Voids and Void Galaxies in the TNG300 Simulation at z=0

Olivia Curtis,

Tereasa Brainerd, Bryanne McDonough

Boston University, Department of Astronomy

Email: amcurtis@bu.edu

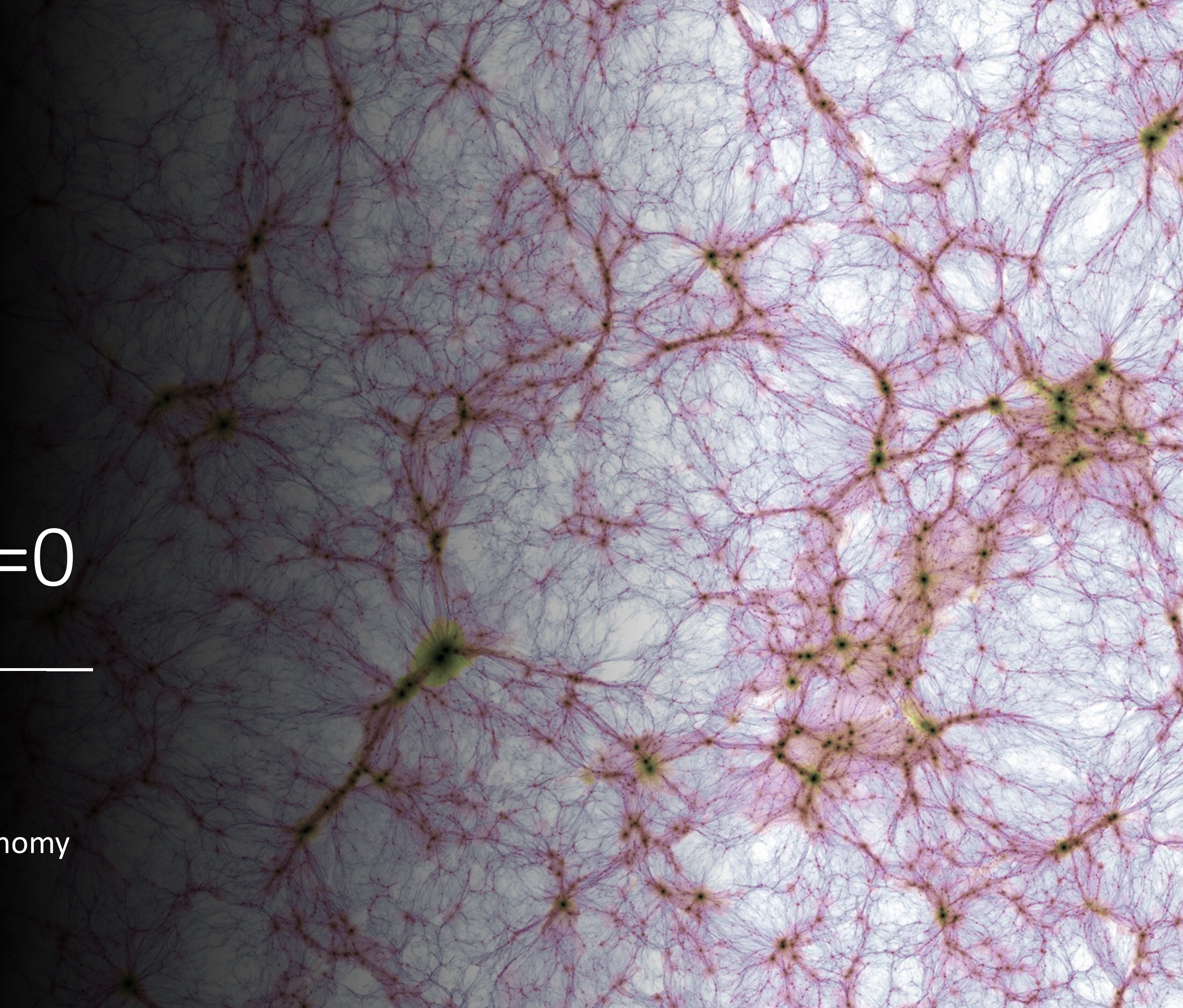
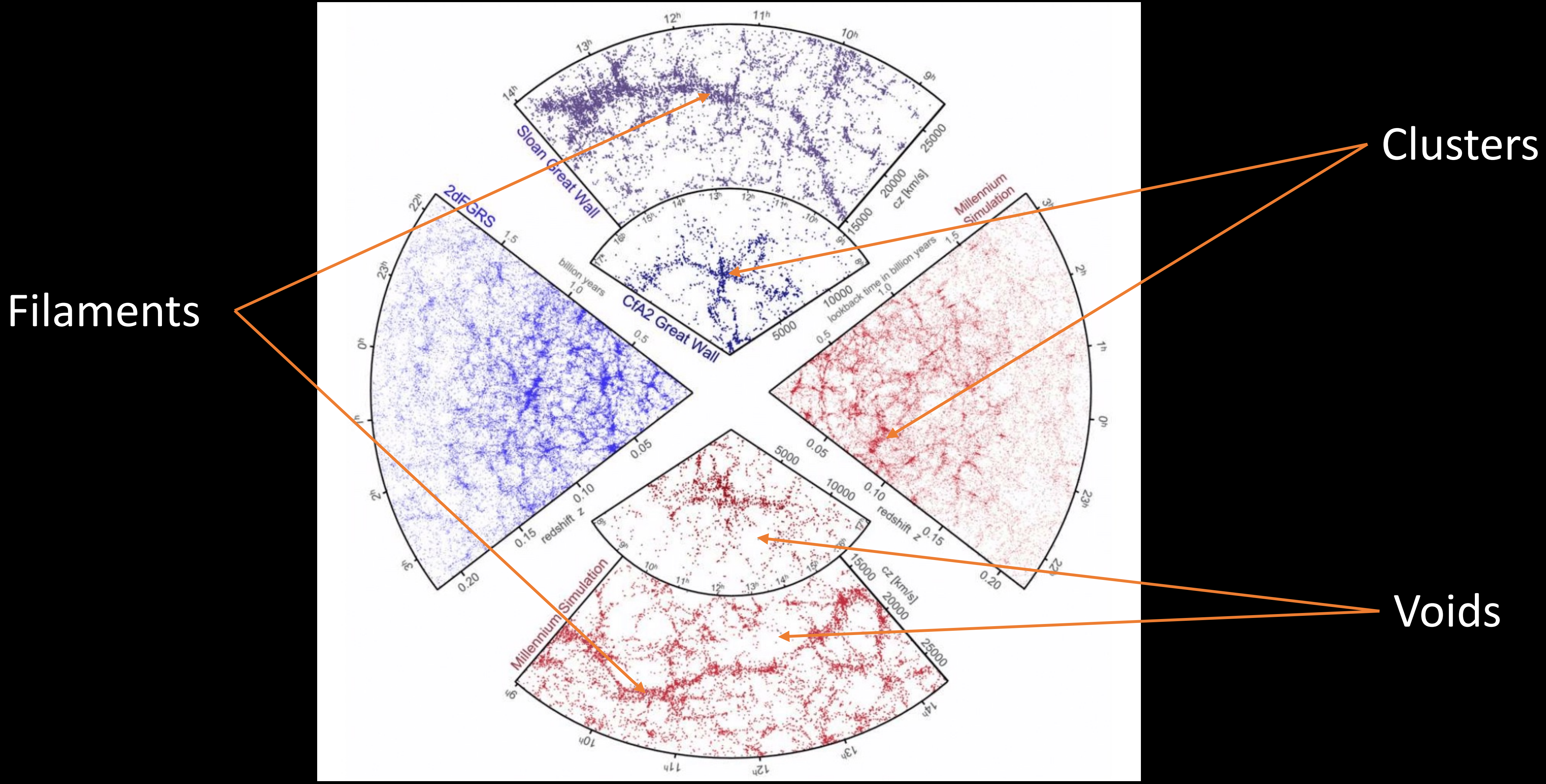


