Void clustering constraint on primordial non-Gaussianity

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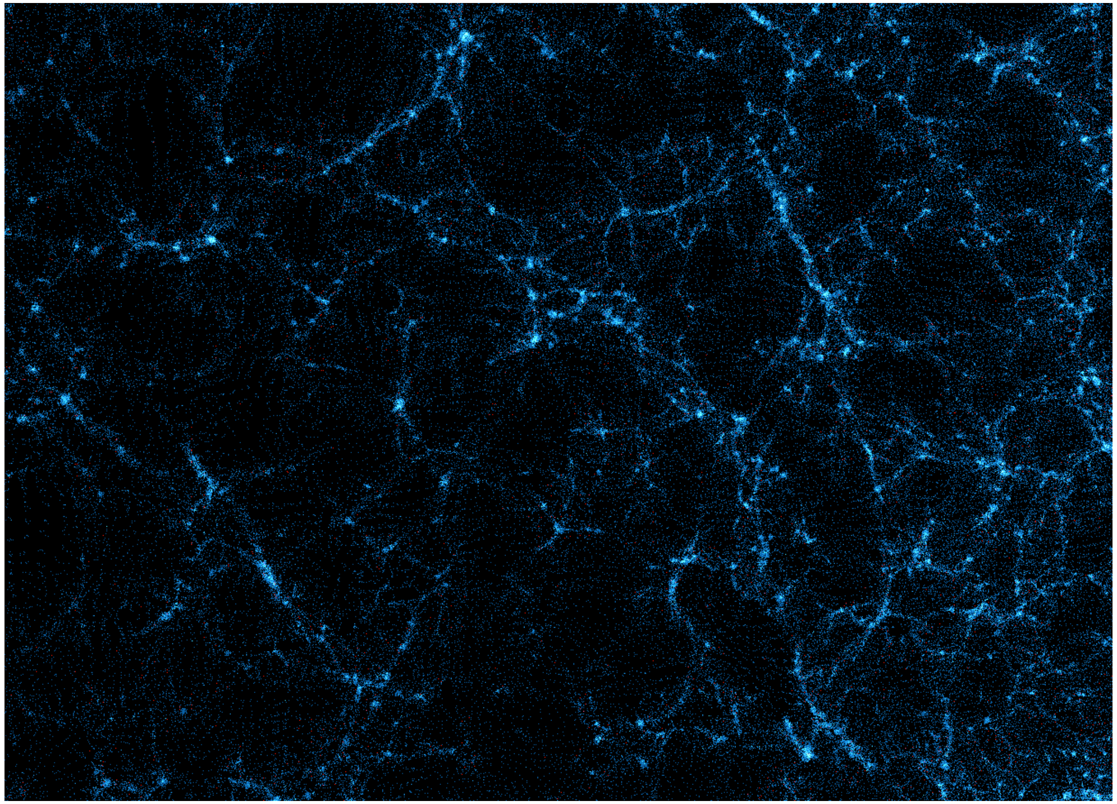
IPMU, 3 Oct 2018

KCC, Hamaus & Desjacques, 1409.3849
KCC, Hamaus, Biagetti, in preparation

Cosmic Voids

- Voids are large under density region, occupy largest volume of the cosmic web, need large volume to get a good statistics
- Hold the information complementary to the halo clustering
- Easy to see by eyes, hard to define. Many algorithms proposed, define similar by not identical voids



Voids

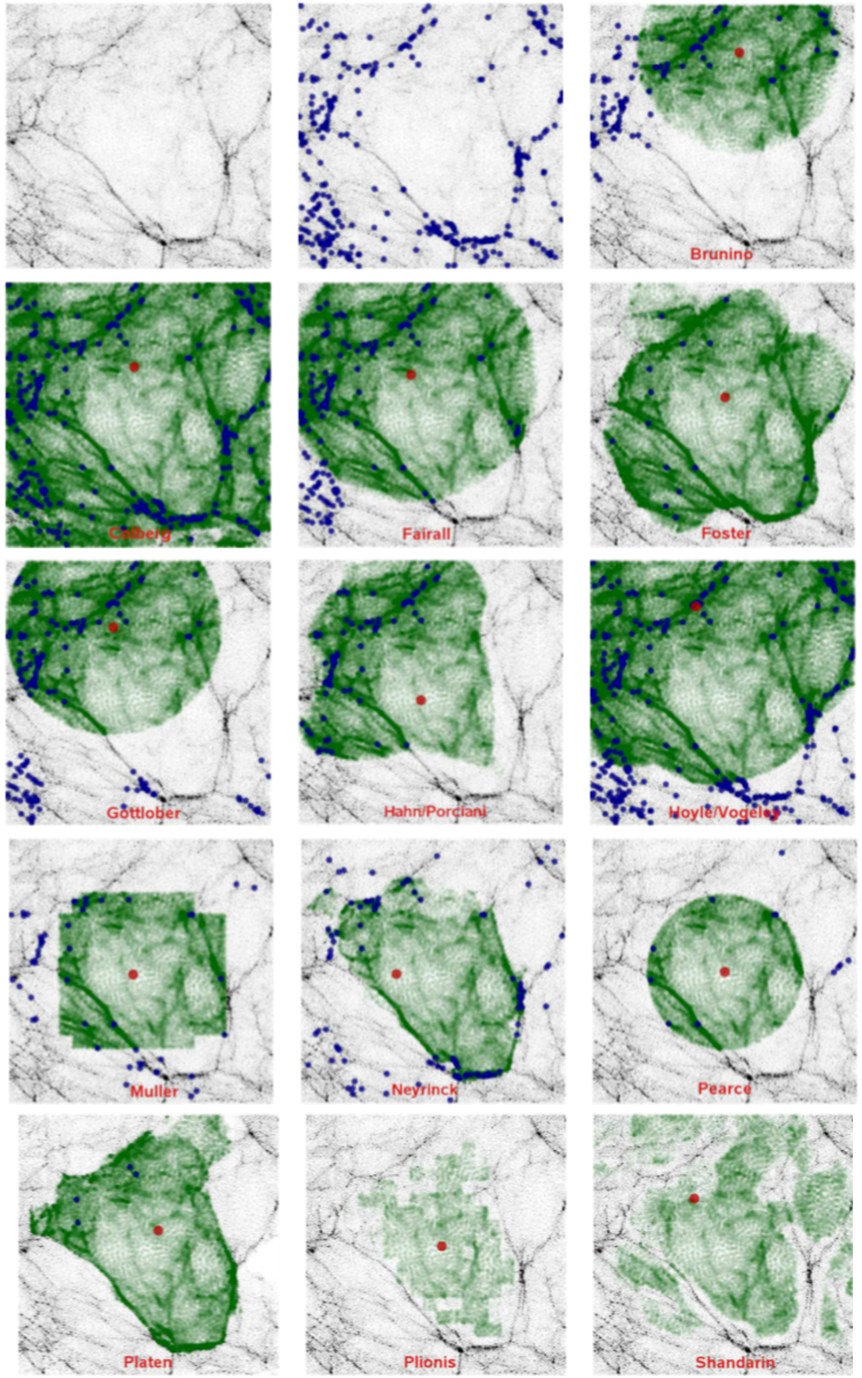
Much ado about nothing.

