MISSOURI S&T

June 7, 2022

PPC 2022 @ Washington University in St. Louis

Hasti Khoraminezhad

THE IMPACT OF RELATIVE BARYON-CDM PERTURBATIONS ON THE EVOLUTION OF THE LARGE-SCALE STRUCTURES

BASED ON

- *Quantifying the impact of baryon-CDM perturbations on halo clustering and baryon fraction*

  Hasti Khoraminezhad, Titouan Lazeyras, Raul E. Angulo, Oliver Hahn, Matteo Viel

  JCAP, **03** (Mar 2021) 023 arXiv: 2011.01037

- *Cosmic voids and BAO with relative baryon-CDM perturbations*

  Hasti Khoraminezhad, Pauline Vielzeuf, Titouan Lazeyras, Carlo Baccigalupi, Matteo Viel

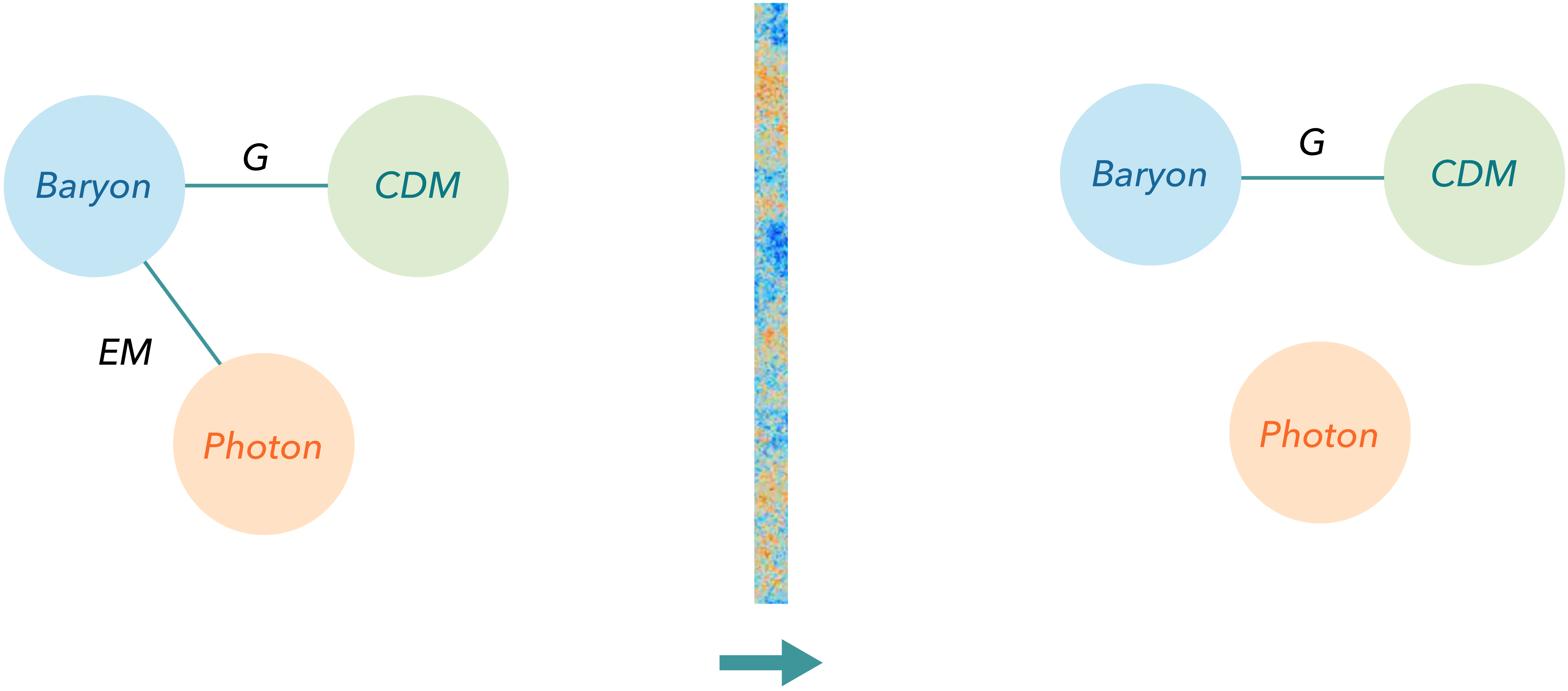
  MNRAS, 511, 3, 4333-4349 (Feb 2022) arXiv: 2109.02949

OUTLINE

- What are the relative baryon-CDM perturbations ?
- How can we include them in gravity-only cosmological N-body simulations ?
- How important is their impact on clustering of halos ?
- How about the cosmic voids ? Do they have any effect on the distribution of the voids ?
- Do they change the position of the BAO peak ?