Image Credit: The IllustrisTNG Project

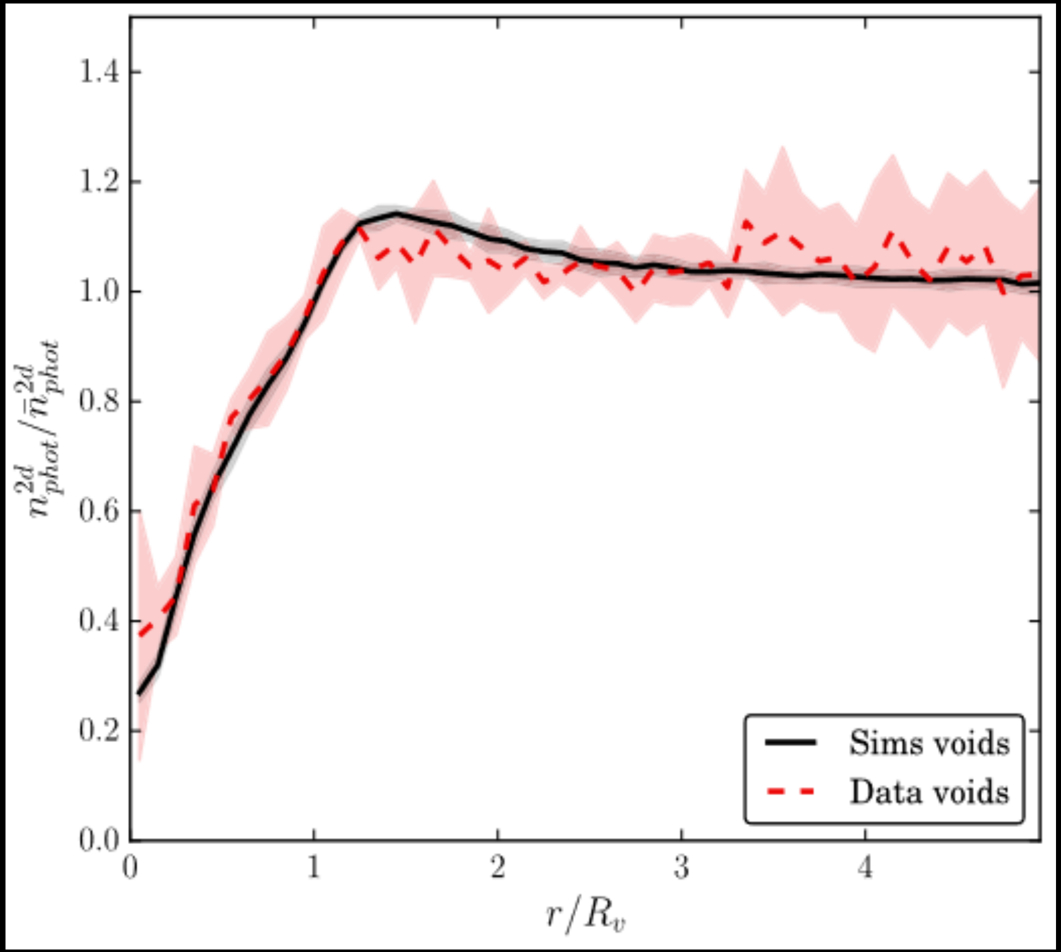
Table of Contents

The cosmic web



Source: Springel, Frenk, and White (2006)