Shakespere; Sheth & van der Weygaert

- Good laboratories for testing modified gravity and dark energy because of low matter content
- Preserve the initial conditions better than halos
- Most studies on the characteristics of individual voids, such as the void profile, easy to increase the S/N by stacking the voids
- The underdense regions also traces the large-scale structure, similar to halos. But need large volume for good statistics

Void Identification

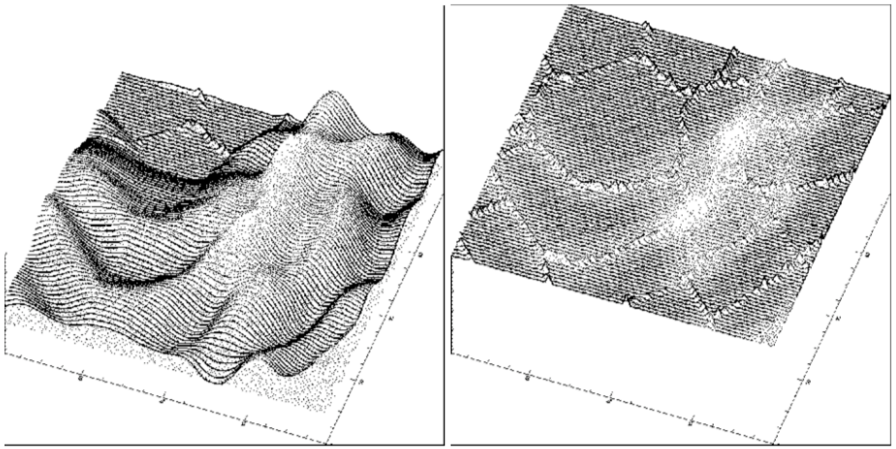
- Different algorithms have been proposed to identify voids.
- Voids identified by different algorithms are somewhat different. Some can be very off.
- The watershed algorithm yields results close to expectation.
- Void identification also depends on the tracers and the number density



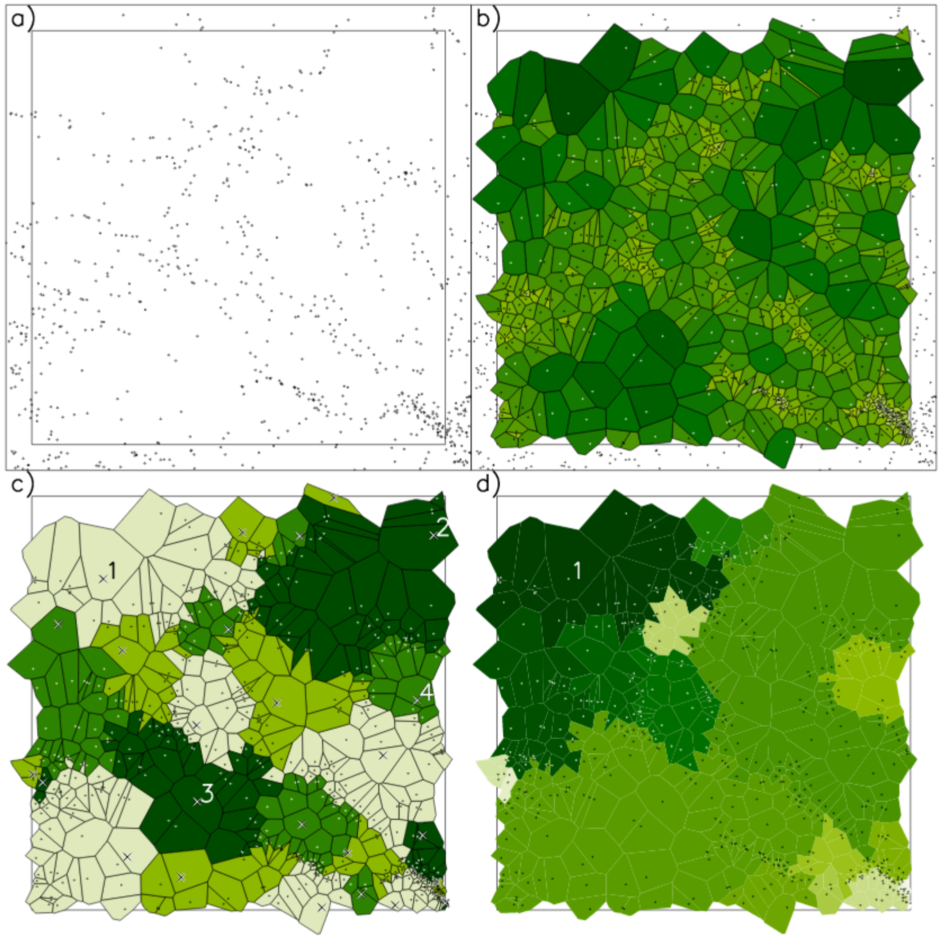
Colberg et al, 0803.0918

ZOBOV / VIDE

- Partition the 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 the topology of the voids



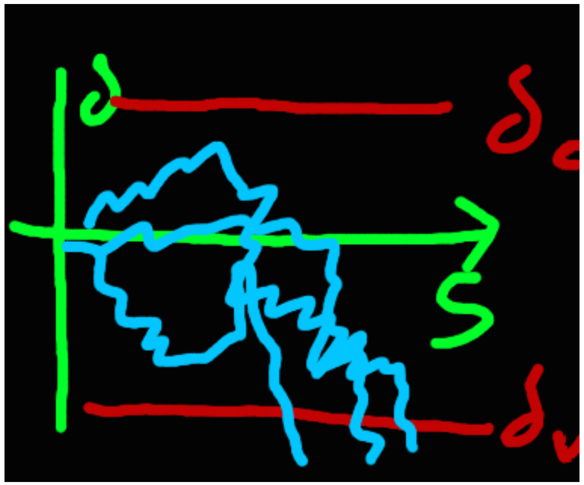
Platen et al, 0706.2788



Neyrinck, 0712.3049

Void Size Distribution

- Excursion set is useful for modeling the halo mass function
- Sheth & van de Weygaert used the excursion set theory with two thresholds to model the void distribution
- A threshold for void formation, delta_v. Analogous to the threshold for halo formation. The value corresponding to shell crossing in spherical collapse, -2.8 is used.
- Since an underdenisty in a large-scale over density will be crushed out of existence when the overdensity collapses, the constraint the trajectory crosses delta_v before crossing delta_c is imposed.



SvdW Void Size Distribution

The void mass function is given by

$$\frac{dn}{d\ln M} = \frac{\bar{\rho}}{M}\nu\mathcal{F}(\nu, \delta_{\rm v}, \delta_{\rm c})\frac{d\ln\nu}{d\ln M}, \qquad \nu = \frac{|\delta_{\rm v}|}{\sigma_M},$$

where $\delta_{\rm c}$ is the halo formation barrier and $\delta_{\rm v}$ is the void formation barrier.

The first crossing distribution $\mathcal{F}(\nu, \delta_{\rm v}, \delta_{\rm c})$ denotes the distribution that first crosses the barrier $\delta_{\rm v}$ at ν without crossing $\delta_{\rm c}$ for $\nu' > \nu$, and it is given by

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

where D is the void-and-cloud parameter $D = -\delta_{\rm v}/(\delta_{\rm c} - \delta_{\rm v})$.

