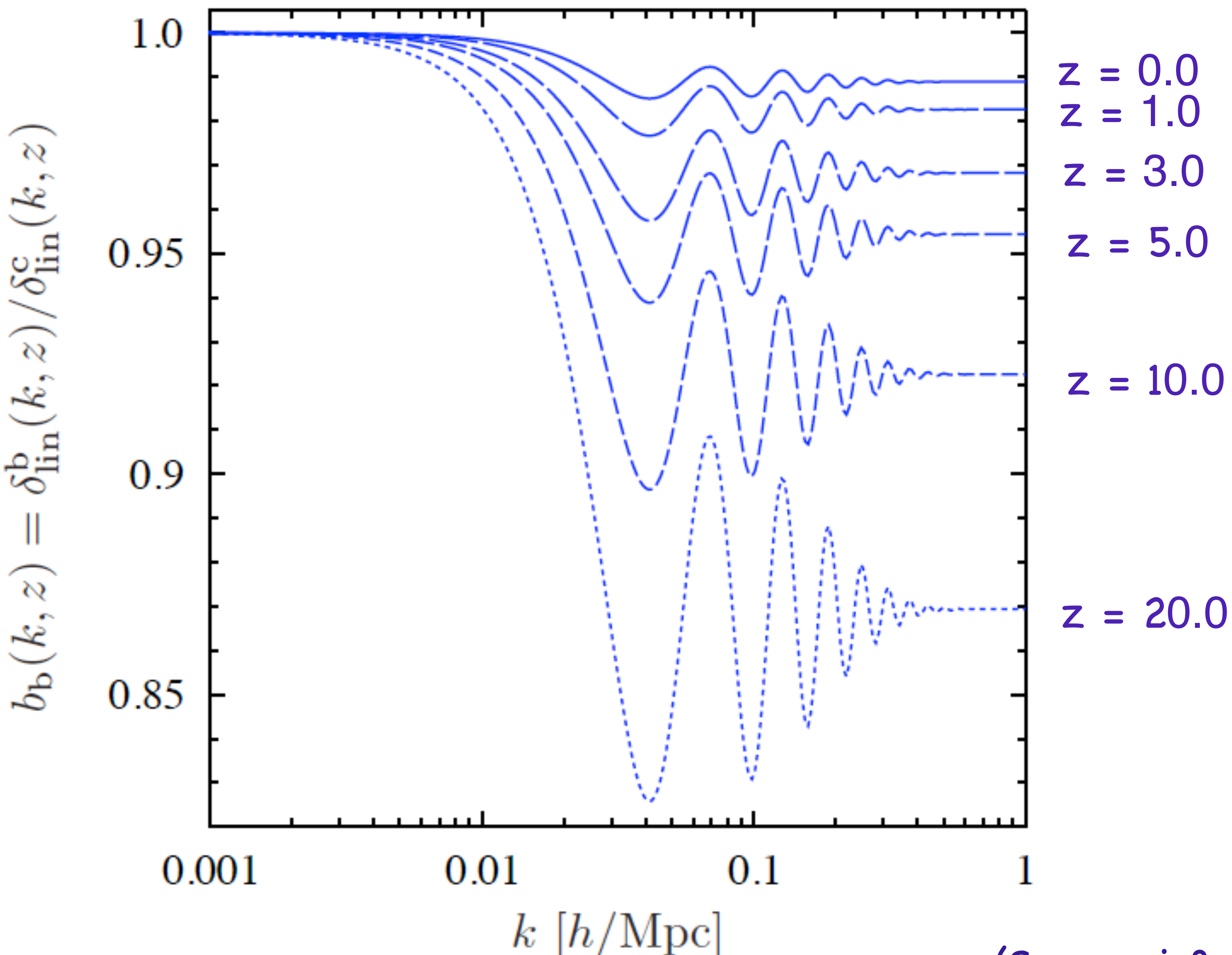
Linear Solution:

Evolution of baryon+CDM for WMAP5 cosmology: z = {100, 20.0, 10.0, 5.0, 3.0, 1.0, 0.0}



(Somogyi & Smith 2010)

Large-Scale Scale-dependent baryon bias:



(Somogyi & Smith 2010)

Going beyond linear theory:

Look for perturbative solutions of the form (c.f. 1-Fluid)

$$\Psi_a(\mathbf{k},\eta) = \sum_{j=0}^{\infty} \Psi_a^{(j)}(\mathbf{k},\eta)$$

allow construction the perturbative solutions

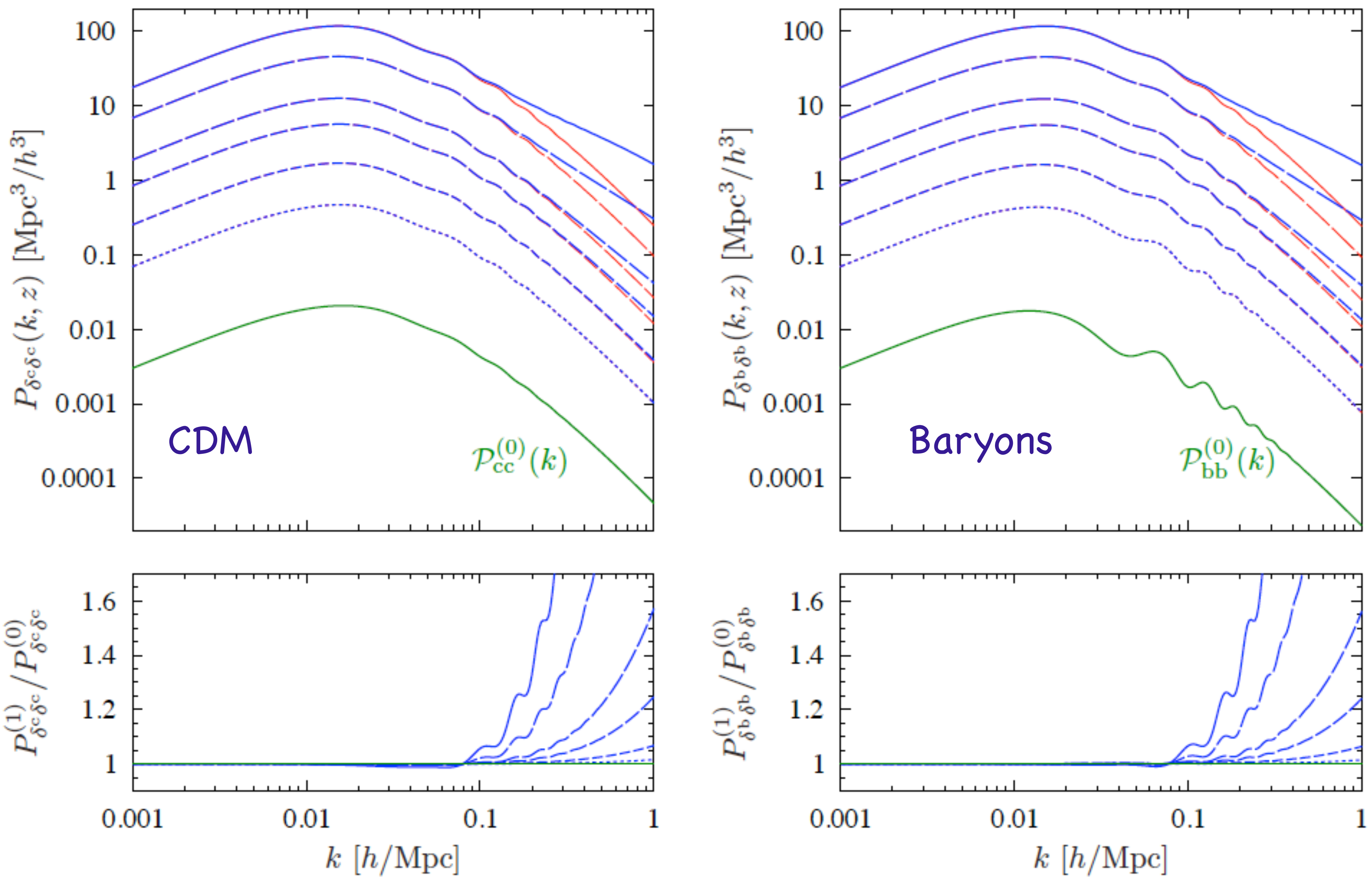
$$\begin{aligned}
\Psi_a^{(0)}(\mathbf{k},\eta) &= g_{ab}(\eta)\phi_b^{(0)}(\mathbf{k})\,; \\
\Psi_a^{(1)}(\mathbf{k},\eta) &= \int_0^\eta \mathrm{d}\eta' g_{ab}(\eta-\eta')\gamma_{bcd}^{(\mathrm{s})}(\mathbf{k},\mathbf{k}_1,\mathbf{k}_2)\Psi_c^{(0)}(\mathbf{k}_1,\eta')\Psi_d^{(0)}(\mathbf{k}_2,\eta')\,; \\
\Psi_a^{(2)}(\mathbf{k},\eta) &= 2\int_0^\eta \mathrm{d}\eta' g_{ab}(\eta-\eta')\gamma_{bcd}^{(\mathrm{s})}(\mathbf{k},\mathbf{k}_1,\mathbf{k}_2)\Psi_c^{(0)}(\mathbf{k}_1,\eta')\Psi_d^{(1)}(\mathbf{k}_2,\eta')\,; \\
\vdots \quad & \quad \vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\
\Psi_a^{(n+1)}(\mathbf{k},\eta) &= \int_0^\eta \mathrm{d}\eta' g_{ab}(\eta-\eta')\gamma_{bcd}^{(\mathrm{s})}(\mathbf{k},\mathbf{k}_1,\mathbf{k}_2)\sum_{m=0}^{n}\Psi_c^{(n-m)}(\mathbf{k}_1,\eta')\Psi_d^{(m)}(\mathbf{k}_2,\eta')\,.
\end{aligned}$$

