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Mock galaxy catalogs with perturbation theory and nonlinear stochastic biasing

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What is the bottle-neck of the computations?

1. the gravity solver
2. resolution (number of particles)

Let us ask a different question:

How can I generate a distribution of halos/galaxies in a statistical way?

(of a certain type within a certain mass range) the answer is:

we need all the higher order statistics from a reference sample
+ a way to draw from such a higher order PDF:

$$N_h \curvearrowleft \mathcal{P}(N_h|\xi_1^h, \xi_2^h, \xi_3^h, \xi_4^h, \ldots)$$

Let us imagine we would know the halo/galaxy density field, i.e. the expected number of halos/galaxies per finite volume (cell).

Stochastic biasing

$$N_h \curvearrowleft \mathcal{P}(N_h|\rho_h)$$

caution! we still need to know the deviation from Poissonity!

over-dispersion modelled by the NB PDF:

$$P(N_i \mid \lambda_i, \beta) = \frac{\lambda_i^{N_i}}{N_i!} \frac{\Gamma(\beta + N_i)}{\Gamma(\beta)(\beta + \lambda)^{N_i}} \frac{1}{(1 + \lambda/\beta)^{\beta}}$$

Kitaura, Yepes & Prada 2014, MNRAS

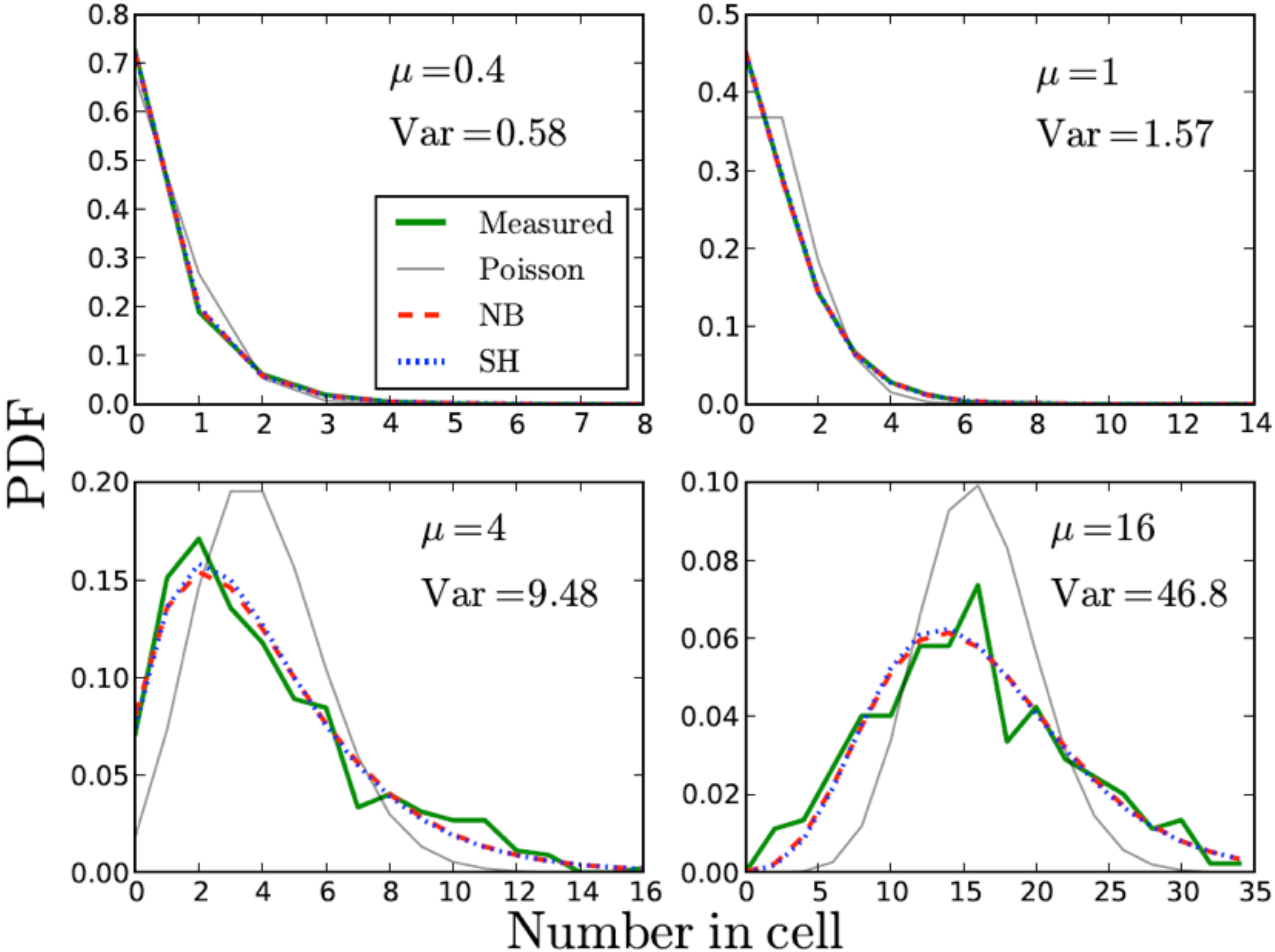
non-Poissonian PDFs:
W.C. Saslaw, A.J.S. Hamilton, 1984, ApJ, 276, 13
Sheth R. K., 1995, MNRAS, 274, 213

stochastic bias:
Dekel A., Lahav O., 1999, ApJ, 520, 24
Sheth R. K., Lemson G., 1999, MNRAS, 304, 767

and many more see references in e.g. Kitaura et al 2013

Somerville et al 2001, MNRAS, 320, 289
Casas-Miranda et al 2002, MNRAS, 333, 730

Neyrinck M et al 2013; Aragon-Calvo M. 2013



Deterministic biasing

we need to know the (deterministic) biasing,
but this implies knowing all the higher order correlation functions!

