

Large Scaling Clustering of Voids

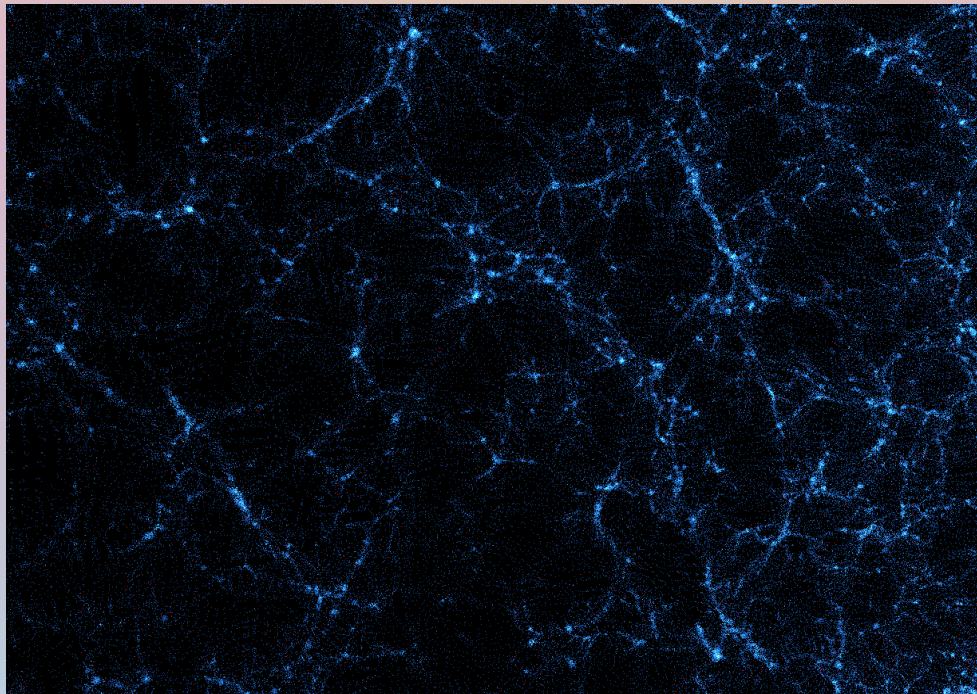
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KCC, N. Hamaus and V. Desjacques, in preparation
KCC and R. Scoccimarro, in preparation

Daejeon Korea, 10 Jul 2014

Cosmic Voids

- Voids are large underdensity region.
- Voids occupy largest volume of the cosmic web, need large survey to get a good statistics.
- Easy to see by eyes, hard to define. Many algorithms proposed, define somewhat different voids.

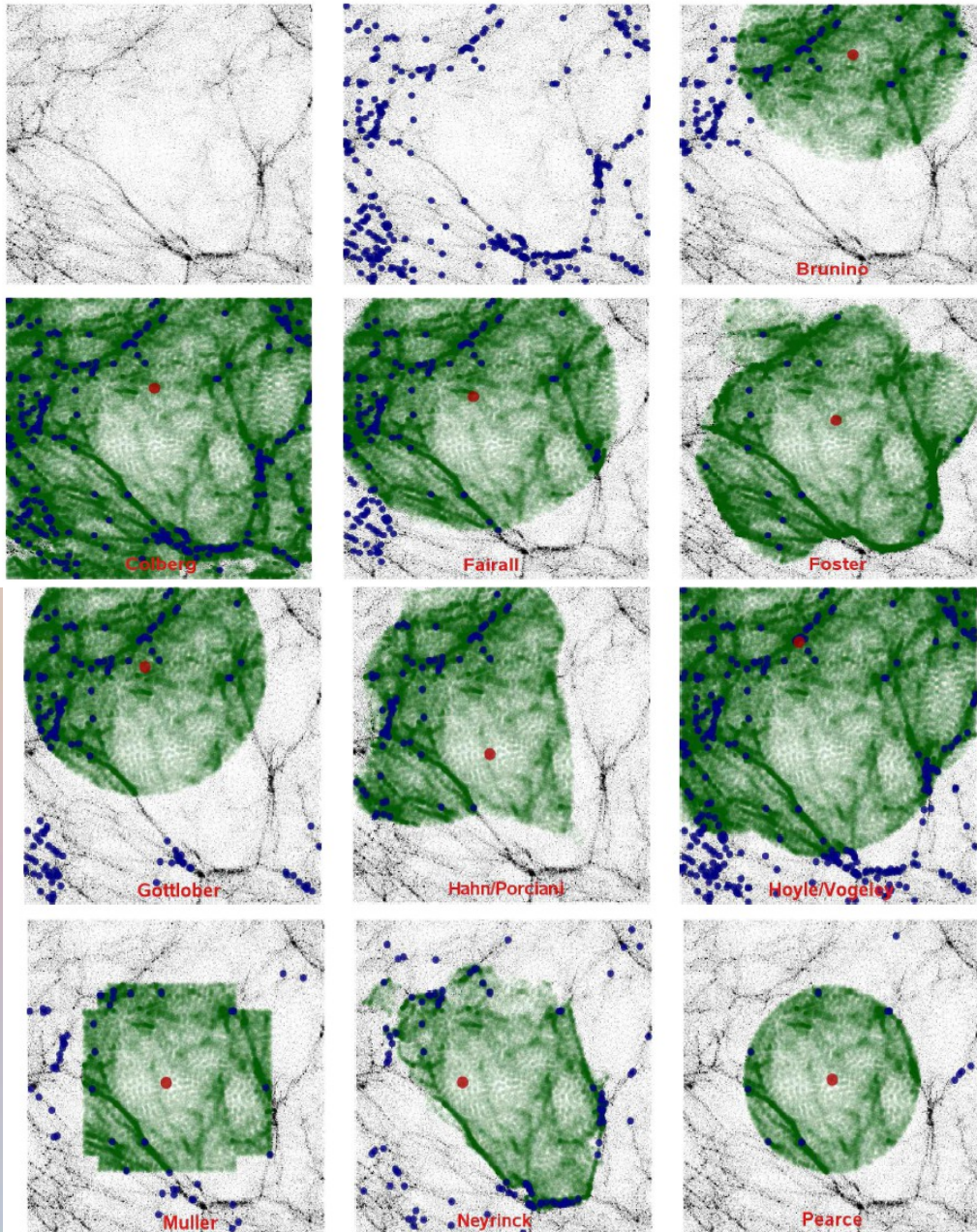


Voids

Much ado about nothing. Shakespeare; SvdW

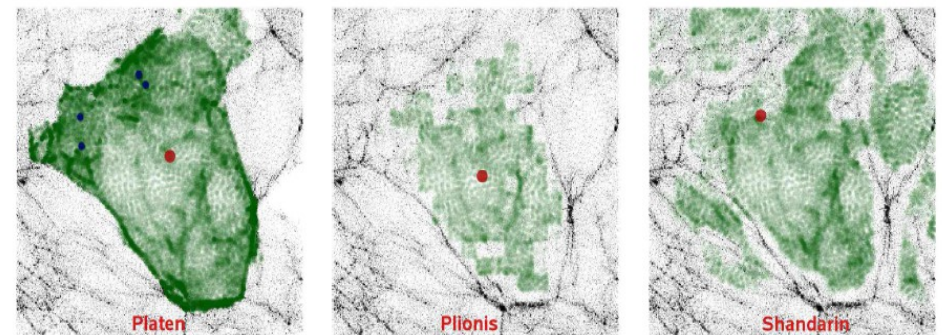
- Good laboratories for testing modified gravity and dark energy because of low matter content.
- Preserve the initial conditions better than halos.
- A lot of studies on the characteristics of individual voids, such as void profile.
- How much cosmological information can we get from the large scale clustering of voids?
- Use N -body simulation to study the clustering of voids.

Void Identification



- Different algorithms to identify somewhat different voids.
- Also depend on the tracers used to construct void.
- The one based on watershed algorithm yield the results close to expectation.

Colberg et al 2008



ZOBOV/VIDE

- Partition particles into cells using Voronoi tessellation.
- Group cells into zones and join zones together to form voids by watershed algorithms.
- (Almost) parameter-free, no assumption on topology of the voids.

