GALAXY EVOLUTION IN COSMIC VOIDS

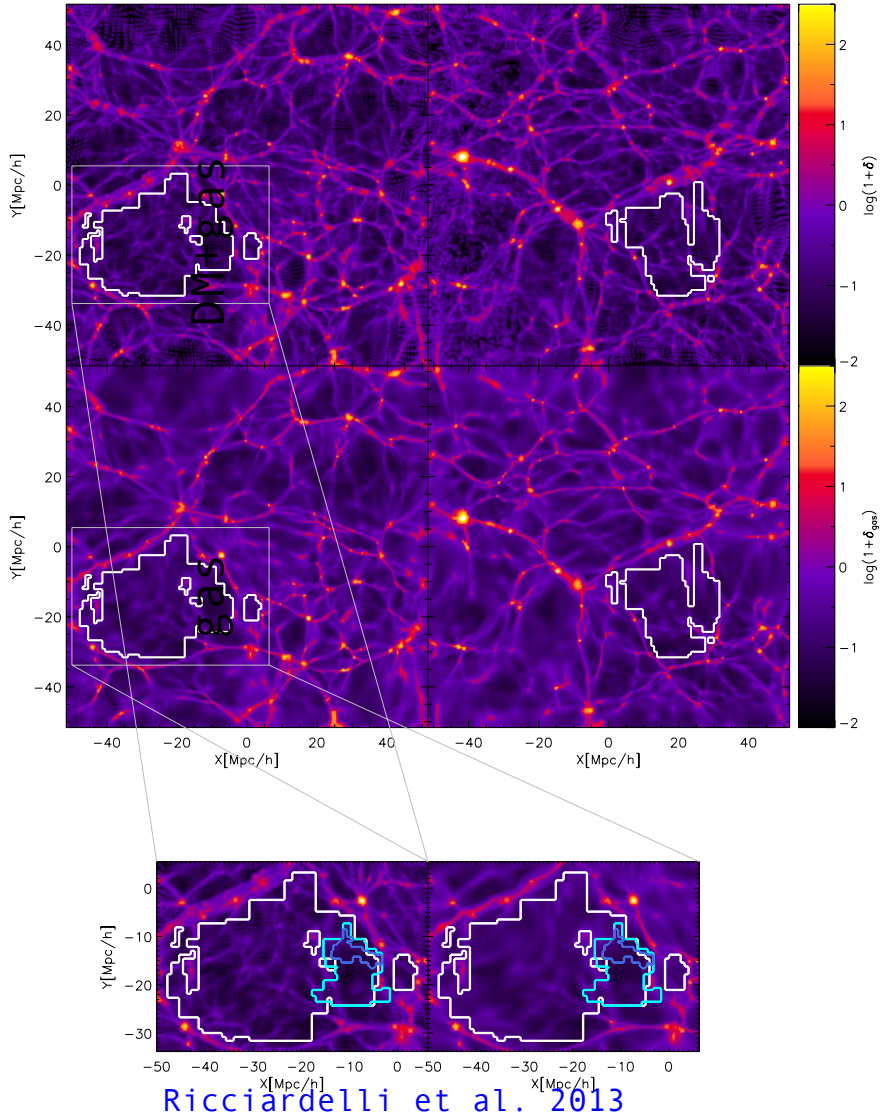
Unveiling galaxy formation in the lowest density regions of the Universe

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Elena Ricciardelli

Ricciardelli, Cava, Varela, Tamone; arXiv:1708.09045
Ricciardelli, Cava, Varela, Quilis; arXiv:1410.0023
Varela, Betancort-Rijo, Trujillo, Ricciardelli; arXiv:1109.2056

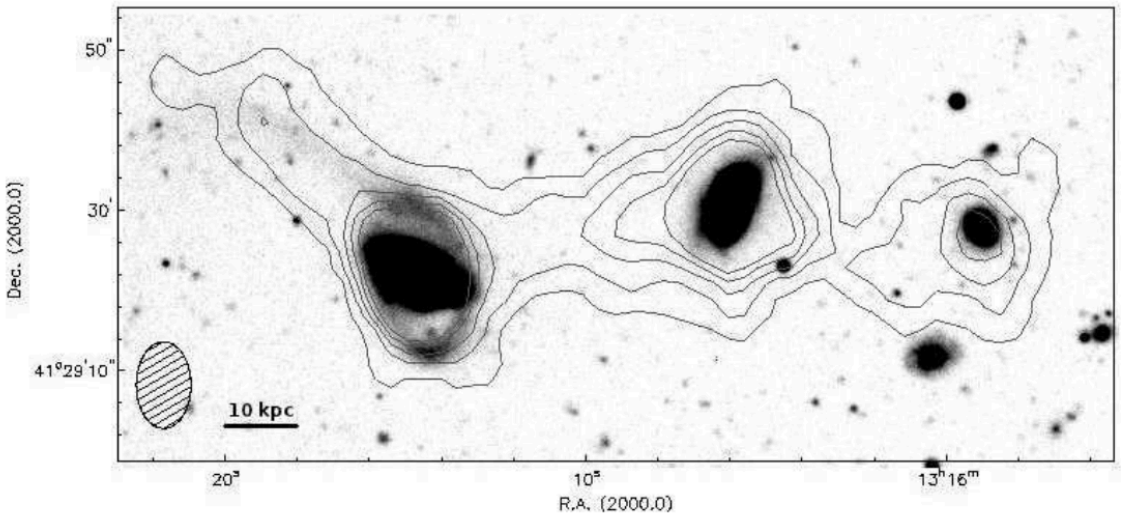
Cosmic Voids



Ricciardelli et al. 2013

- Numerical simulations and large redshift surveys have shown that **voids occupy most of the volume of the Universe (FF=50-90 %)**
- Extremely interesting objects for precision cosmology (e.g. EUCLID)
- **Voids are not empty** !! Void substructures emerge as we look at voids at higher resolution: network of walls and tenuous filaments

Void Galaxies



Credits: Beygu et al. 2013

Void Galaxy Survey:

Filamentary alignment of three gas-rich galaxies embedded in the same HI envelop

- Cold gas accretion ?
- VG not necessarily isolated

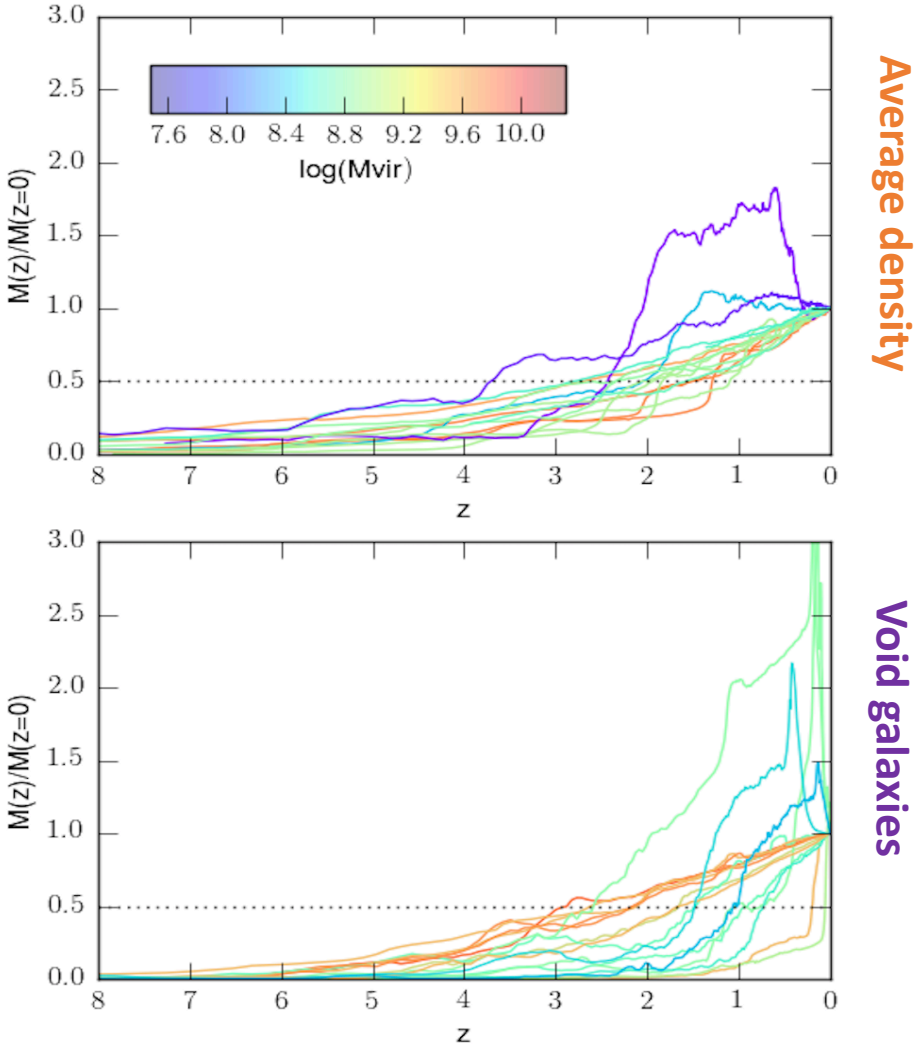
Galaxy formation in voids expected to take place in local overdense regions, tenuous filaments and walls.