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

$$\mathcal{F}_{\rm approx}(\nu) = \sqrt{\frac{2}{\pi}}\exp\Big(-\frac{\nu^2}{2}\Big)\exp\Big(-\frac{|\delta_{\rm v}|}{\delta_{\rm c}}\frac{D^2}{4\nu^2} - 2\frac{D^4}{\nu^4}\Big).$$

For large R, the first crossing distribution reduces to that of one barrier $\delta_{\rm v}$ problem,

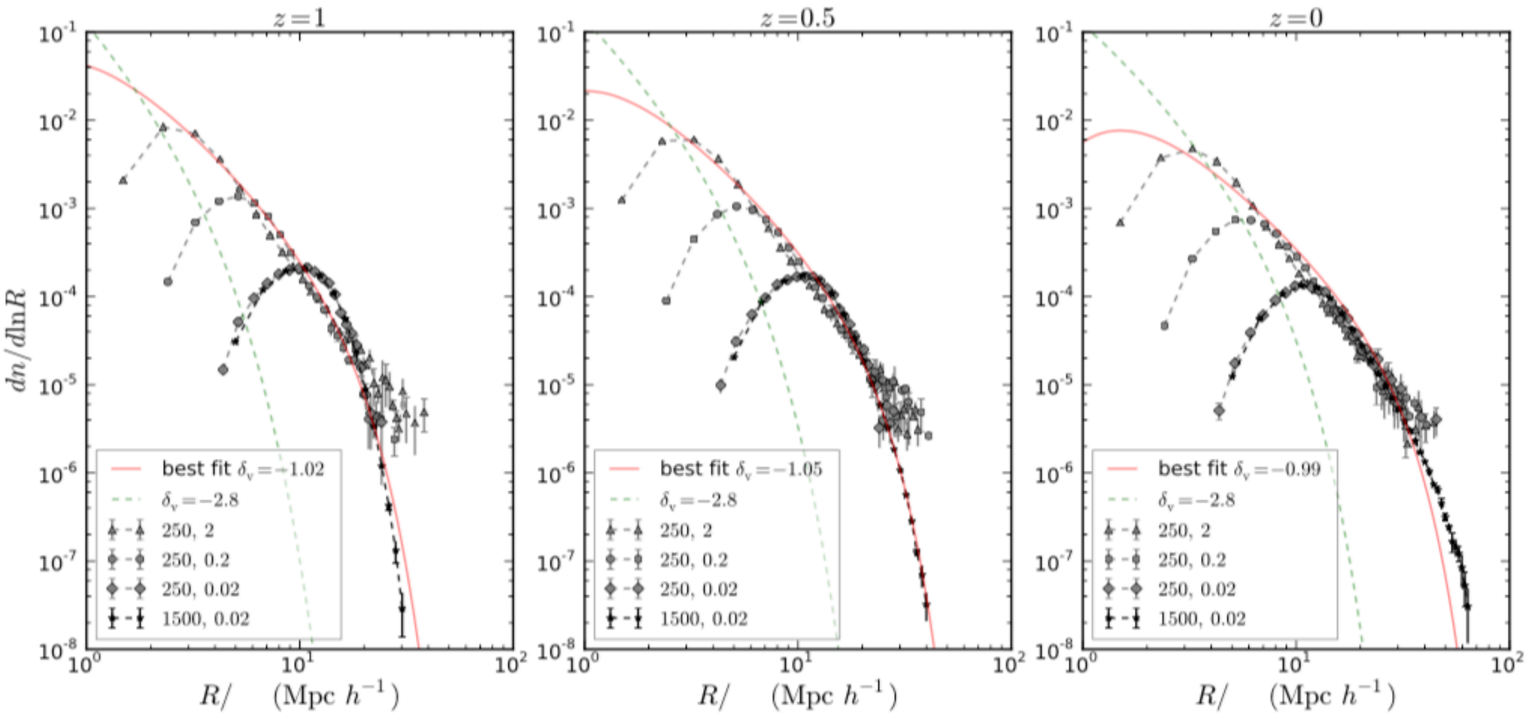
$$\mathcal{F}_{\rm one}(\nu) = \sqrt{\frac{2}{\pi}}\exp\Big(-\frac{\nu^2}{2}\Big)$$

Void size distribution

- The void size distribution is sensitive to the number density of the particles used to construct them. Medium voids break us voids smaller ones when tracer density is low, but large ones are unaffected.

- SvdW form approximately fits the void size distribution when delta_v is taken as a free parameter.

- As the the numerical voids may correspond to the SvdW voids, some apply further processing on the watershed voids to get closer to theoretical one, e.g. Jennings et al 11304.6087, at a cost of further reducing the number density.



Peak-background split (Gaussian) void bias

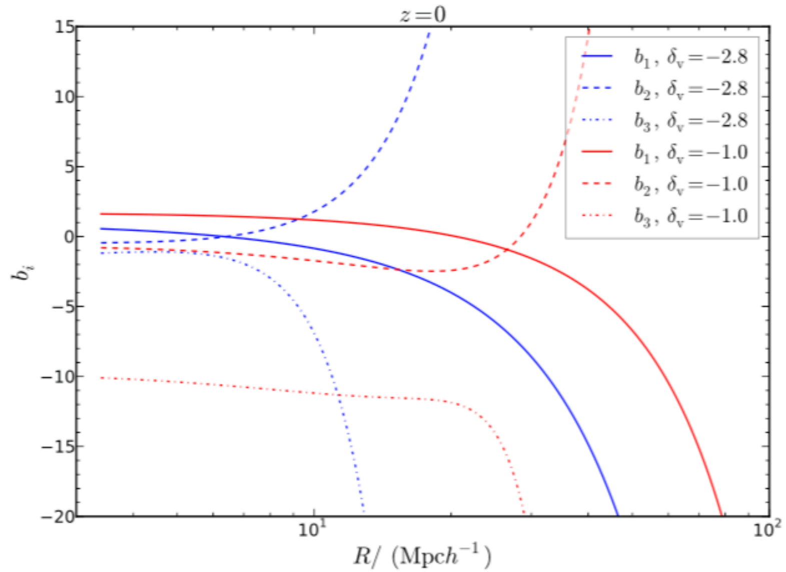
In the presence of a long wavelength perturbation $\delta_{\rm L}$, the thresholds $\delta_{\rm v}$ and $\delta_{\rm c}$ are shifted as

$$\delta_{\rm v} \rightarrow \delta_{\rm v} - \delta_{\rm L}, \quad \delta_{\rm c} \rightarrow \delta_{\rm c} - \delta_{\rm L}.$$