Cosmic voids are the largest, emptiest regions of space

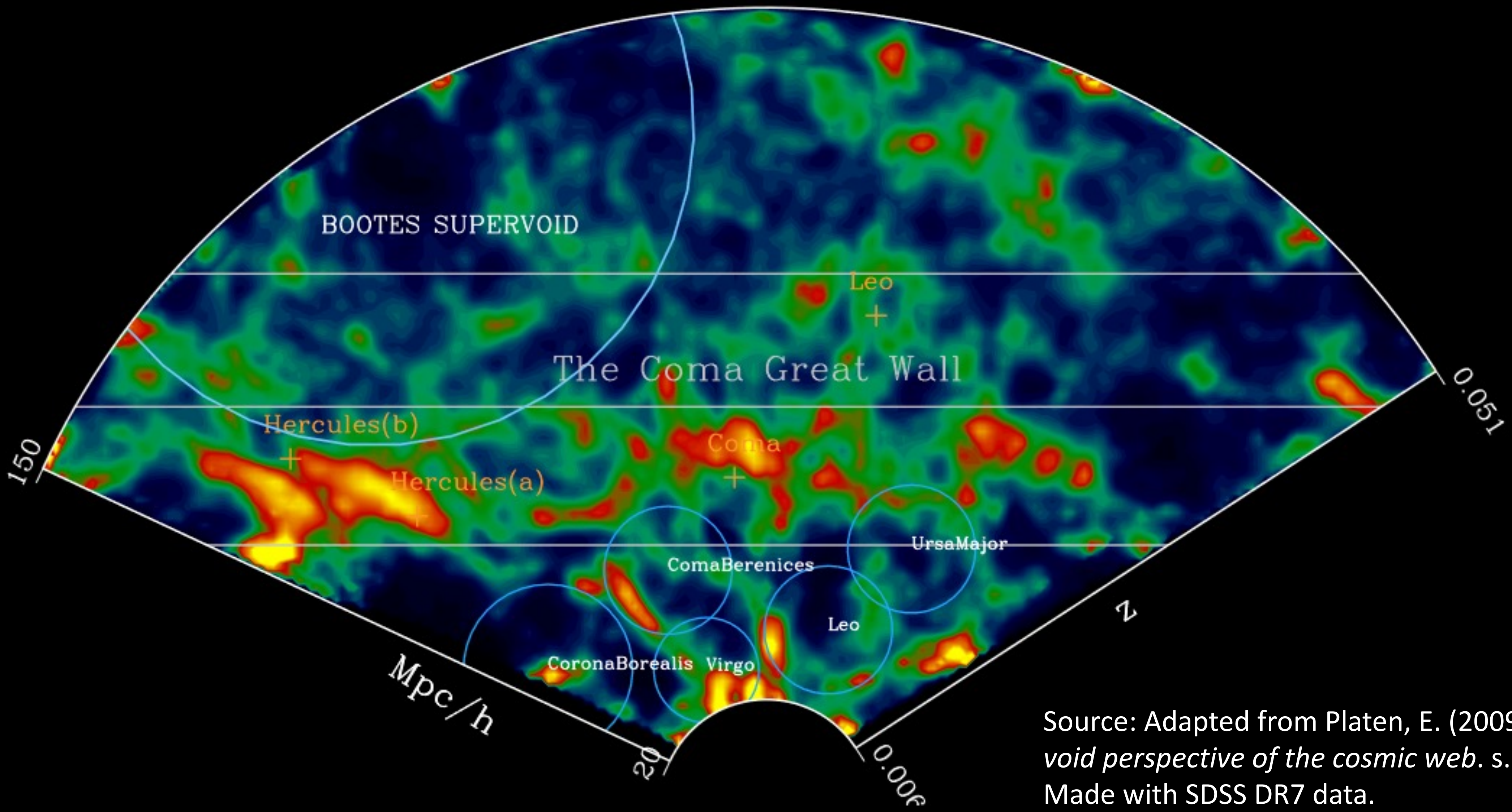


Source: The Dark Energy Survey (Sànchez et al., 2017)

The Dark Energy Survey Reported 87 voids in their 139 sq. degree survey.

- $\langle R_v \rangle$ = 37 Mpc/h
- R_v^{max} = 120 Mpc/h
- R_v^{min} = 18 Mpc/h
- $\langle \theta_v \rangle$ = 1.5 degrees
- Redshift Range 0.2 < z < 0.8
- $\langle z \rangle$ = 0.57

Voids are underdense but still show significant substructure.



Source: Adapted from Platen, E. (2009). *A void perspective of the cosmic web*. s.n. Made with SDSS DR7 data.

Voids are not completely devoid of matter

- Void Galaxy Survey provided HI imaging of 60 void galaxies (and their companions) seen in the Sloan Digital Sky Survey.

- Found void galaxies are:
    - gas rich,
    - contain typical HI masses for their luminosity,
    - actively star forming,
    - and show evidence of ongoing gas accretion.

Source: Adapted from Kreckel et al., 2012 (The Void Galaxy Survey)

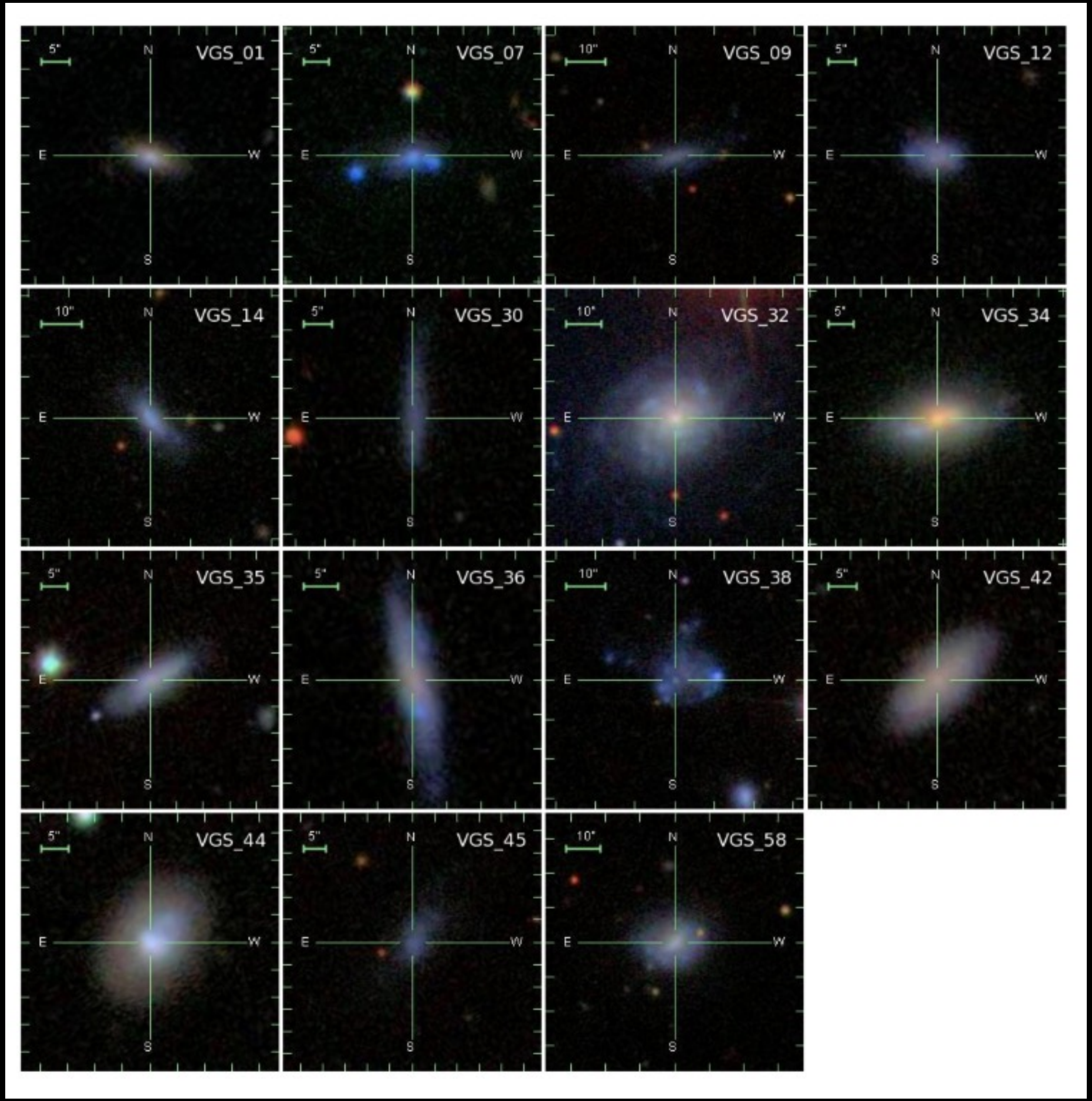


Table of Contents

The TNG Project

- Suite of cosmological magnetohydrodynamical galaxy formation simulations.