Compute the power spectra:

$$\left\langle \Psi_a(\mathbf{k},\eta)\Psi_b(\mathbf{k}',\eta)\right\rangle = P_{ab}(\mathbf{k},\eta)\delta^D(\mathbf{k}+\mathbf{k}')\,.$$

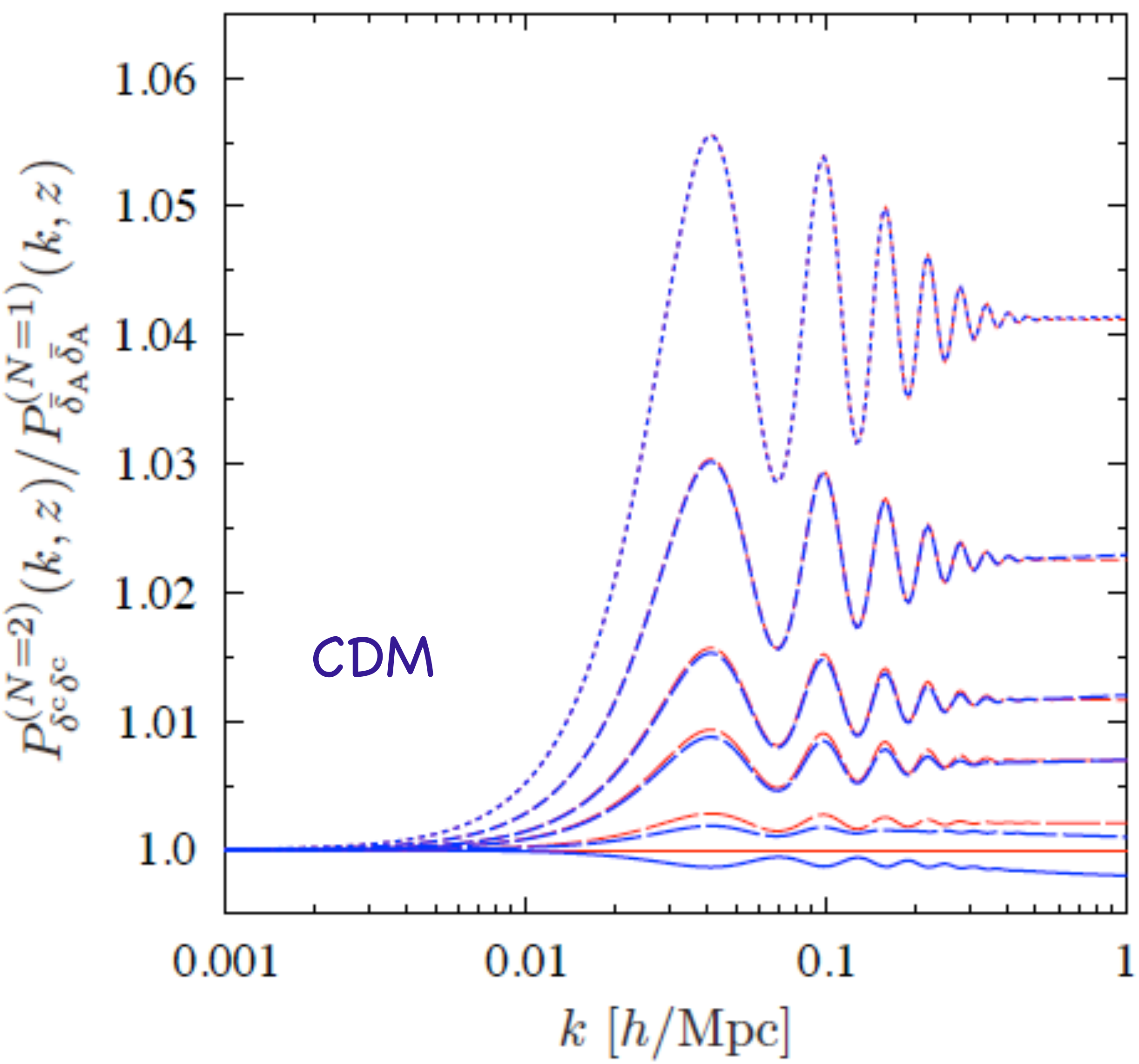
Power spectra at NLO:

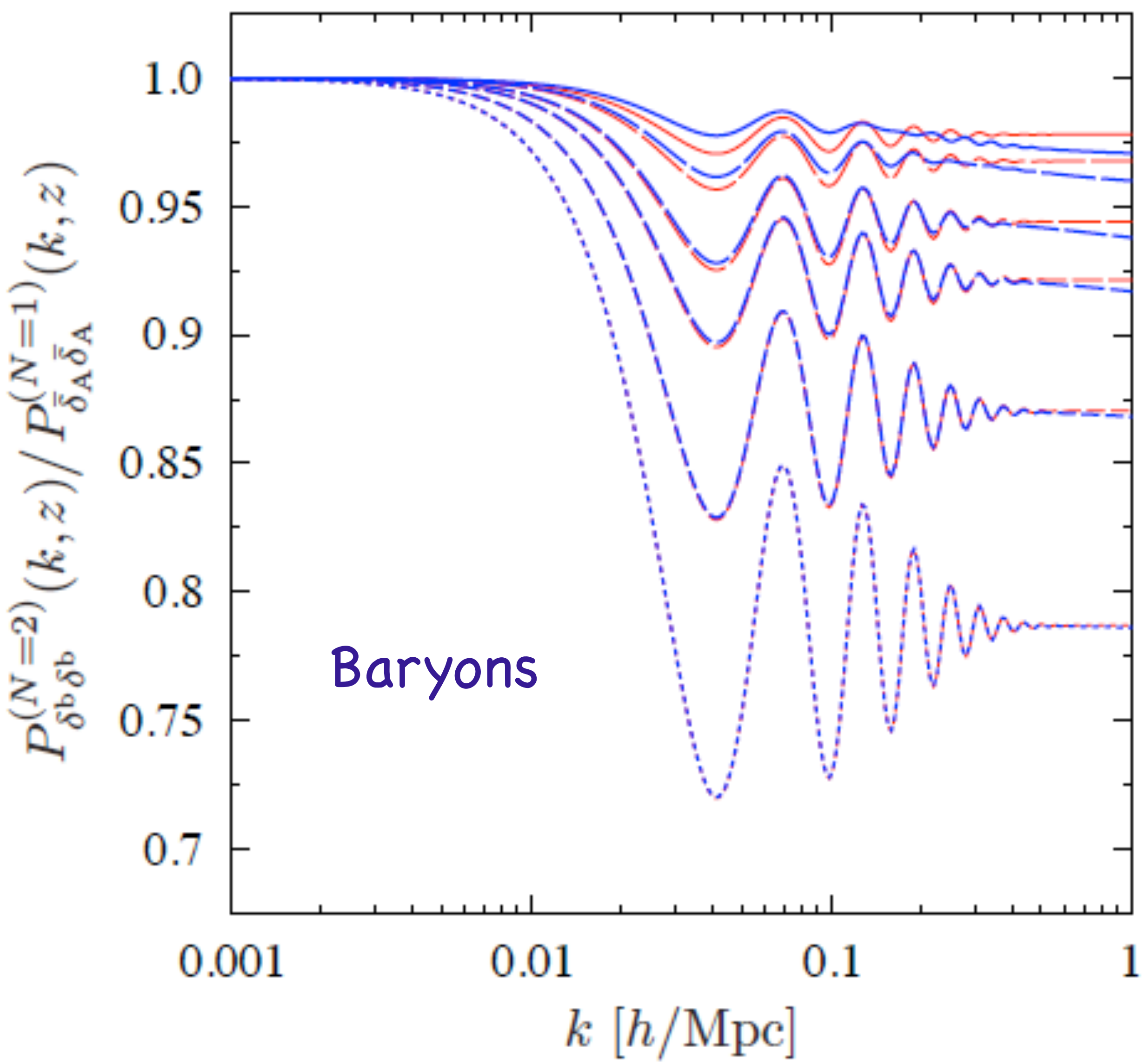
Evolution of baryon+CDM for WMAP5 cosmology: z = {100, 20.0, 10.0, 5.0, 3.0, 1.0, 0.0}



Ratio of 2-Fluid to 1-Fluid Power

Evolution of baryon+CDM for WMAP5 cosmology: z = {20.0, 10.0, 5.0, 3.0, 1.0, 0.0}





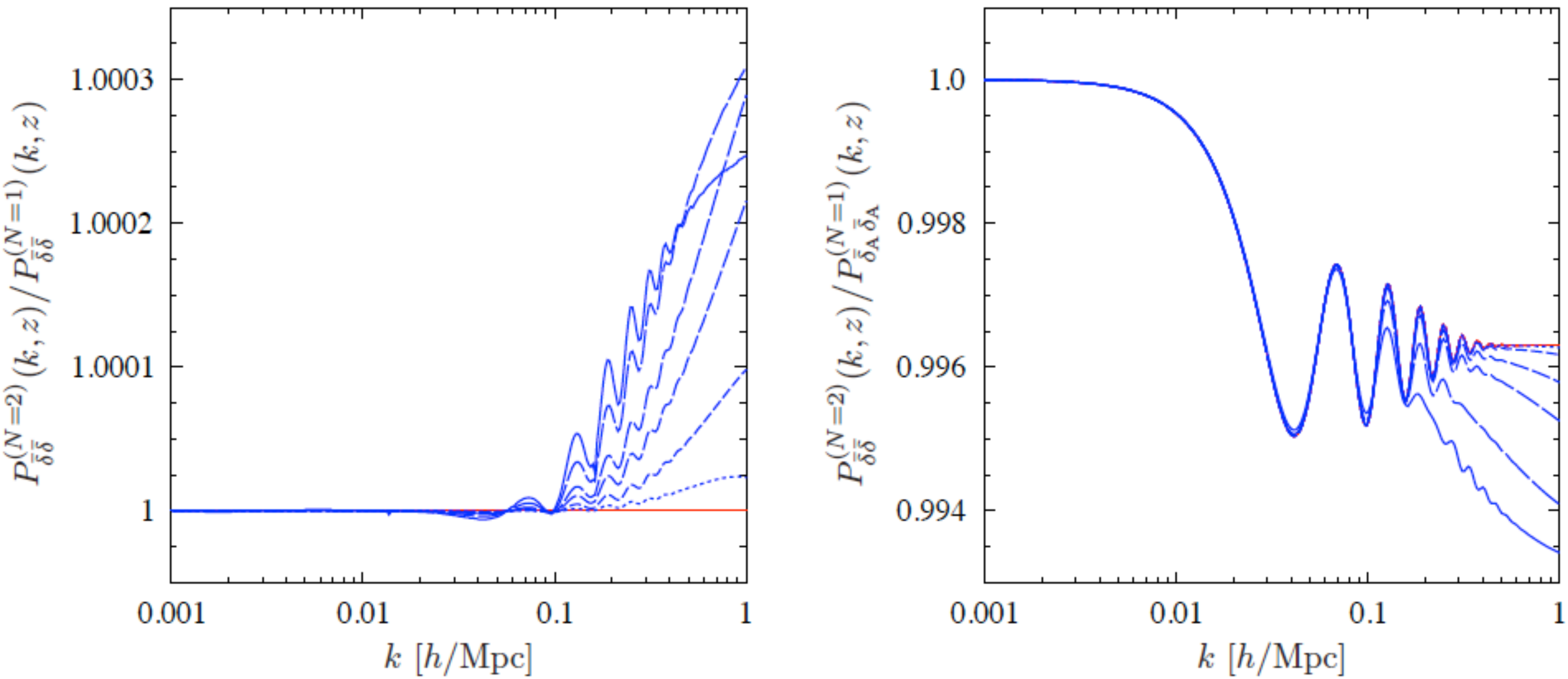
Bad news for baryon probes:
i.e. Lalpha forest, 21cm HI surveys

The good news….

Mean field power spectra

Good news for probes that are sensitive to the mass, i.e. Weak Lensing....
Evolution of total mass P(k) can be accurately simulated through a mean mass field.

$$P_{\bar{\delta}\bar{\delta}}(\mathbf{k},z) = (1-f^{\rm b})^2 P_{\delta^{\rm c}\delta^{\rm c}}(\mathbf{k},z) + 2(1-f^{\rm b})f^{\rm b}P_{\delta^{\rm c}\delta^{\rm b}}(\mathbf{k},z) + (f^{\rm b})^2 P_{\delta^{\rm b}\delta^{\rm b}}(\mathbf{k},z)$$



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Some reasons why to use Halo Model (HM).....