Void Galaxies

- Evolution in Voids is slowed down with respect to high-density environment (e.g. Hahn+07)

- Previous observational studies have shown that void galaxies are in general small, star- forming blue galaxies, with later morphological type and higher specific star formation rates (SFRs) than the galaxies in average-density environments

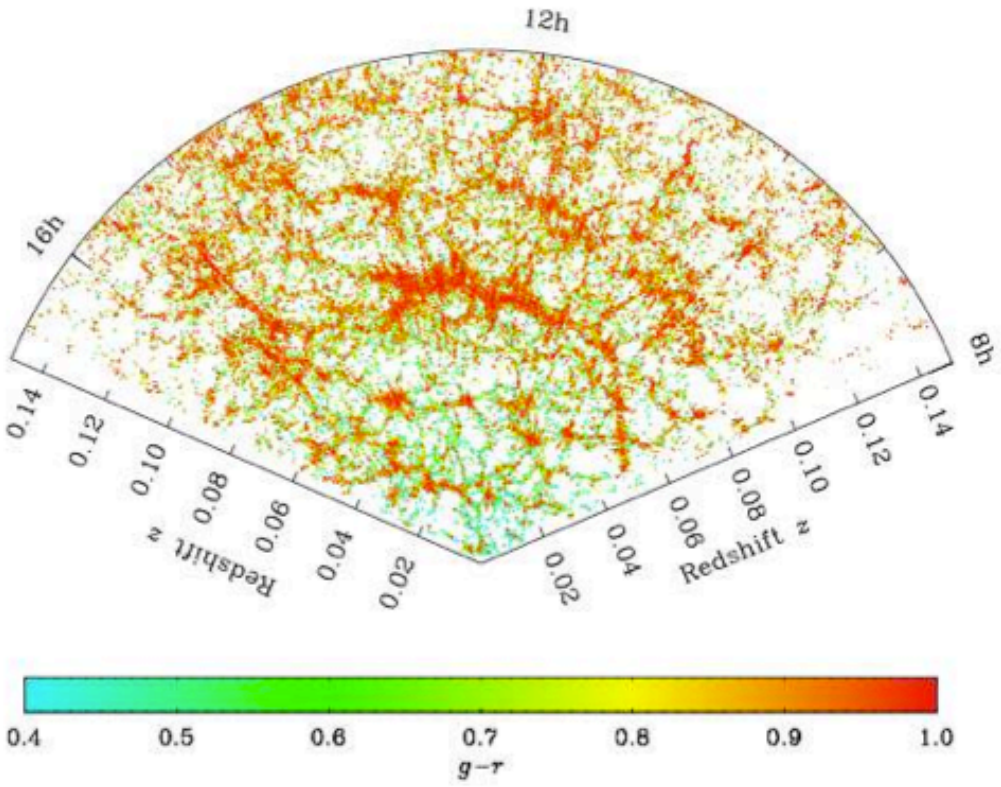
- Low metallicity dwarfs ? (e.g. Pustilnik+11, Filho1+5, Douglass+17)



Why void galaxies?

- Are they really peculiar object?
- Study galaxy evolution in a pristine environment in (almost) absence of nurture
- Impact of the large scale environment on galaxy evolution

Void Identification



SDSS-DR7 void catalog
(spectroscopic catalog: 3D)

Void definition (Varela+12):

Spherical volume devoid of any galaxy brighter than our completeness limit (M_r = -20.17)

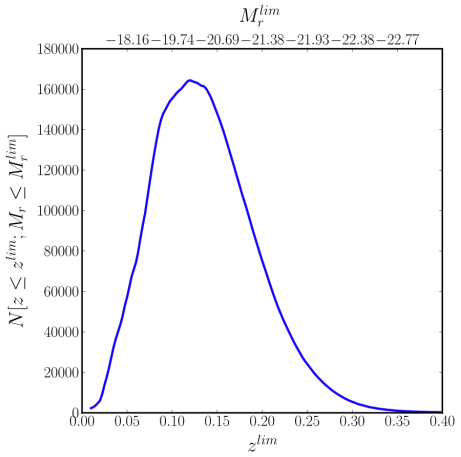
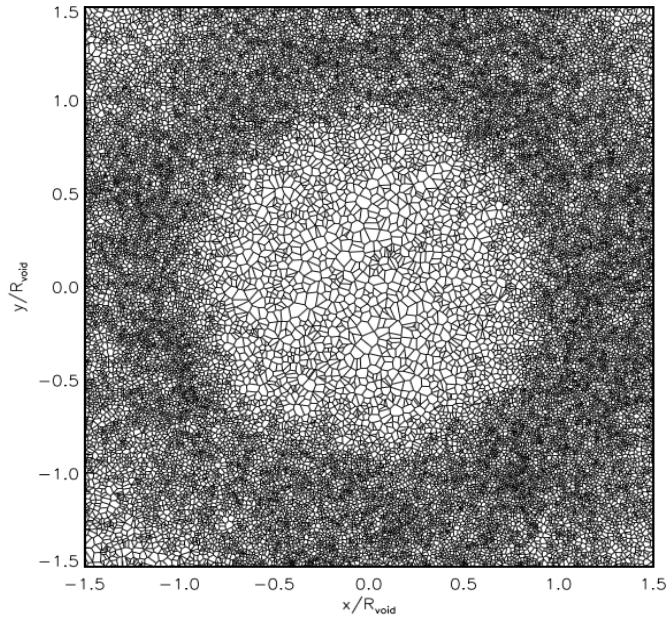
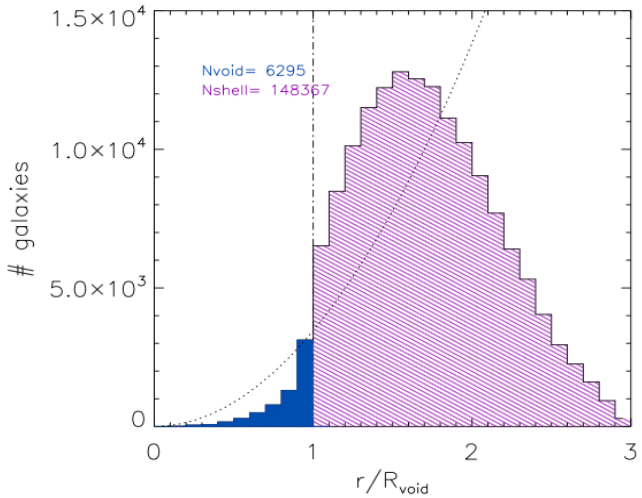


Table 1
Summary of Properties of the Reference Catalog

Reference catalog	NYU-VAGC (Galaxies)
Spectroscopic completeness limit	$r \leqslant 17.8$
Redshift limits	$0.005 < z < 0.12$
Absolute magnitude limit	$M_r - 5 \log h \leqslant -20.17$
Number of galaxies	142127
Total projected area	1.941484 sr
	$0.1545 \times 4\pi$
Total volume	$0.0276556\ (h^{-1}\ \mathrm{Gpc})^3$
Average density of galaxies	$0.00514\ (h^{-1}\ \mathrm{Mpc})^{-3}$

Void Identification

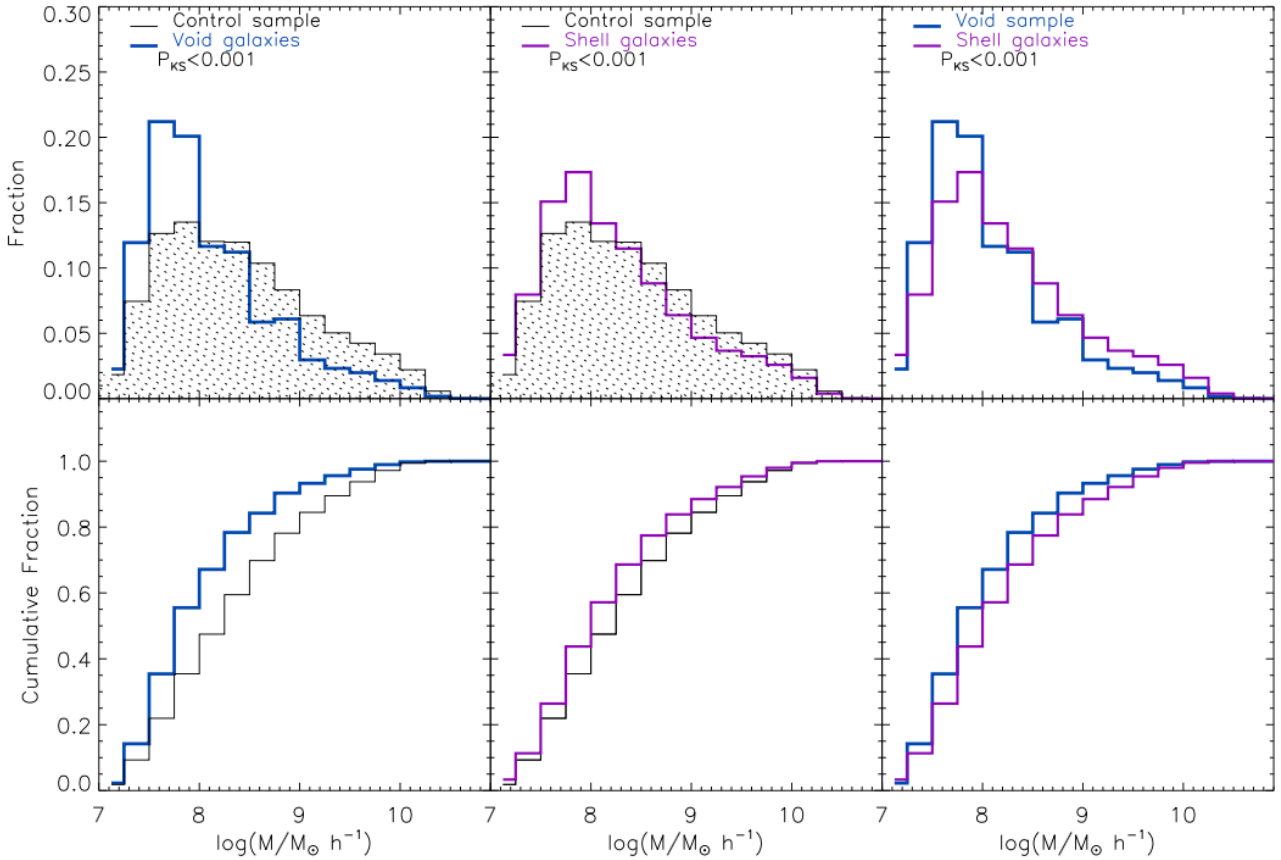




Void catalog:

- 630 voids, which, by definition, can host only galaxies fainter than *Mr* = -20.17
- redshift<0.12
- $\delta = (n - \langle n \rangle) / \langle n \rangle \sim -0.8$
- Void radii: 10 -18 Mpc/h
- Steep profiles

Stellar Mass of VG



Void galaxies are shifted towards low-mass
Gradual shift towards high-mass systems moving from voids to shells and control sample (i.e. average environment)

Homogeneous magnitude cut: $M_r \geq -20.17$

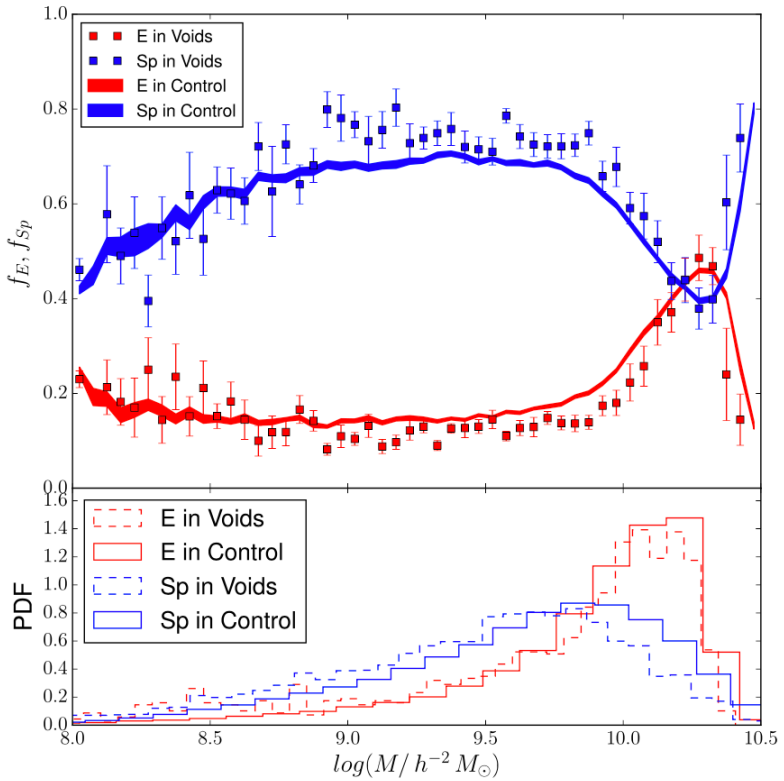
Void galaxies:
~6000 galaxies

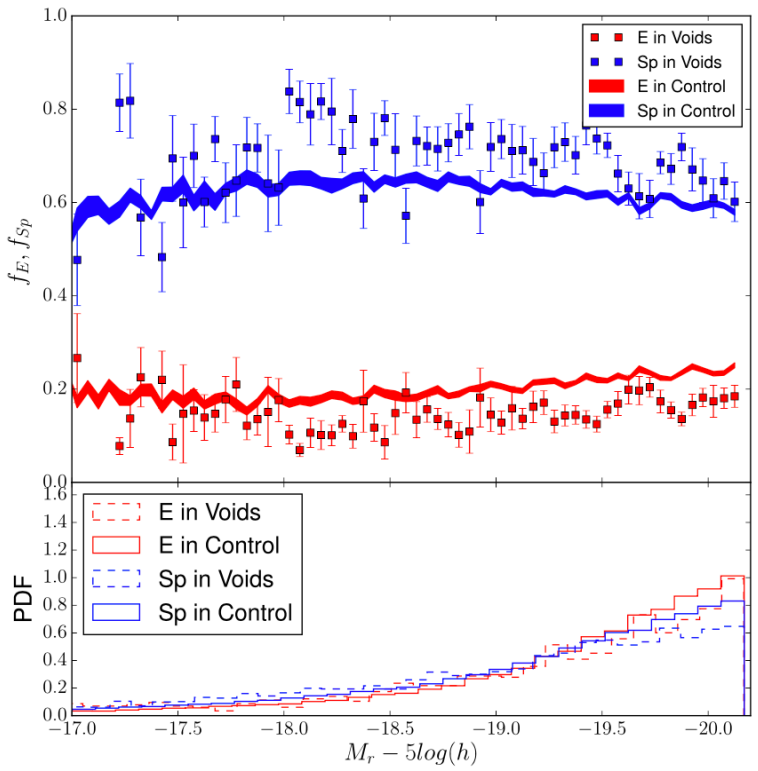
Shell galaxies:
$1 \leq d_{void}/R_{void} \leq 1.5$; ~ 15000 galaxies

Control Sample: ~ 200000 galaxies
all SDSS galaxies with the same magnitude cut

Stellar mass from spectral fit (Kauffmann+03)

Morphology of VG





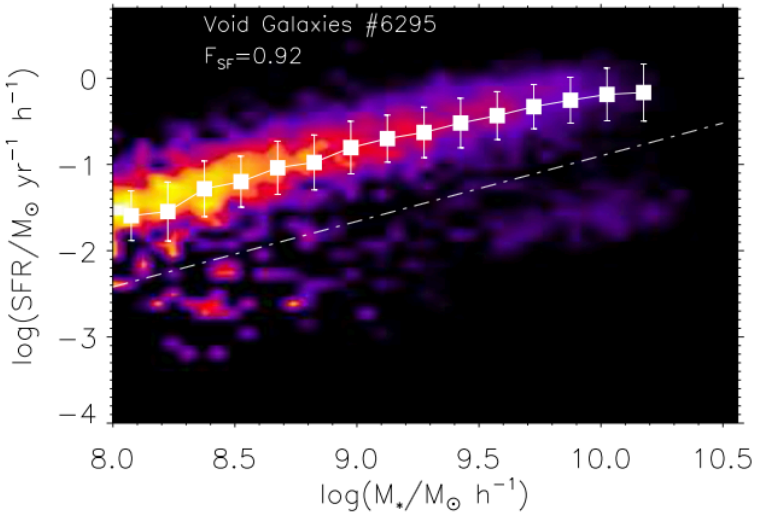
Visual morphology from Galaxy Zoo Project (Lintot+2008):

Each galaxy has been classified by several users into classes: “Elliptical” “Spiral” “Merger” and “Do not know”
The proportion of classifications in each class has been translated into likelihood (f_E, f_{Sp})

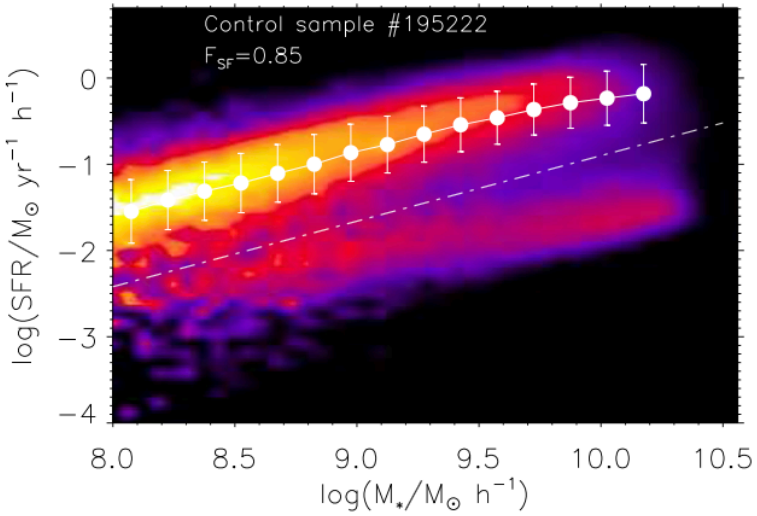
At all stellar masses and absolute magnitudes, the fraction of elliptical (spiral) galaxies in voids is smaller (larger) than in the control sample: pure environmental effect, independent on the mass bias