RELATIVE BARYON-CDM PERTURBATIONS

- 2 dominant matter components: CDM & baryons. Commonly: as a single, comoving matter fluid
- Coupling of baryons to radiation –> relative perturbation in the density & velocity of the baryons & CDM



RELATIVE BARYON–CDM PERTURBATIONS

- The evolution of baryons and CDM after baryon-photon decoupling:

Approx: Pressureless fluid

Linear order

$$\frac{\partial}{\partial\tau}\delta_s(\mathbf{x},z) = -\,\theta_s(\mathbf{x},z)\,, \quad s\in\{b,c\}$$

$$\frac{\partial}{\partial\tau}\theta_s(\mathbf{x},z) + \mathscr{H}\theta_s(\mathbf{x},z) = -\frac{3}{2}\Omega_m(a)\mathscr{H}^2\delta_m(\mathbf{x},z)$$

$\delta_m = (\Omega_b\delta_b + \Omega_c\delta_c)/\Omega_m$

$f_b = \Omega_b/\Omega_m$

$\delta_m = f_b\delta_b + (1-f_b)\delta_c$

$$\frac{\partial^2}{\partial\tau^2}\delta_m + \mathscr{H}\frac{\partial}{\partial\tau}\delta_m - \frac{3}{2}\Omega_m\mathscr{H}^2\delta_m = 0$$

$$\delta_m(\mathbf{x},z) = A_+(\mathbf{x})D_+(z) + A\_(\mathbf{x})H(z)$$

$\delta_r = \delta_b - \delta_c$

$$\frac{\partial^2}{\partial\tau^2}\delta_r + \mathscr{H}\frac{\partial}{\partial\tau}\delta_r = 0$$

$$\delta_r(\mathbf{x},z) = R_+(\mathbf{x}) + R\_(\mathbf{x})D_r(z)$$

$$R_+ \equiv \delta_{bc}$$

Ref: Fabian Schmidt (2016)

RELATIVE BARYON–CDM PERTURBATIONS IN HALOS

$$\delta_r(\mathbf{x}, z) = \delta_{bc}(\mathbf{x}) + \frac{\theta_{bc,0}(\mathbf{x})}{H_0} D_r(z)$$

$$\delta_h(\mathbf{x}, z) = \sum_{\mathcal{O}} b_{\mathcal{O}(z)} \mathcal{O}(\mathbf{x}, z)$$

$$\delta_h(\mathbf{x}, z) \supset b_{\delta_{bc}}(z)\delta_{bc}(\mathbf{x}) + b_{\theta_{bc}}(z)\theta_{bc}(\mathbf{x}, z)$$

$$\delta_h(\mathbf{x}, z) = b_1(z)\delta_m(\mathbf{x}, z) + b_{\delta_{bc}}(z)\delta_{bc}(\mathbf{x}) + b_{\theta_{bc}}(z)\theta_{bc}(\mathbf{x}, z)$$

MAPS OF THE DENSITY FIELDS

cosmology:

$\Omega_b = 0.0490$

$\Omega_c = 0.2621$

$\Omega_m = 0.3111$

$n_s = 0.9665$

$\sigma_8 = 0.8261$

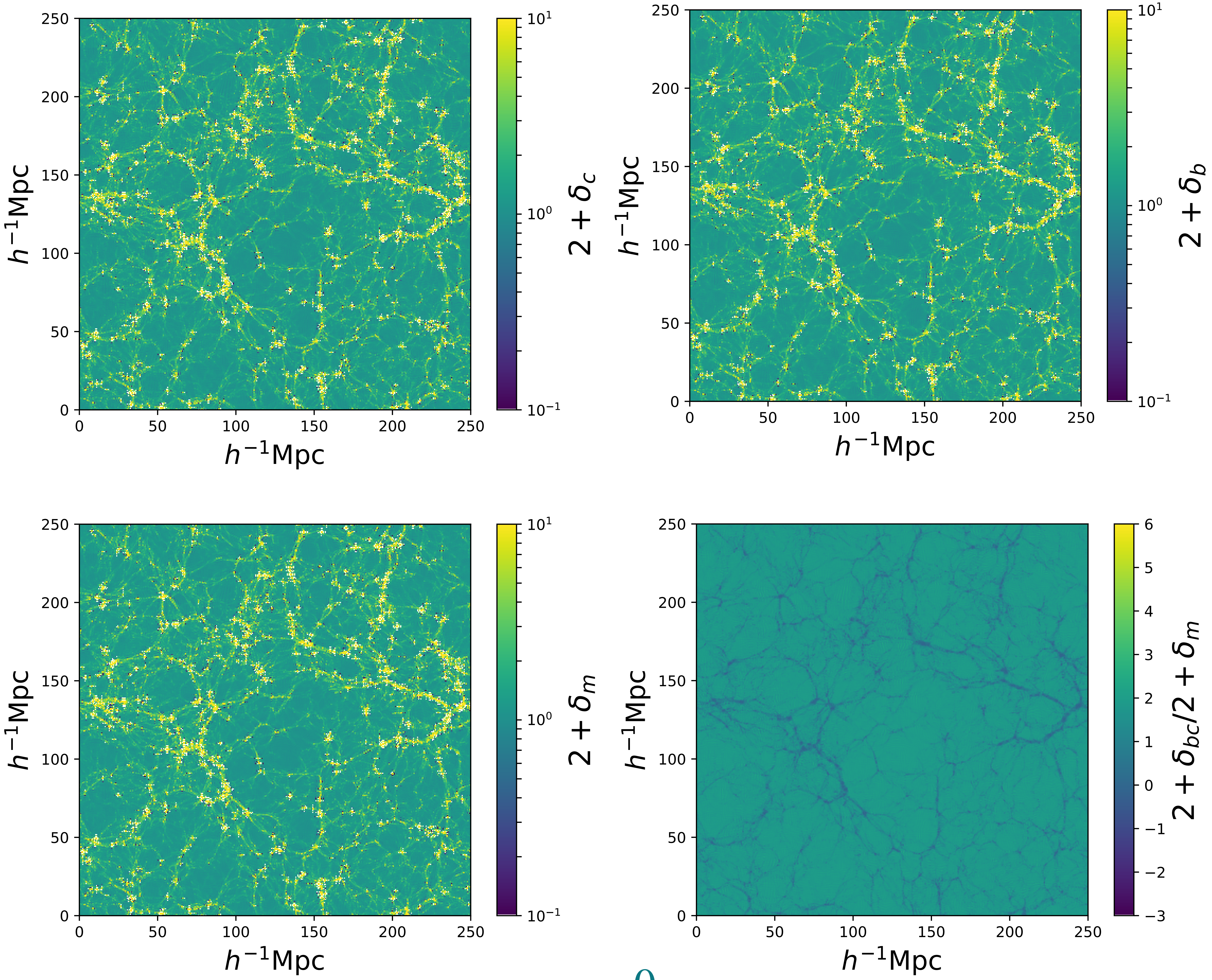
$h = 0.6766$

Slice of thickness: $10\,h^{-1}\mathrm{Mpc}$

$[10^{10}\,M_{\odot}/h]$

Name	N_b	N_c	m_b	m_c	Ω_c	Ω_b	$N_{\rm real}$	TFs
1-fluid Fid	0	512^3	–	1.0051	0.2621	0.049	16	–
1-fluid High	0	512^3	–	1.0051	0.2596	0.0515	16	–
1-fluid Low	0	512^3	–	1.0051	0.2645	0.0466	16	–
2-fluid-diff	512^3	512^3	0.1583	0.8468	0.2621	0.049	4	2
2-fluid-same	512^3	512^3	0.1583	0.8468	0.2621	0.049	4	1

