ON THE UNIVERSALITY OF VOID DENSITY PROFILES

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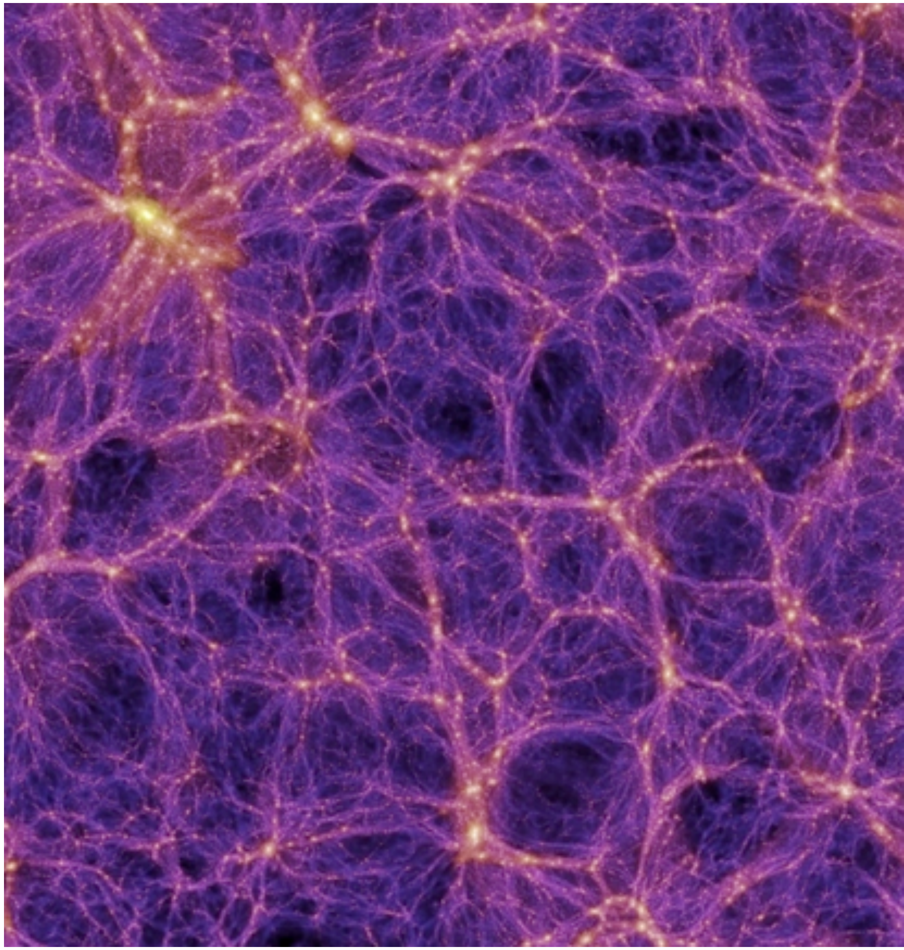
Cosmic Voids

- Cosmic voids are large underdense regions, forming an **essential feature of the cosmic web** and occupying most of the volume of the Universe (FF=0.5-0.9)

- Voids have a huge potential in probing cosmological parameters:

  the average shape of voids is sensitive to dark energy parameters, through the **Alcock-Paczynski test** (Lavaux & Wandelt 2012, Sutter+2012)