$$B(\rho_h|\rho_{\rm M}) = B(\rho_h|\rho_{\rm M}, \xi_1^h, \xi_2^h, \xi_3^h, \xi_4^h, \ldots)$$

$$N_h \curvearrowleft \mathcal{P}(N_h|B(\rho_h|\rho_{\rm M}, \xi_1^h, \xi_2^h, \xi_3^h, \xi_4^h, \ldots))$$

Deterministic biasing parametrization

Fry & Gaztañaga 1993

$$\rho_h = f_h^a \sum_i a_i \delta_{\mathrm{M}}^i$$

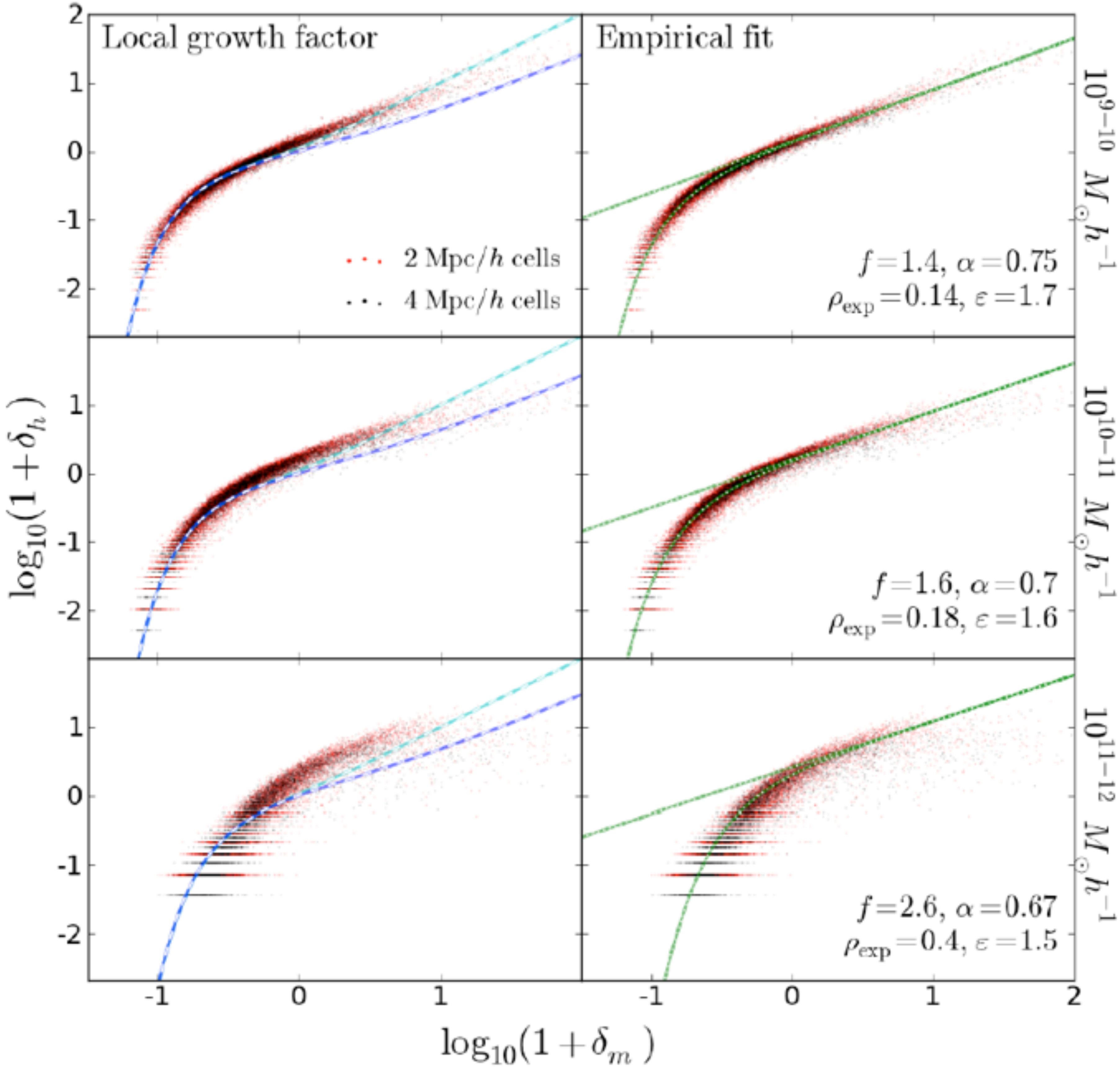
Cen & Ostriker 1993; de la Torre & Peacock

$$\rho_h = f_h^b \exp\left[\sum_i b_i \log\left(1+\delta_{\mathrm{M}}\right)^i\right]$$

Kitaura, Yepes & Prada 2014 + Neyrinck et al 2014

$$\rho_h = f_h \, \theta(\rho_{\mathrm{M}} - \rho_{\mathrm{th}}) \, \rho_{\mathrm{M}}^{\alpha} \exp\left[-\left(\frac{\rho_{\mathrm{M}}}{\rho_{\epsilon}}\right)^{\epsilon}\right]$$

Neyrinck M et al 2013; Aragon-Calvo M. 2013



How can we do it?

given the dark matter field
(from low resolution N-body or approximate solver)
parametrize the bias
and constrain the bias parameters, in such a way that
the higher order correlation functions are matched

expensive!