ICs: MUSIC SIM: Gadget-2



$z = 0$

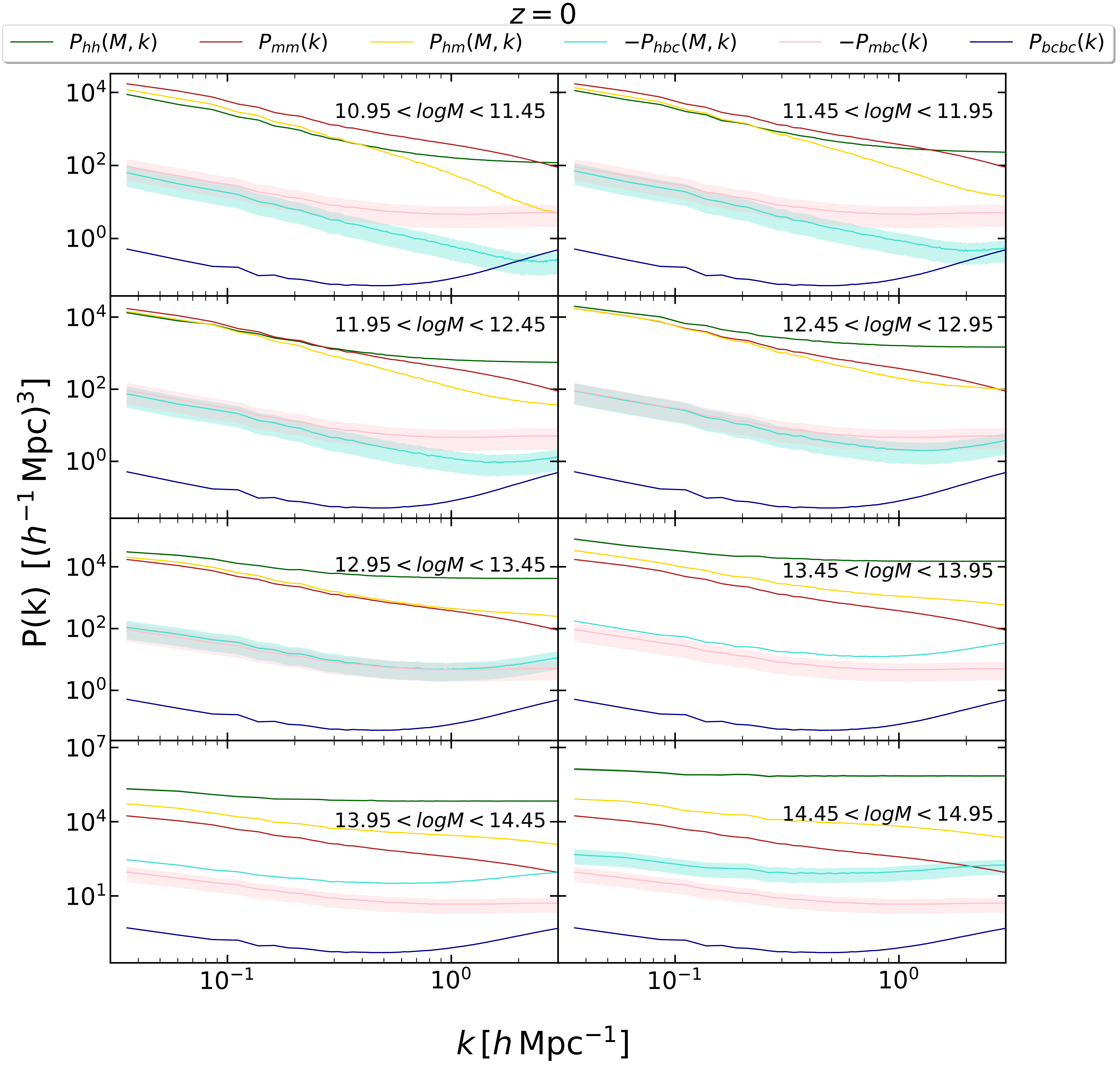
FORCE CALCULATION: SOFTENING LENGTH

too high force resolution for the mass resolution could cause a spurious coupling between CDM and baryons affecting their clustering features and the growth of structures on all scales.