I: Good way to use current phenomenology
II: Galaxy distributions can be explored through HOD
III: Faster than a simulation
IV: PT is a subset of the HM

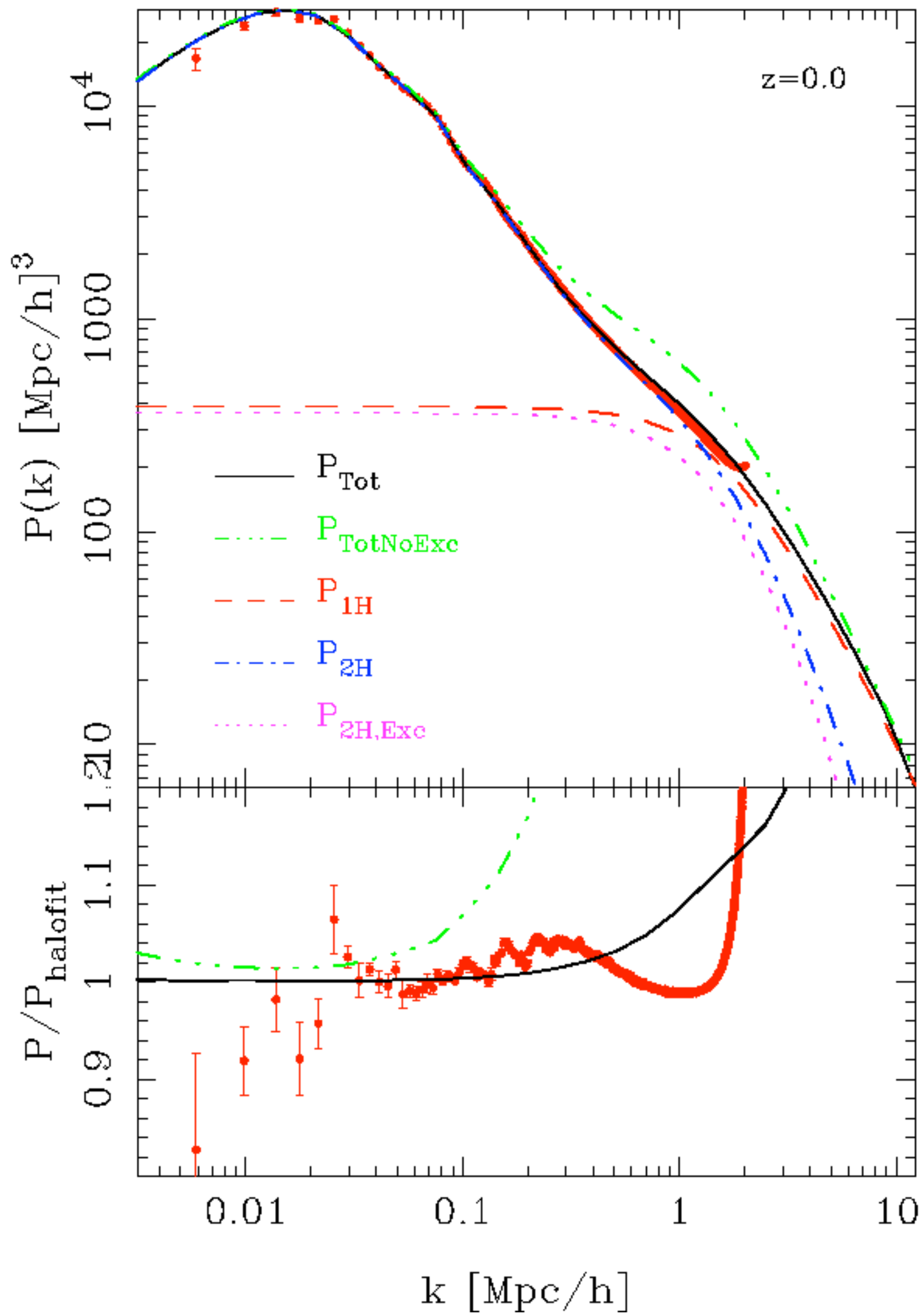
Some reasons why not to use HM.....

I: Fails to get the correct large scale power (see Scoccimarro talk)
II: HOD requires us to assume an unknown parametric model
III: HOD may depend on other variables besides halo mass
IV: Hard to be consistent with model ingredients

Fixing the Large scale P(k) problem in HM:

$$P_{1H}(\mathbf{k}) = \frac{1}{\bar{\rho}^2}\int_0^\infty dM n(M) M^2 |U(\mathbf{k}|M)|^2 \;;$$

$$P_{2H}(\mathbf{k}) = \frac{1}{\bar{\rho}^2}\int_0^\infty \prod_{l=1}^{2}\{dM_l n(M_l) M_l U_l(\mathbf{k}|M_l)\} \times P^{\rm hh}_{\rm cent}(\mathbf{k}|M_1,M_2), \;,$$



Halo exclusion in HM (Takada & Jain 2003):

$$\xi^{\rm hh}_{\rm cent}(r|M_1,M_2) = -1 \;; \quad (r < r_{\rm vir,1} + r_{\rm vir,2})$$

Halo centre power spectrum with exclusion becomes

$$\begin{aligned} P^{\rm hh}_{\rm cent}(k|M_1,M_2) &= \int {\rm d}^3\mathbf{r}\,\xi^{\rm hh}_{\rm cent}(k|M_1,M_2) j_0(kr) \\ &= \int_{r_{\rm vir,1}+r_{\rm vir,2}}^{\infty} {\rm d}^3\mathbf{r}\, b(M_1)b(M_2)\xi(r) j_0(kr) + \int_0^{r_{\rm vir,1}+r_{\rm vir,2}} {\rm d}^3\mathbf{r}(-1) j_0(kr) \\ &= \int_0^\infty {\rm d}^3\mathbf{r}\, b(M_1)b(M_2)\xi(r) j_0(kr) - \int_0^{r_{\rm vir,1}+r_{\rm vir,2}} {\rm d}^3\mathbf{r}\,[1 + b(M_1)b(M_2)\xi(r)]\, j_0(kr) \\ &= P^{\rm NoExc,hh}_{\rm cent}(k|M_1,M_2) - P^{\rm Exc,hh}_{\rm cent}(k|M_1,M_2)\;, \end{aligned}$$

(c.f. Smith, Scoccimarro & Sheth 2007)

Impact of Primordial Non-Gaussianity on LSS

The local model for the Bardeen's potential can be written:

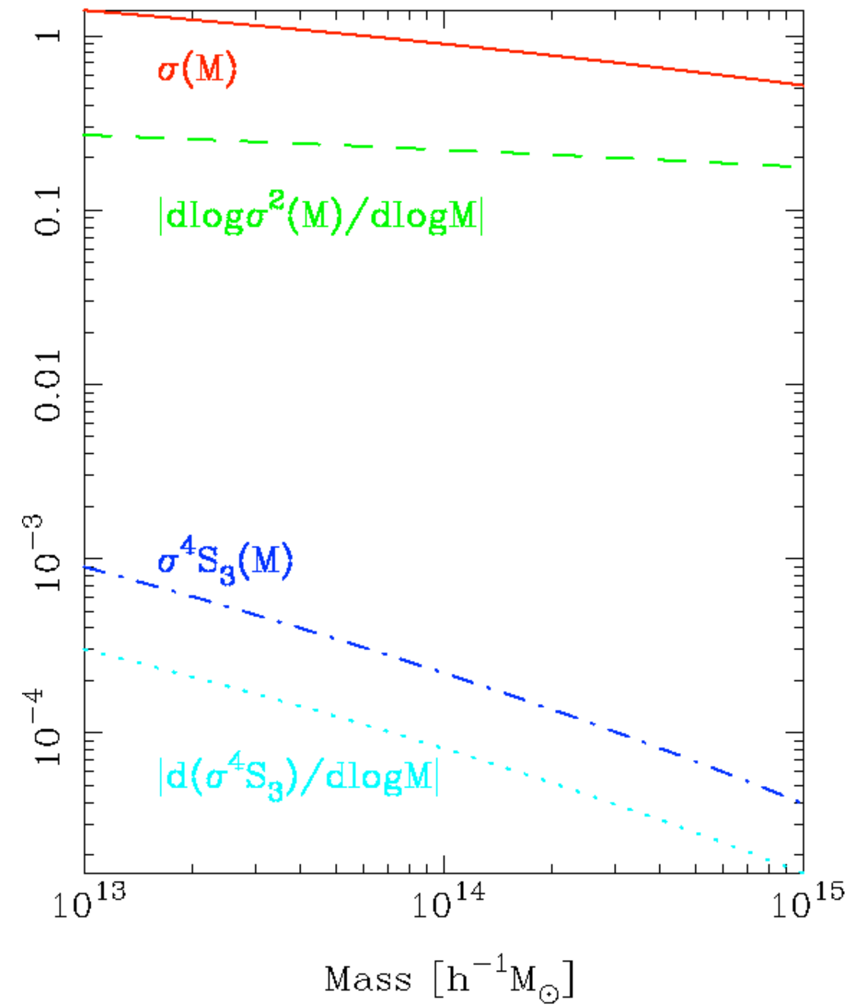
$$\Phi_{\rm NG}({\bf x}) = \phi_{\rm G}({\bf x}) + {\rm f_{NL}}\left[\phi_{\rm G}({\bf x})^2 - \langle\phi^2_{\rm G}({\bf x})\rangle\right]$$

(Matarresse et al 2000, + ...)