How can we do it?

$$\bar{N}_h = \langle \rho_h \rangle \leftarrow \xi_1^h$$

$$P_h(k) \leftarrow \xi_2^h$$

$$\mathcal{P}^1(\rho) = \int_{-\sqrt{-1}\infty}^{\sqrt{-1}\infty} \frac{\mathrm{d}t}{2\pi\sqrt{-1}} \exp\left(t\rho + \mathcal{C}(t)\right)$$

$$\mathcal{P}_h^1\left(B\left(\rho_h|\rho_\mathrm{M}\right)\right) \leftarrow \{\xi_1^h, \xi_2^h, \xi_3^h, \xi_4^h, \ldots\}$$

$$N_h \curvearrowleft \mathcal{P}(N_h|B(\rho_h|\rho_\mathrm{M}, \bar{N}_h, P_h(k), \mathcal{P}_h^1))$$

our approach:

Let us use low resolution + approximate gravity solvers and augment all the missing halos!

- The approximate gravity solver accurately models the higher order statistics of the dark matter density field.

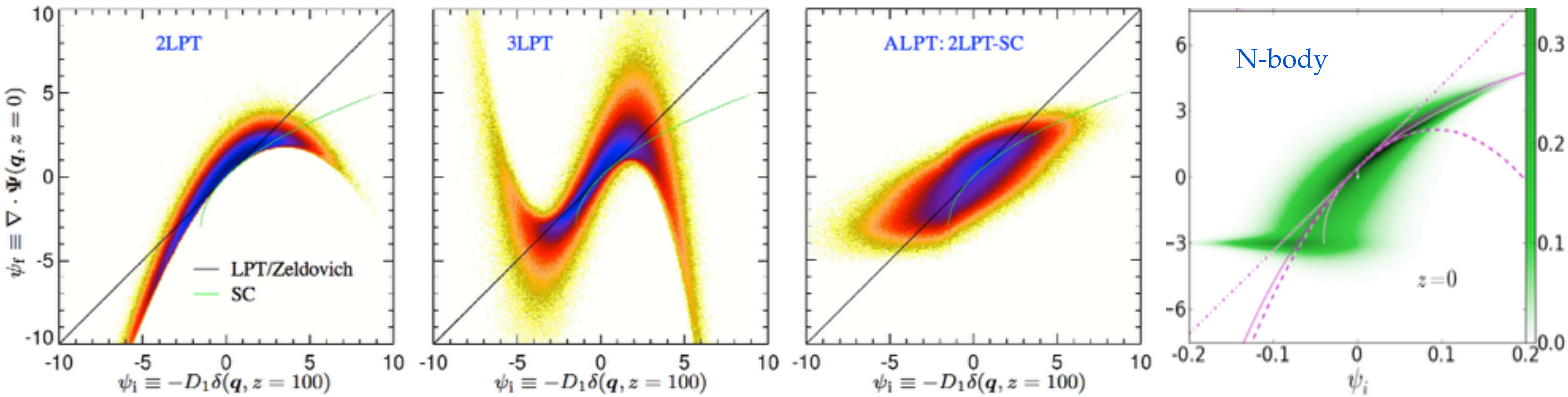
(low N-body resolution or perturbation theory based method)

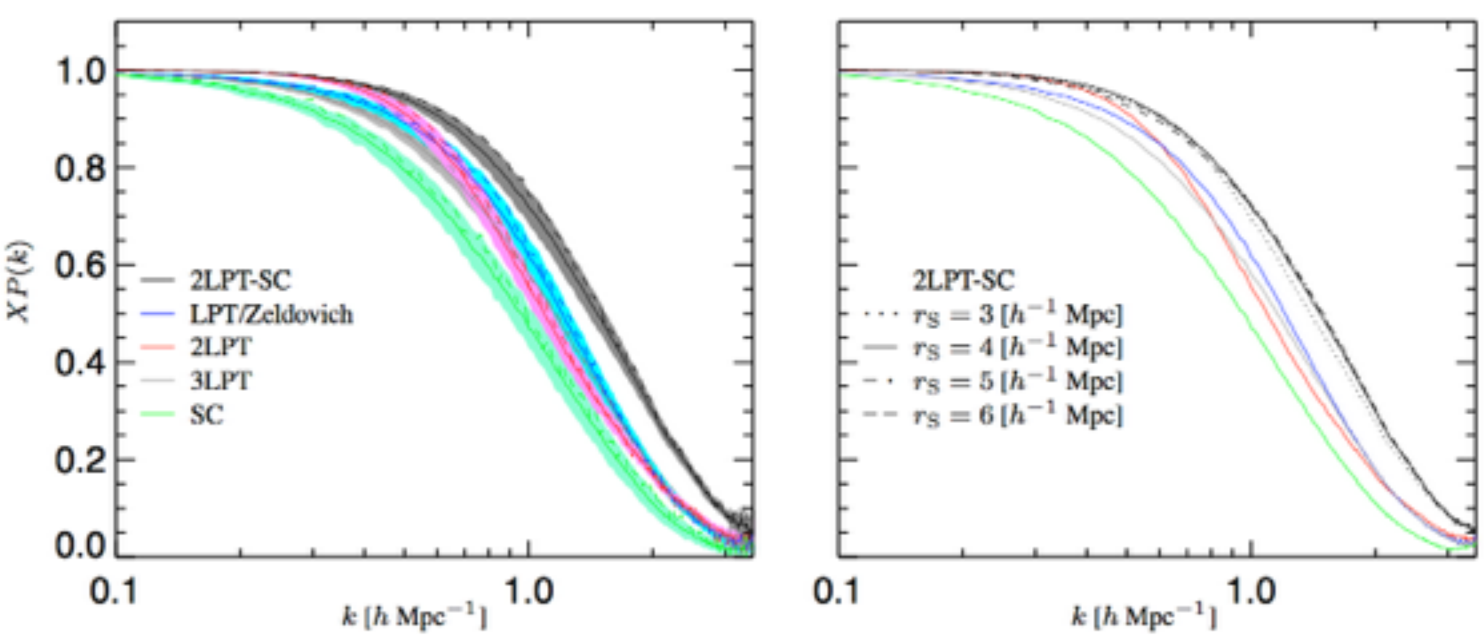
- The biasing model accurately connects the dark matter phase- space distribution with the halo distribution.