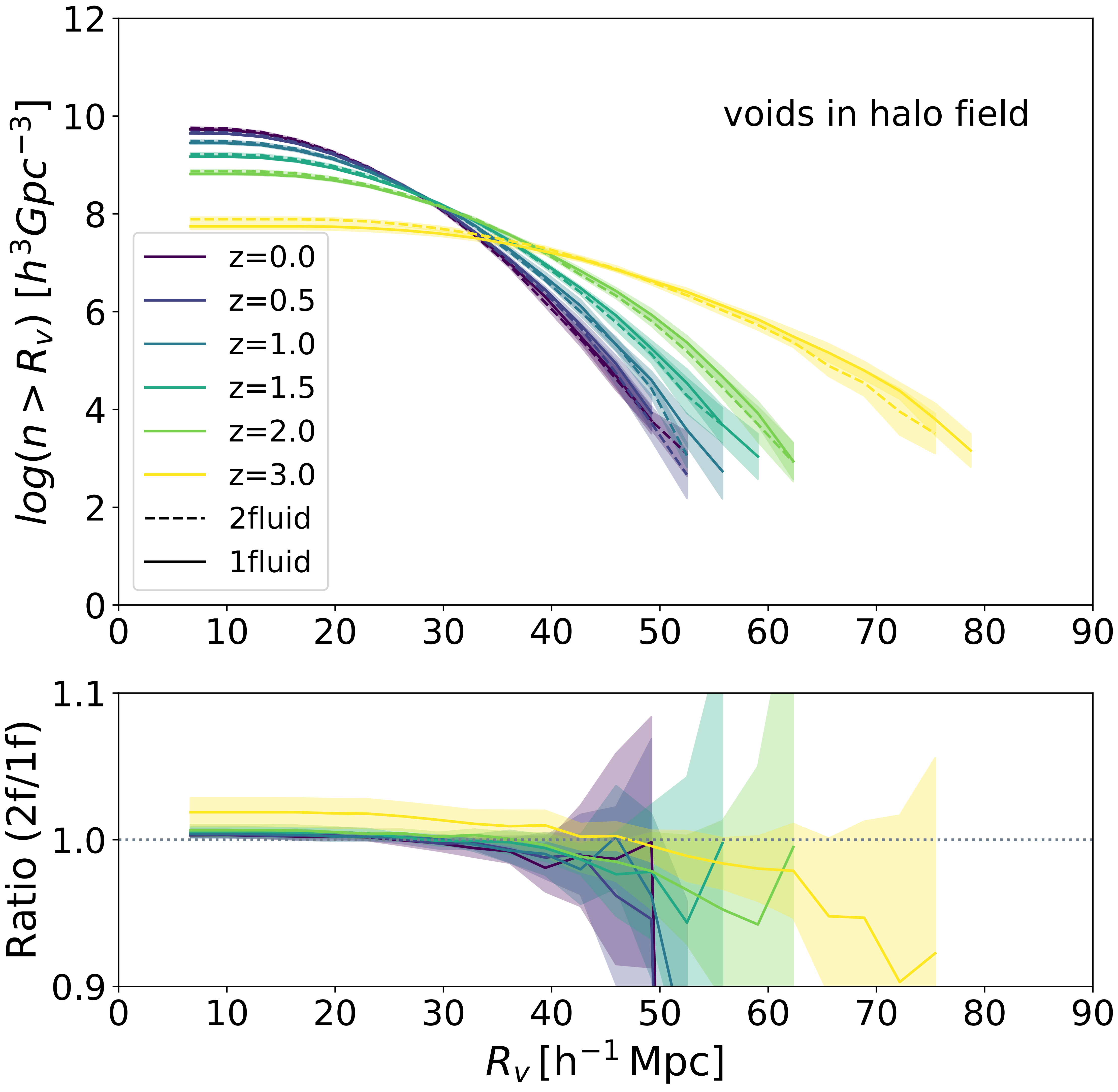
$$\ddot{\mathbf{x}} = -G \sum_i^N \frac{m_i(\mathbf{x} - \mathbf{x_i})}{|\mathbf{x} - \mathbf{x_i}|^3} \quad \Rightarrow \quad \ddot{\mathbf{x}} = -G \sum_i^N \frac{m_i(\mathbf{x} - \mathbf{x_i})}{(|\mathbf{x} - \mathbf{x_i}|^2 + \epsilon^2)^{3/2}}$$

Adaptive gravitational softening: (AGS) allows the softening length to vary in space and time according to the density of the environment.