This leads to a primordial density bispectrum first oder in f_NL:

$$B_{\Phi_{\rm NG}}({\bf k}_1,{\bf k}_2) \;=\; 2f_{\rm NL}\left[P_{\phi_{\rm G}}({\bf k}_1)P_{\phi_{\rm G}}({\bf k}_2) + P_{\phi_{\rm G}}({\bf k}_2)P_{\phi_{\rm G}}({\bf k}_3) + P_{\phi_{\rm G}}({\bf k}_3)P_{\phi_{\rm G}}({\bf k}_1)\right]$$

This generates skewness in the density field



The f_NL N-body Simulations:

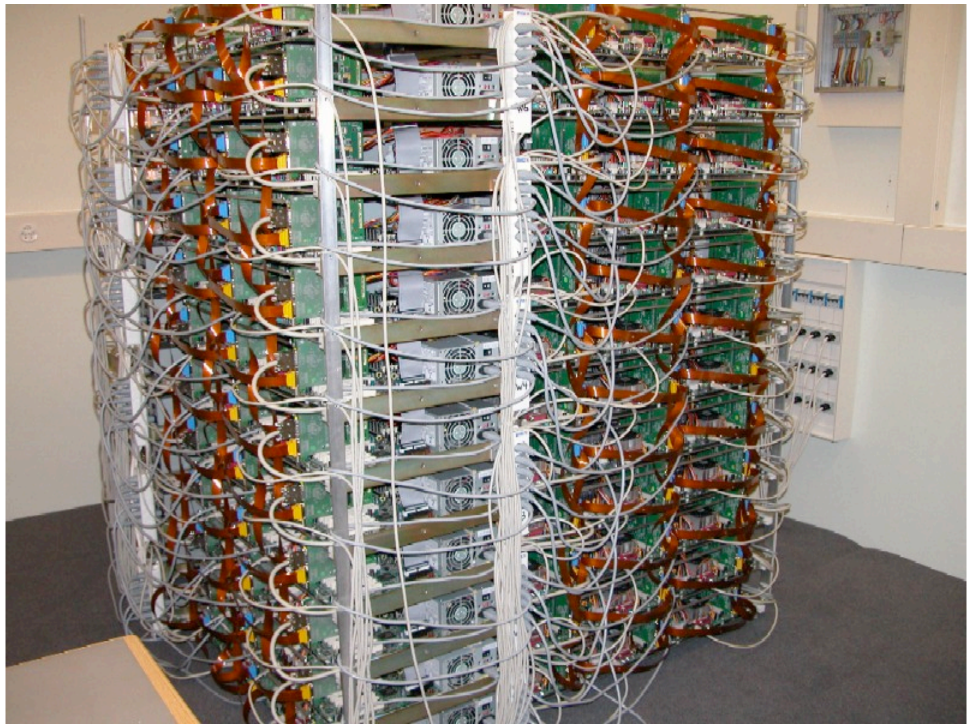
Ensemble of 36 simulations of cubical patch of the LCDM Universe, with cosmological parameters given by WMAP5

$$V = 1.6^3 [\mathrm{Gpc}/h]^3,\ N = 1024^3,\ \Omega_m = 0.274,\ \Omega_{\mathrm{DE}} = 0.726, \sigma_8 = 0.812, n_s = 0.960$$

12 Simulations per model: $f_{\mathrm{NL}} = 0$, $f_{\mathrm{NL}} = 100$, $f_{\mathrm{NL}} = -100$.

Using: GADGET-2, with 1LPT ICs, and CAMB Tfs.
Run on 256 processors of the zBox3 cluster

(see Desjacques et al 2009 for details)

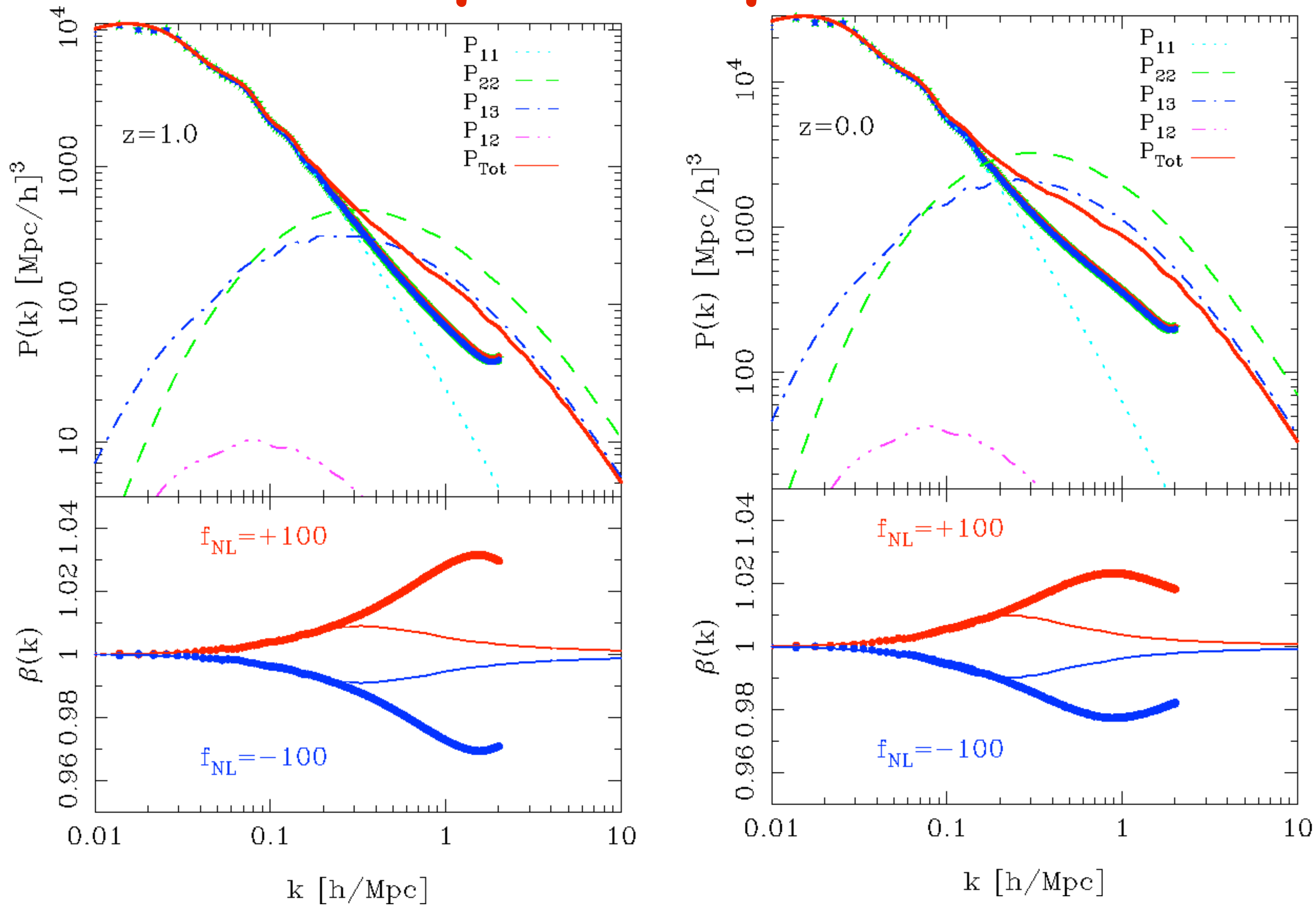


zBOX3

Impact of PNG on mass power spectrum

Using standard PT
2nd order corrections
generate 1st order
f_nl correction to P(k)

(Smith et al. 2010, in prep.)