The bias parameters in Eulerian space are given by

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

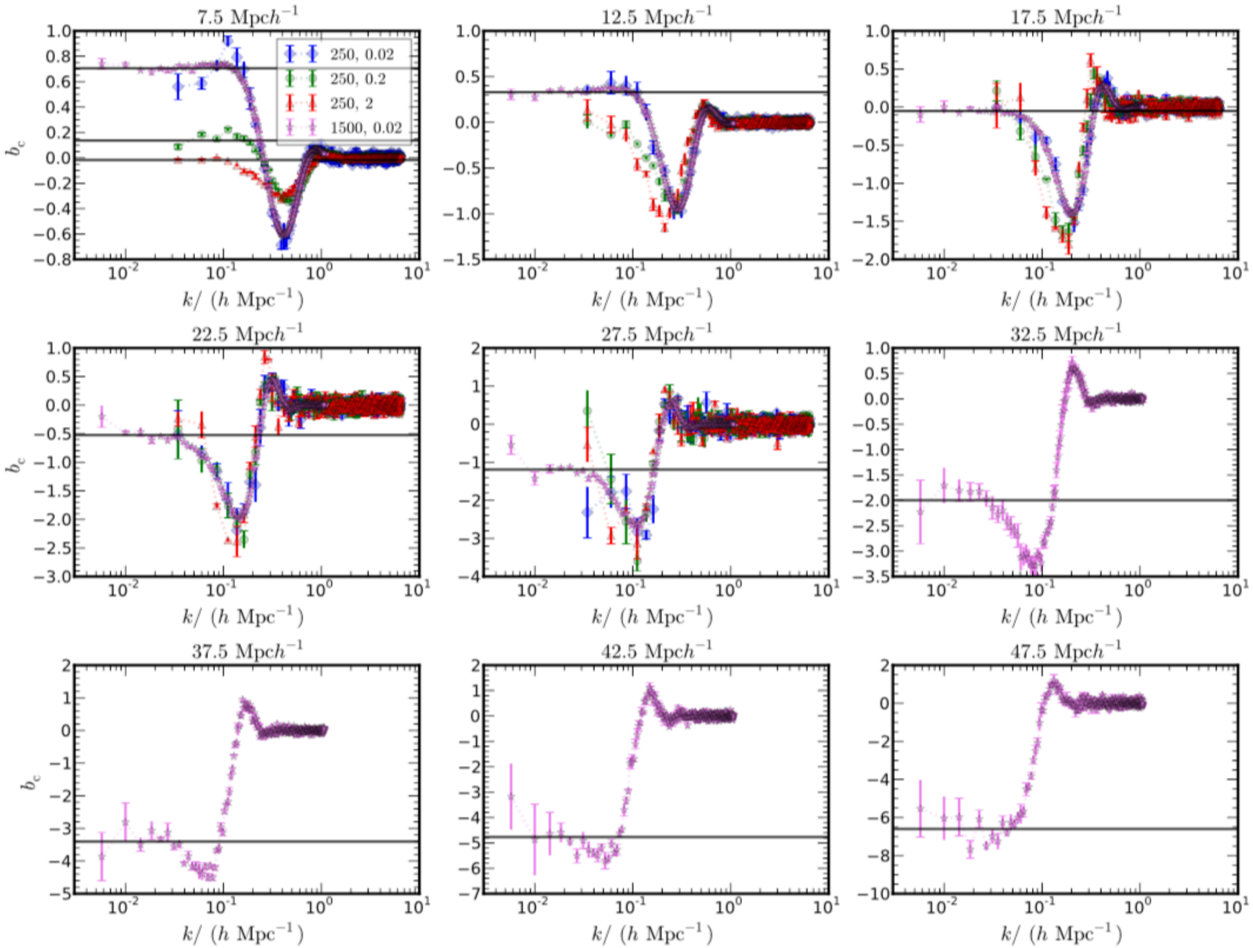
$$\begin{aligned} b_1 &= 1 + \frac{\nu^2 - 1}{\delta_{\rm v}} + \frac{\delta_{\rm v} D}{4\delta_{\rm c}^2 \nu^2}, \\ b_2 &= \frac{2(\nu_2 - 1)}{\delta_{\rm v}} + \frac{D}{2\delta_{\rm c}^2} + \frac{\nu^2}{\delta_{\rm v}^2}[2\delta_{\rm v}(1-\nu_2) - 3] + \frac{\nu^4}{\delta_{\rm v}^2} \frac{D\delta_{\rm v}}{2\delta_{\rm c}^2 \nu^2}\left(1 - \nu_2 + \frac{1}{D\delta_{\rm c}}\right) + \frac{D^2 \delta_{\rm v}^2}{16 \delta_{\rm c}^4 \nu^4} \end{aligned}$$



Cross bias of void

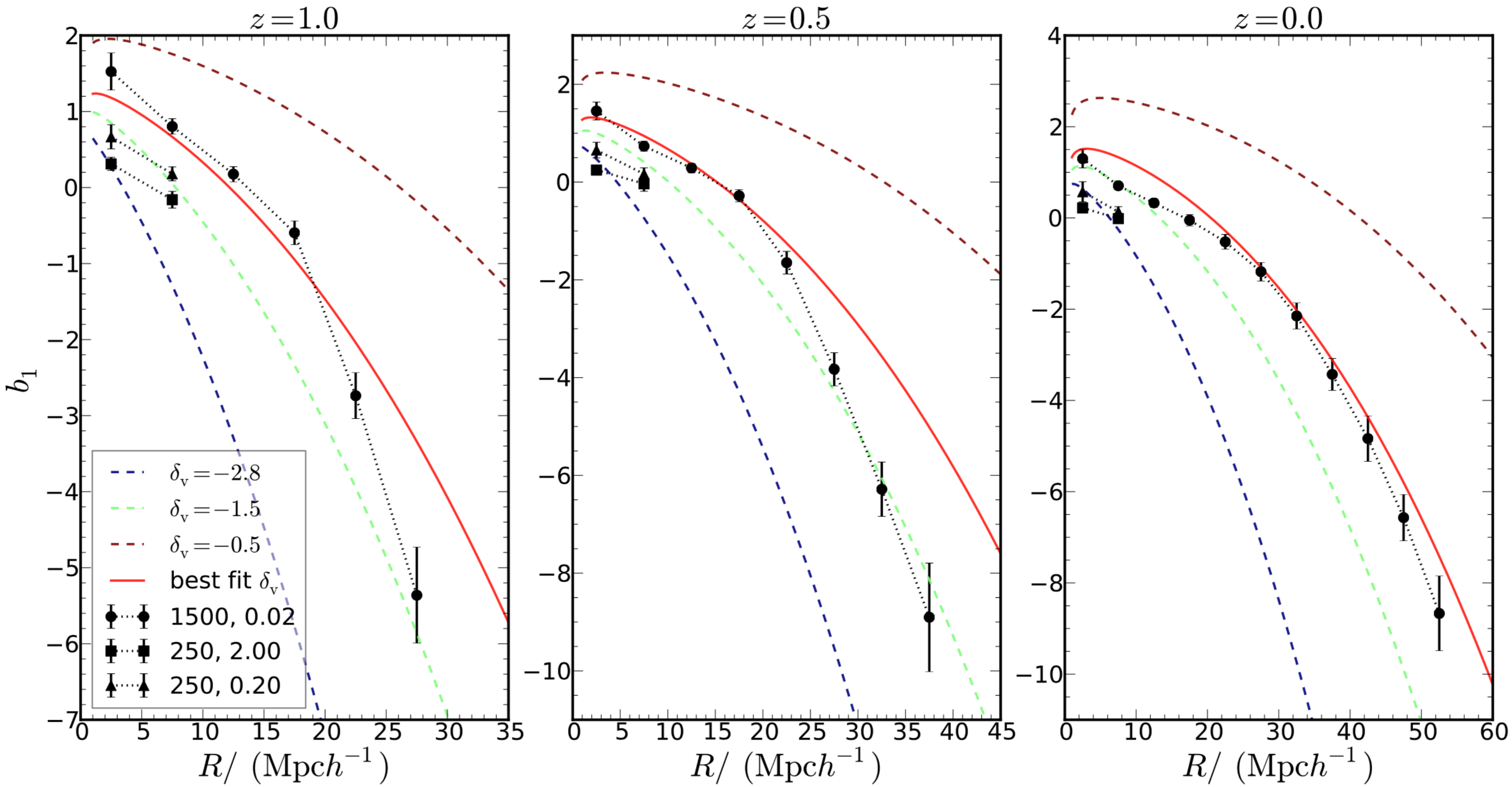
- Using the cross spectrum between void and DM to measure the cross bias.
- the bias reaches a constant on large scale, small scale shows strong wiggles b/c of the void profile
- the bias of the small voids depend on the sampling density, for large enough voids, convergence is reached