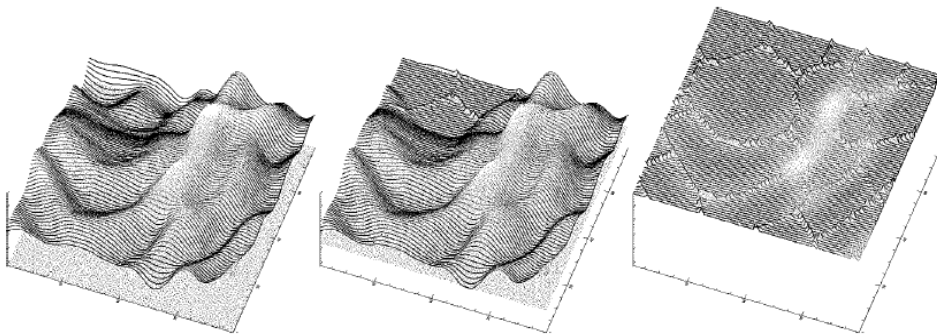
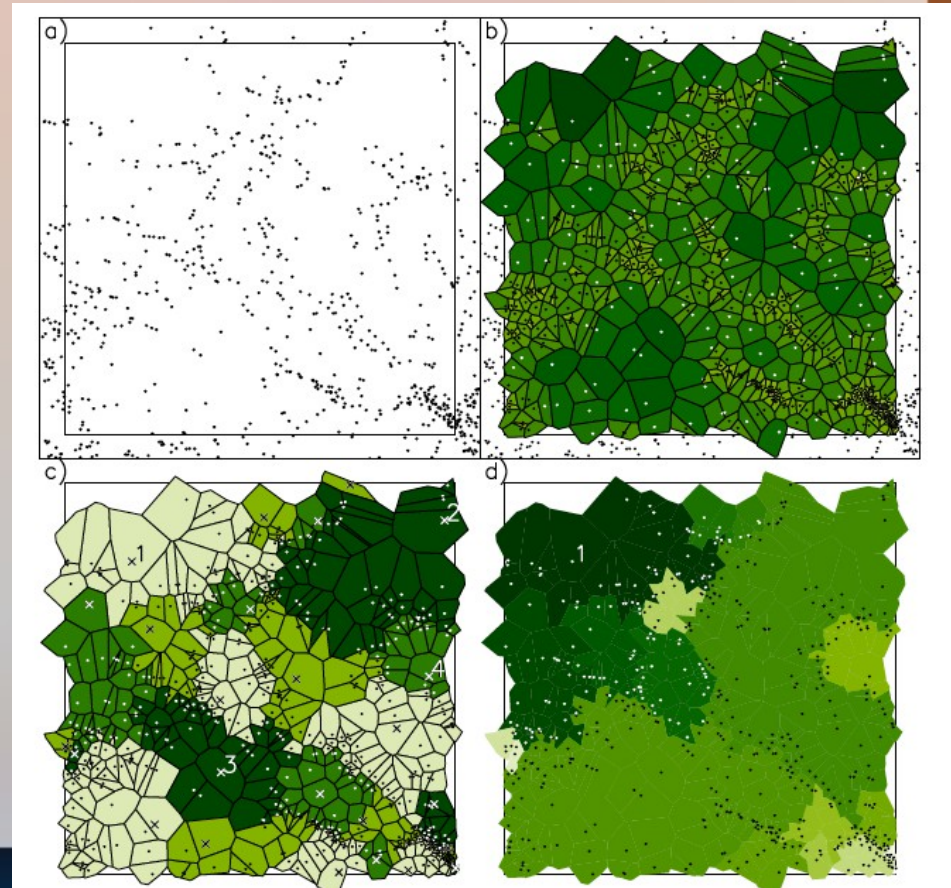


Figure 1. Three frames illustrating the principle of the WST. The left-hand frame shows the surface to be segmented. Starting from the local minima the surrounding basins of the surface start to flood as the water level continues to rise (dotted plane initially below the surface). Where two basins meet up near a ridge of the density surface, a 'dam' is erected (central frame). Ultimately, the entire surface is flooded, leaving a network of dams defines a segmented volume and delineates the corresponding cosmic web (right-hand frame).

Platen et al 2007



Neyrinck 2007

Voids in SDSS

- Voids are identified using SDSS DR7 in Sutter et al 2012, 1207.2524
- Identified using ZOBOV.
- Used main sample ($z < 0.2$) and LRG ($z < 0.4$).
- Maximum number of galaxies in each subsample is about 2×10^5

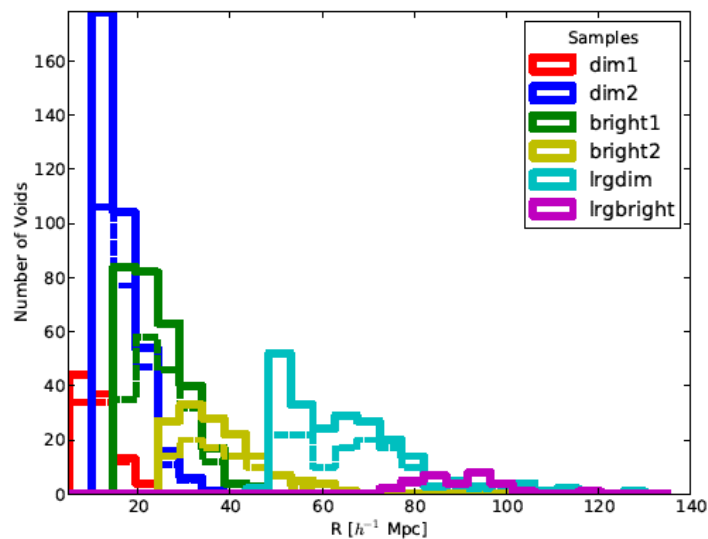
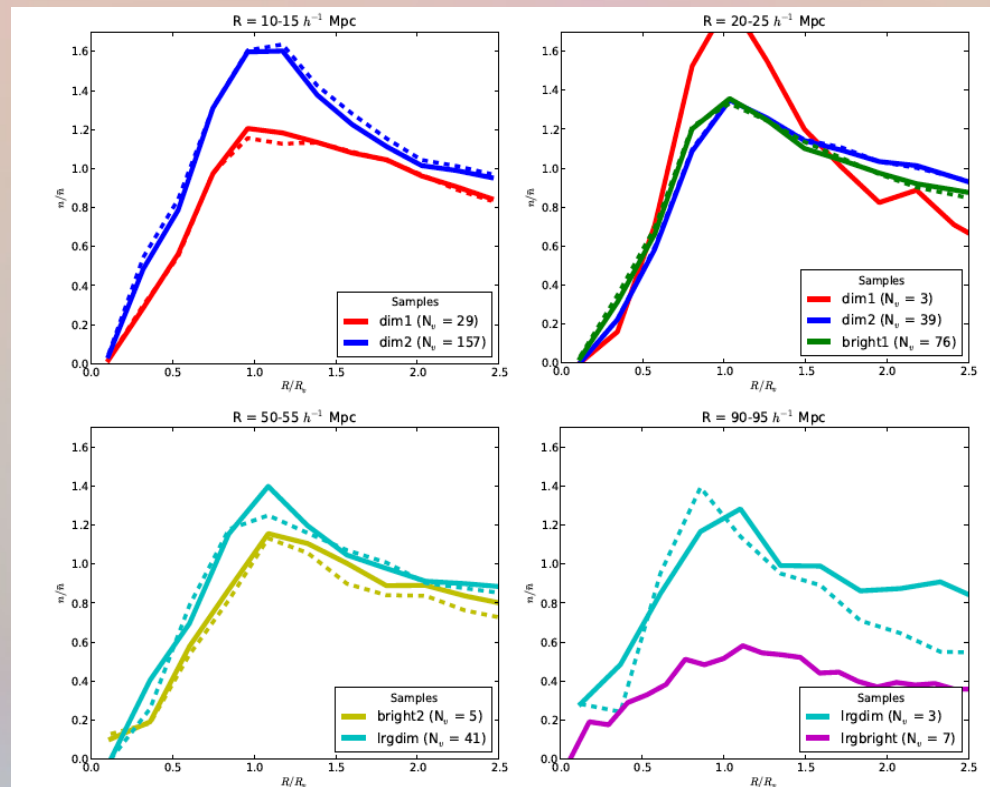


FIG. 7.— *Distribution of void sizes.* We plot histograms of void radii, colored by sample. Solid lines are from the all-void sample, while dashed lines are central voids.



Void Size Distribution (SvdW)

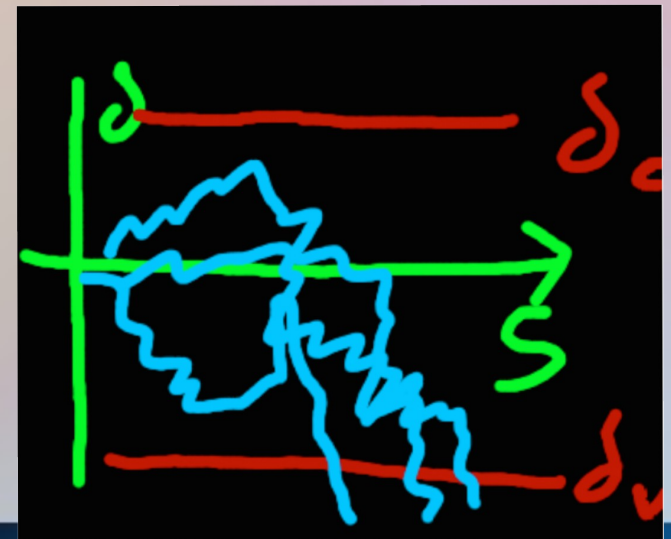
- Excursion set is useful for modeling halo mass function.
- The mass function is mapped to finding a first crossing distribution.
- Sheth and van de Weygaert uses the first crossing distribution with two barriers to model void size distribution.
- δ_v is the threshold for void formation, shell crossing threshold in spherical collapse with a top-hat perturbation, -2.8.
- Excursion set solves cloud-in-cloud problem.
- Voids can't exist in large overdensity region, need the halo formation threshold as well (void-in-cloud problem).