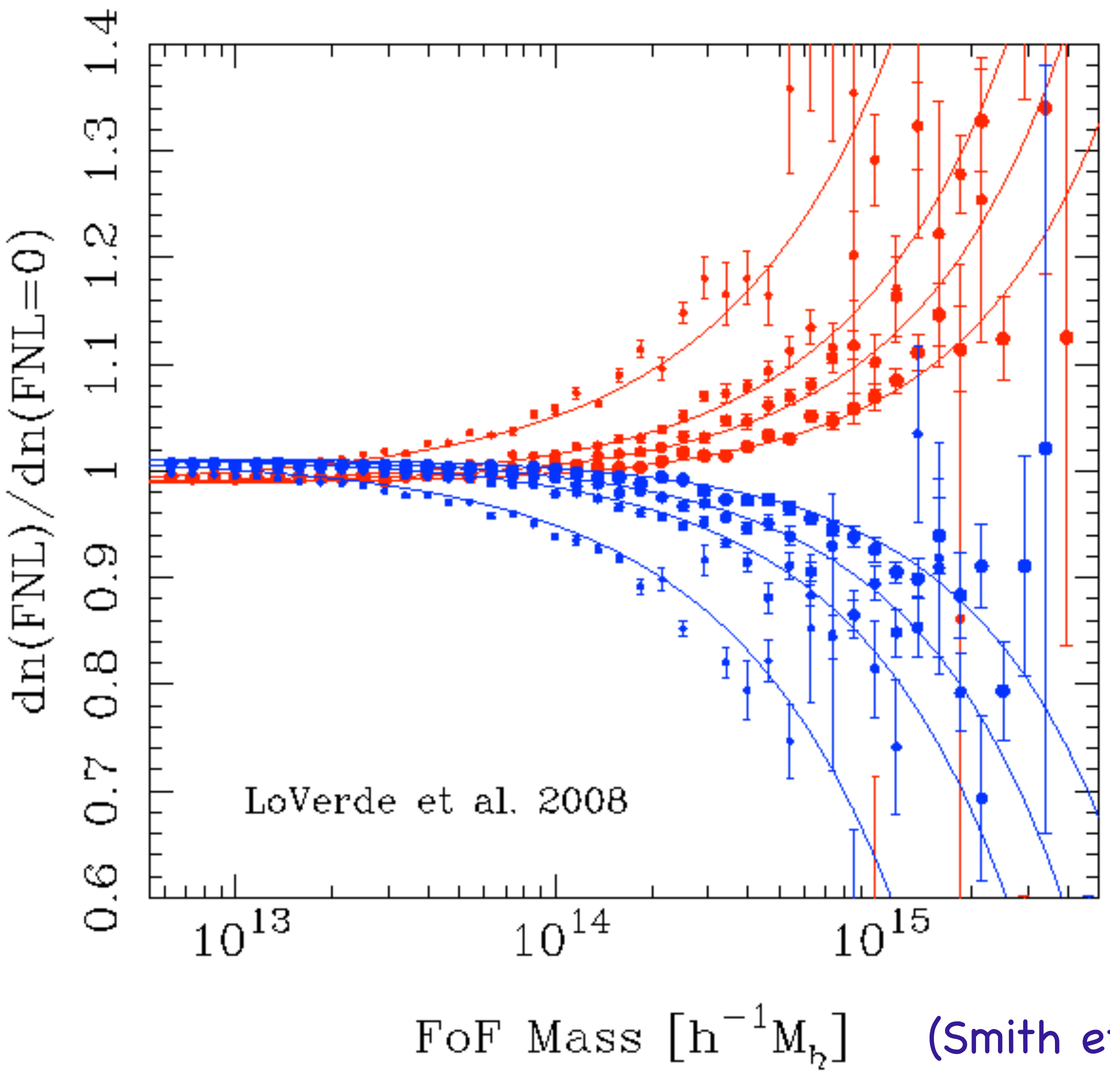
$$P_{12}(k,z;f_{\rm NL}) = \frac{2 f_{\rm NL} k^3 \alpha(k)}{7(2\pi)^2} \int_0^\infty dx\, x\, \alpha(kx) \int_{-1}^{+1} d\mu \left(\frac{3x + 7\mu - 10\mu^2 x}{1 + x^2 - 2\mu x}\right) \alpha(q) \left[P_\phi(k) P_\phi(kx) + \ 2 \text{ perms}\ \right]$$

$$\beta(k, f_{\rm NL}) \equiv 1 + \frac{P_{12}(k, f_{\rm NL}, a)}{P_{11}(k,a) + P_{13}(k,a) + P_{22}(k,a)}$$

(Taruya et al 2007, Desjacques et al 2009)

Evolution of Ratio of FOF Mass function....

Mass functions can be calculated: i.e. LoVerde et al used an Edgeworth expansion of PDF