- We need a model to describe their internal structure



Void evolution

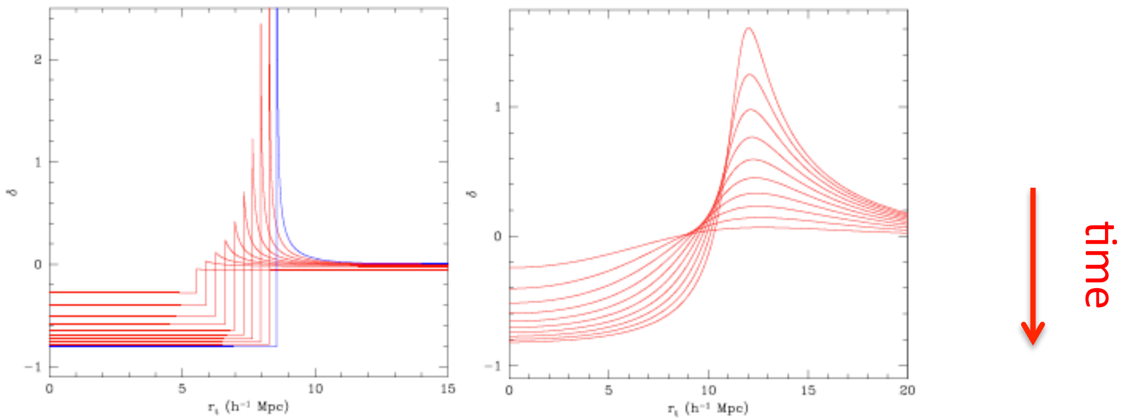


Fig. 2. Spherical model for the evolution of voids. Left: a pure (uncompensated) tophat void evolving up to the epoch of shell-crossing. Initial (linearly extrapolated) density deficit was $\Delta_{lin,0} = -10.0$, initial (comoving) radius $\tilde{R}_{i,0} = 5.0h^{-1}$Mpc. Right: a void with an angular averaged SCDM profile. Initial density deficit and characteristic radius are same as for the tophat void (left). The tendency of this void to evolve into a tophat configuration by the time of shell crossing is clear. Shell-crossing, and the formation of a ridge, happens only if the initial profile is sufficiently steep.

Van de Weygaert & Platen 2011 (see Rien VdW's talk)

- Emerging from negative density perturbations in the primordial Gaussian field
- As a result of their underdensity voids represent a region of weaker gravity → evolve from the inside out
- As they expand, the density in the interior continuously decreases and matter accumulates to the boundaries, asymptotically reaching the pure emptiness (δ=-1)

Outline

- The hydro-simulation
- SDSS voids
- Void density profiles
- Dependence on void size: is there a universal density profile?

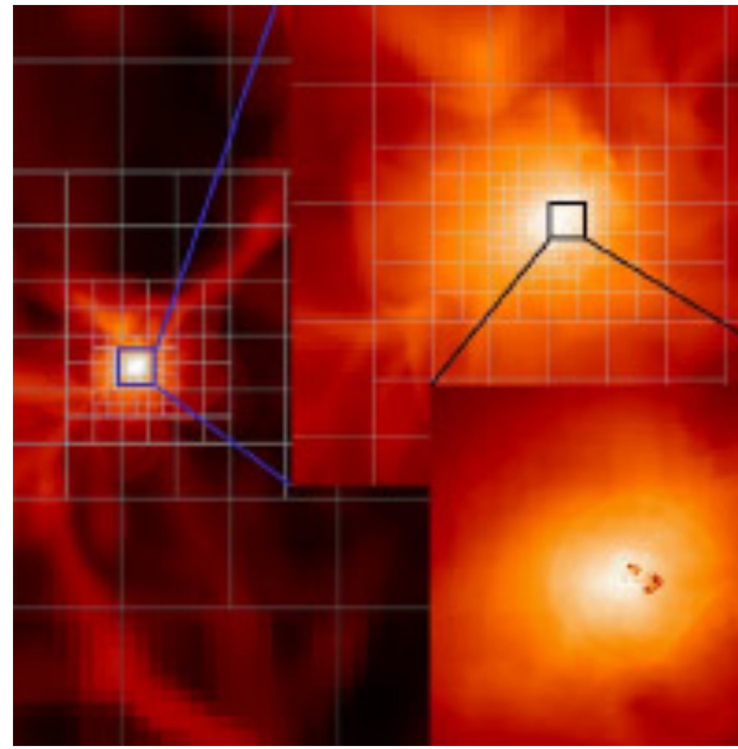
Simulation

MASCLET

Mesh Adaptive Scheme for Cosmological structurE evoluTion
cosmological N-body and Eulerian hydrodynamic code (Quilis 2004)
Based on the Adaptive Mesh Refinement (AMR):

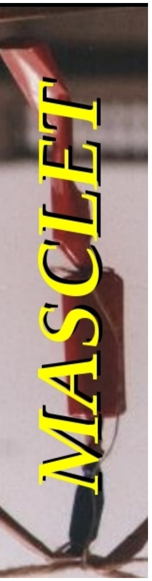
Standard AMR scheme:

Computational grid is refined in the cells satisfying some predefined conditions (usually the high density of the cells)
→ hierarchy of nested grids (or levels of refinement)



Simulations

- New AMR scheme designed to study the formation and evolution of low density regions: (Ricciardelli, Quilis, Planelles 2013)



First level of refinement: (l=1): computational grid refined in low density regions ($\rho/\rho_b<10$)