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



Void bias measurement from simulation

- When delta_v is taken as a free parameter, the void bias can approximately fit the simulation measurement. Best fit delta_v ~ -1.

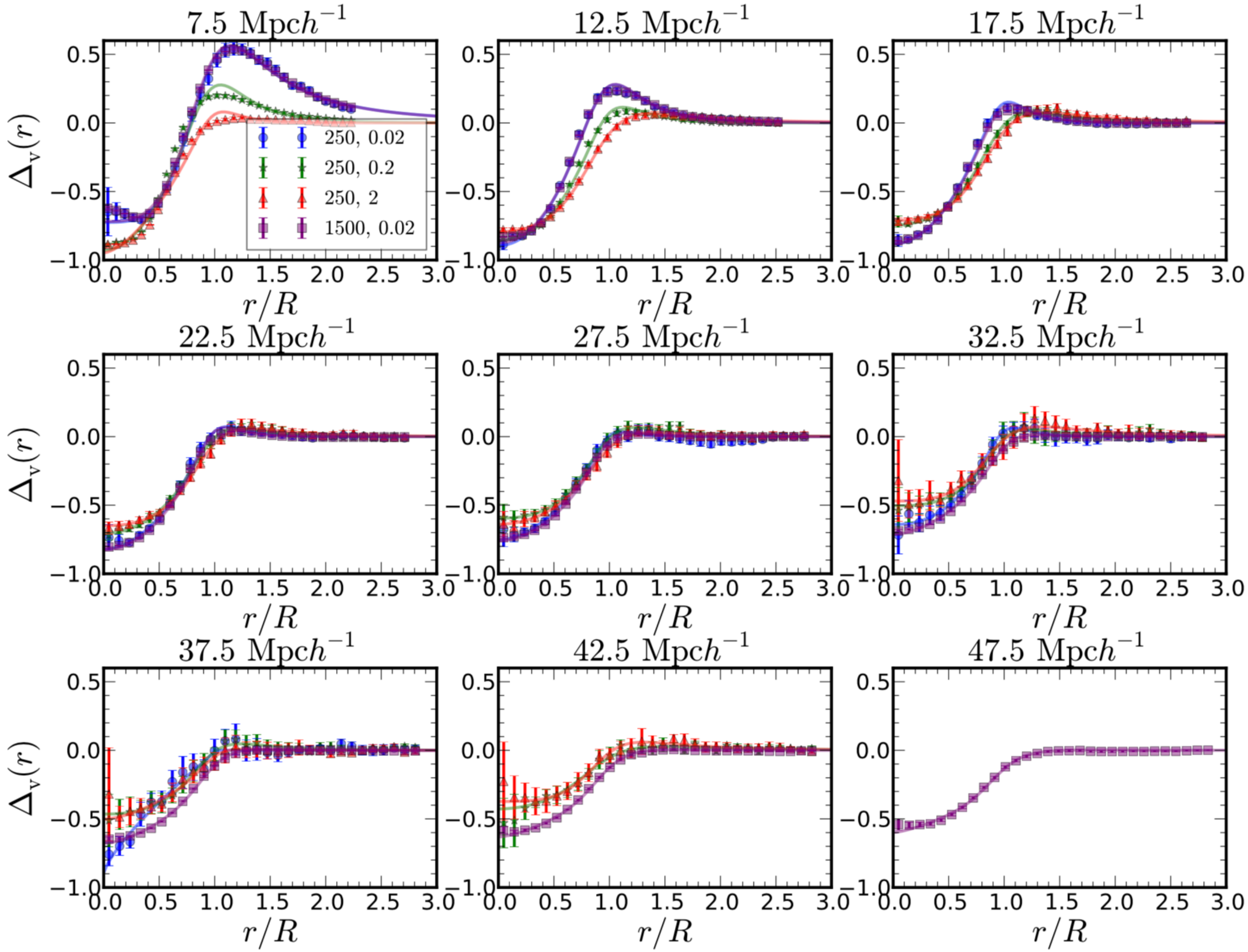


Void Profile

- The void profile can be fitted by the parametrization

$$\Delta_{\rm v} = \delta_{\rm cen} \frac{1-(r/r_{\rm s})^{\alpha}}{1-(r/R)^{\beta}}$$