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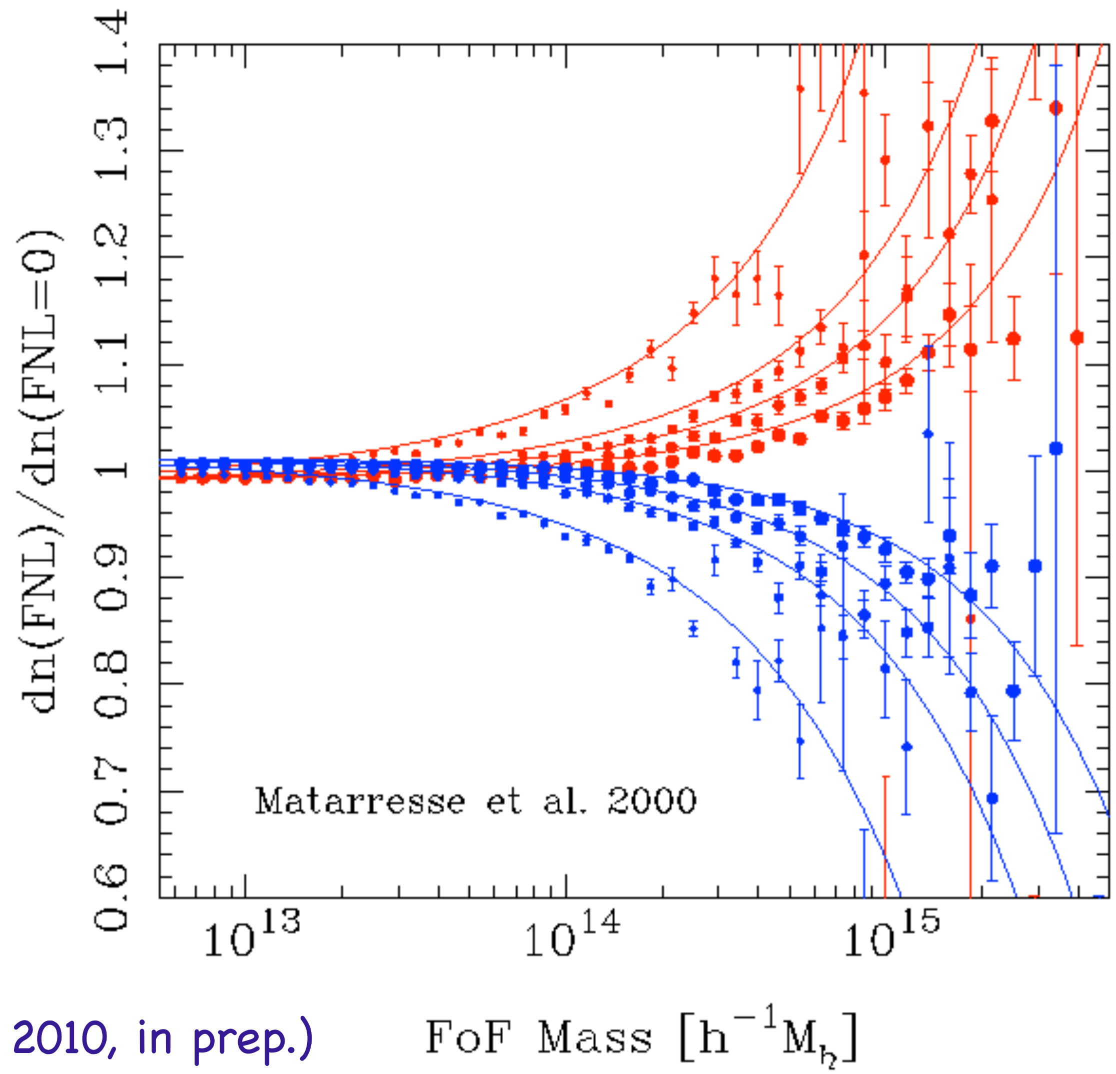
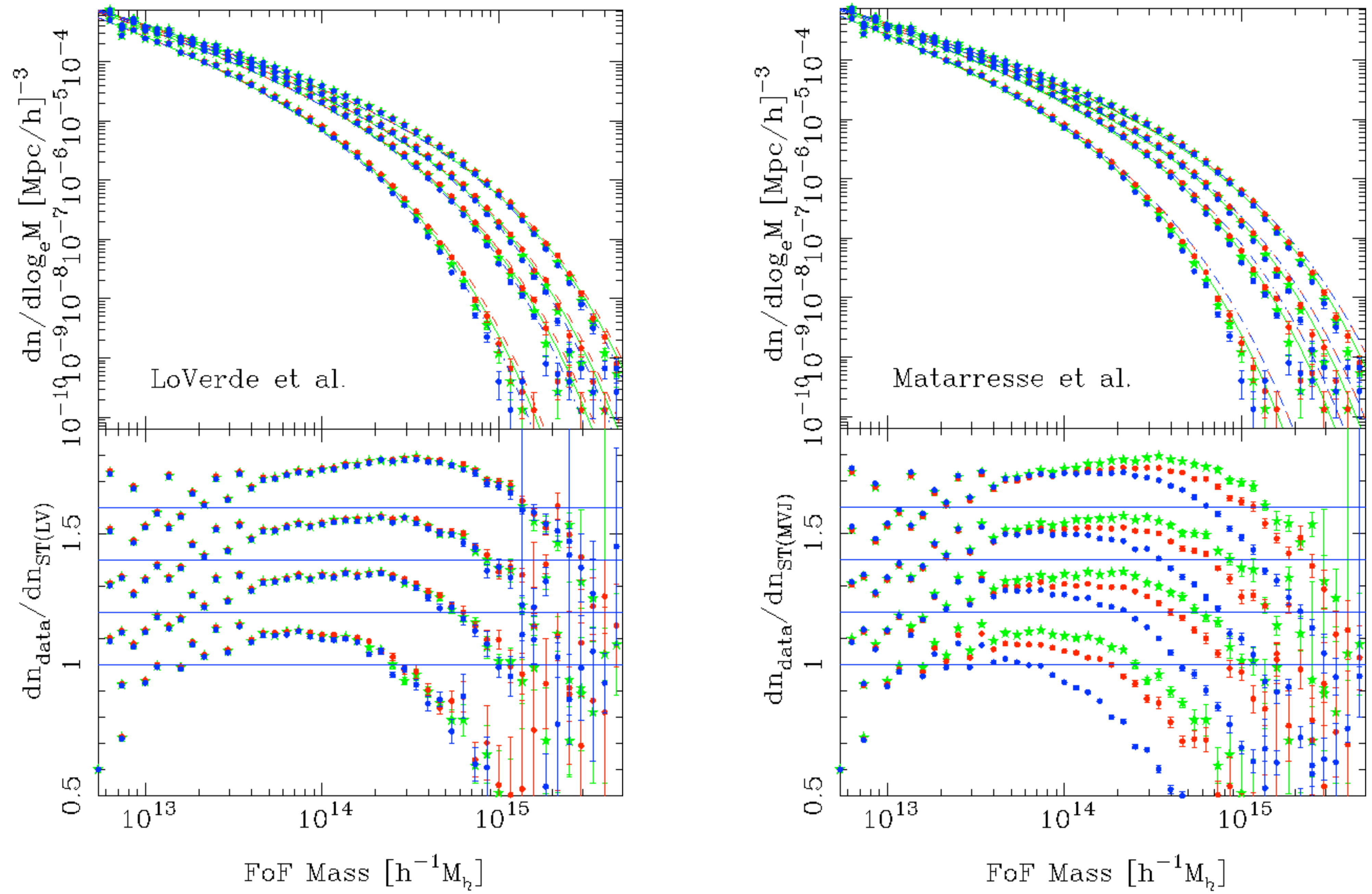


$$R_{\rm MVJ}\left[\nu, f_{\rm NL}\right] = \exp\left[\frac{\delta_{\rm ec}^3(a) S_3(M,a_0)}{6\sigma^2(M,a_0)}\right]\left|\frac{1}{6}\frac{\delta_{\rm ec}(a)}{\sqrt{1-\delta_{\rm ec}(a)S_3(M,a_0)/3}}\frac{dS_3(M,a_0)}{d\log\sigma} + \sqrt{1-\frac{1}{3}\delta_{\rm ec}(a)S_3(M,a_0)}\right|$$

$$R_{\rm LV}\left[\nu, f_{\rm NL}\right] = 1 + \frac{1}{6}\sigma(M|a_0)S_3(M|a_0)\left[\tilde{\nu}^3(a) - 3\tilde{\nu}(a)\right] + \frac{1}{6}\frac{d\left[\sigma(M|a_0)S_3(M|a_0)\right]}{d\log\sigma}\left[\tilde{\nu}(a) - \frac{1}{\tilde{\nu}(a)}\right]$$

Evolution of Mass function & PNG....