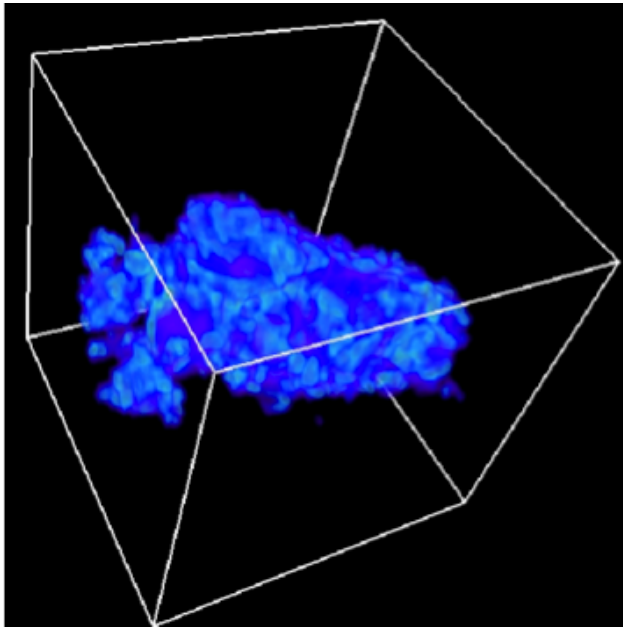
Higher levels (l>1): Refined in the densest regions to follow the formation of structures within voids

Simulation details

Side length of the box: 512 Mpc/h
Levels of refinement: 1
Best resolution (l=1): 1024^3 (0.5 Mpc/h)
Best particle mass: m=6E10 $M_\odot$
Cosmology: $\Omega m=0.27$; $\Omega\Lambda=0.73$, h=0.71
Grids used for voids search: 512^3 (0.8 Mpc/h)
Cosmology: $\Omega m=0.27$; $\Omega_\Lambda=0.73$

Void finder

New void finder optimally suited to find voids in AMR simulations and to capture void morphology (Ricciardelli, Quilis, Planelles 2013)



Basic assumptions:

(i) Voids have positive velocity divergence in the interior, with the inner shells expanding faster than the outer regions → centers in the cells with highest divergence

(ii) The matter density at the edges has a sharp increase, hence a steep gradient. Void edges found at jumps in the density gradient

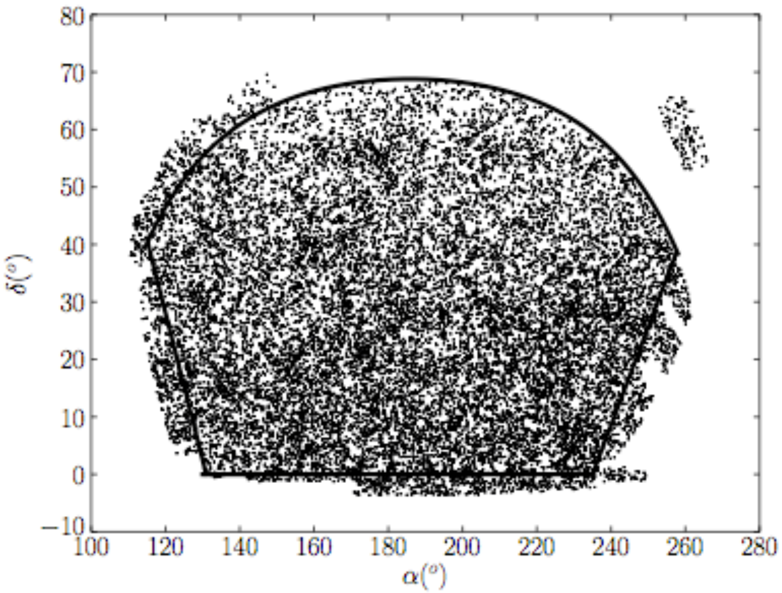
Overlapping voids are allowed under certain conditions → arbitrary shape