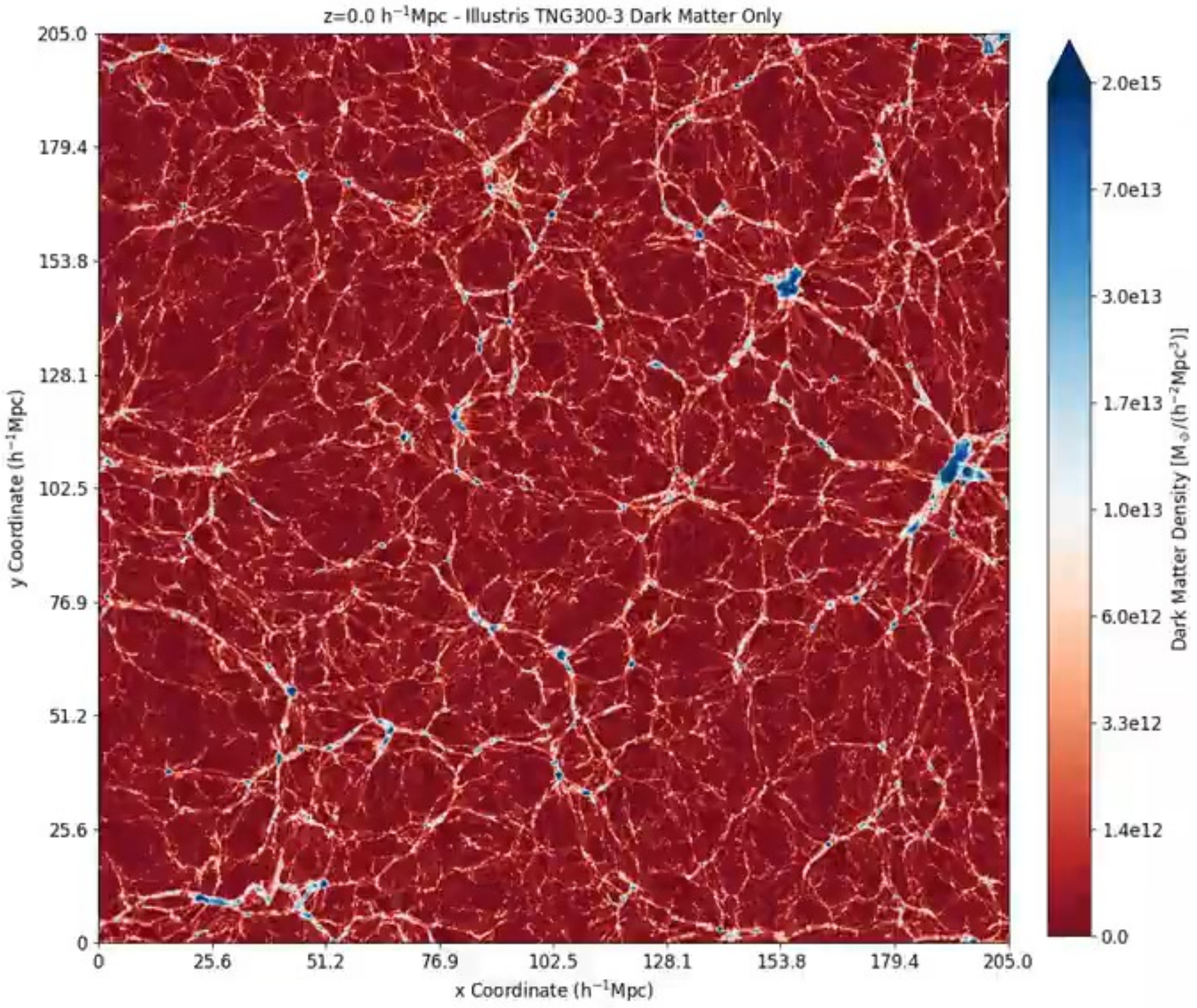
- Consists of three simulations of volumes 50^3, 100^3, and 300^3 Mpc^3, respectively.

- TNG300 contains over 2500^3 dark matter particles and gas cells, $\sim10^5$ black hole “particles”, and $\sim10^8$ stellar “particles”.

Source: TNG50 – Formation of Typical Disk Galaxy

Colors: Orange – Gas Density.

Blue – Gas velocity.

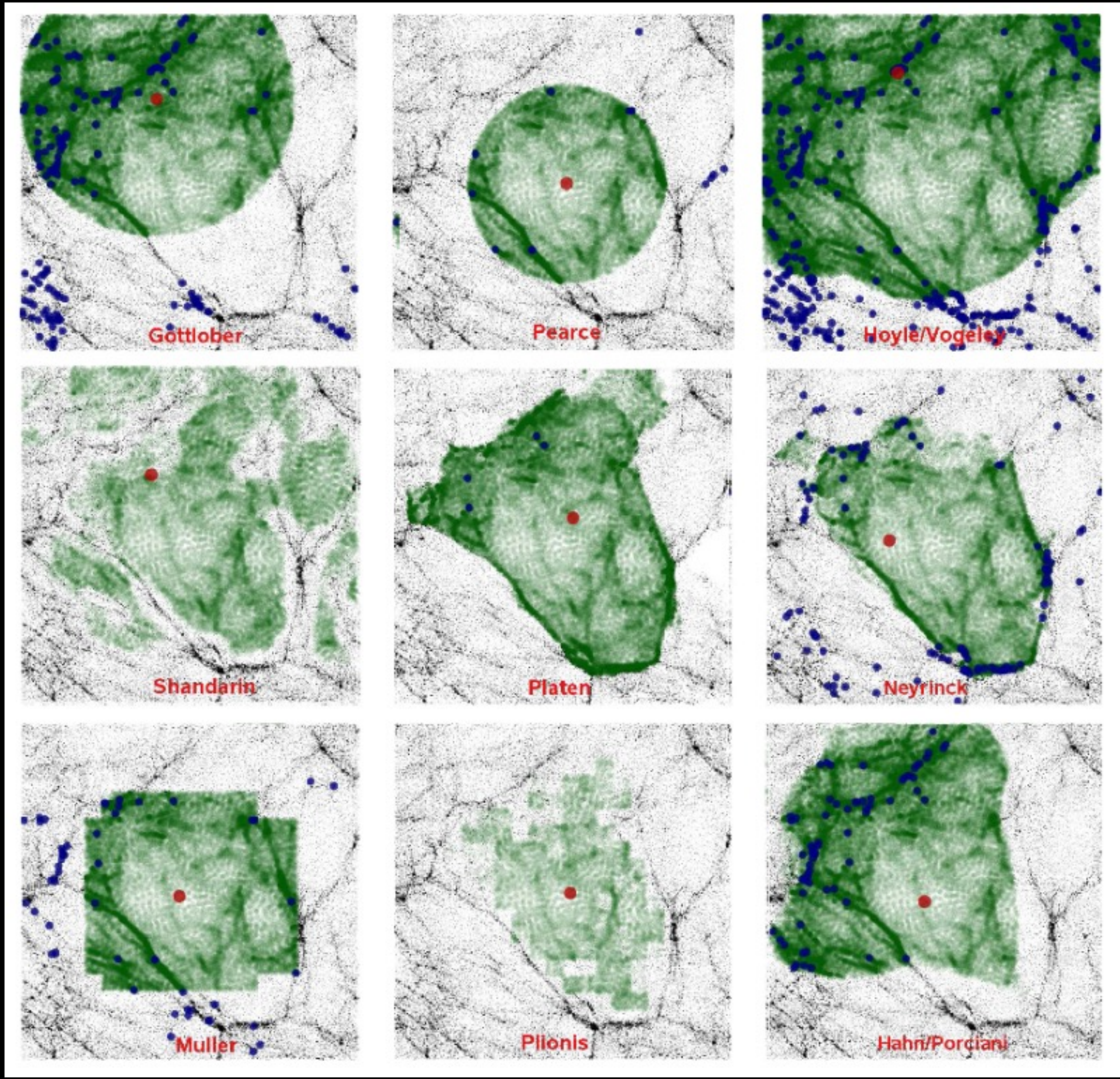


Source: Video by Olivia Curtis, 2021.
Particle data from TNG300

Void shape and abundance heavily depends on how voids are defined.