Simple efficient accurate one-step gravity solver…

ALPT: Augmented Lagrangian Perturbation Theory

Kitaura F. S. & Heß S. 2013, MNRAS, 435, L78

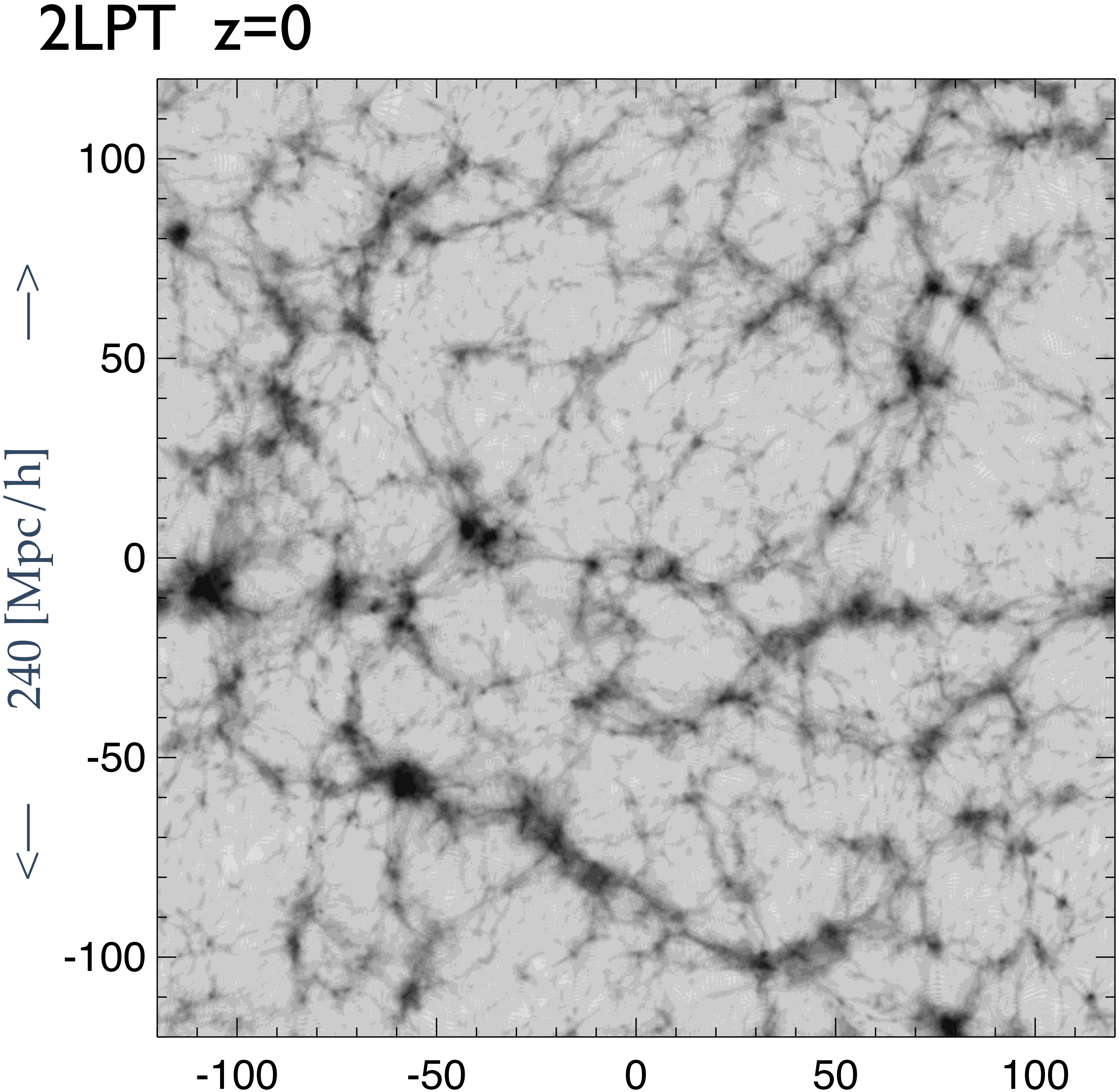




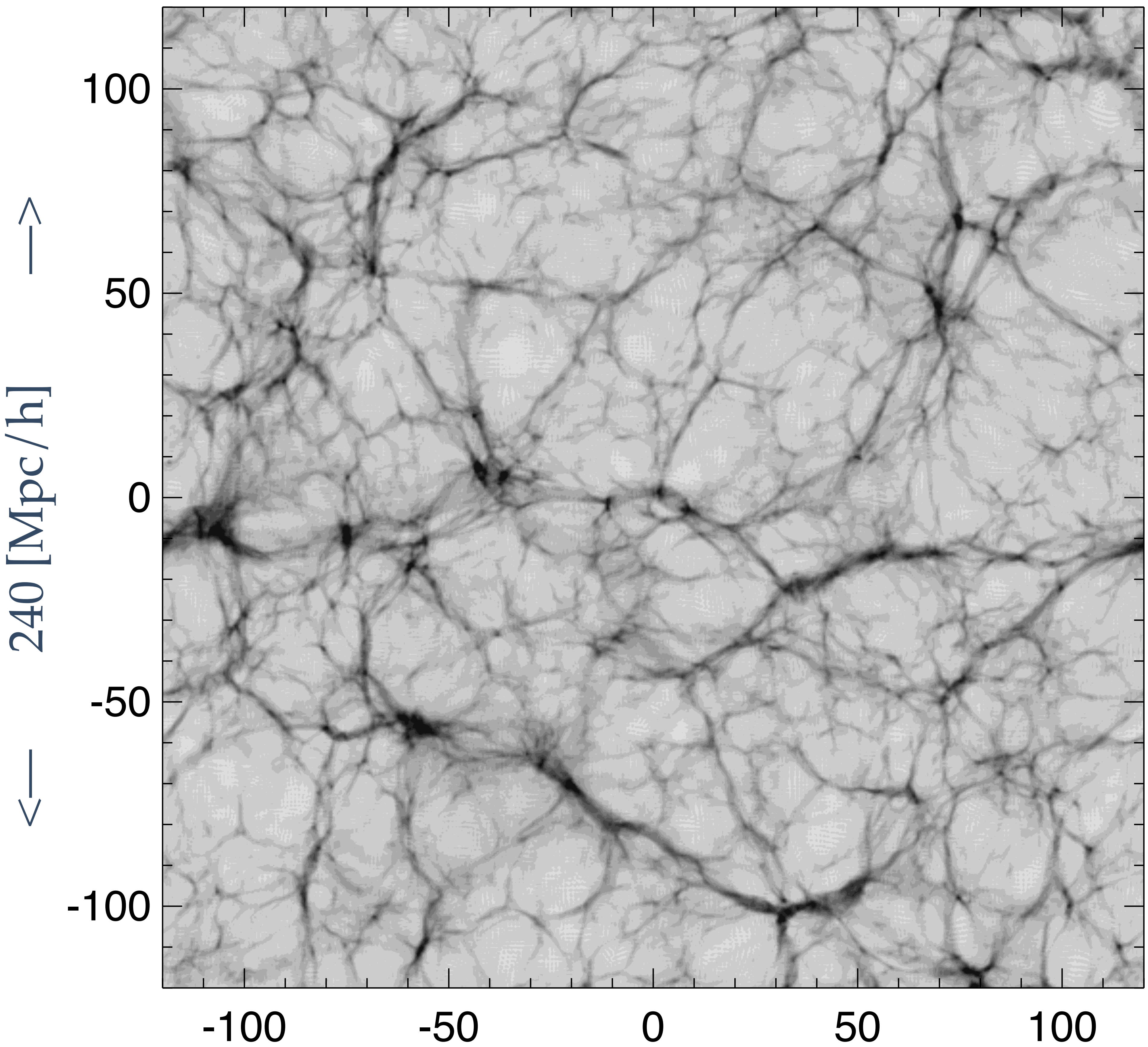
Top: relation between displacement field divergence vs ICs density field
Left: normalised cross-power spectra (propagator) at z=0 for different approximations vs N-body

for N-body relation see Neyrinck M. C., 2013, MNRAS, 428, 141
for the spherical collapse relation see also Bernardeau F. 1994; Mohayee R. 2006

see also Tassev S. & Zaldarriaga M., 2012, JCAP, 4, 13 for other LPT improvements with transfer functions (less correlated with the N-body solution than ALPT)


2LPT z=0
240 [Mpc/h]
100
50
0
-50
-100
-100
-50
0
50
100

ALPT z=0



Calibration with N-body simulations for CMASS LRG type galaxies

we are performing mocks for BOSS, 4MOST, JPAS, EUCLID,…

Reference N-body simulation (Gadget): BIGMULTIDARK

Volume: (2500 Mpc/h)^3

Hess et al in prep

Prada et al in prep

Number of particles: 3840^3 (2M cpu hs)

halos selected with bdm (density peaks) according to vmax>~350 km/s (LRGs)

-> I consider 8 sub-volumes of (1250 Mpc/h)^3

Simulations with PATCHY: PerturbAtion Theory Catalog generator of Halo/galaxY distributions

Kitaura, Yepes & Prada 2014, MNRAS

Volume: (1250 Mpc/h)^3

Grid number of cells: 512^3

53 times lower resolution required!

Resolution of the grid: (2.4 Mpc/h)^3

same cosmology (Planck-like)