The void mass function is given by

$$\frac{dn}{d \ln M} = \frac{\bar{\rho}}{M} \nu \mathcal{F}(\nu, \delta_v, \delta_c) \frac{d \ln \nu}{d \ln M},$$

where

$$\nu = \frac{|\delta_v|}{\sigma_M}.$$



Void Size Distribution (SvdW)

The first crossing distribution $\mathcal{F}(\nu, \delta_v, \delta_c)$ denotes the distribution that first crosses the barrier δ_v at ν without crossing δ_c for $\nu' > \nu$, and it is given by

$$\mathcal{F}(\nu) = \frac{2D^2}{\nu^3} \sum_{j=1}^{\infty} j\pi \sin(Dj\pi) \exp\left(-\frac{j^2\pi^2 D^2}{2\nu^2}\right),$$

where D is the void-and-cloud parameter

$$D = \frac{-\delta_v}{\delta_c - \delta_v}.$$

For large ν , \mathcal{F} can be approximated by

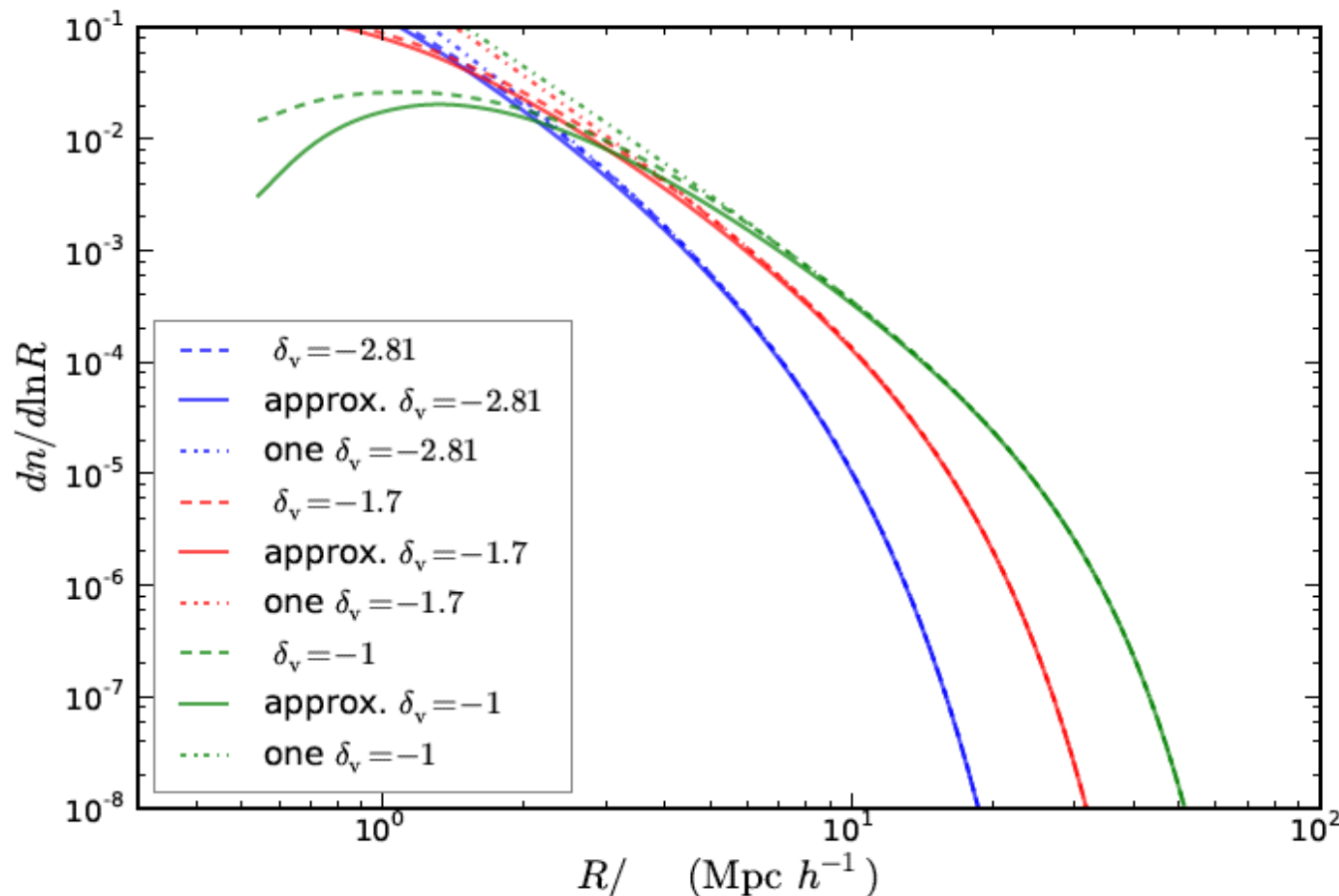
$$\mathcal{F}_{\text{approx}}(\nu) = \sqrt{\frac{2}{\pi}} \exp\left(-\frac{\nu^2}{2}\right) \exp\left(-\frac{|\delta_v|}{\delta_c} \frac{D^2}{4\nu^2} - 2\frac{D^4}{\nu^4}\right).$$

For large R , the first crossing distribution reduces to that of one barrier δ_v problem,

$$\mathcal{F}_{\text{one}}(\nu) = \sqrt{\frac{2}{\pi}} \exp\left(-\frac{\nu^2}{2}\right)$$

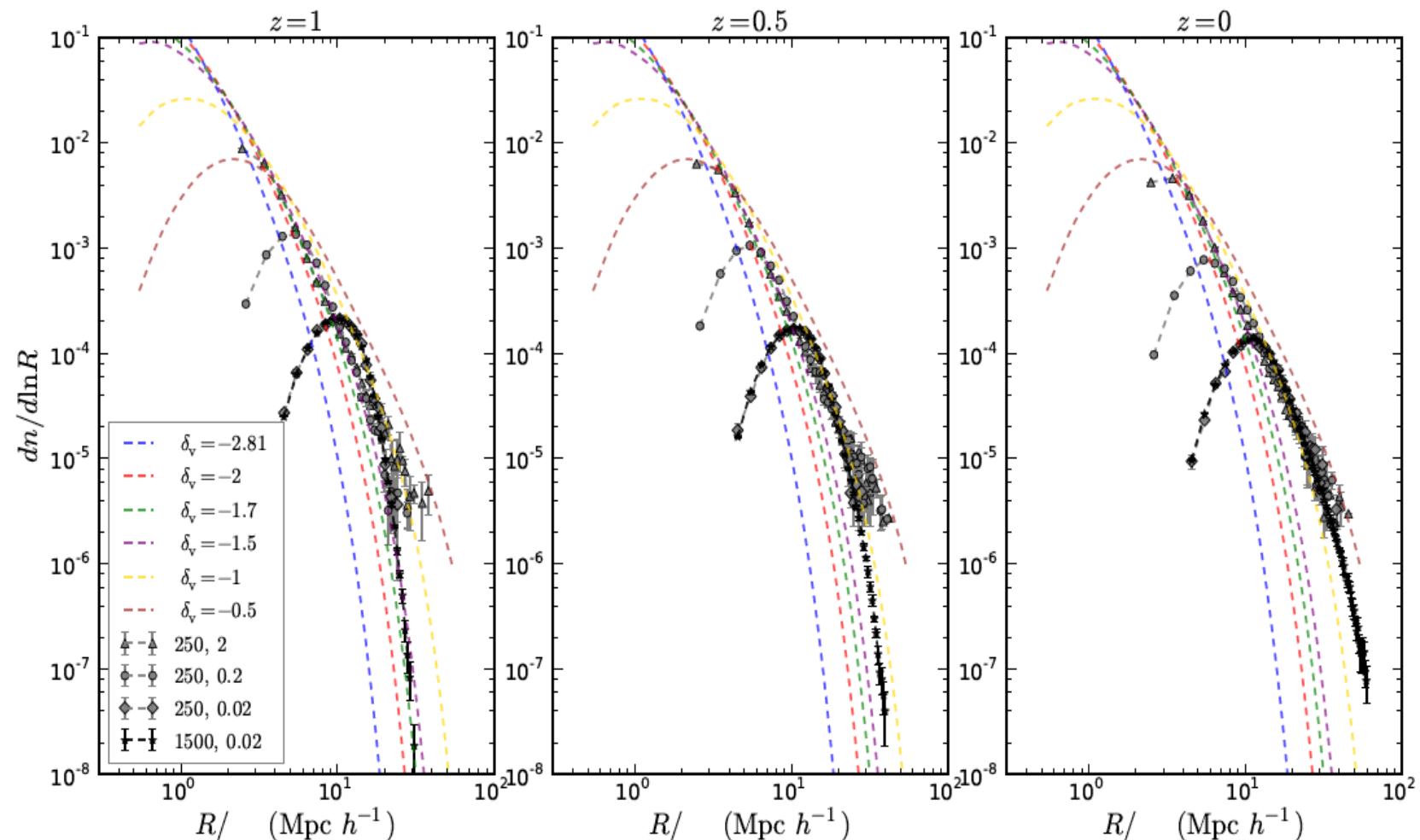
Void Size Distribution (SvdW)

- Lagrangian size is mapped to Eulerian one using spherical collapse model $R_L = 0.58R$
- Use SvdW distribution with δ_v as a free parameter