Star Formation Properties of VG

Void Galaxies



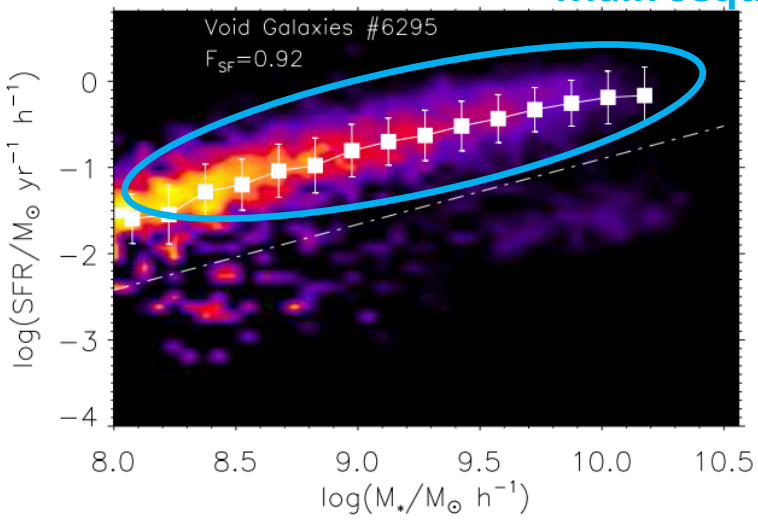
Control Sample



Star Formation Properties of VG

Main sequence (SF galaxies)

Void Galaxies



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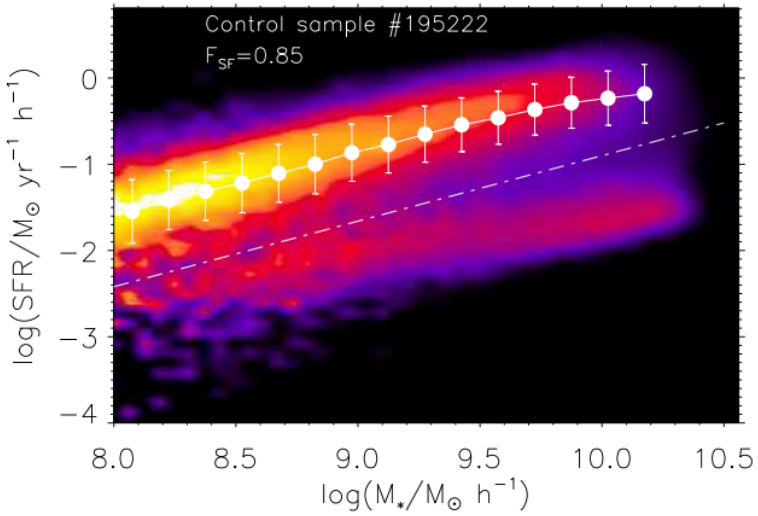

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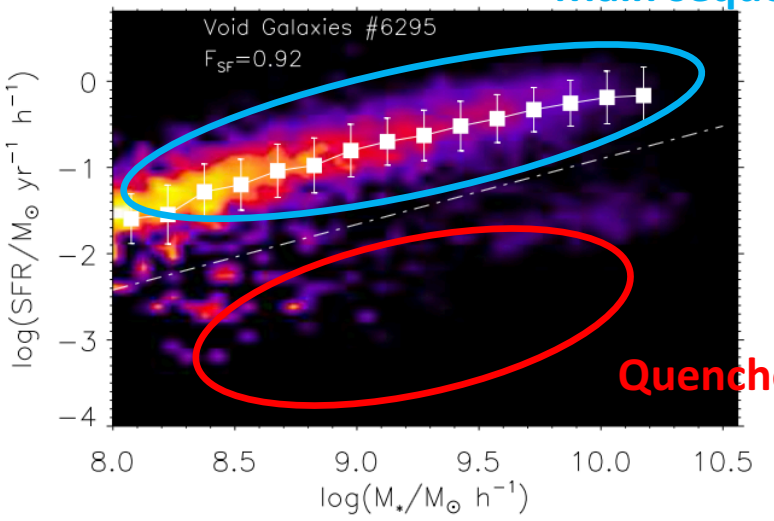
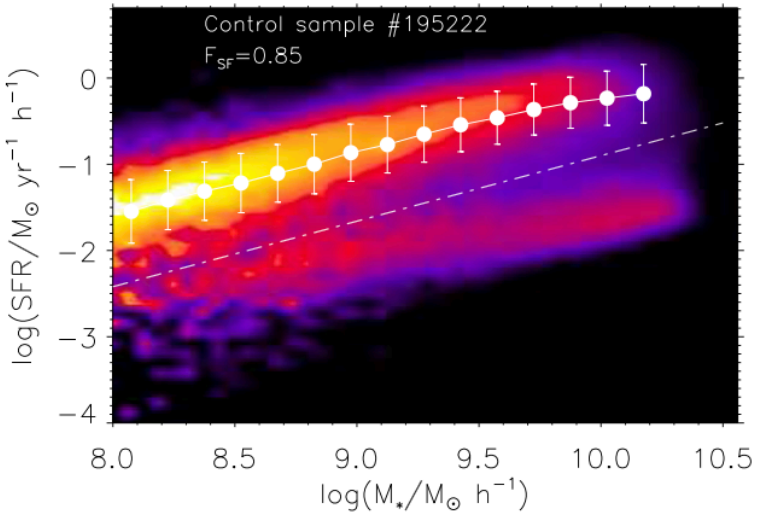


Quenched galaxies

Control Sample



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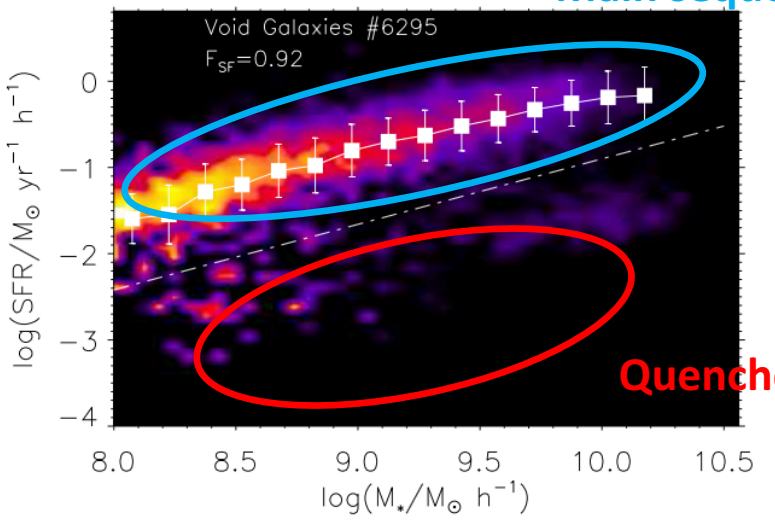
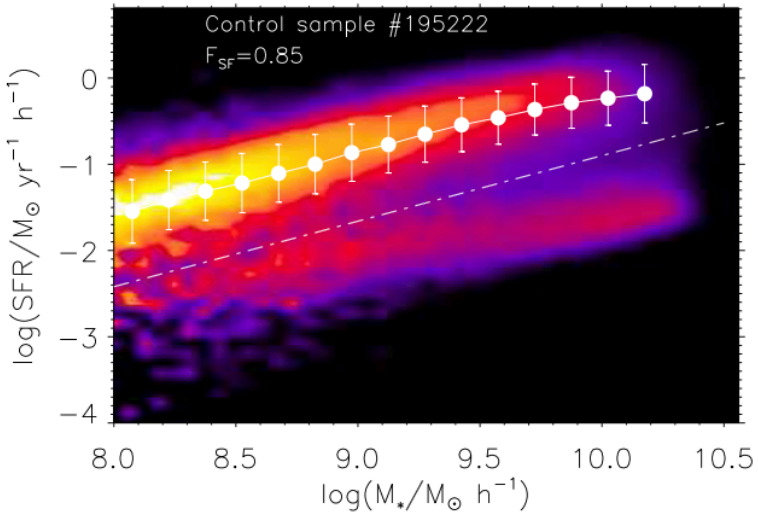


Quenched galaxies

Void galaxies are star forming (on the MS) at all stellar masses

Quenched galaxies in voids are largely missing, at all stellar masses

Control Sample



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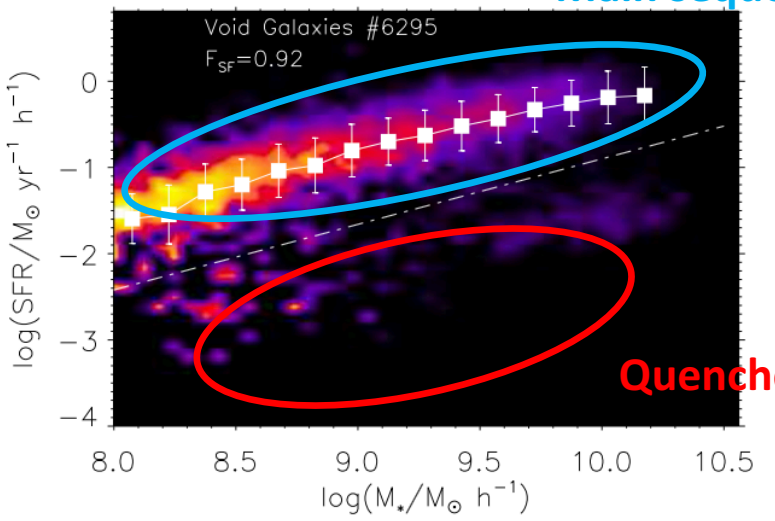