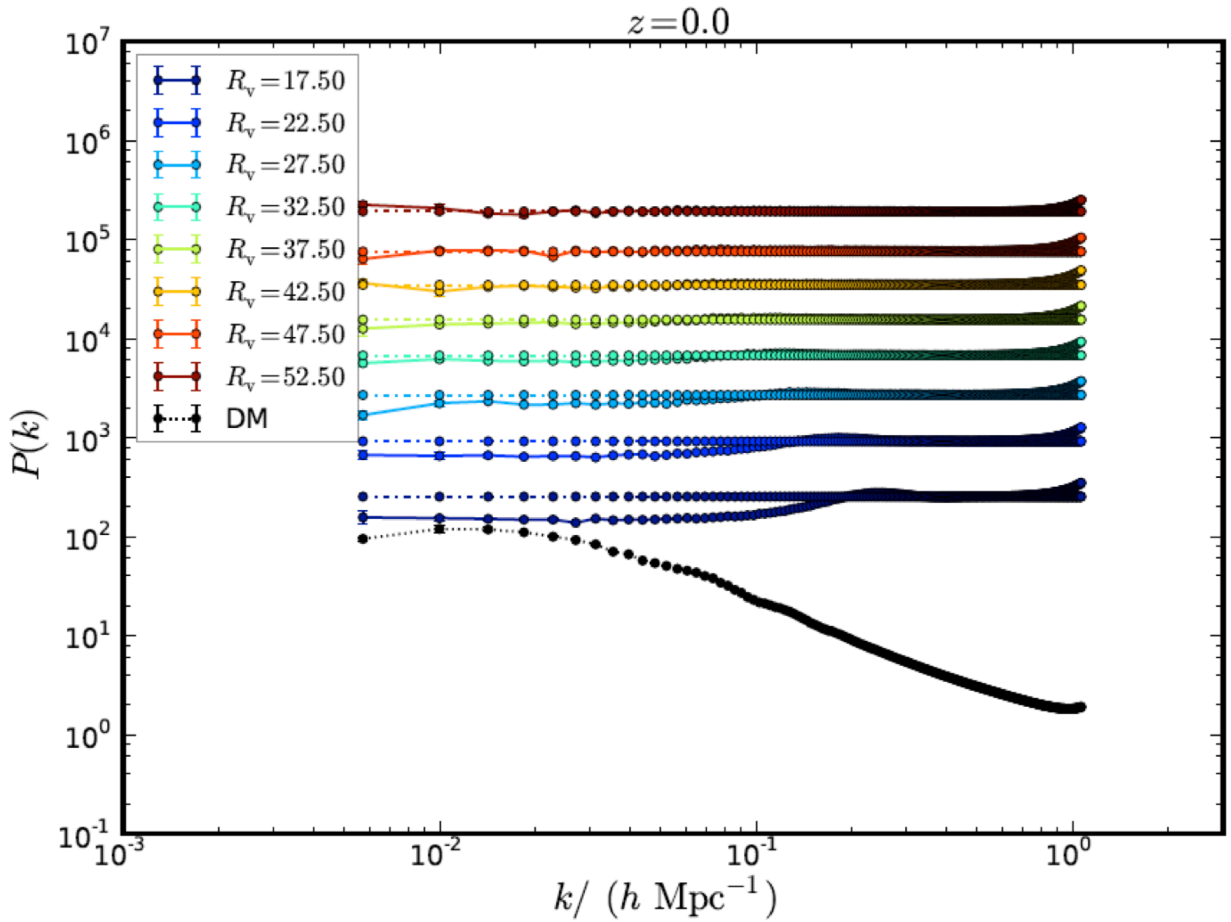
Hamaus et al, 1403.5499



Void auto-power spectrum

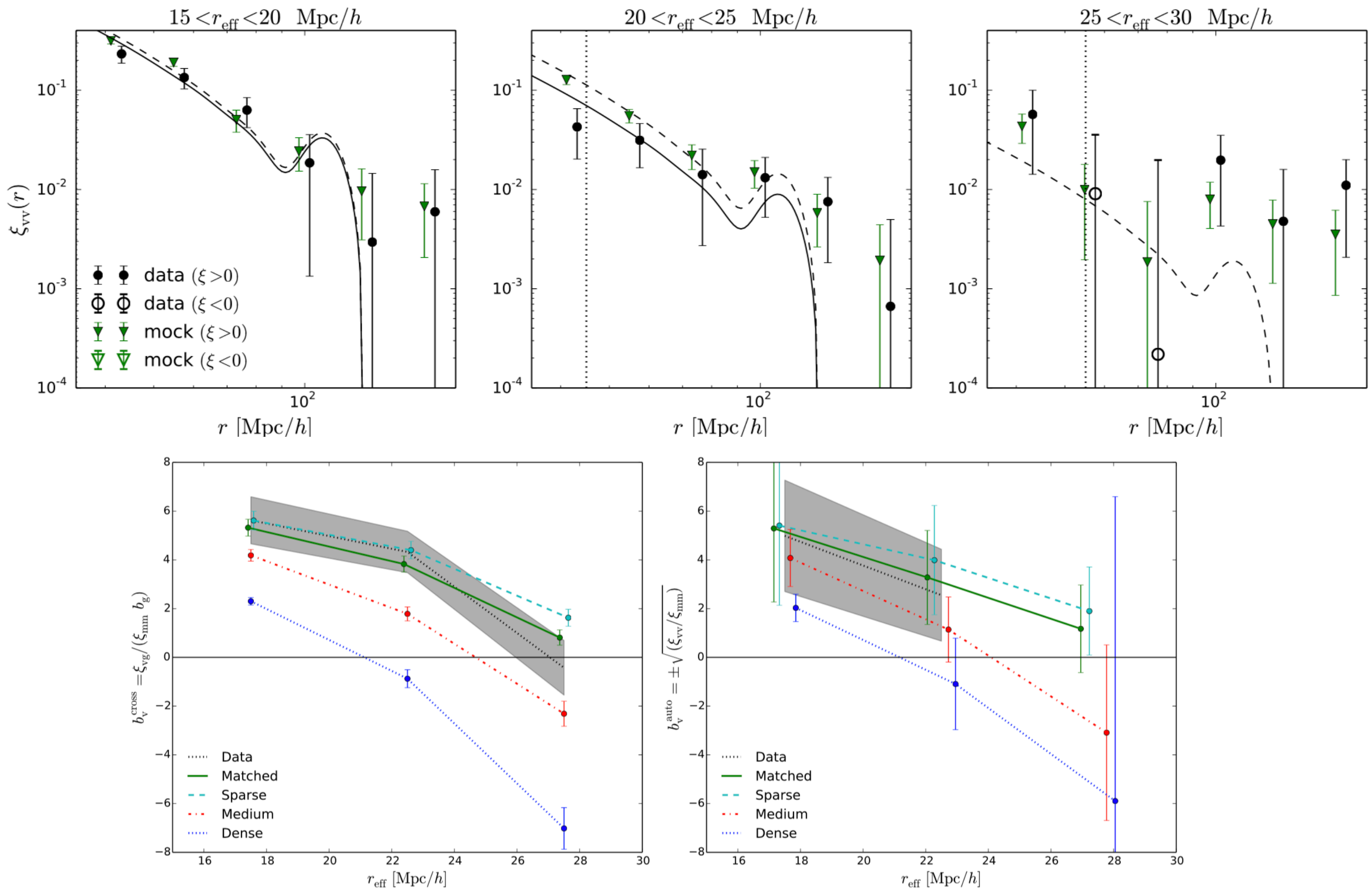
- Because of its voids are large in volume, the number density is low. The void power spectrum is dominated by shot noise and exclusion effect.

- Hard to model, exclusion effect extends to large scales



The void bias measurement from the SDSS data

- Using the SDSS data, Clampitt et al, 1507.08031 measured the void bias parameters in the configuration space.



- The void bias is interesting, so what?

Local Primoridal non-Gaussianity (PNG)

- The initial density perturbation in the early universe is very close to Gaussian

- Various models of inflation predict small amount of PNG.

- The local PNG model often arises from the multi-field inflation.