- For this study, I used the 3D spherical voidfinder algorithm of Paillas et al., 2017.

- Approximates voids as the largest sphere enclosing an underdense region of space that meets some underdensity threshold.



Source: Colberg et al., 2008

Voidfinder Summary

The algorithm of Paillas et al., 2017 can be summarized in four steps:

I. A grid is constructed over the galaxy distribution. A cell which contains no galaxies is considered a void center.

II. Spheres are expanded outwards from each void center until the largest sphere with an integrated density contrast Δ_{void}<-0.8 is found. The radius of this sphere has its radius defined to be the radius of the void.

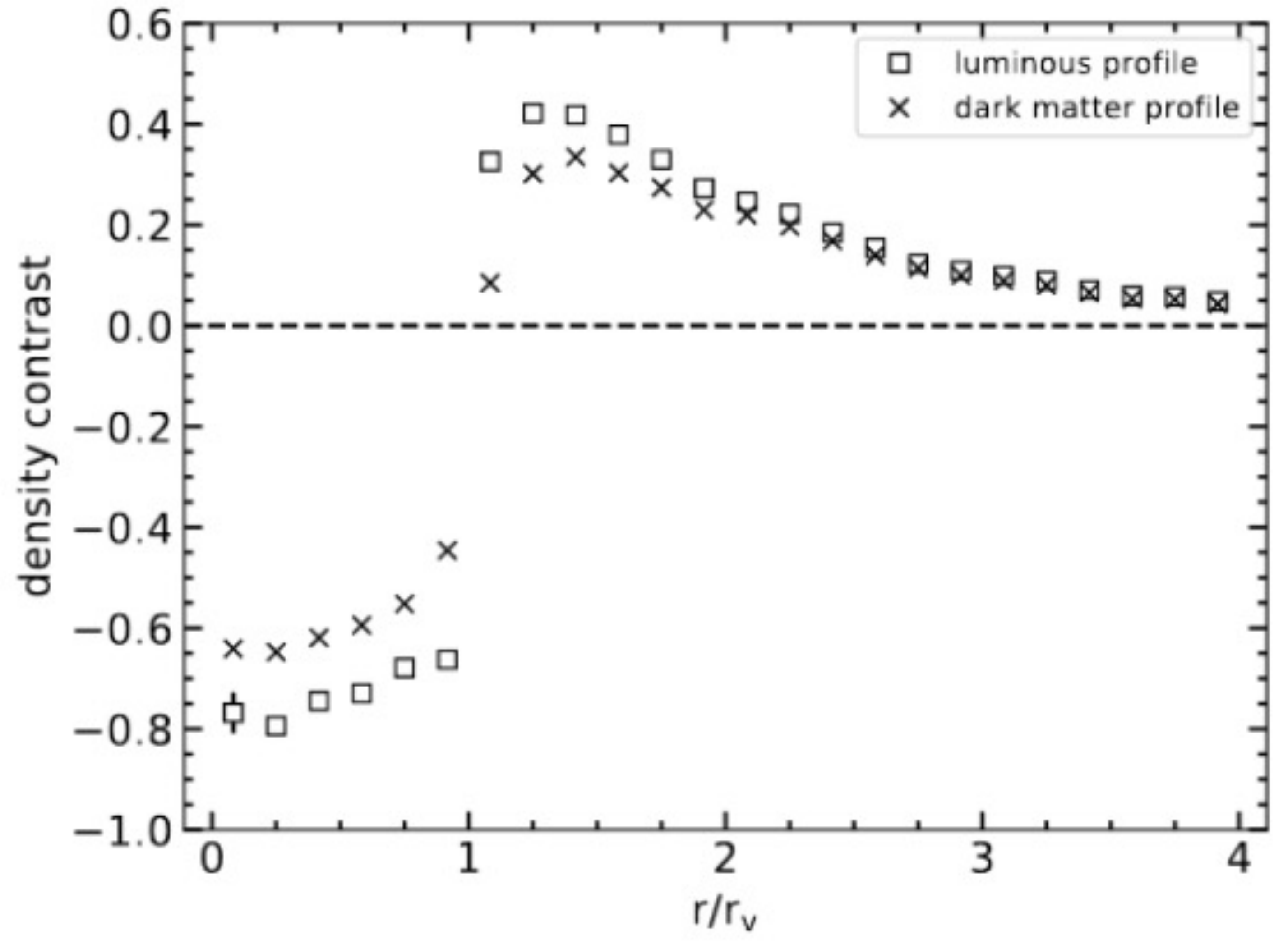
III. Any void that neighbors a larger void by more than 20% of the sum of the radii of both voids is rejected.

IV. Remaining voids have their centers perturbed in random directions to determine whether their radii can be increased. If a shift results in a larger sphere that still upholds the requirement of step II. then the center and radius of the void are updated to these new values.

Voidfinder Results

- Found 5,078 voids
  - Covers 83% of the volume of the simulation.
  - Median radius of 4.4h^{-1} Mpc.
  - Largest void has radius 24h^{-1} Mpc
- We defined two populations of field galaxies
  - 75,220 objects were labeled as “void galaxies”
  - 527,454 objects were labeled as “non-void galaxies”

Void Radial Profiles.