same redshift: z=0.577

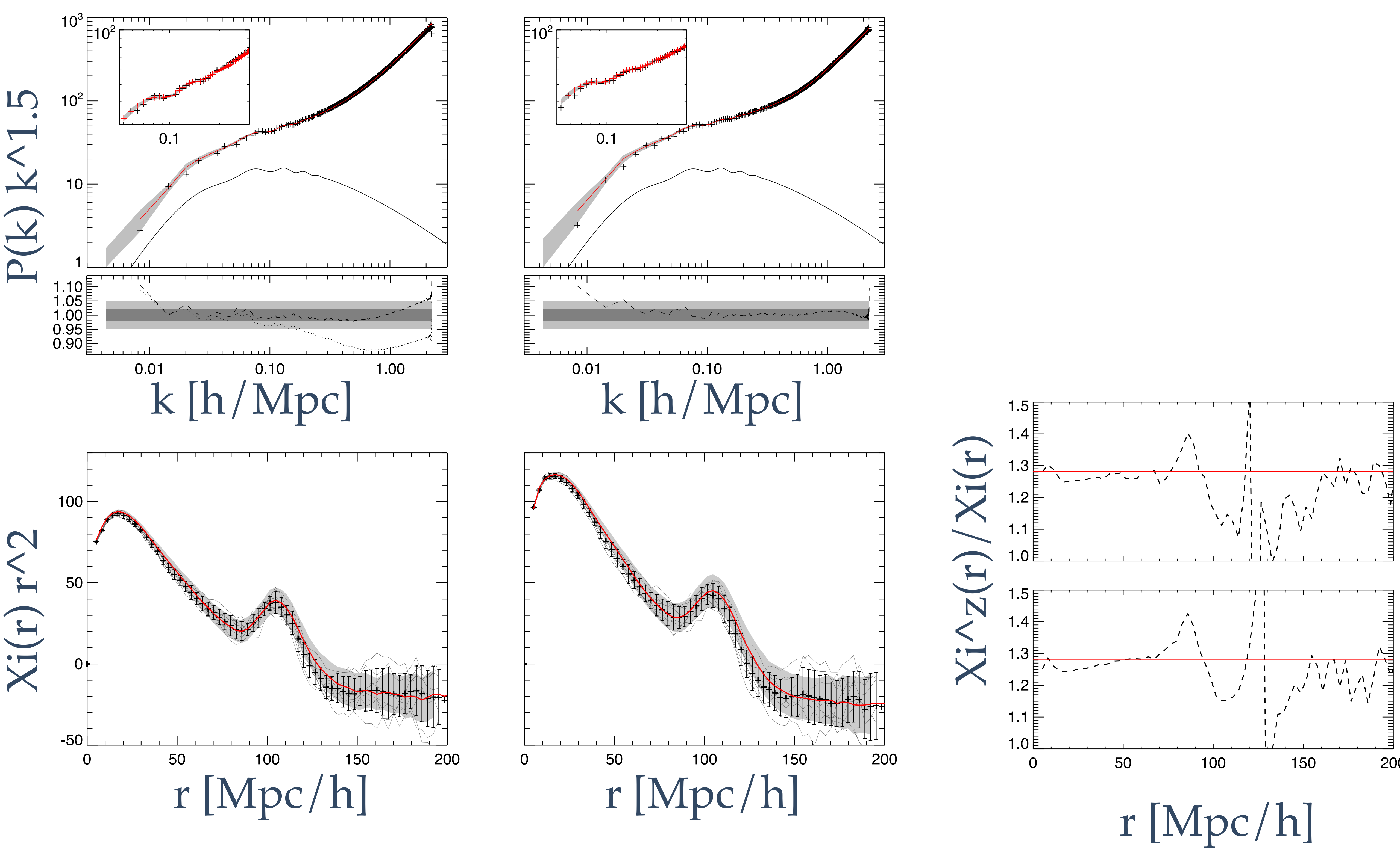
on my laptop (quad core i7, 4 cpus+4 virtual cpus, 8 Gb RAM)