- In local PNG, the Bardeen potential is

$$\Phi = \phi + f_{\rm NL}(\phi^2 - \langle\phi^2\rangle)$$

- Measurement of the nonlinear parameter gives important insight on the inflation physics, it has been tightly constrained by the Planck mission’s bispectrum measurement

$$f_{\rm NL} = 2.7 \pm 5.8$$

Scale-dependent halo bias

- Dalal et al, 0710.4560, discovered that in the local PNG model, the large-scale halo bias exhibits scale-dependent correction
- In the Gaussian case, there is no coupling between the large-scale mode and the small scale mode.
- Local PNG model introduces coupling btw the small-scale mode with the large-scale one
- This coupling modulates the small-scale halo formation

The PNG bias as a response of the halo mass function n to the local value of σ_8 (Slosar et al, 0805.3580)

$$b^{\mathrm{NG}} = \frac{1}{n} 2 f_{\mathrm{NL}} \mathcal{M}^{-1} \frac{\partial n}{\partial \ln \sigma_8(\boldsymbol{x})},$$

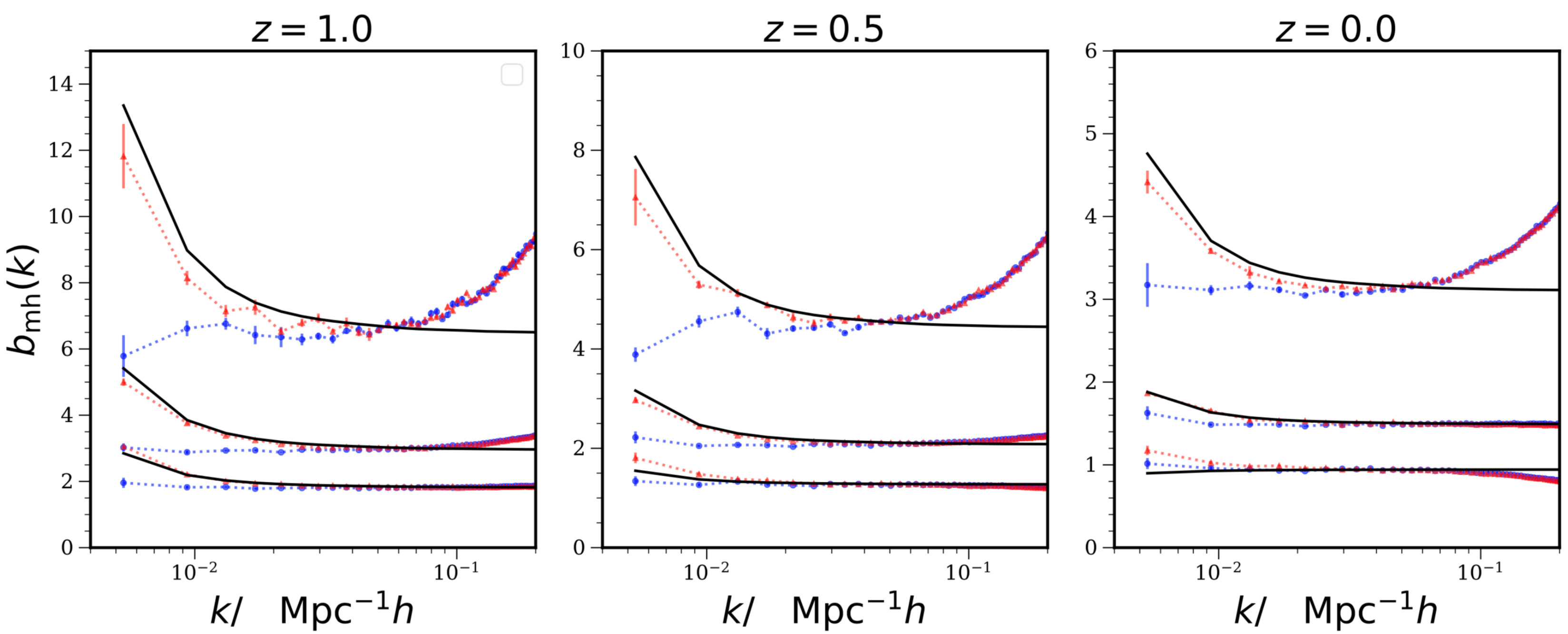
$$\mathcal{M}(k) = \frac{2}{3} \frac{c^2 k^2 T(k) D}{\Omega_{m0} H_0^2}.$$

Scale-dependent halo bias

- Assuming universal mass function, the PNG halo bias can be written as

$$b_{\rm h}^{\rm NG} = \frac{3 f_{\rm nl} \Omega_{\rm m0} H_0^2}{k^2 T(k) D(z)} \delta_{\rm c} (b_{\rm h}^{\rm G} - 1).$$

- This prescription gives ~10% accuracy compared with simulation



LSS constraint on f_NL

- The PNG signals is on large scale, less likely to be contaminated by astrophysical effects. However, systematics like the stellar contamination can give false signals.
- Using the multiple galaxies data sample, Giannantonio et al, 1303.1349, got f_NL = 5 +- 21. From quasar samples, Leistedt et al, 1311.2597 got -39< f_NL < 23
- Many studies suggest that the bound on f_NL is future experiments is expected to tightened by an order of magnitude or so.
- We explore the constraint on f_NL by including the clustering info from voids.

PNG void bias

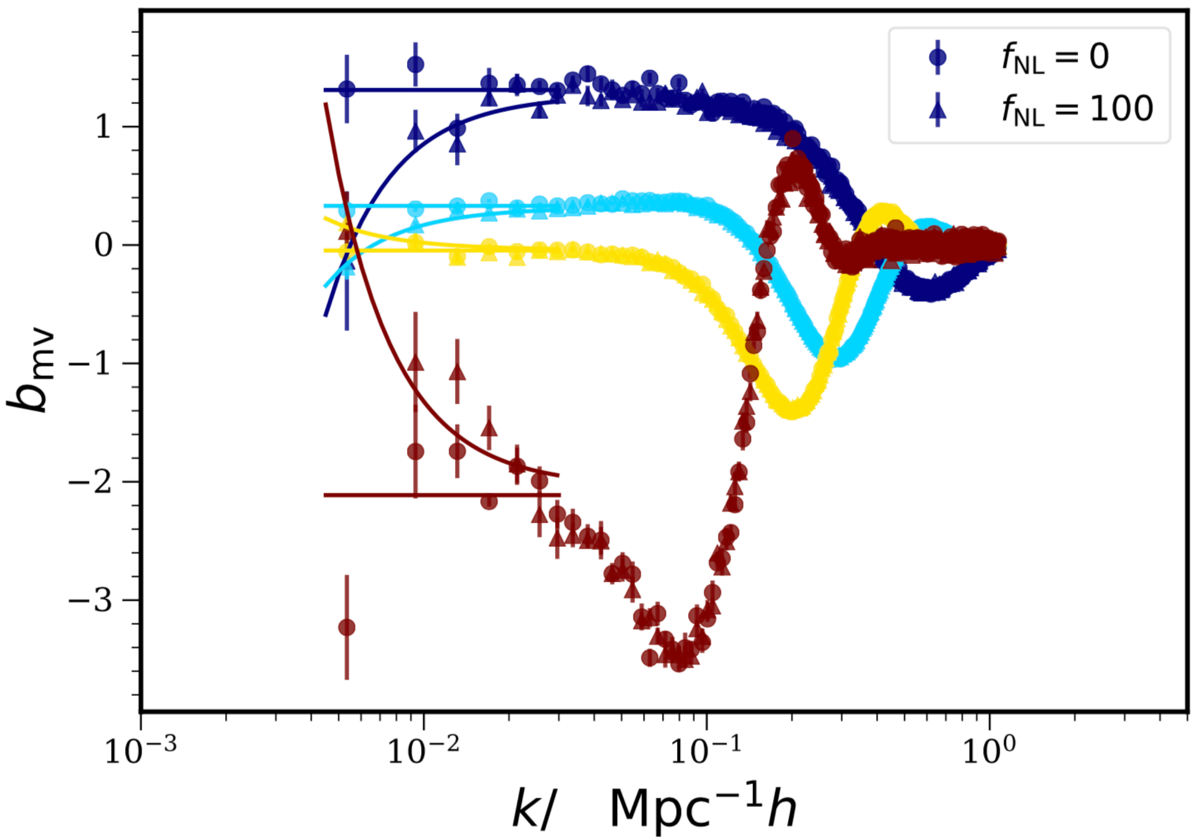
- Applying the SvdW void size distribution to the PNG bias formalism, we expect that voids also exhibit scale dependent bias as the halos