Void Size Distribution

- Voids are sensitive to the number density of the particles used to construct them.
- Medium voids break up into small ones when the number density is low, but large ones are unaffected



Peak-Background Split Bias of Voids

In the presence of a long wavelength perturbation δ_L , the thresholds δ_v and δ_c are shifted as

$$\delta_v \rightarrow \delta_v - \delta_L, \quad \delta_c \rightarrow \delta_c - \delta_L.$$

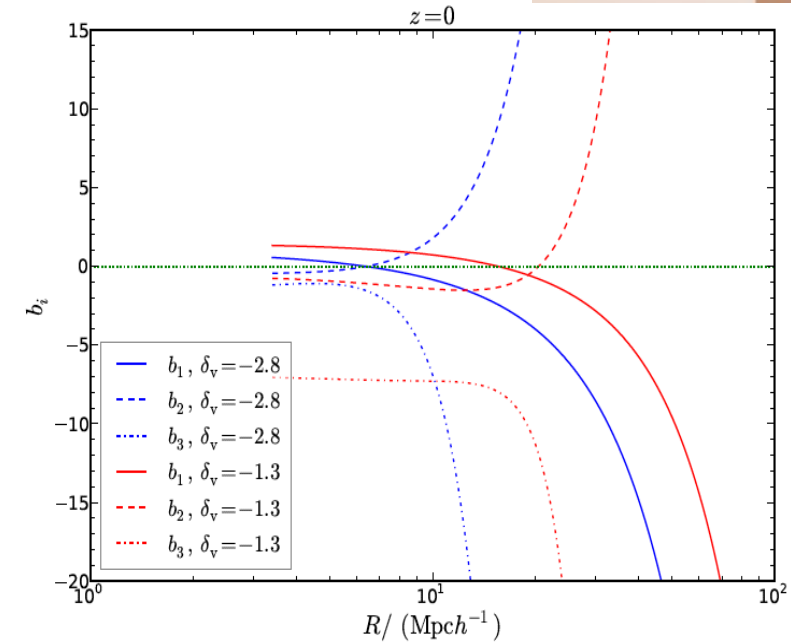
The bias parameters in Eulerian space are given by

$$b_i = \frac{1}{n_0} \frac{\partial^i}{\partial \delta^i} [(1 + \delta)n(\delta_L)] \Big|_{\delta=0},$$

$$b_1 = 1 + \frac{\nu^2 - 1}{\delta_v} + \frac{\delta_v D}{4\delta_c^2 \nu^2},$$

$$b_2 = \frac{2(\nu_2 - 1)}{\delta_v} + \frac{D}{2\delta_c^2} + \frac{\nu^2}{\delta_v^2} [2\delta_v(1 - \nu_2) - 3]$$

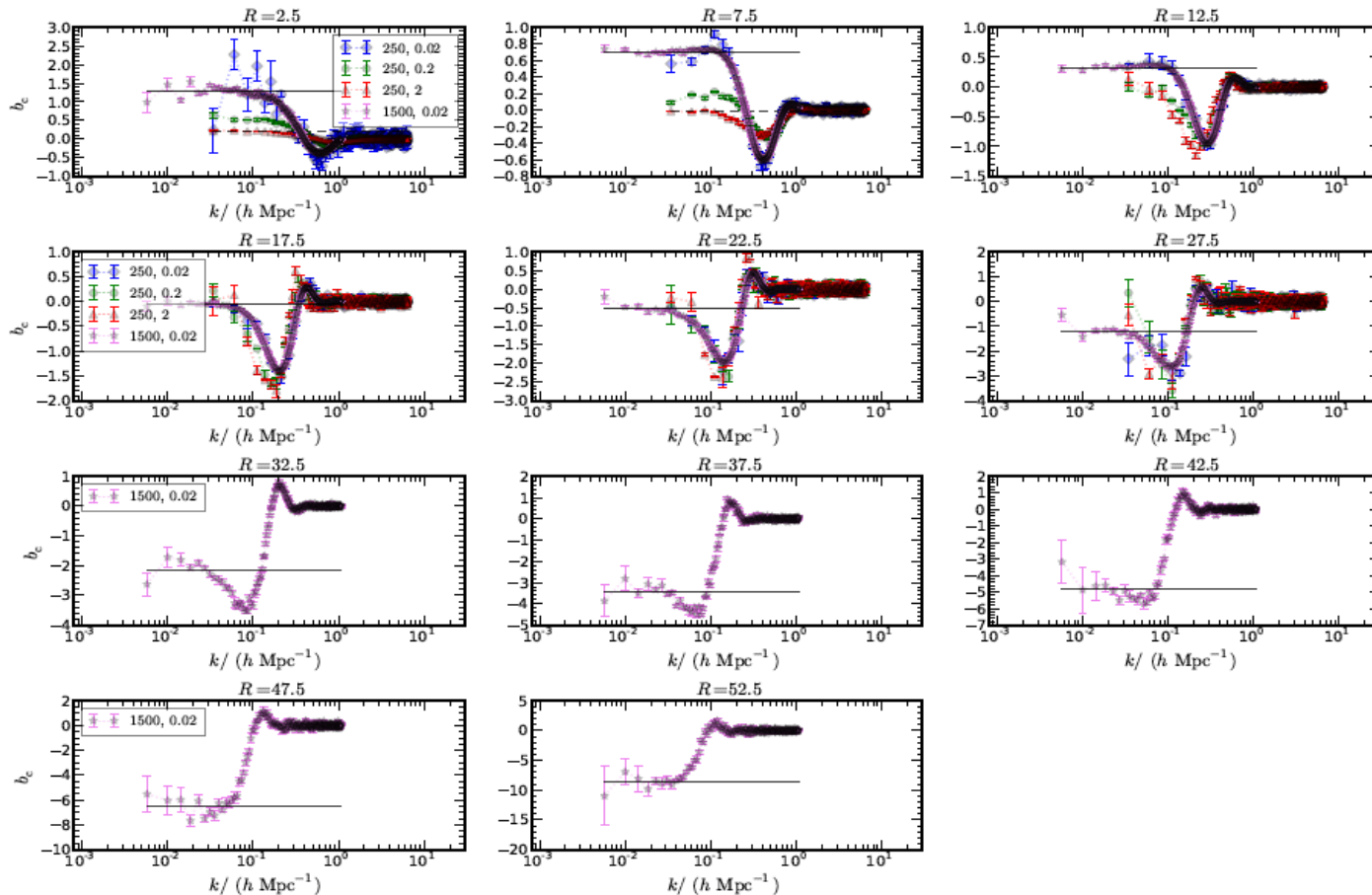
$$+ \frac{\nu^4}{\delta_v^2} \frac{D\delta_v}{2\delta_c^2 \nu^2} \left(1 - \nu_2 + \frac{1}{D\delta_c}\right) + \frac{D^2 \delta_v^2}{16\delta_c^4 \nu^4}$$



Cross Bias of Voids

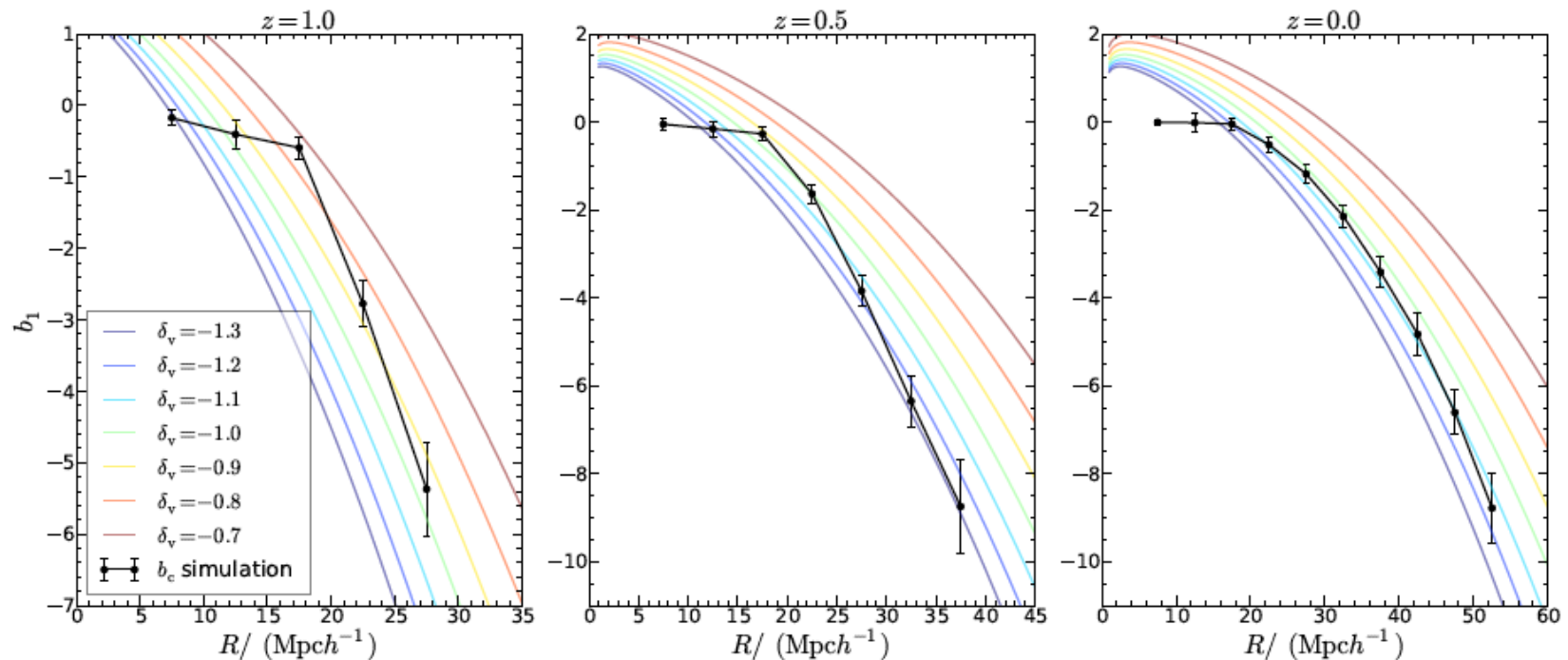
- Using the cross power spectrum btw void and DM to define
- Large scale reaches a constant, small scale show oscillations
- The bias of small voids depends on the sampling density, for large enough voids, convergence is reached.