about 15 mins

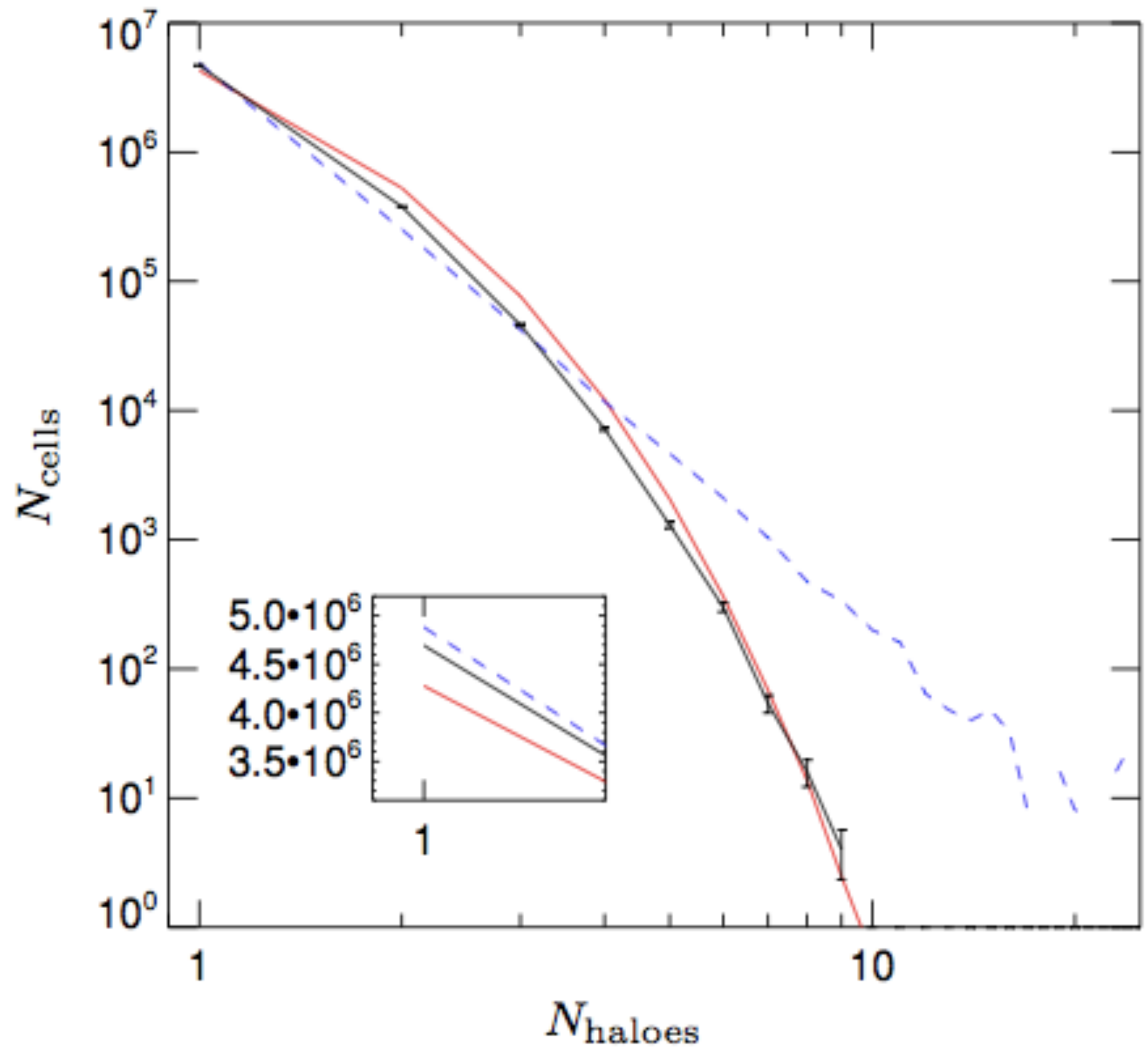
Calibration with N-body simulations

Kitaura, Yepes & Prada 2014, MNRAS

real-space　　　　redshift-space



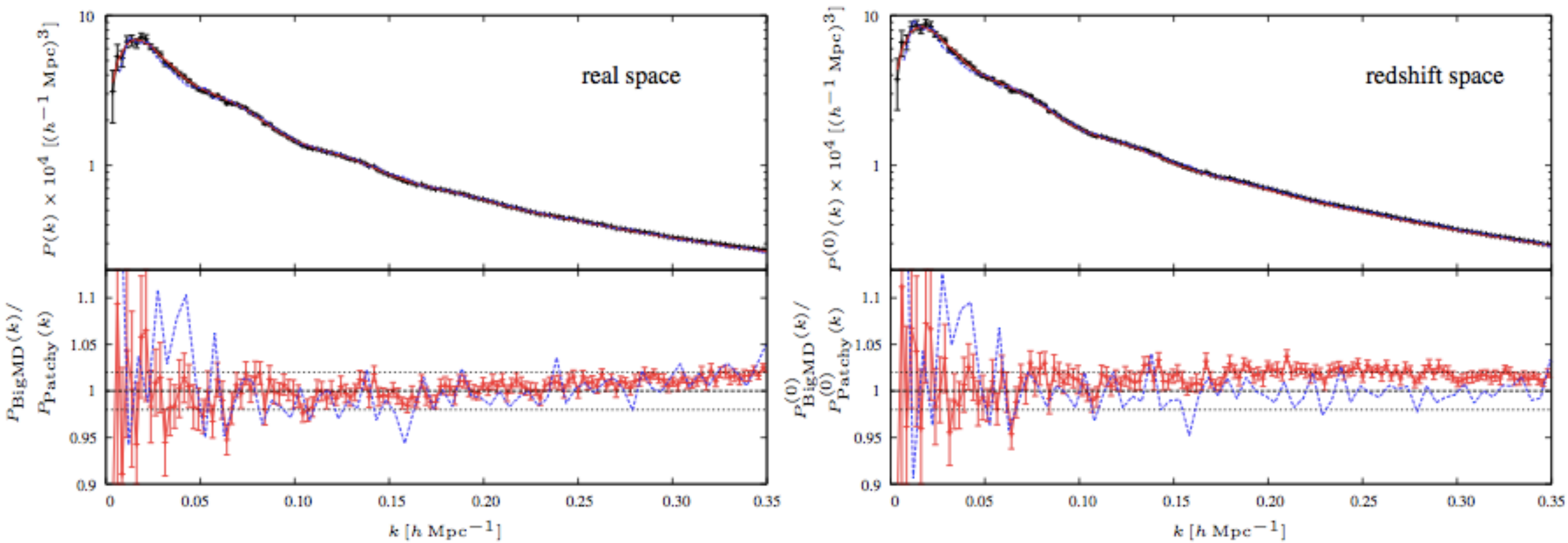
PDF



10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
$N_{\rm cells}$
1
10
$N_{\rm haloes}$
5.0•10^6
4.5•10^6
4.0•10^6
3.5•10^6
1