~35000 voids with R>7Mpc/h and ρ/ρ_b~0.2

SDSS Voids

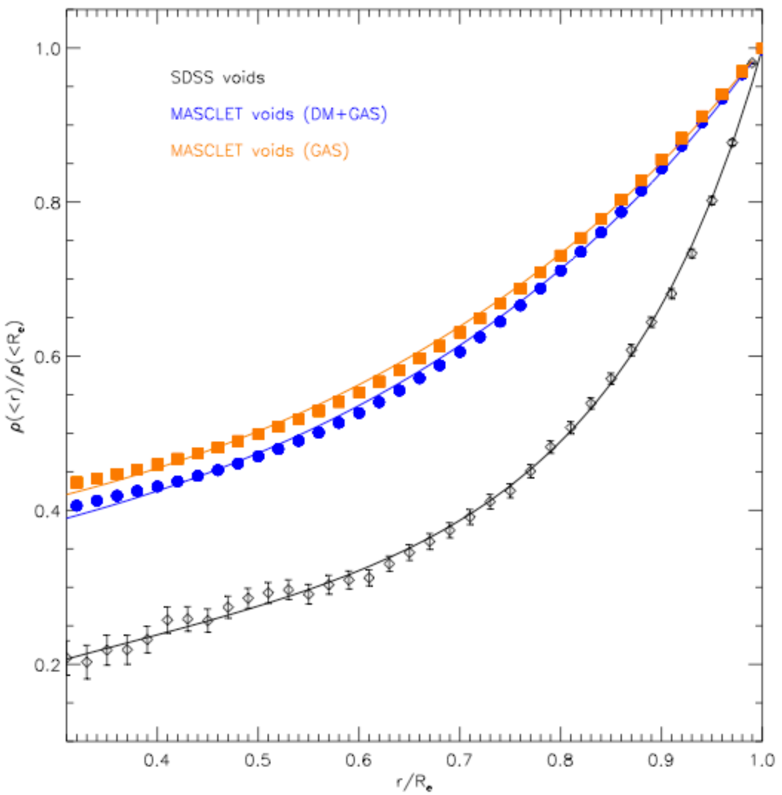
(Varela,Betancort,Trujillo,Ricciardelli 2012)

- **The Data**: sample selected from NYU-VACGS catalogue (Blanton et al. 2007), based on SDSS/DR7
- **Void definition**: spherical volume devoid of galaxies brighter than the mag limit (-20.17)
- **Void catalogue**: ~4453 voids larger than 7 Mpc/h, including >40000 galaxies



Simulations vs Observations

Ricciardelli, Quilis, Varela 2014



$$\frac{\rho(<r)}{\rho(<\mathrm{Re})} = \left(\frac{r}{\mathrm{Re}}\right)^{\alpha} \exp\left[\left(\frac{r}{\mathrm{Re}}\right)^{\beta} - 1\right]$$