$$b_c = \frac{P_{vm}}{P_m}$$



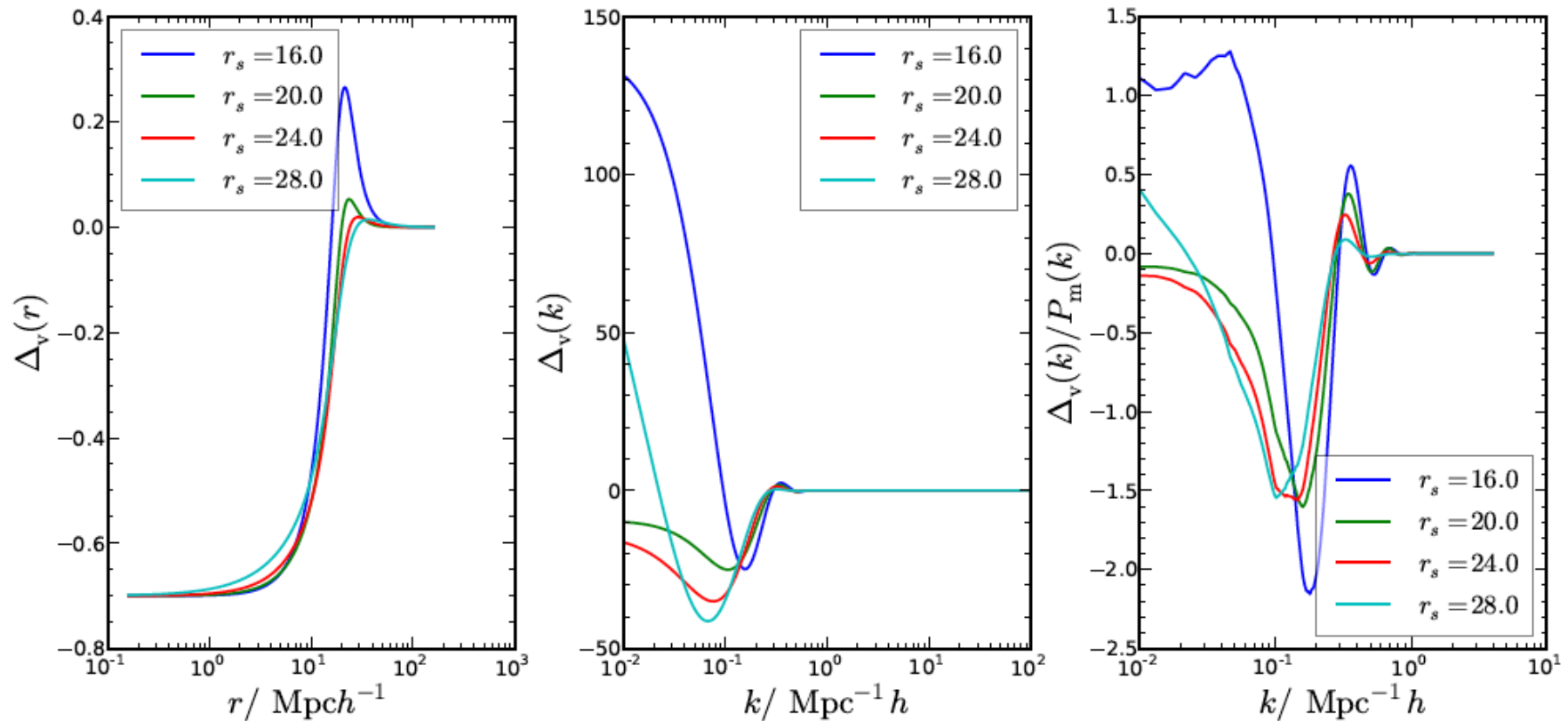
Linear Bias Parameter

- Comparison of linear bias from PBS and simulations.
- No single threshold value work for the whole range, particularly bad for small void.
- Void bias receives large correction from the void profile.



Void Profile

- The cross power spectrum is equal to the Fourier transform of the void profile, $\Delta_v = \frac{\rho_v}{\bar{\rho}_m} - 1$



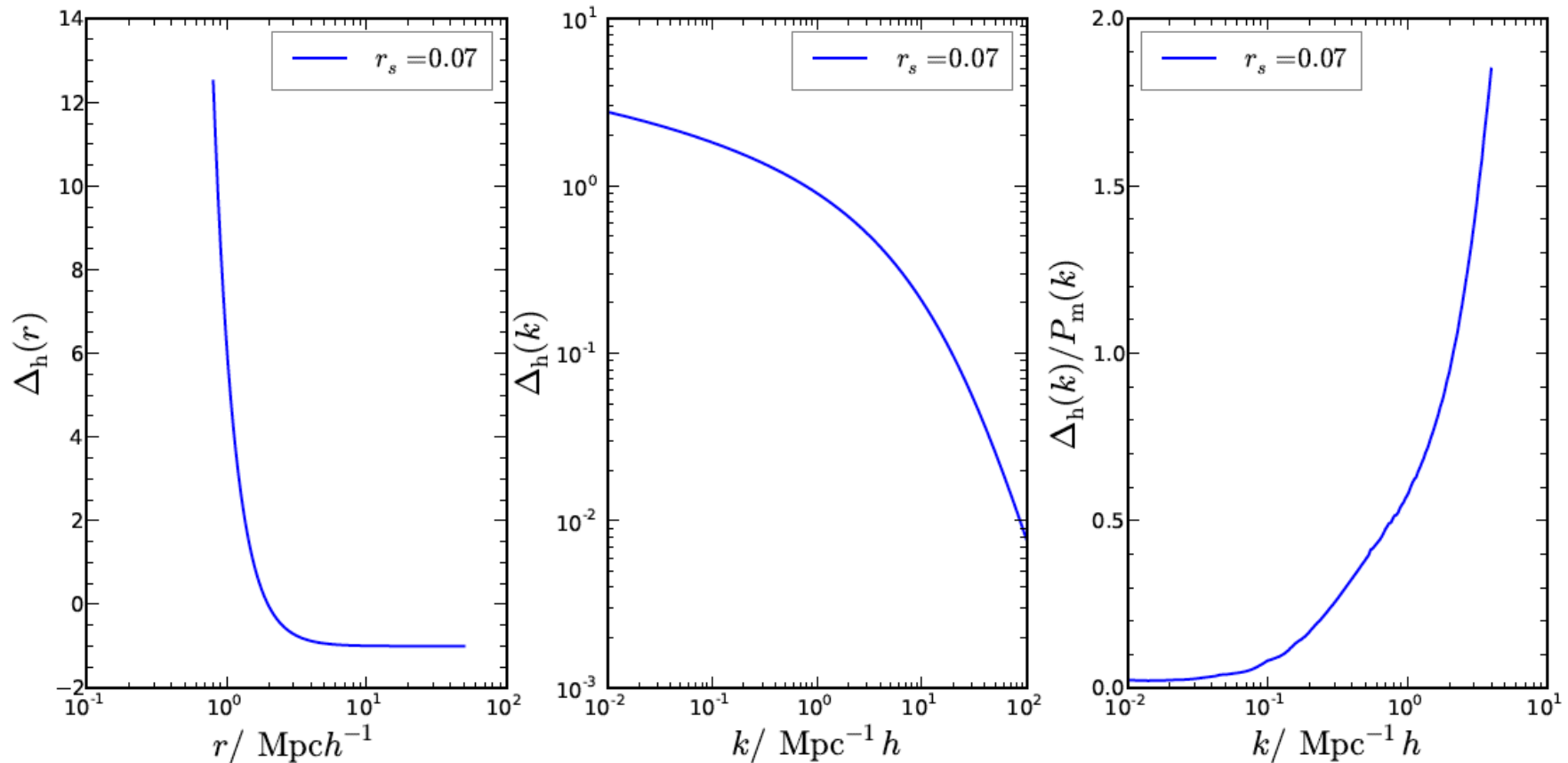
$$\Delta_v = \delta_{\text{cen}} \frac{1 - \left(\frac{r}{r_s}\right)^\alpha}{1 - \left(\frac{r}{R}\right)^\beta},$$

Hamaus et al, 1403.5499

The shape looks similar to that in cross bias. At large scales, in addition to b_1 from clustering, b_c also get contributions from the finite size correction

Halo Profile

At $z = 0$, for $M = 10^{13} M_{\odot} h^{-1}$, $r_{\text{vir}} = 0.54 \text{ Mpc } h^{-1}$, $r_s = 0.07 \text{ Mpc } h^{-1}$, $\rho_s = 1.8 \times 10^{15} M_{\odot} \text{ Mpc}^{-3} h^2$.