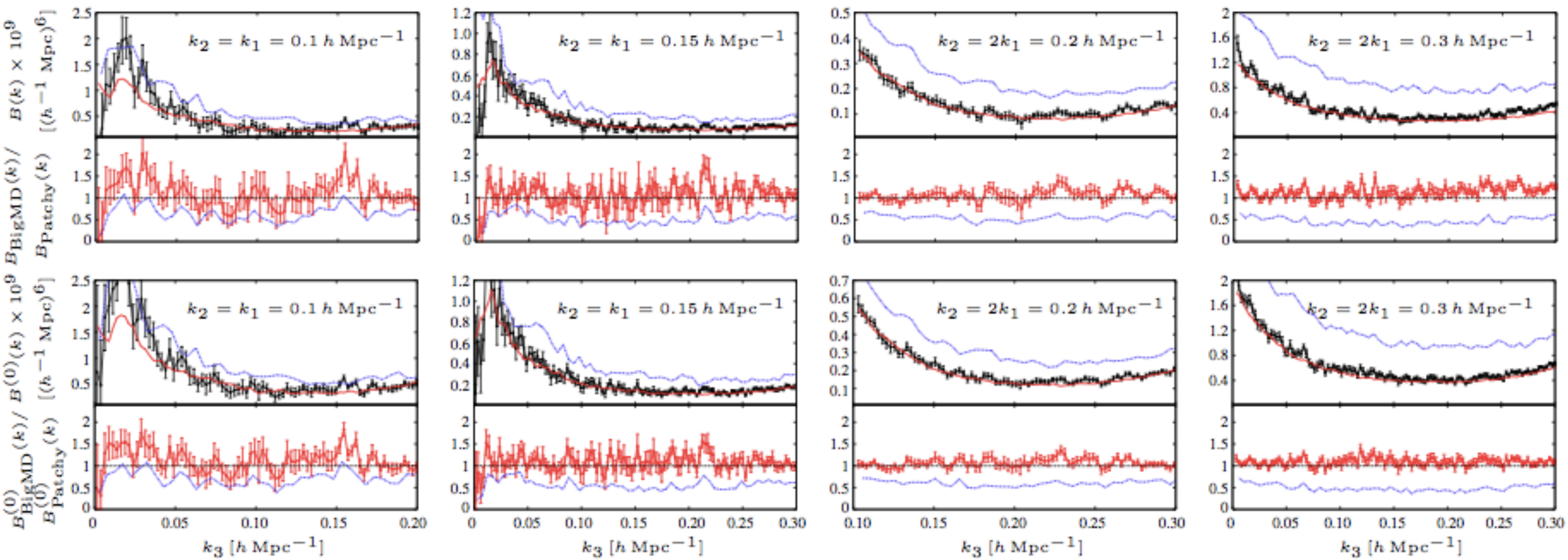
calculations by Hector Gil-Marin

Power spectrum and Monopole



calculations by Hector Gil-Marin

Bispectrum



Three-point function

calculations by Volker Müller

◇ u=1.5

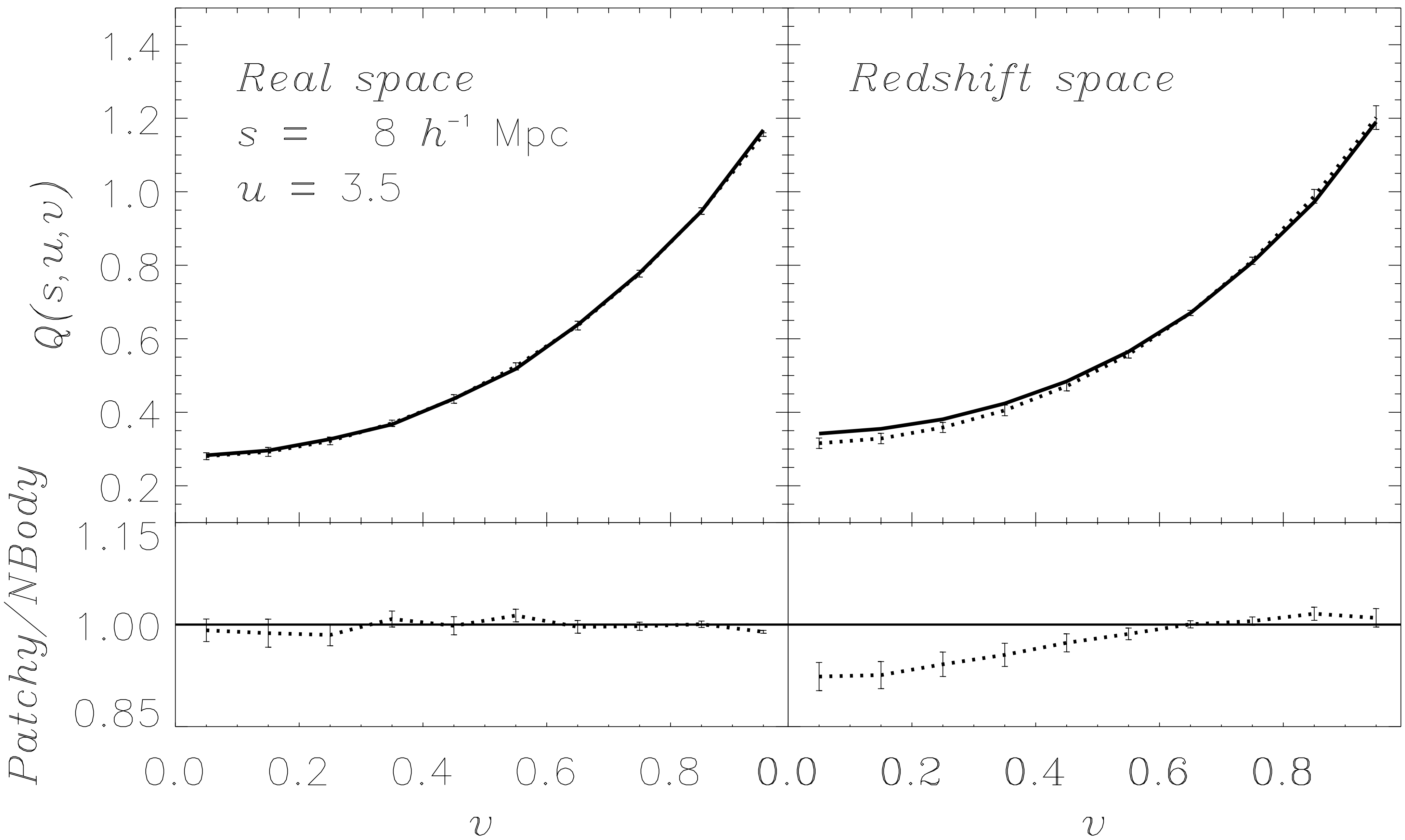
△ u=2.5

□ u=3.5

○ u=4.5

Triangle sides: s, su, and s(u+v)

The 3-point function is described by the hierarchical ansatz
Q(s,u,v) =   (s,u,v)/((r12)   (r23)+c.c.),
i.e. the increase from v=0 to 1 means transition to linear structures.



What parameters are found for LRGs?

$$\rho_h = f_h\,\theta(\rho_{\rm M} - \rho_{\rm th})\,\rho_{\rm M}^{\alpha}\,\exp\left[-\left(\frac{\rho_{\rm M}}{\rho_\epsilon}\right)^{\epsilon}\right]$$

Why do LRGs have a constant linear bias of about 2?

mainly because they reside in the high density peaks!
rho_th and not alpha!

Conclusions

Regarding PATCHY:

- We can efficiently model structure formation with Augmented Lagrangian Perturbation Theory $\longrightarrow$ saves computational time
- We can use an effective statistical biasing description (nonlinear, stochastic, scale-dependent) $\longrightarrow$ saves memory requirements (factor about 50)
- This statistical description can be used for Bayesian inference!
- We have done more than 1000 mocks for BOSS (Scoccola et al in prep)
- PATCHY caveats: PDF still not perfectly fit; needs to be calibrated for each halo population from N-body simulations; not predictive!