$\alpha=-0.18$ $\beta=1.85$ $\alpha=0.5$ $\beta=4.15$

MASCLET stack

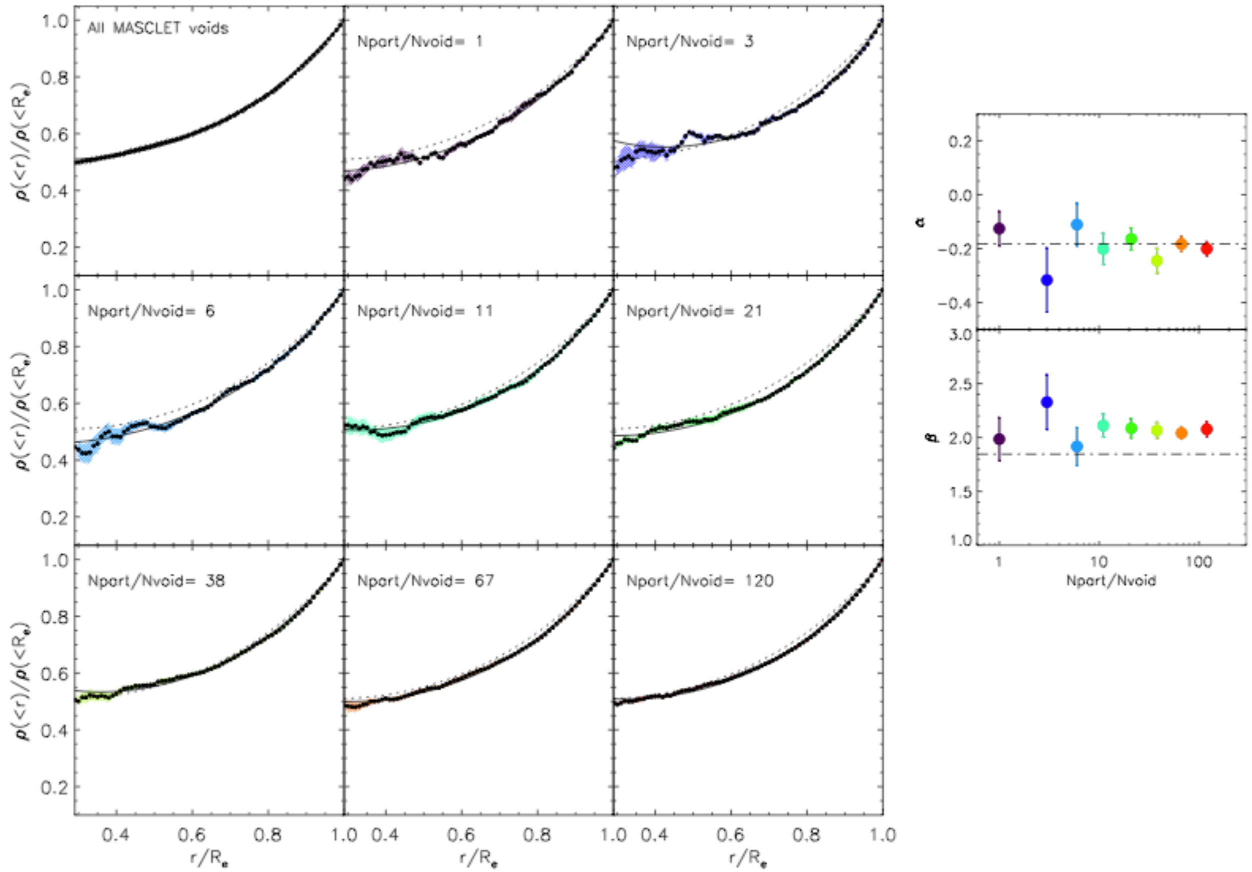
SDSS stack

- The same functional form can describe both the observed and simulated profile
- Good agreement between gas and total matter profile
- The observed profile is much steeper than the simulated one

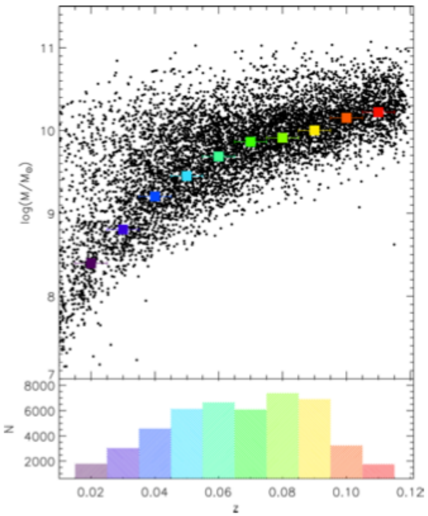
Impact of sparsity

Subsamples of voids populated with a increasing number of tracers (N_{part}/N_{void}=[1:120])

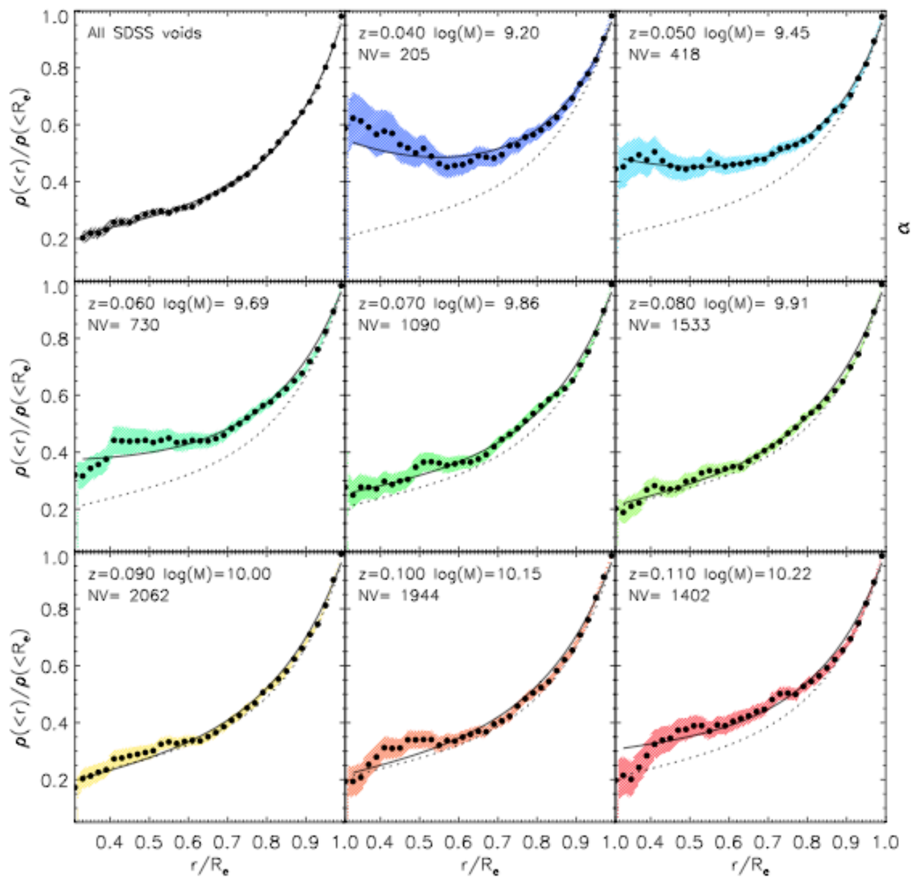
No systematic effect is observed for underpopulated samples