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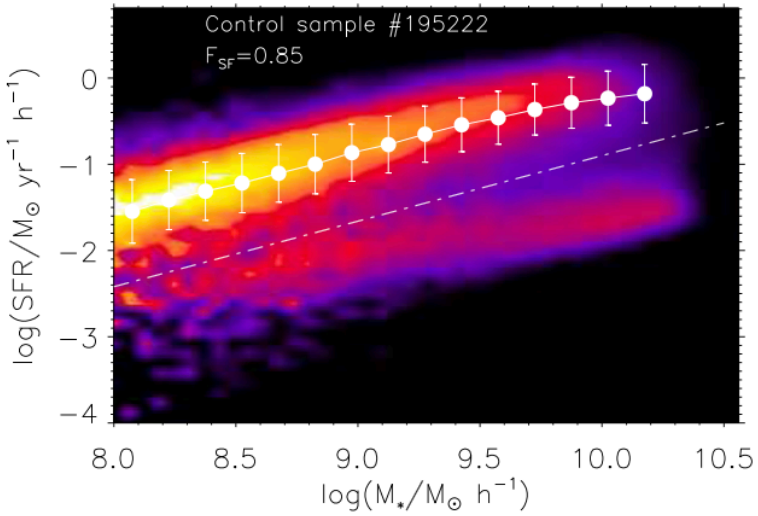
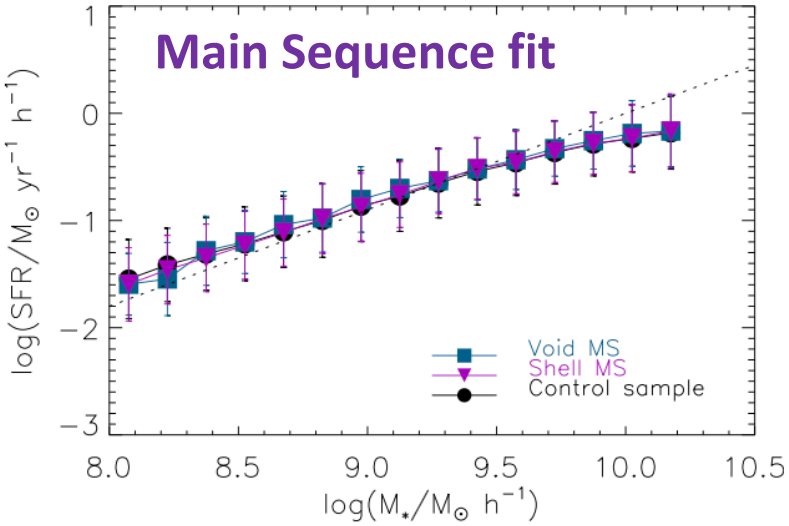
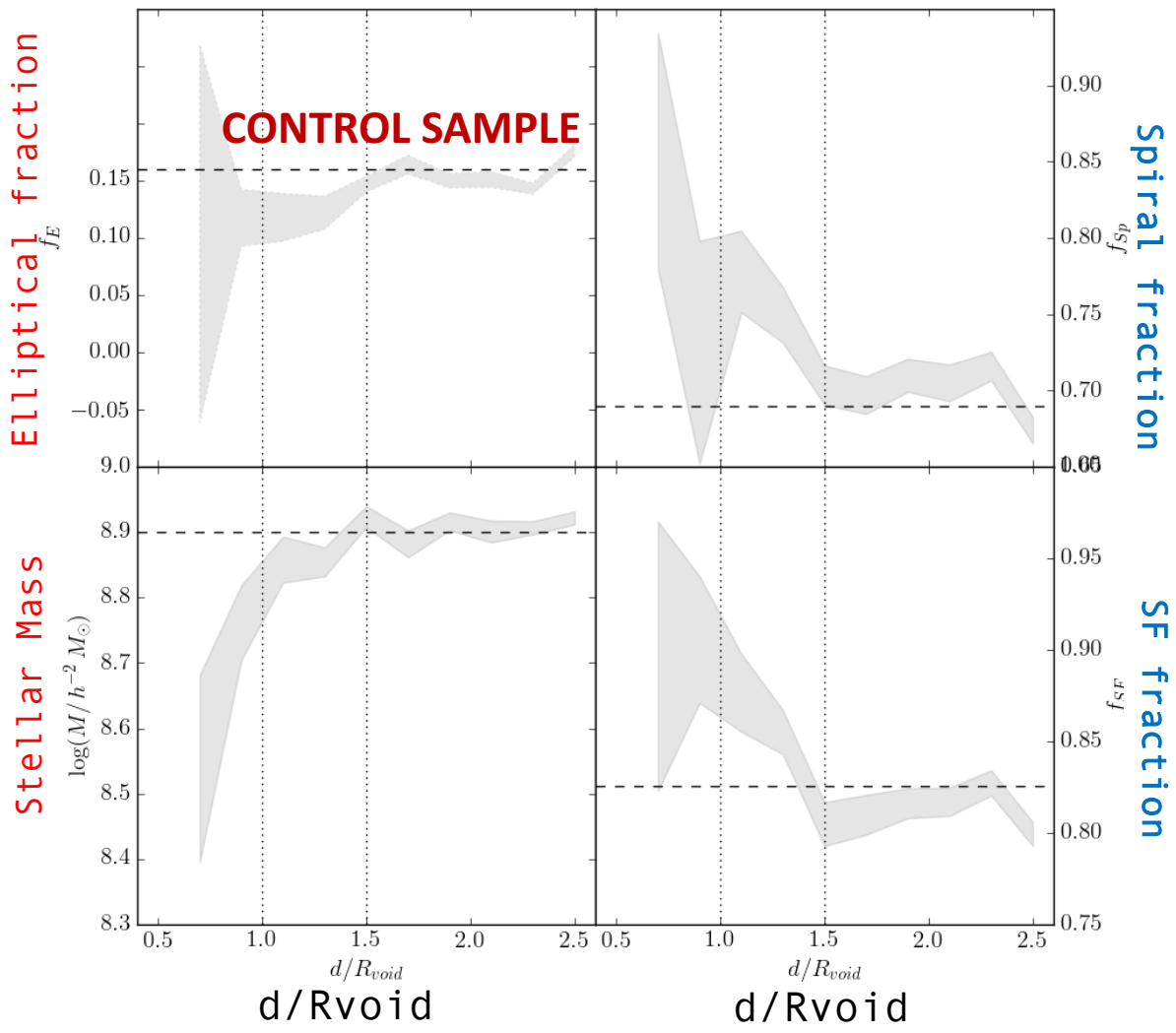




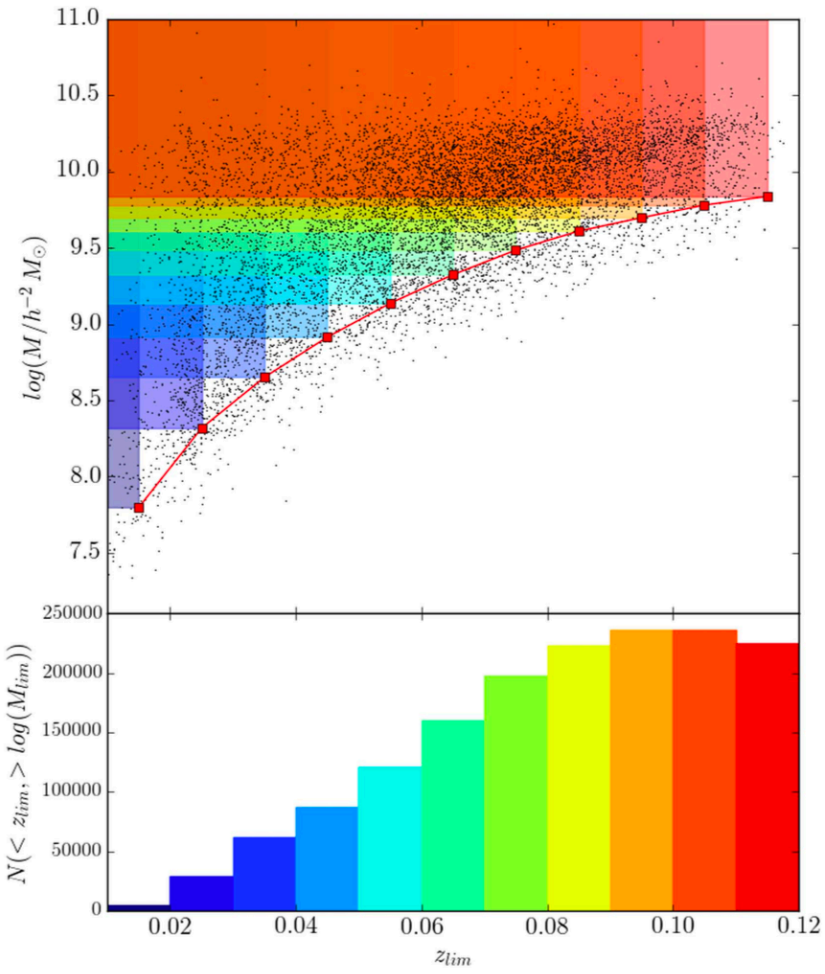
when only MS galaxies are selected:
void galaxies form stars at the same rate than galaxies in high density environment