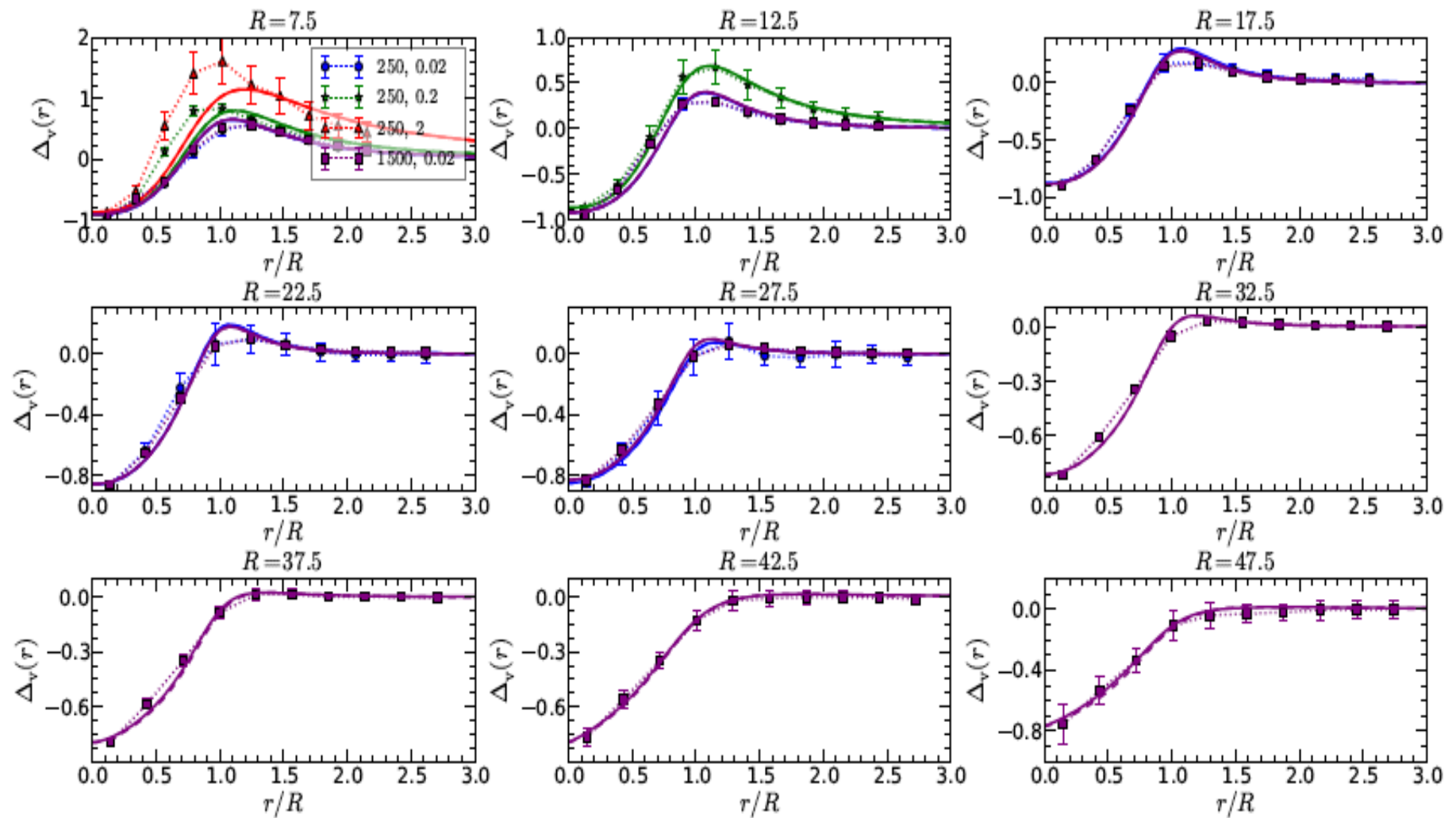


The NFW is given by

$$\rho_h(r) = \frac{\rho_s}{\frac{r}{r_s} \left(1 + \frac{r}{r_s}\right)^2}.$$

Because of its compact size, the halo profile gives negligible contribution to large scale power.

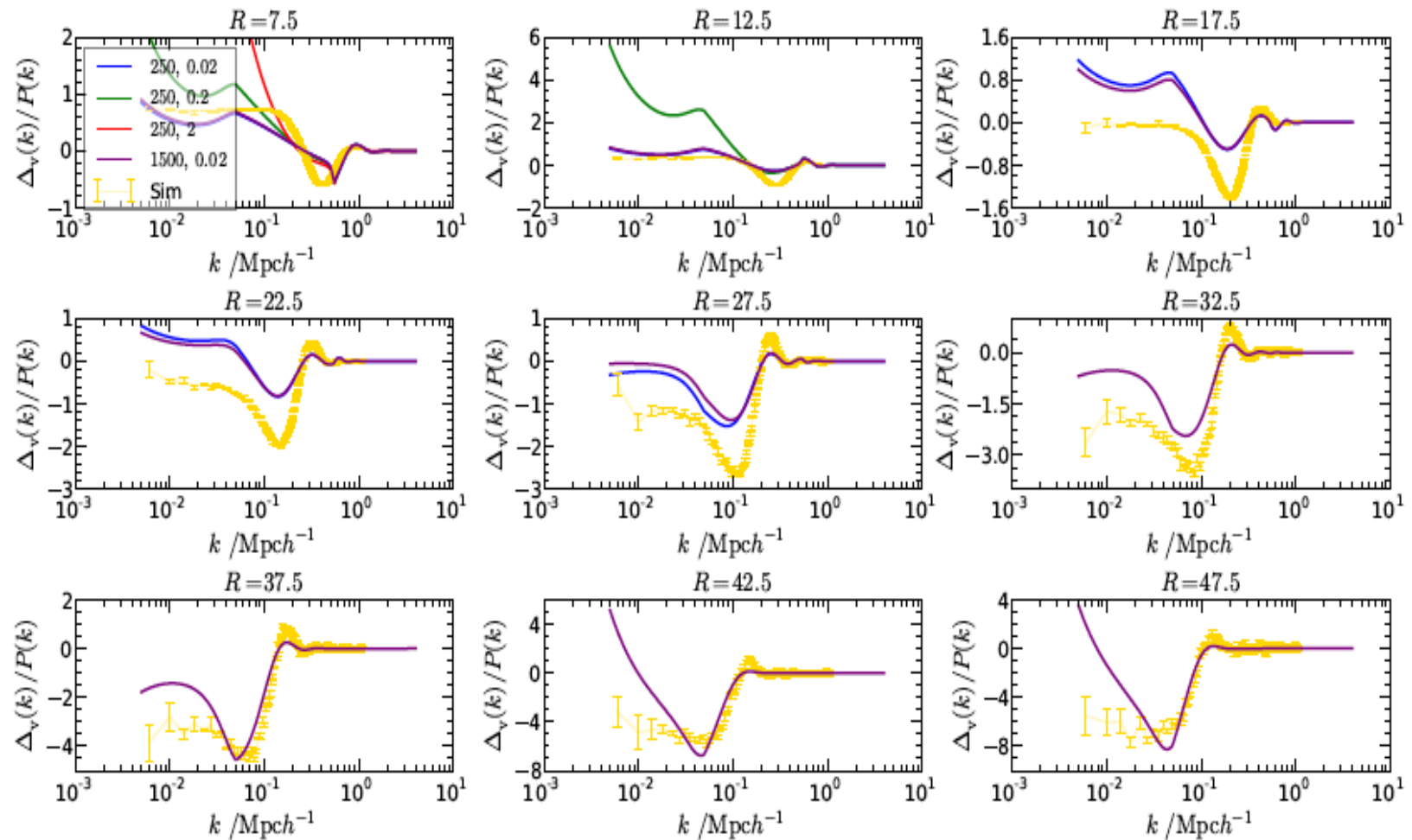
Void Profile



$$\Delta_v = \delta_{\text{cen}} \frac{1 - \left(\frac{r}{r_s}\right)^\alpha}{1 - \left(\frac{r}{R}\right)^\beta},$$

The fit to simulation void is good except for some feature mismatch.