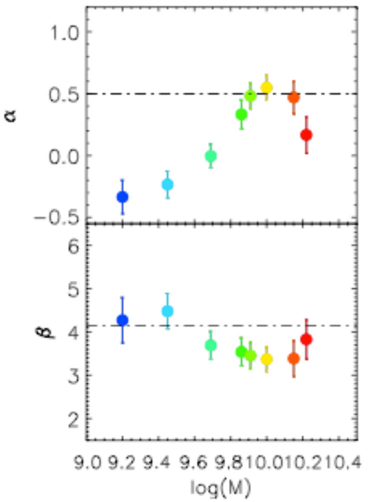


Impact of the mass tracers



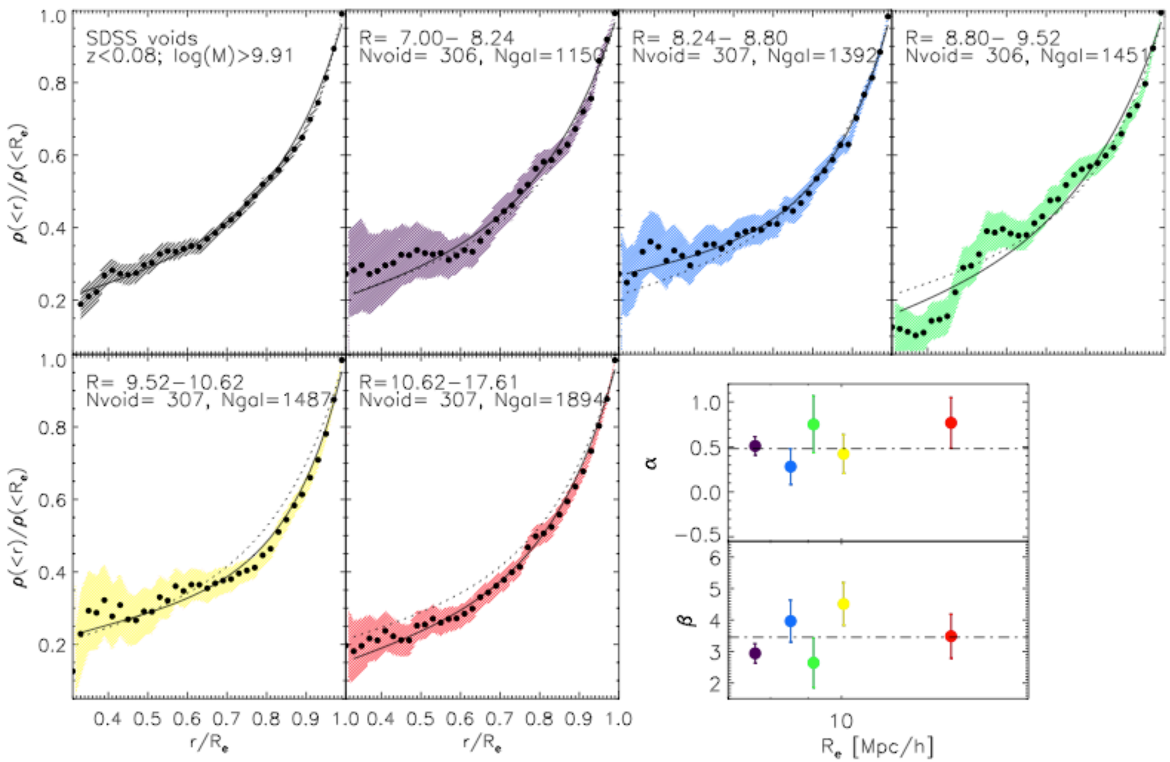
Volume limited samples of galaxies having mass down to the completeness limit