Segregation of galaxy properties



- Significant correlation between average galaxy properties and void-centric distance
- The most massive and early-type galaxies are found at large void-centric distances, whereas late-type and star-forming galaxies are located at small void-centric distances
- The properties of VG converge to those of the control sample at ~1.5Rvoid

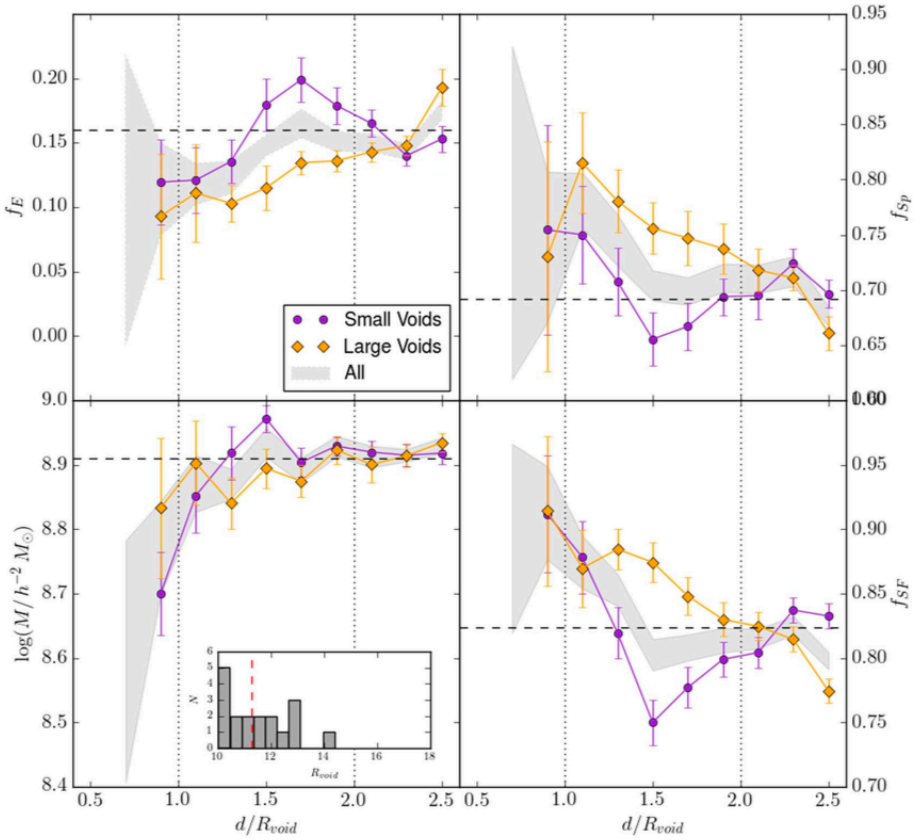
Impact of void size:

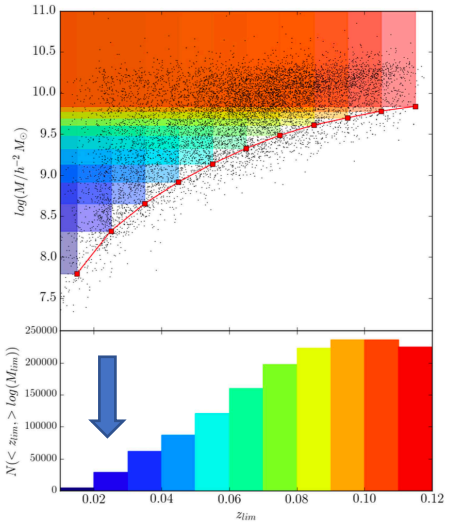


- Large voids are preferentially located at high redshift, where only bright galaxies are observed
- To avoid Malmquist bias effect only volume-limited samples are considered when comparing galaxies in voids of different sizes

Impact of void size

z<0.025; log(M)>8.3





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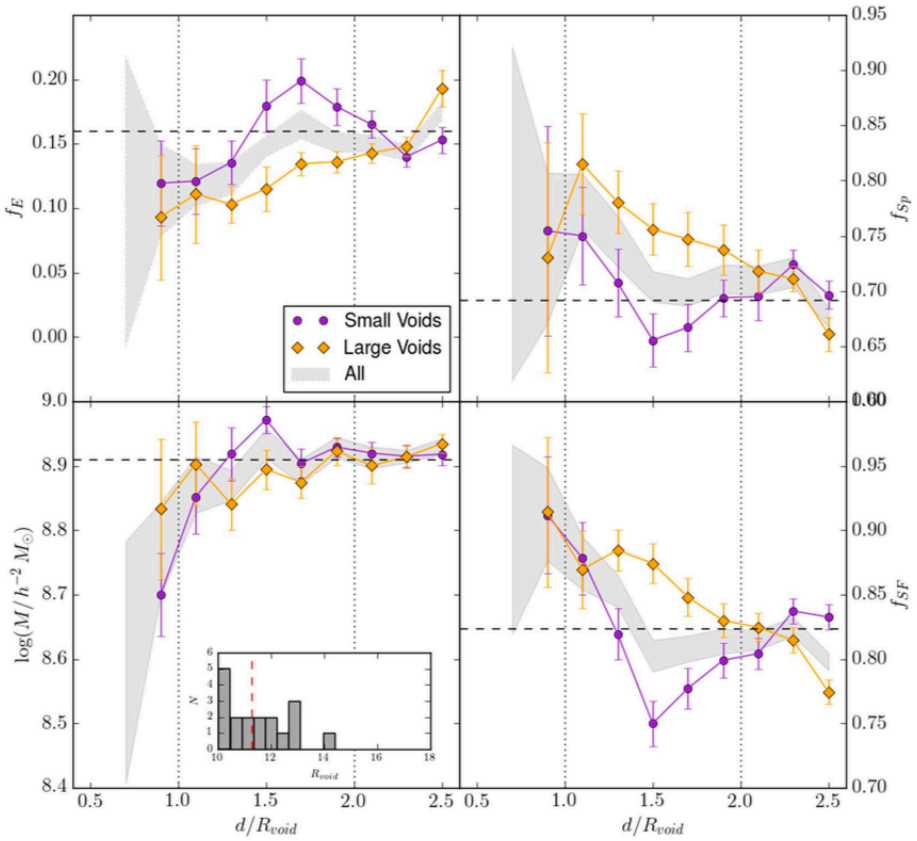
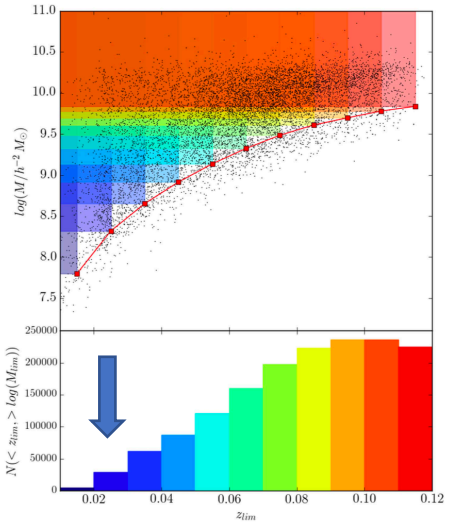


significant difference in galaxy properties in the surroundings of voids of different sizes:
excess of early-type galaxies in small voids and of late-type galaxies in large voids