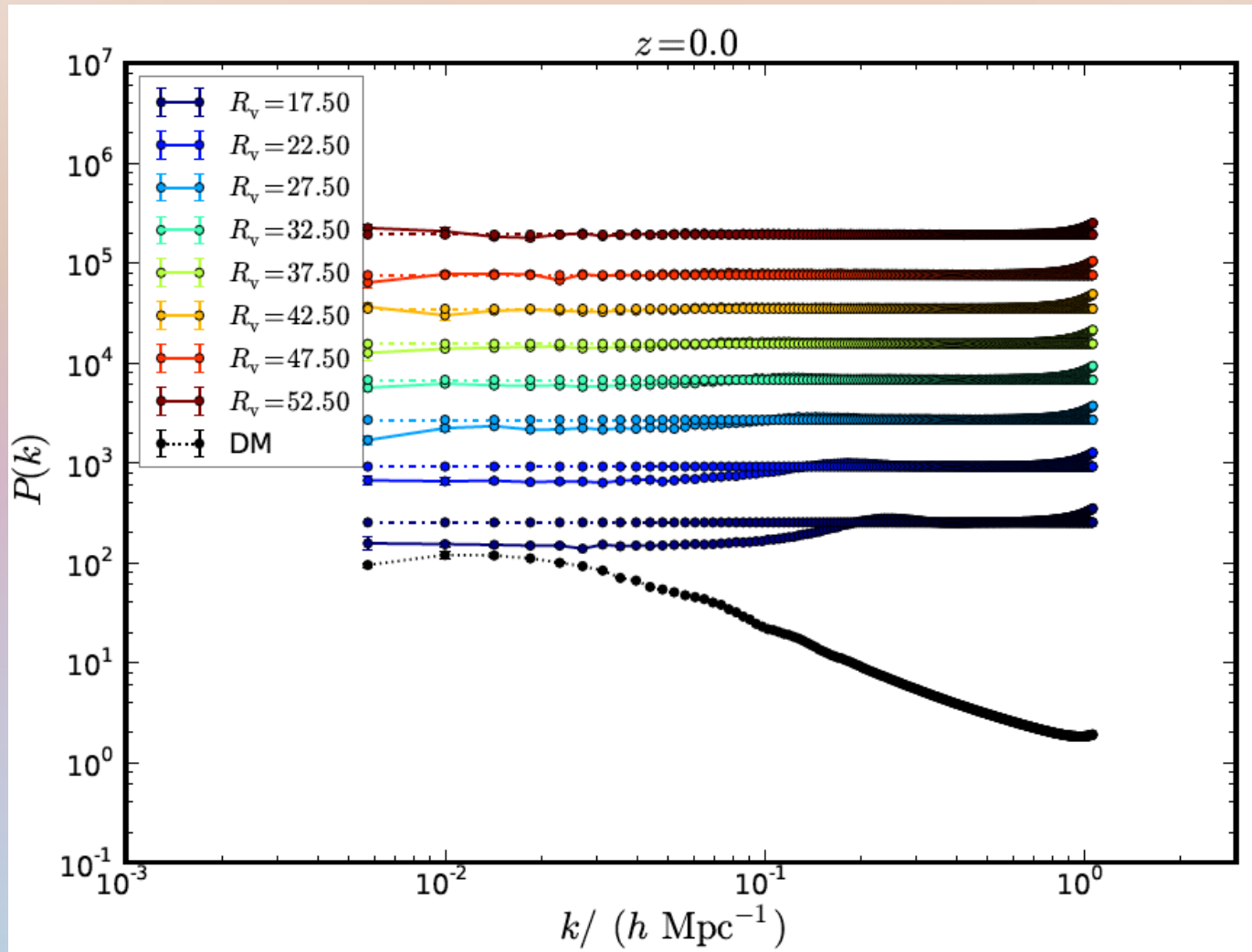
Void Profile vs Void Cross Power Spectrum



- Qualitatively agree with each other.
- The low k part is not right as the void profile is not accurately for $r >$ a few void radius.
- The “phase” of oscillatory parts are correct, but the amplitudes are slightly too large.

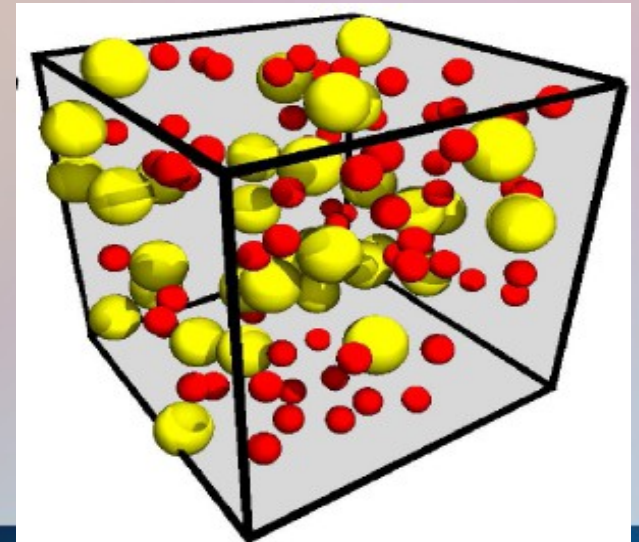
Void Power Spectrum

- Void power spectrum is dominated by Poisson shot noise and void exclusion effect.



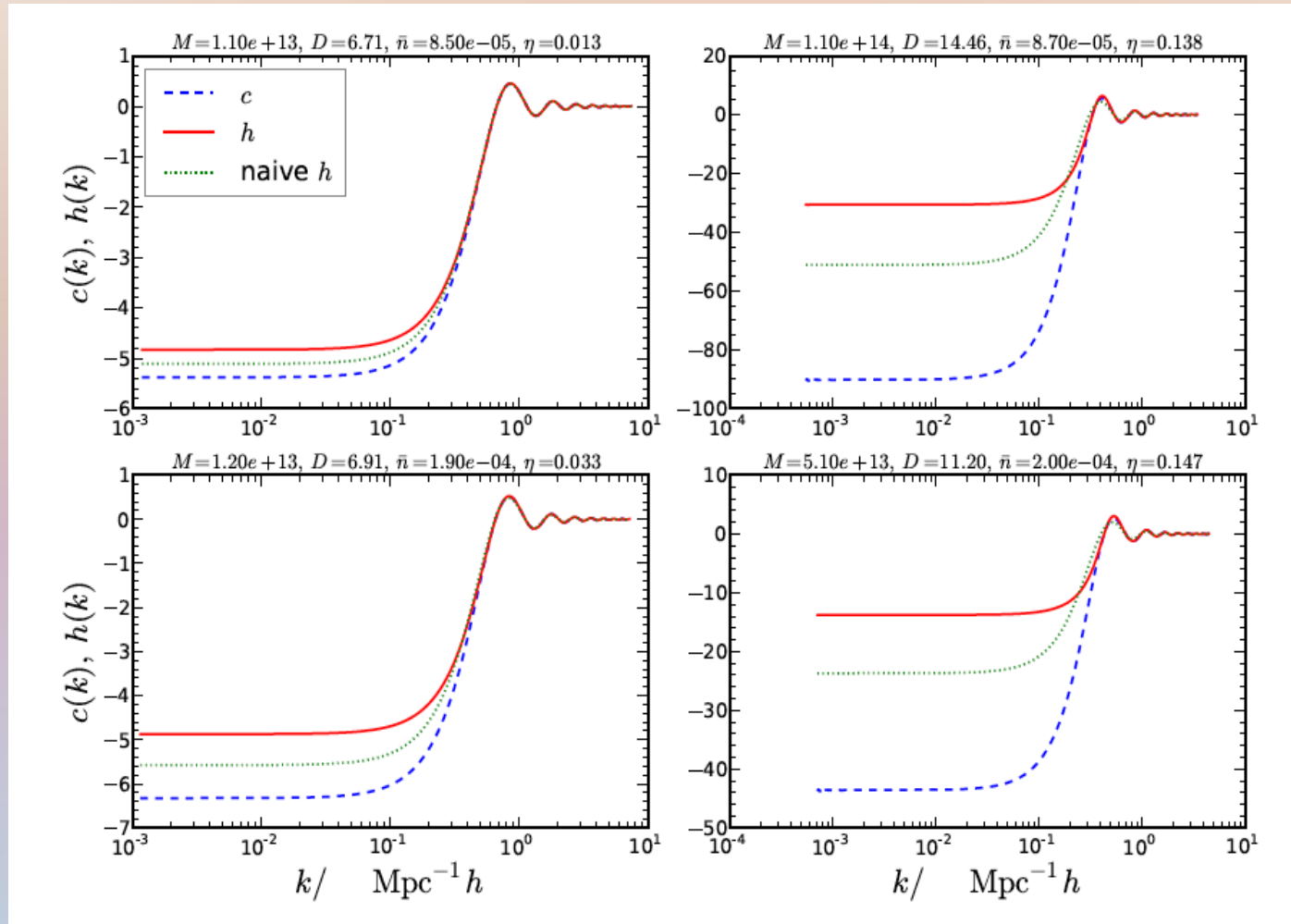
Hard Sphere Model

- Non-penetrating hard spheres are used in statistical mechanics for modeling non-ideal gas and liquids.
- Use hard spheres to model the halo and void exclusion effects.
- Borrow well-known results from statistical mechanics, in particular the the correlation functions of a system of hard spheres in equilibrium.