$$b_{\mathrm{v}}^{\mathrm{NG}}(k) = \frac{3 f_{\mathrm{nl}} \Omega_{\mathrm{m0}} H_0^2}{k^2 T(k) D(z)} \left(\nu^2 - 1 - \frac{|\delta_{\mathrm{v}}| \mathcal{D}^2}{2 \delta_{\mathrm{c}} \nu^2} - \frac{8 \mathcal{D}^4}{\nu^4} \right).$$

PNG void bias

- The Gaussian void bias approaches a constant value on large scale
- The PNG void bias shows scale dependent bias at low k
- Fit the NG bias model to the numerical results, shows that the scale dependence is 1 / [k^2 T(k)], but the best fit delta_v varies with R

Void size: 2.5, 12.5, 17.5, 32.5 Mpc/h



Fisher forecast

- Consider all the halo power spectra, auto and cross, void power spectra, auto and cross, and the halo-void cross spectra
- Consider one parameter f_NL
- Use Gaussian covariance, and the derivatives are compute numerically from measured spectra.

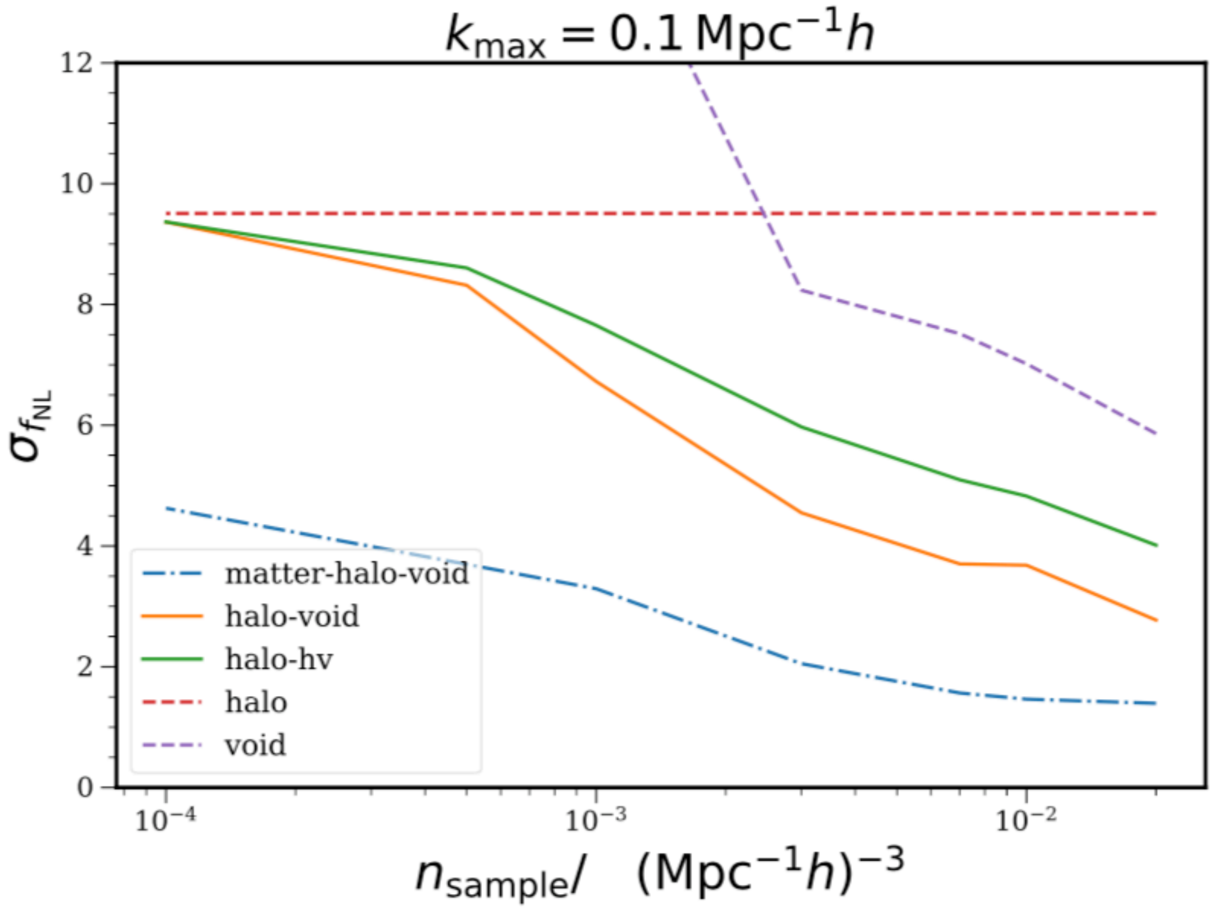
$$F_{f_{\rm NL} f_{\rm NL}} = \sum_{k<k_{\rm max}} \left[\frac{\partial \boldsymbol{P}}{\partial f_{\rm NL}} \Sigma^{-1} \frac{\partial \boldsymbol{P}}{\partial f_{\rm NL}} + \frac{1}{2} {\rm Tr} \left(\Sigma^{-1} \frac{\partial \Sigma}{\partial f_{\rm NL}} \Sigma^{-1} \frac{\partial \Sigma}{\partial f_{\rm NL}} \right) \right].$$

$$\Sigma_{ab,cd}(k_i, k_j) = \frac{\delta_{ij}}{N_{\rm s}(k_i)} \left[P_{ac}(k_i) P_{bd}(k_i) + P_{ad}(k_i) P_{bc}(k_i) \right]$$

Constraint on f_NL from void clustering

- For void clustering, the shot noise is the most serious issue
- When the number density of the sample tracer is sufficiently high, the constraint from void clustering is comparable to the halo clustering
- When the cross correlation with voids is added the constraint is improved when the sample density is ~ 10^{-4}.

$$\sigma_{f_{\rm NL}} = \frac{1}{\sqrt{F_{f_{\rm NL} f_{\rm NL}}}}$$



DM voids vs Halo voids

- The constraint is derived from the DM voids
- In galaxy surveys, voids are derived from galaxies, the galaxy bias has to be taken into account. The bias of the galaxy voids tend to be higher
- The peak of the voids distribution shifts to larger size
- The galaxy void study is ongoing.

Conclusion

- We study the clustering of voids, especially the void bias
- The void bias approaches a constant on large scale
- The PNG voids exhibits scale dependent bias similar to halos
- We show that when the tracer density is sufficient high, the constraining power from void clustering can be comparable to the halos