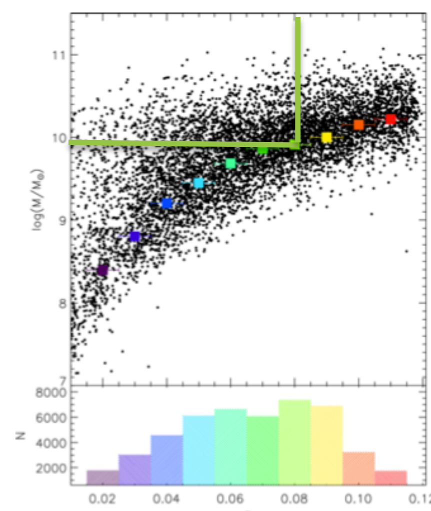
The profiles steepen as galaxies at higher stellar mass are used

Dependence on void size I



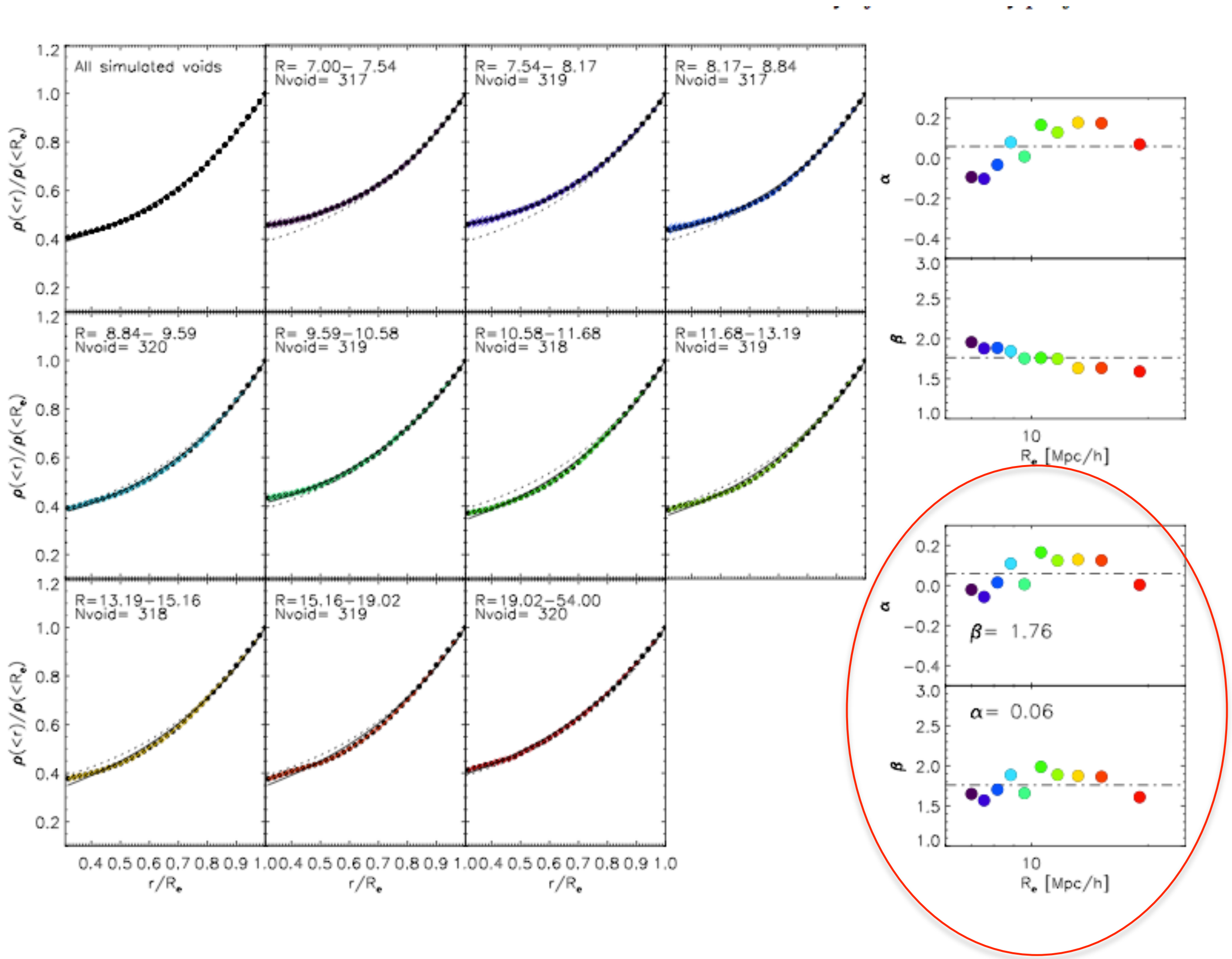
SDSS voids
R_{void}=[7:18 Mpc/h]

homogenous sample of galaxies



No dependence on size !!