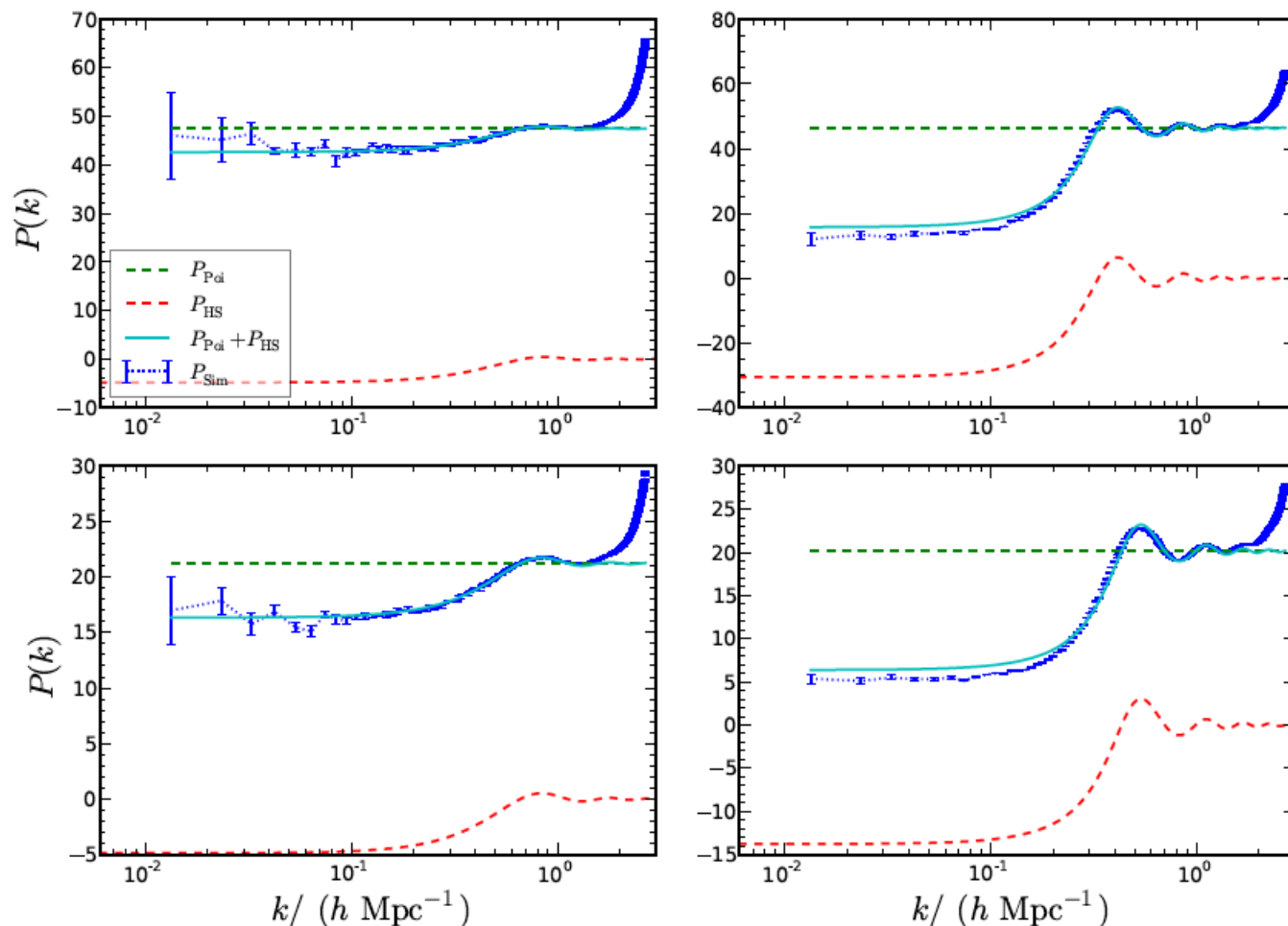
Hard Sphere Model

- The hard sphere power spectrum



Hard Sphere Model

- Generate spheres by Random Sequential Addition, and compare its power spectrum with Hard Sphere model.



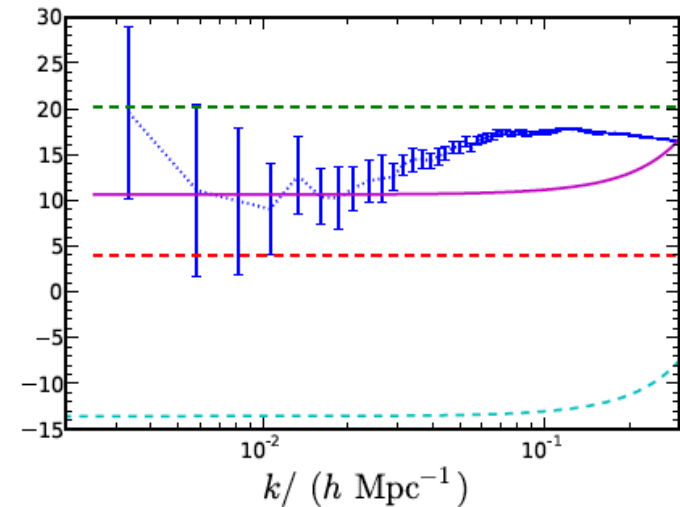
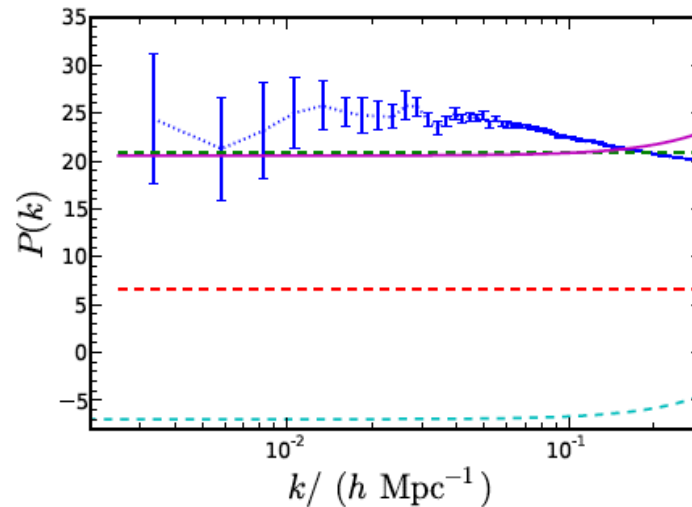
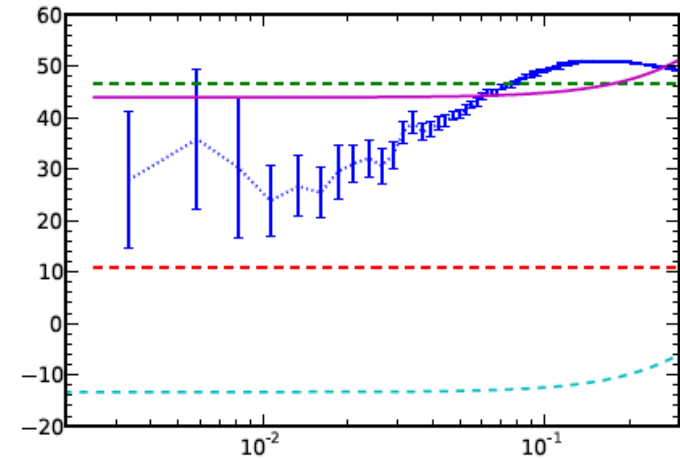
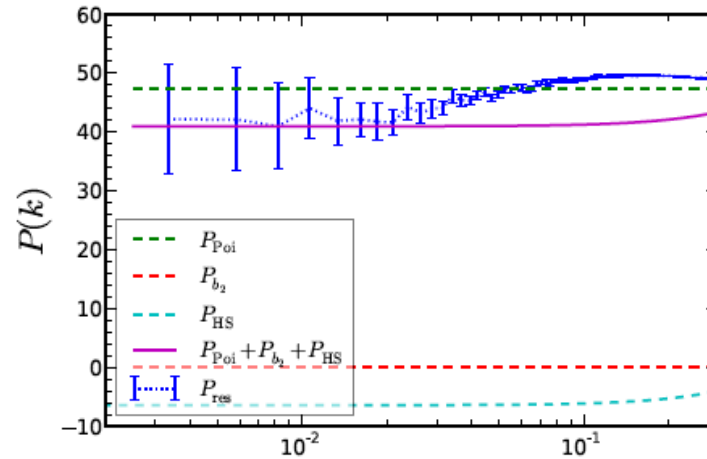
Noise in halo power spectrum

- Imagine there is a continuous distribution, perturbatively determined by bias parameters.
- Sampling of this continuous field introduce two additional correlation: the Poisson shot noise due to discreteness of halos, and the hard spheres exclude each other.
- At large scale, nonlinear bias also introduces noise at large scales

$$P_{b_2} = \frac{b_2^2}{2} \int d^3q P^2(q).$$

Noise in halo power spectrum

$$P_{\text{res}} = P_{\text{h}} - b_1^2 P_{\text{m}},$$



b_1 measured from cross power spectrum, b_2 measured from cross bispectrum.

Void exclusion

- Hard sphere model should be able to model the void exclusion effect in void power spectrum ...

Conclusion

- We study the size distribution of voids, and the bias parameter of voids using numerical simulations.
- We relate the cross power spectrum with the void profile.
- We show the exclusion effect of halo power spectrum can be modeled by hard sphere model and possibly for voids.