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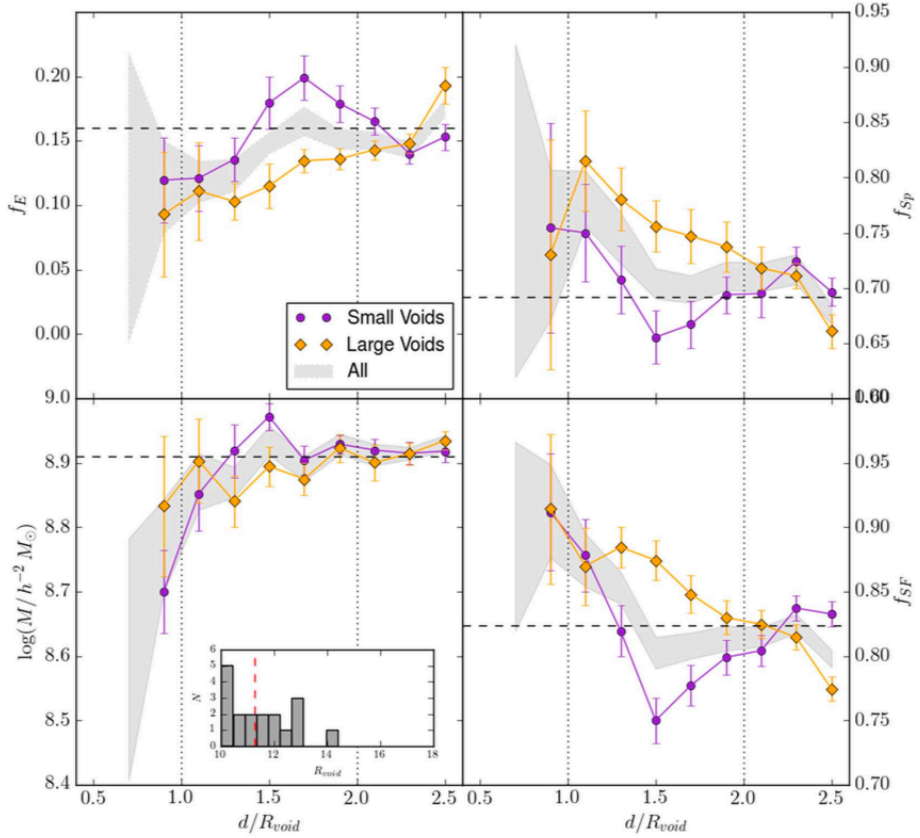
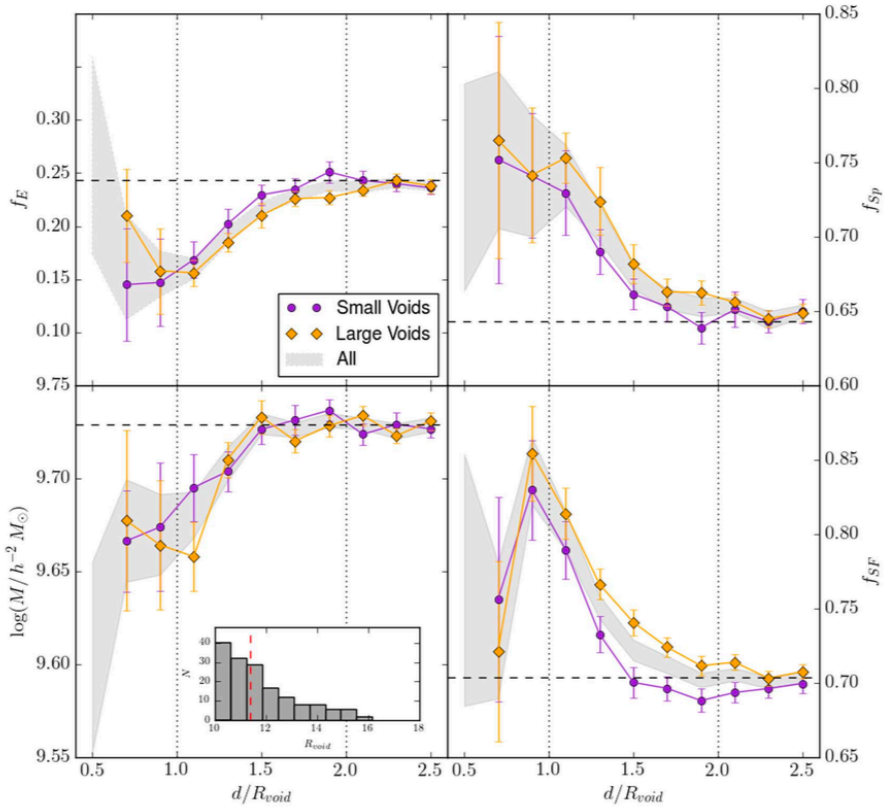
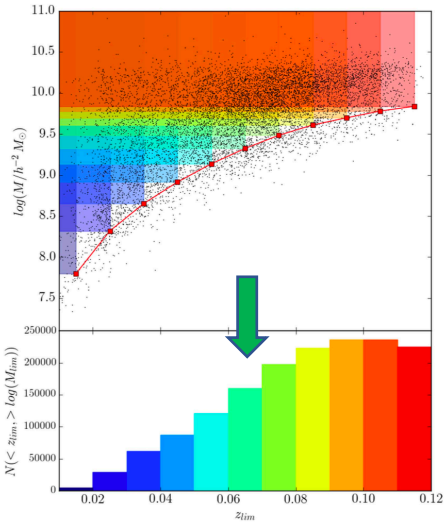




z<0.065; log(M)>9.3



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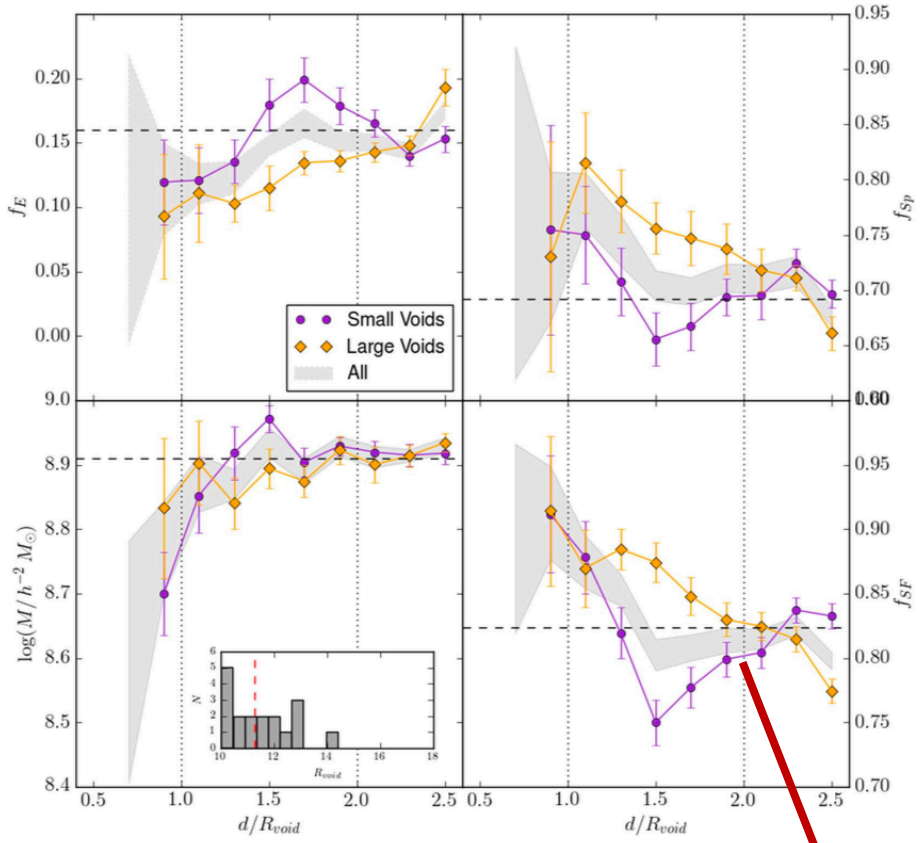
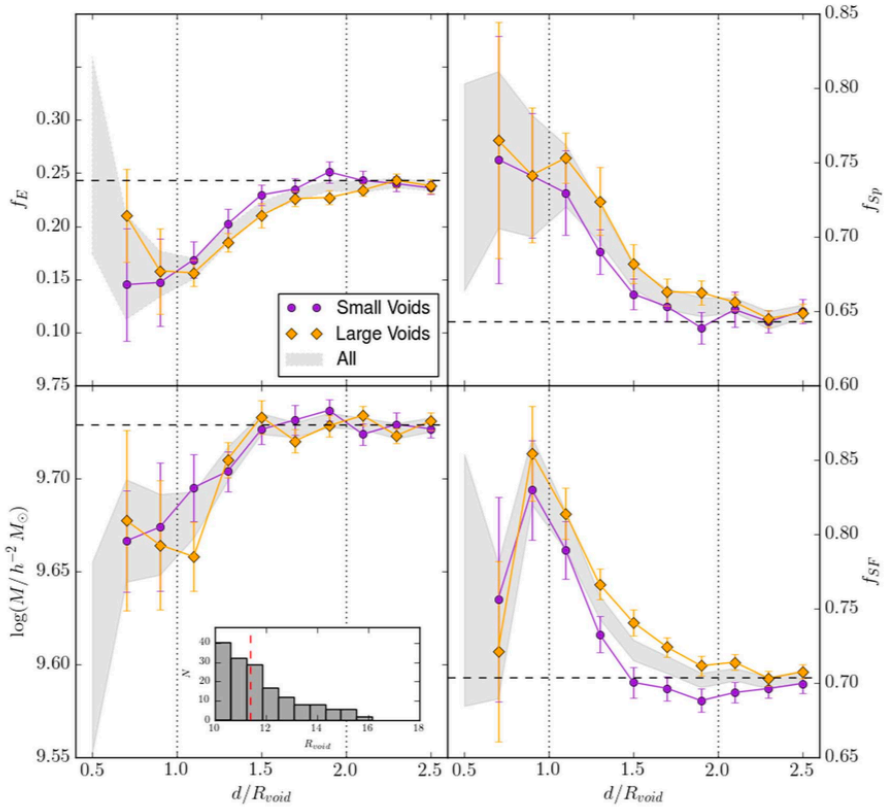
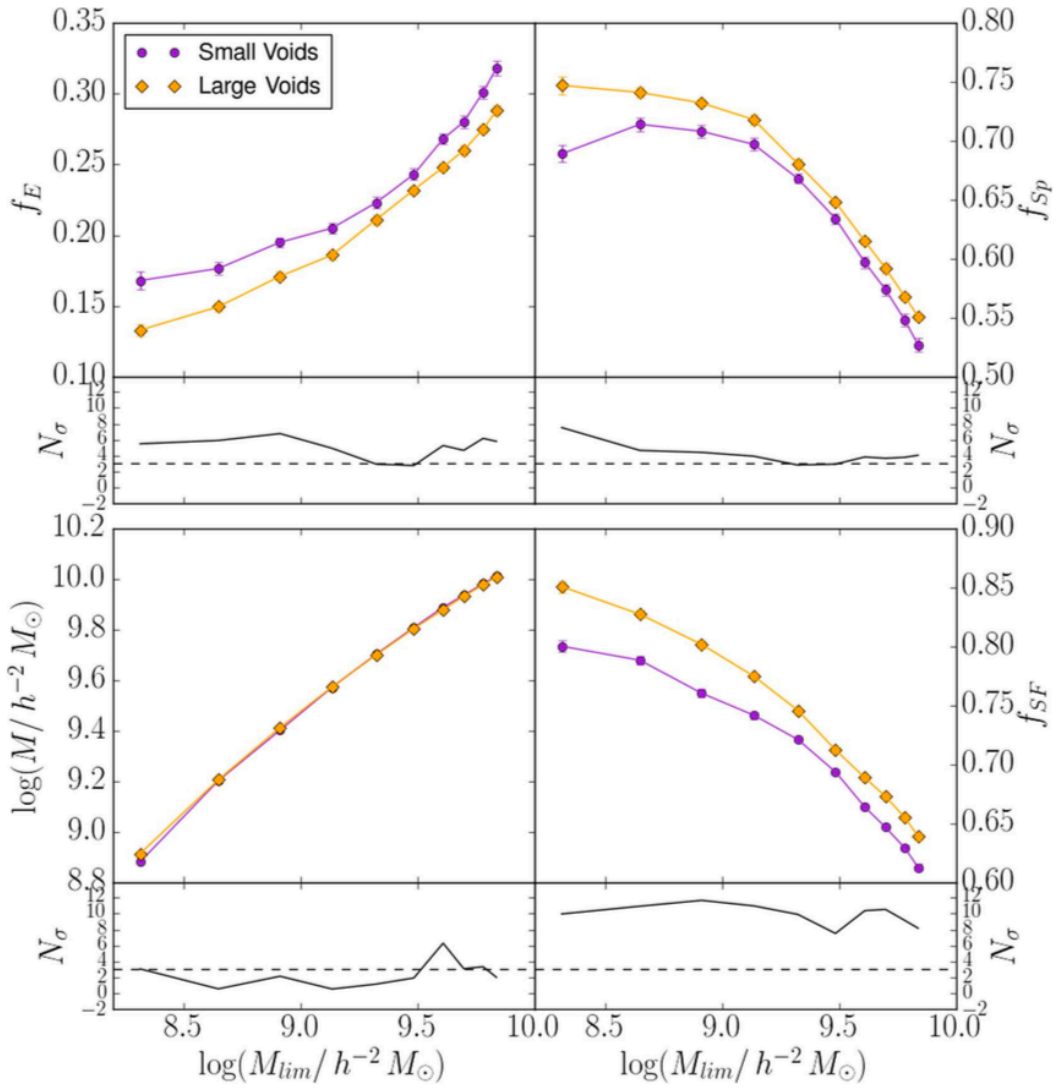