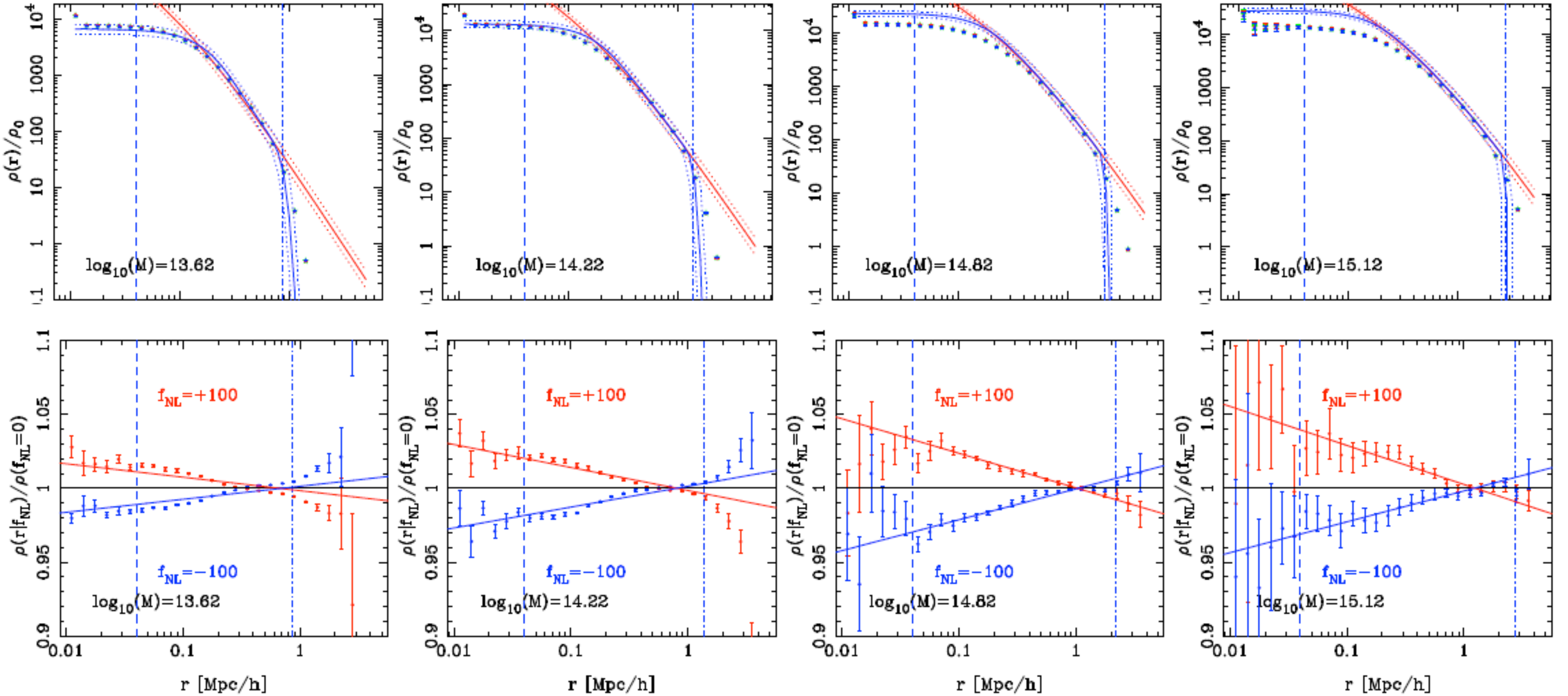


(Smith et al. 2010, in prep.)

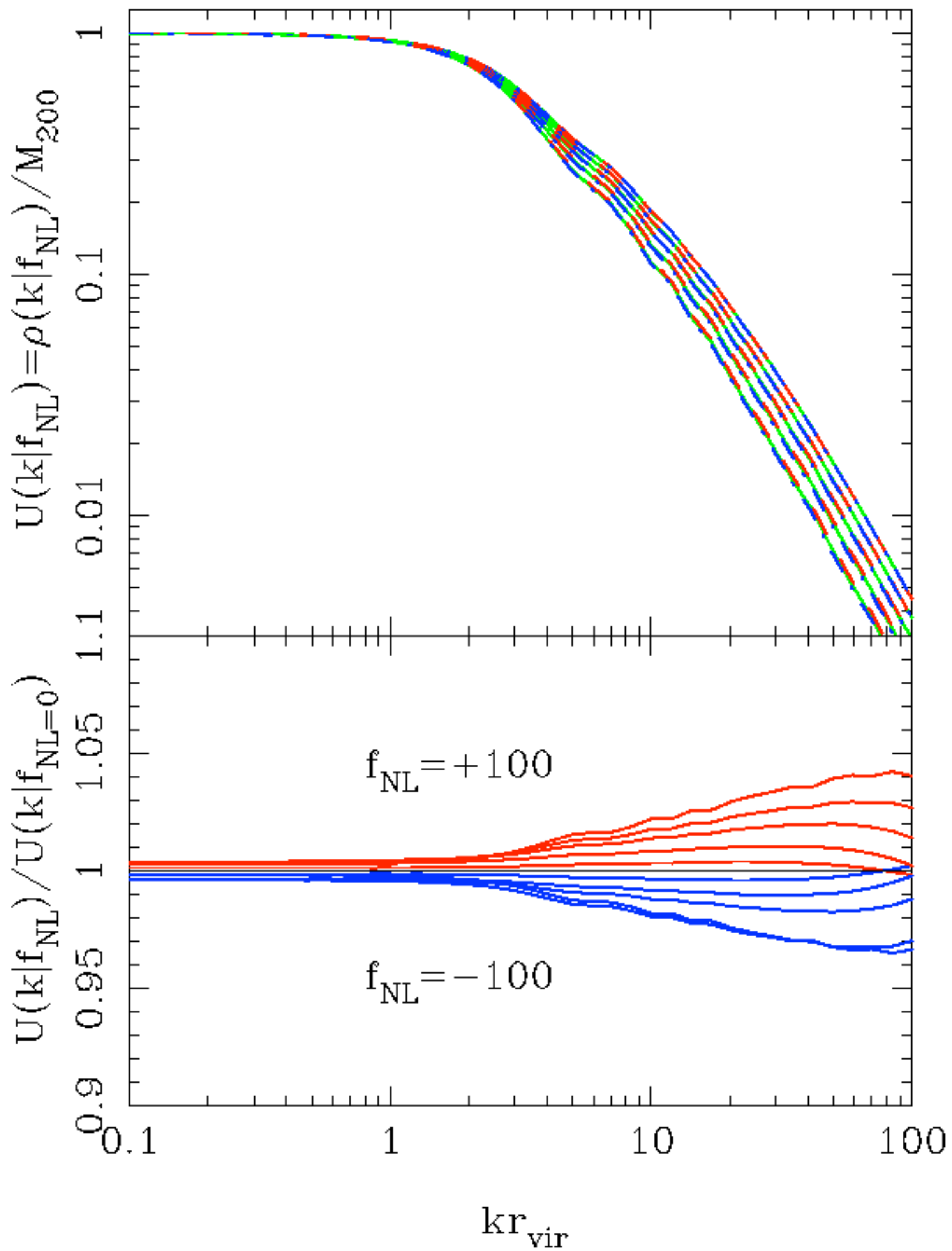
Impact of PNG on CDM density profiles

Assume that the profiles have NFW like form, and convolve with Gaussian filter to simulate the resolution dependent effects

$$\tilde{\rho}_{\rm NFW}(r|M) = \int \frac{d^3k}{(2\pi)^3} M U_{\rm NFW}(k|M) W(k) j_0(kr) \qquad W(k) \equiv \exp\left[-(2.5 l_{\rm soft} k)^2/2\right]$$



Impact of PNG on CDM density profiles



Conclusions:

Baryon+CDM fluids

If one wants to 1% matter P(k), a good approximation can be obtained by using weighted sum of baryon+CDM transfer functions at z=0.

If one wants 1% CDM P(k), one must be careful to pick the transfer function for the redshift required, otherwise baryon effects can not be neglected.

If one wants 1% baryon P(k) then one must simulate two fluids from z=100.
=> One can not paint Lyman alpha forest on to CDM only simulations!

Primordial Non-Gaussianities and LSS

Halo model will be useful for helping to constrain PNG from LSS

Halo model phenomenology in good shape: Mass functions, Profiles, 1-Loop P(k), Halo Corr

Halo-Halo correlation functions are strong indicators for f_NL especially at BAO scale!

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