Dependence on void size II



MASCLET voids
R_{void}=[7:50]Mpc/h

No evidence of a dependence of the profiles on radius
→ univerality of void density profiles

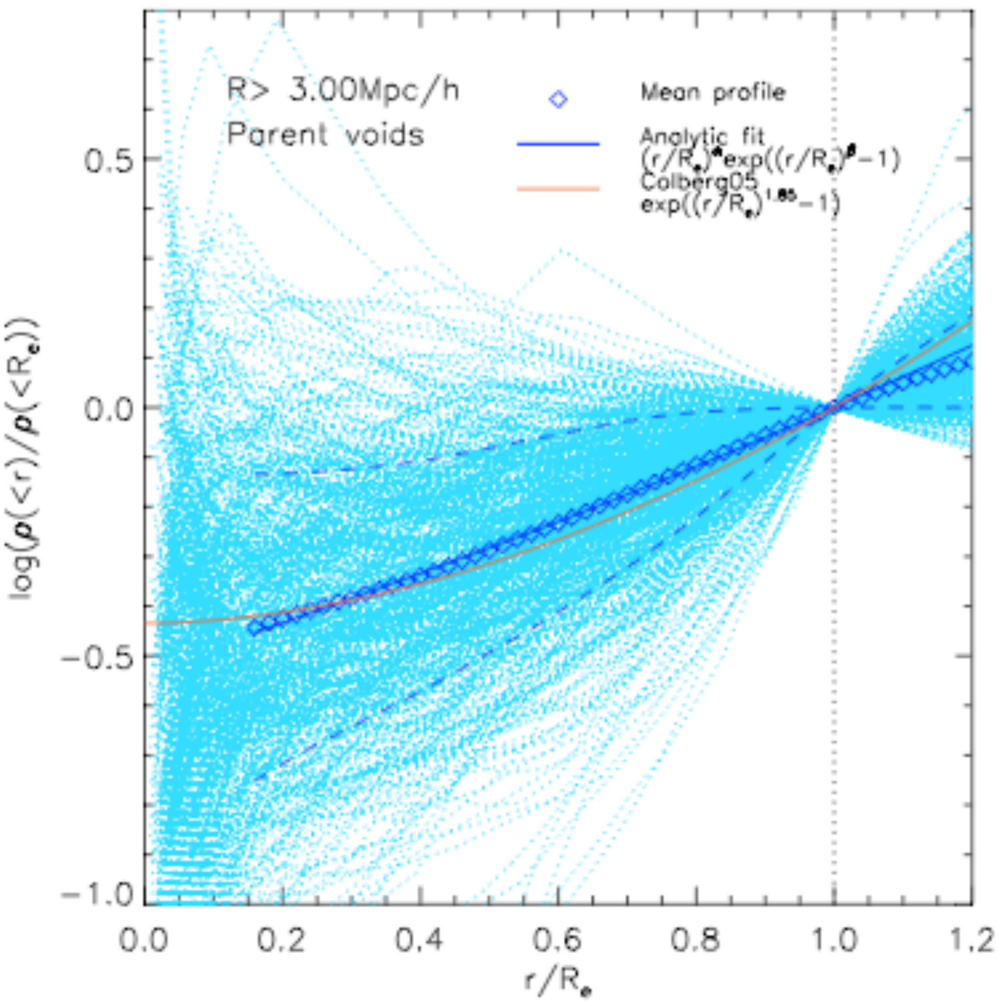
- Universality of void density profiles: when properly rescaled void density profiles do not depend on void size

- Simulated and observed profiles have the same qualitative shape but the observed ones are much steeper than in the simulation

- We exclude sparsity as the source of the difference, the steepness of the observed profiles seems to lie in the biased galaxy formation

- To be tested with high-resolution simulations

Comparison with other simulations (Colberg+05)



MASCLET profile

Colberg et al. (2005)