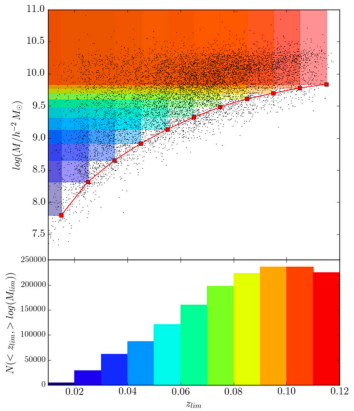


z<0.065; log(M)>9.3

Region of influence of voids up to $2R_{void}$ (~20 Mpc/h)

Impact of void size

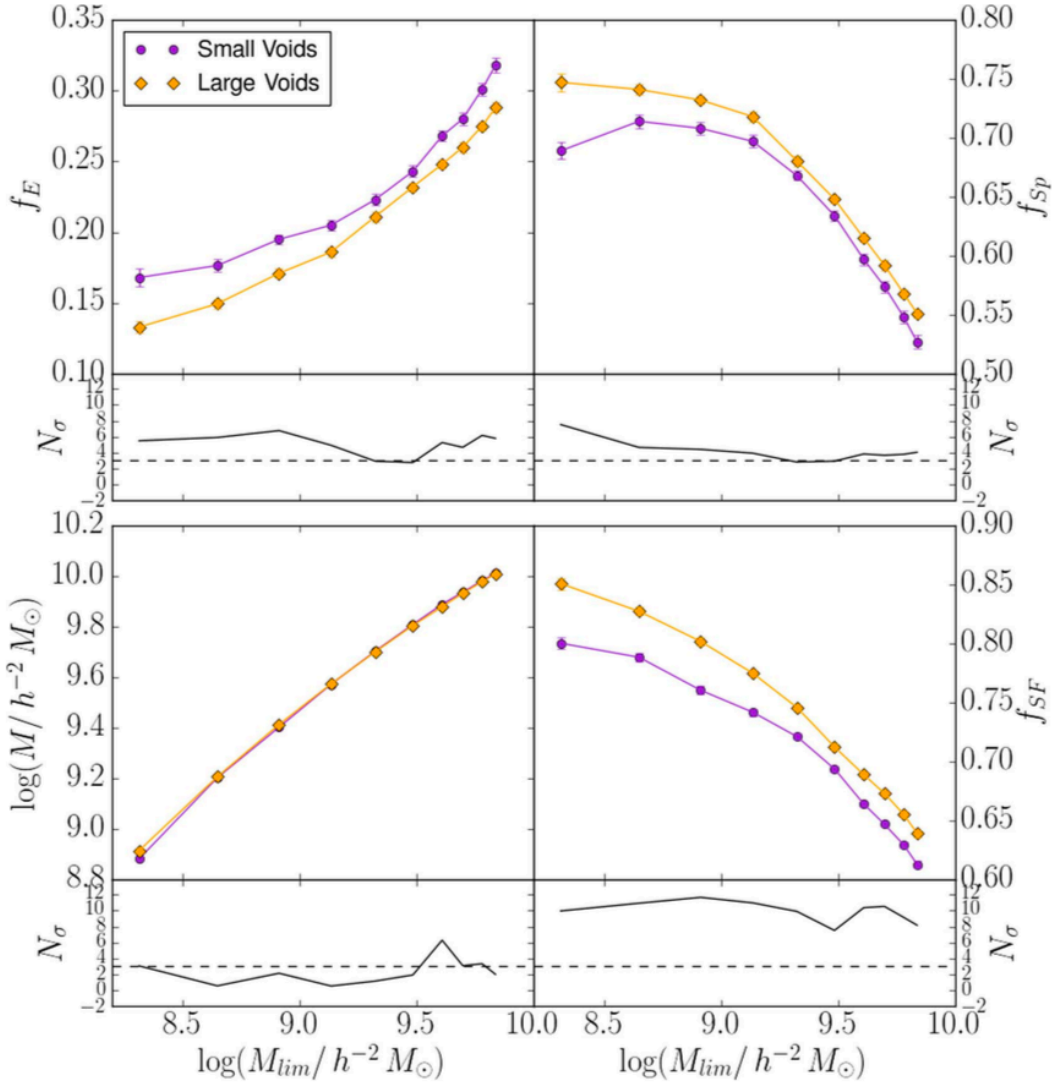




Median morphological fractions, stellar masses, and star-forming fractions in the region of influence of voids: $0<d_{void}/R_{void}<2$

- The difference between **small** and **large** voids is significant (at least 3σ) in all the volume-limited samples probed
- Stellar mass does not show any dependence on the void location
- Large signal at low-masses, but small statistical significance

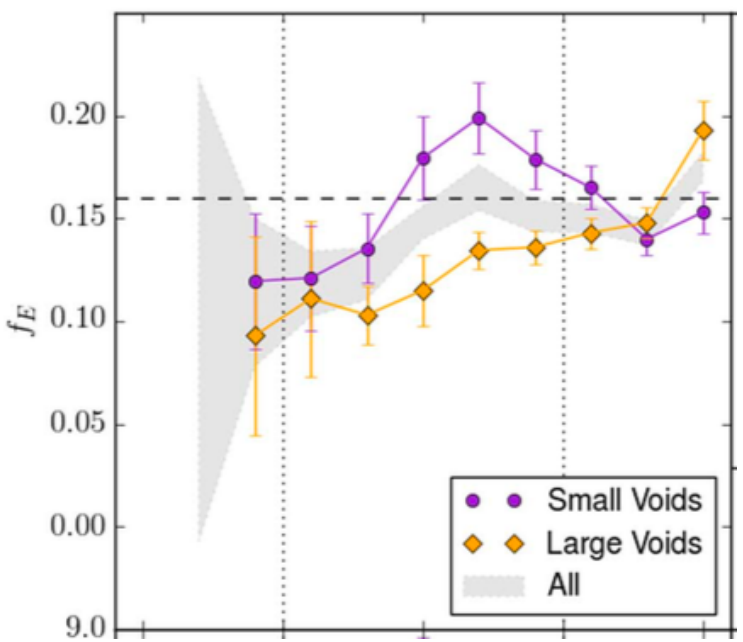
Impact of void size



Effect of the different dynamical history of voids of different sizes (see Ceccarelli+13, Hamaus+14, Paillas+17) ?

Possibly related to the void dichotomy: *void-in-void* and *void-in-cloud* (Sheth&vandeWeygaert04)

Conclusions



1) Void galaxies have different galaxy properties (SFR, morphology) with respect to galaxies in average density environment, when compared across the same stellar mass

2) Segregation of galaxy properties

3) The surroundings of large voids host galaxies of a later-type and more star forming than small voids, but with the stellar mass: large-scale density effect. Significant correlation up to 2 void radii

4) Hint of a stronger effect in low-mass galaxies

Thank you !!