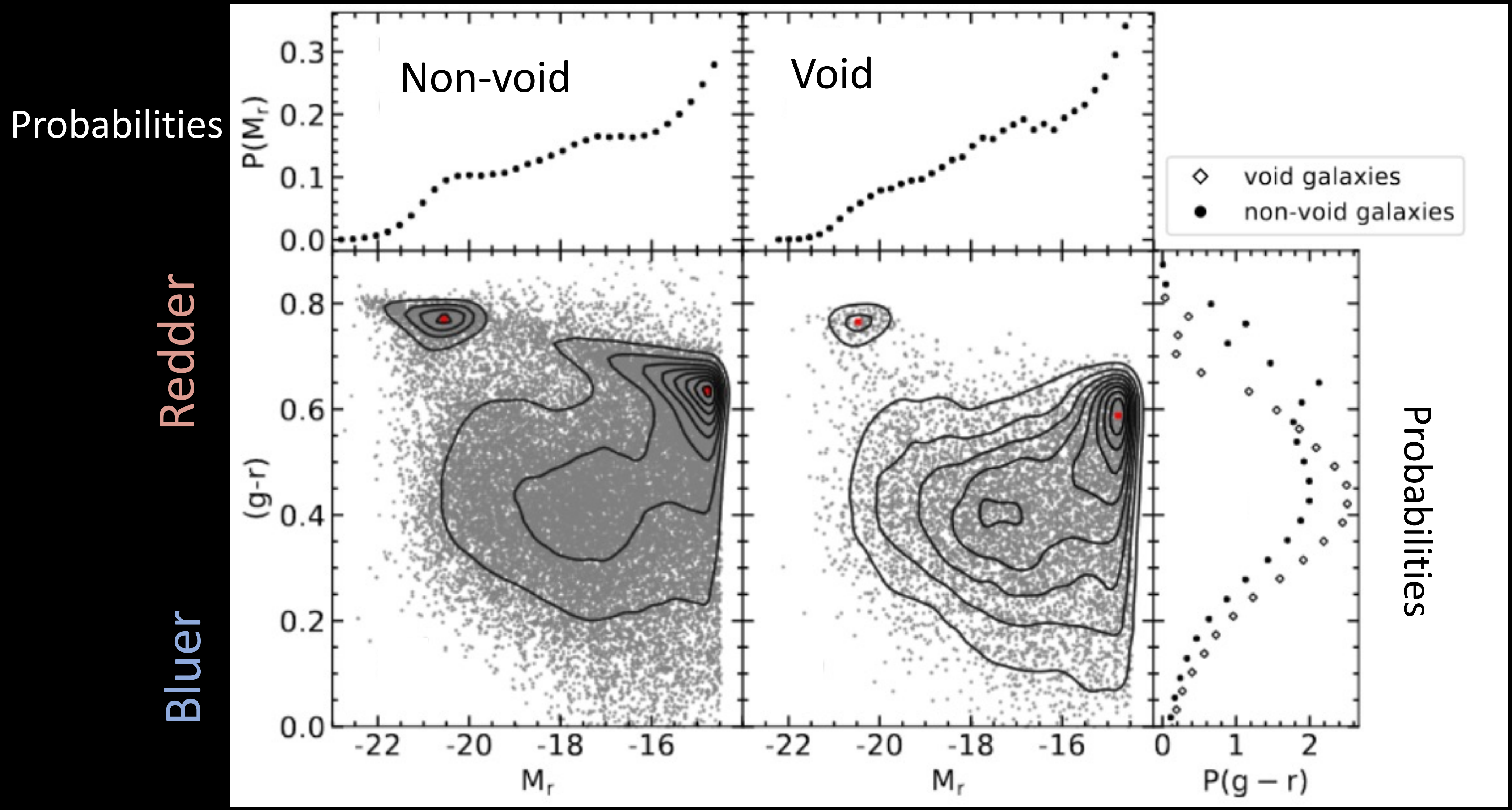
Define density contrast as

$$\Delta = 1 - \frac{n(r)}{\bar{n}(r)}$$

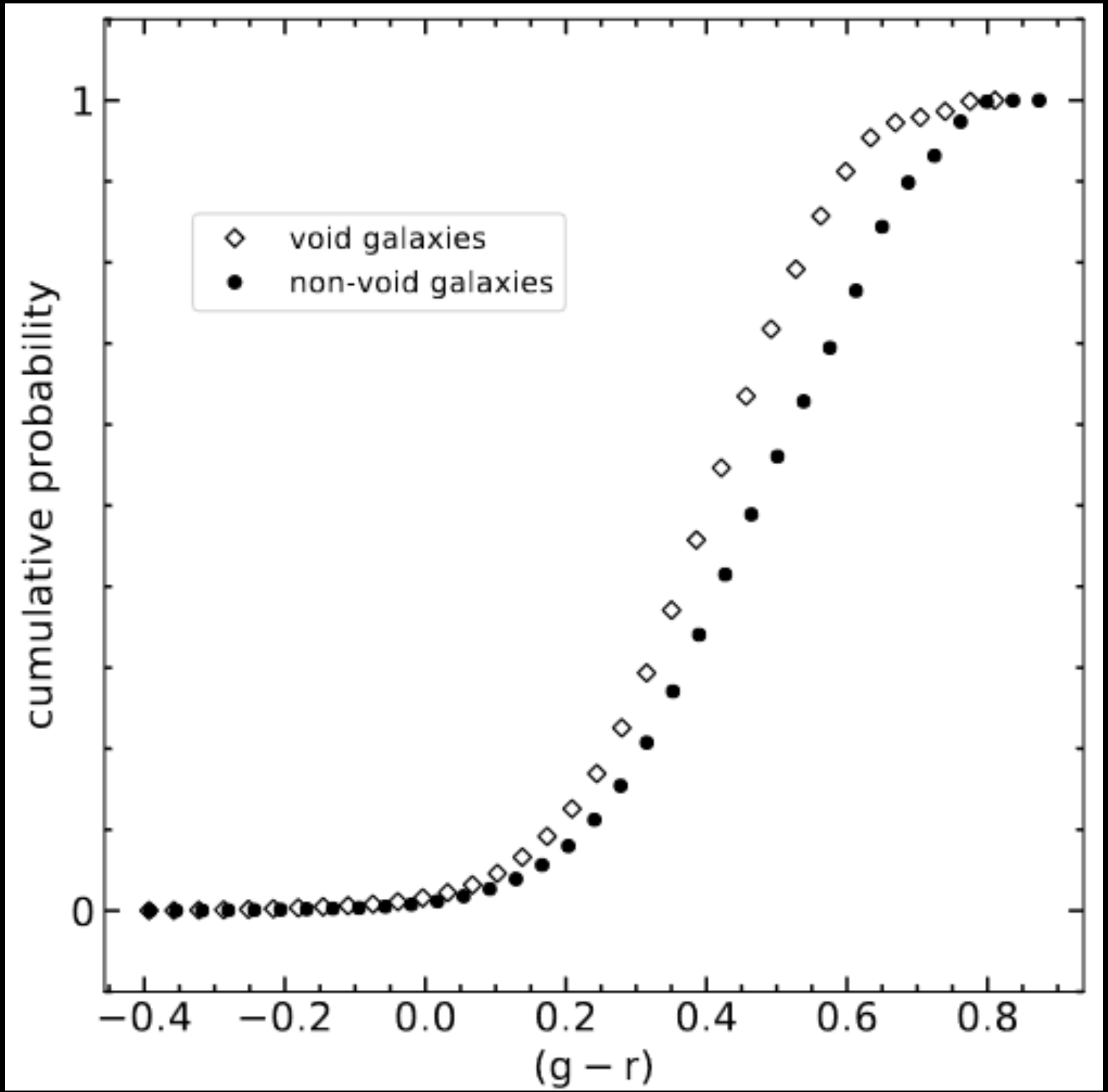
where n(r) is the number of galaxies within a radial bin of thickness δr and $\bar{n}(\mathrm{r})$ is the average number of galaxies or dark matter particles.