POWER SPECTRA

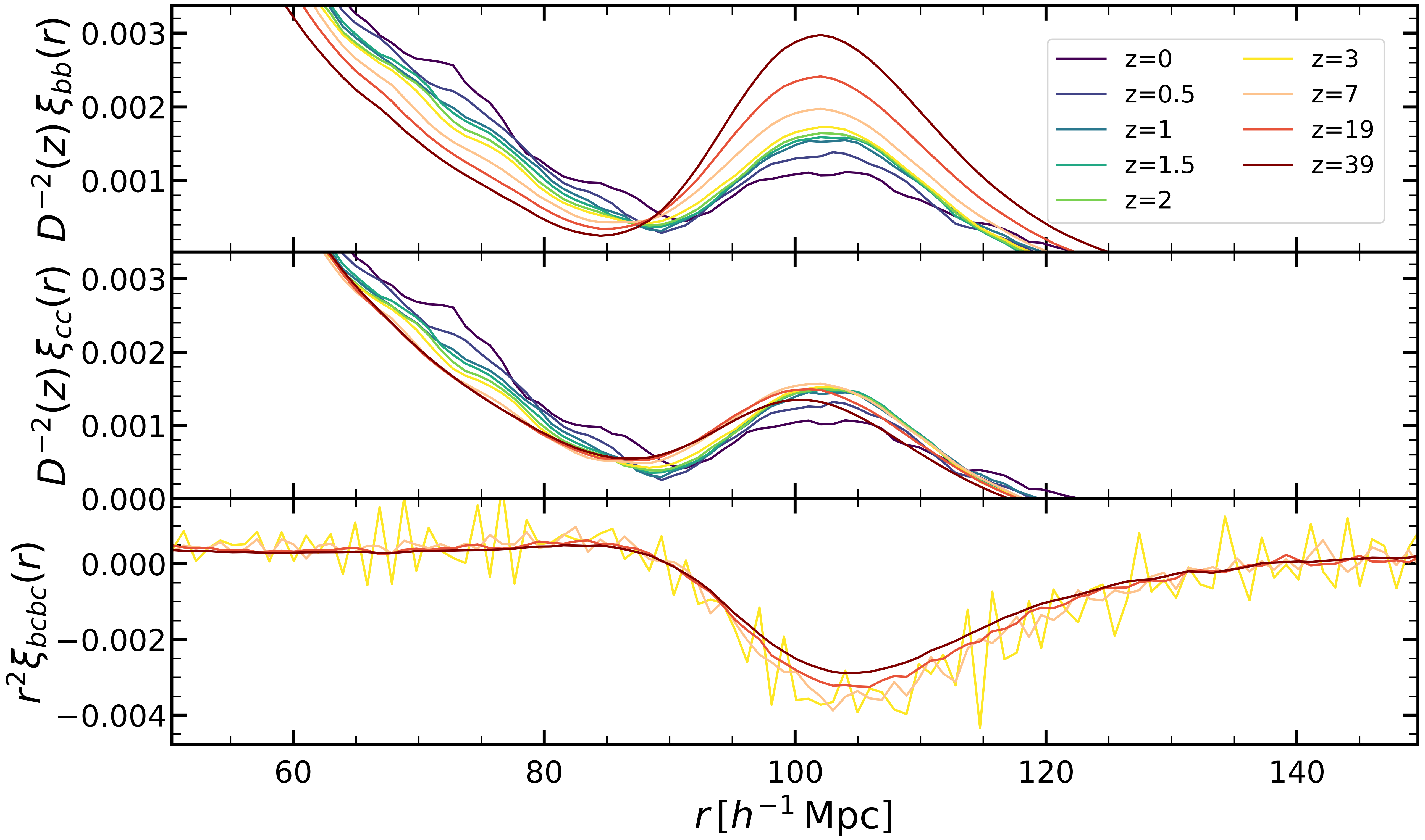


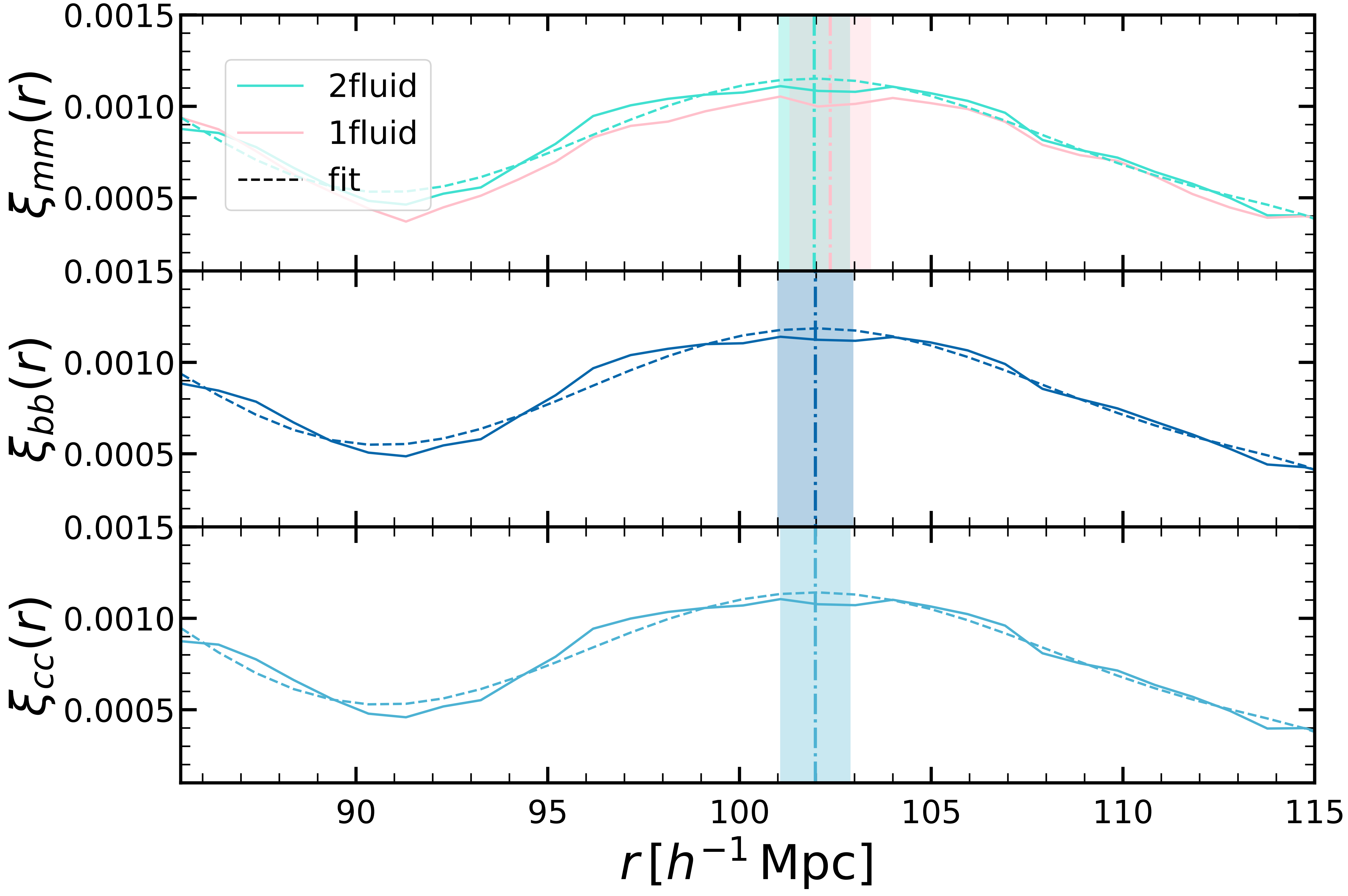
VOID SIZE FUNCTION (VSF)



CORRELATION FUNCTION, BAO PEAK

$$\xi^{\mathrm{fit}}(r) = \sum_{n=0}^{N} a_n r^n$$





CONCLUSIONS

- P_{hbc} is nonzero –> bc perturbation affect the clustering. (P_{hbc} and P_{mbc} are negative –> bc reduce the clustering)
- bc is more important at high z
- More abundant small voids in presence of bc and less larger voids –> consequence of acting against clustering (bc)
- The δ_{bc} present a dip as the BAO feature consistent with: on these scales CDM particles lag behind baryons
- No evidence of statistically significant effect of the impact of the bc perturbations on the position of the BAO peak

CONCLUSIONS

- P_{hbc} is nonzero –> bc perturbation affect the clustering. (P_{hbc} and P_{mbc} are negative –> bc reduce the clustering)
- bc is more important at high z
- More abundant small voids in presence of bc and less larger voids –> consequence of acting against clustering (bc)
- The δ_{bc} present a dip as the BAO feature consistent with: on these scales CDM particles lag behind baryons
- No evidence of statistically significant effect of the impact of the bc perturbations on the position of the BAO peak

THANK YOU FOR YOUR ATTENTION !