Table of Contents

I. Color Magnitude Diagrams



I. Color Magnitude Diagrams



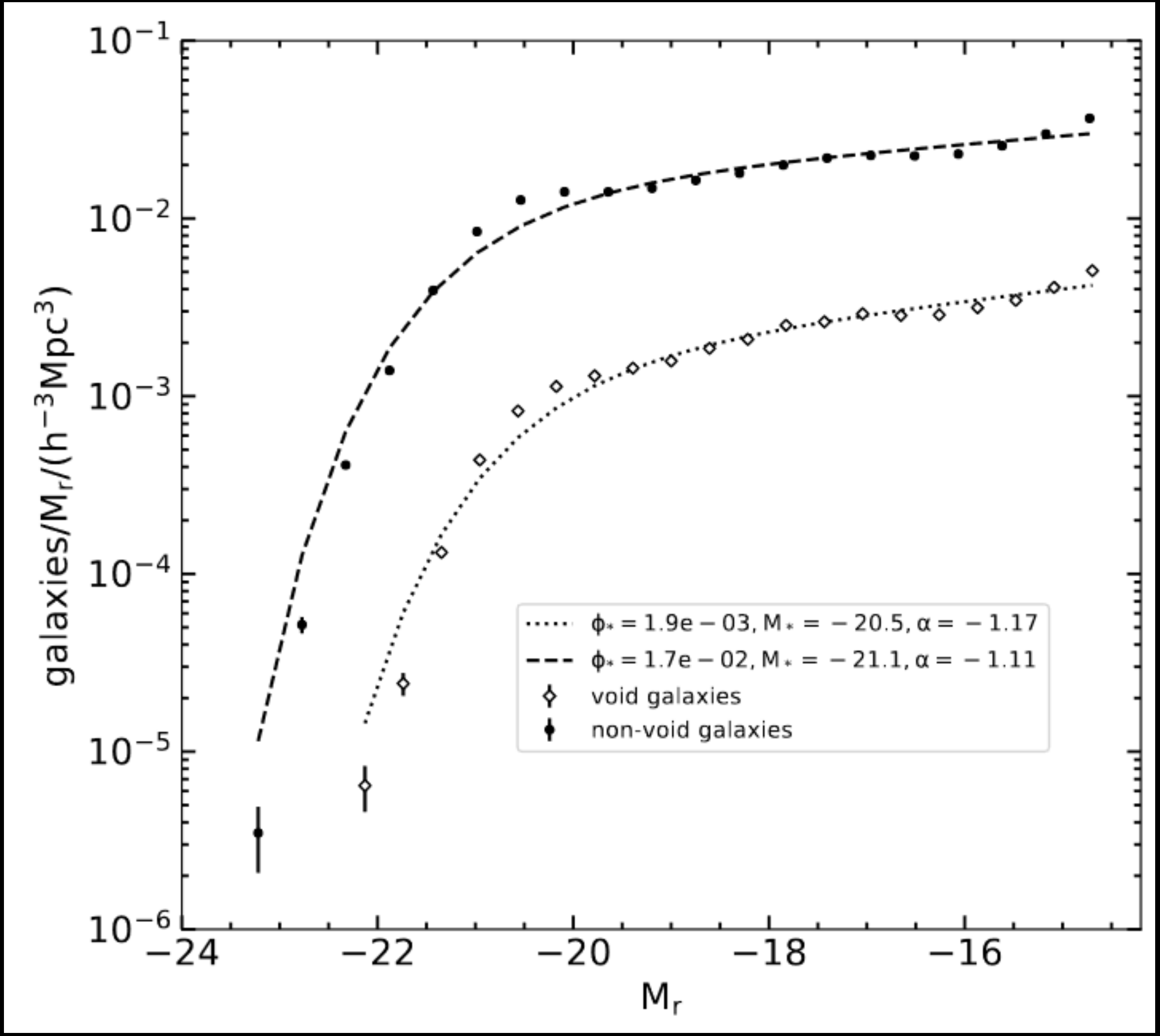
Two sample Kolmogrov-Smirnov test concludes both samples were drawn from different underlying distributions (statistic=0.19, p=0.000)

II. Luminosity Functions

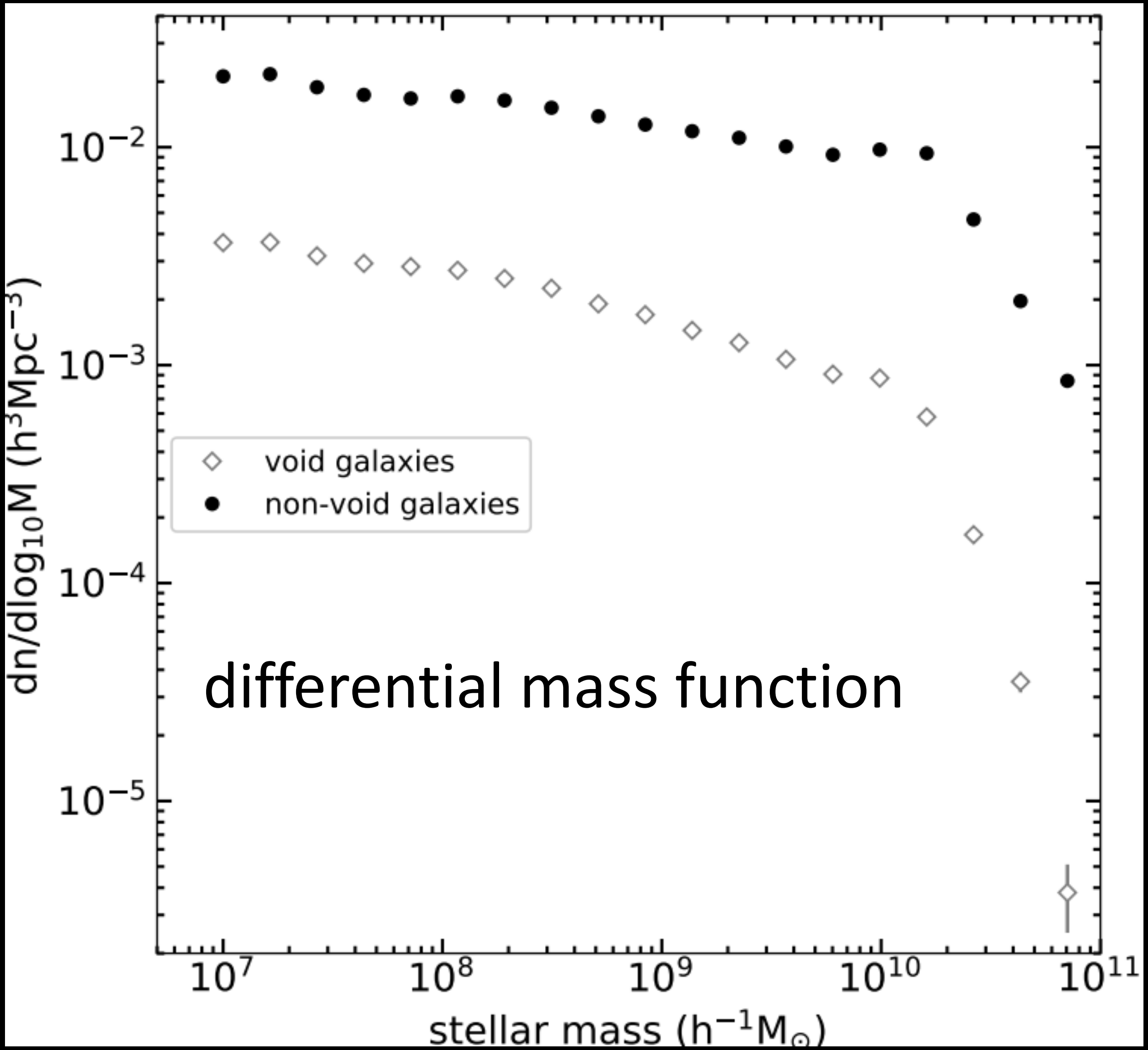
- Fit with an analytic solution known as a Schechter function.

- Void: $M_* = -20.5 \pm 0.1$
  $\alpha = -1.17 \pm 0.03$
  $\phi_* = (1.9 \pm 0.2)$e-03

- Non-void: $M_* = -21.1 \pm 0.1$
  $\alpha = -1.11 \pm 0.02$
  $\phi_* = (1.7 \pm 0.2)$e-03

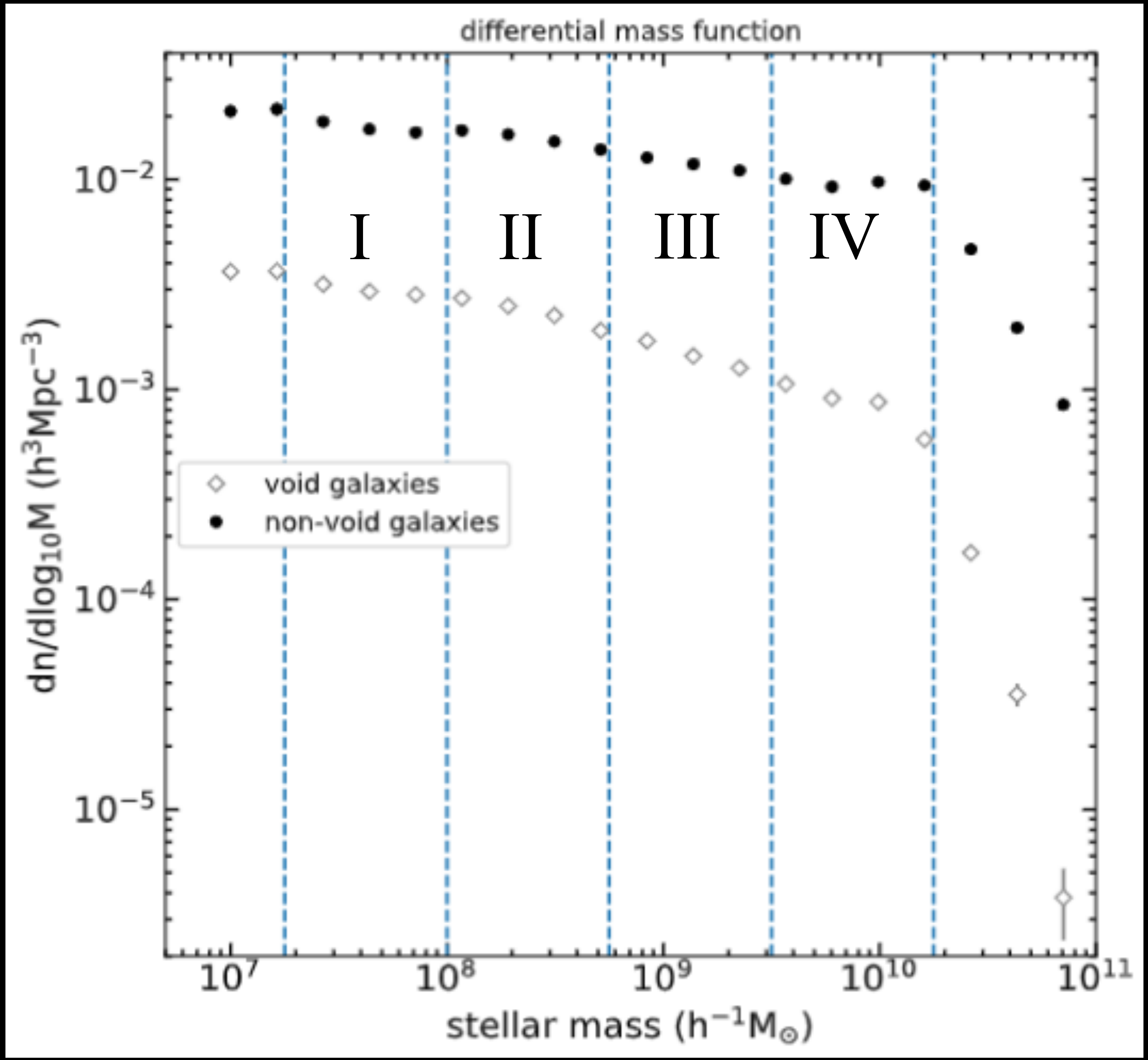


III. Differential Mass Functions



- Most galaxies in both populations have stellar masses $\lesssim 10^9 h^{-1}$ M $\odot$
- Median non-void galaxy stellar mass is $10^{8.2\pm0.65}$ h^{-1} M $\odot$.
- Median void galaxy stellar mass is $10^{8.1\pm0.49}$ h^{-1} M $\odot$.

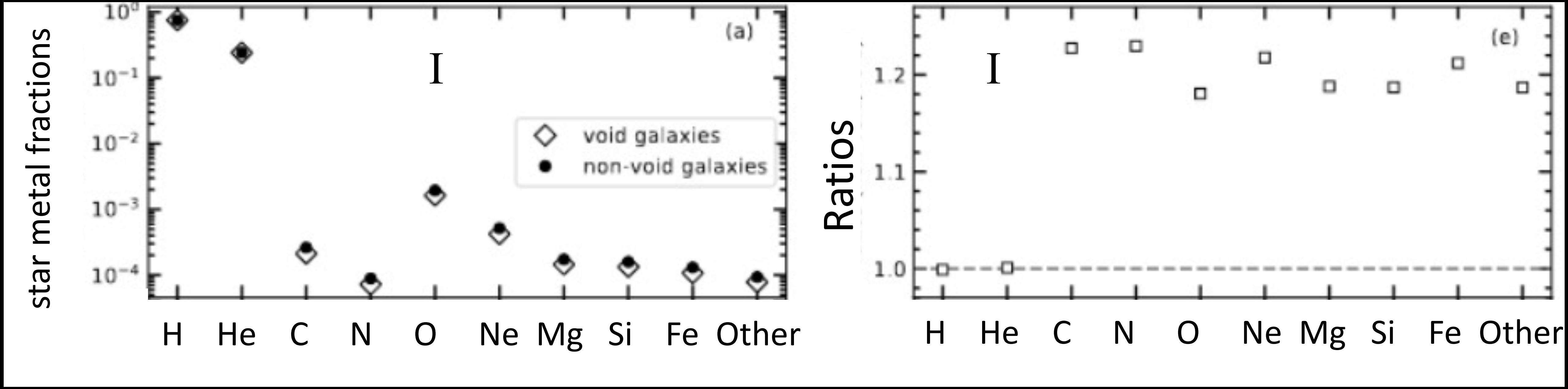
III. Differential Mass Functions



- Define four stellar mass bins between $10^7 - 10^{10.25}$ h^{-1} $M_\odot$ to analyze metal fractions of stars within these galaxies.

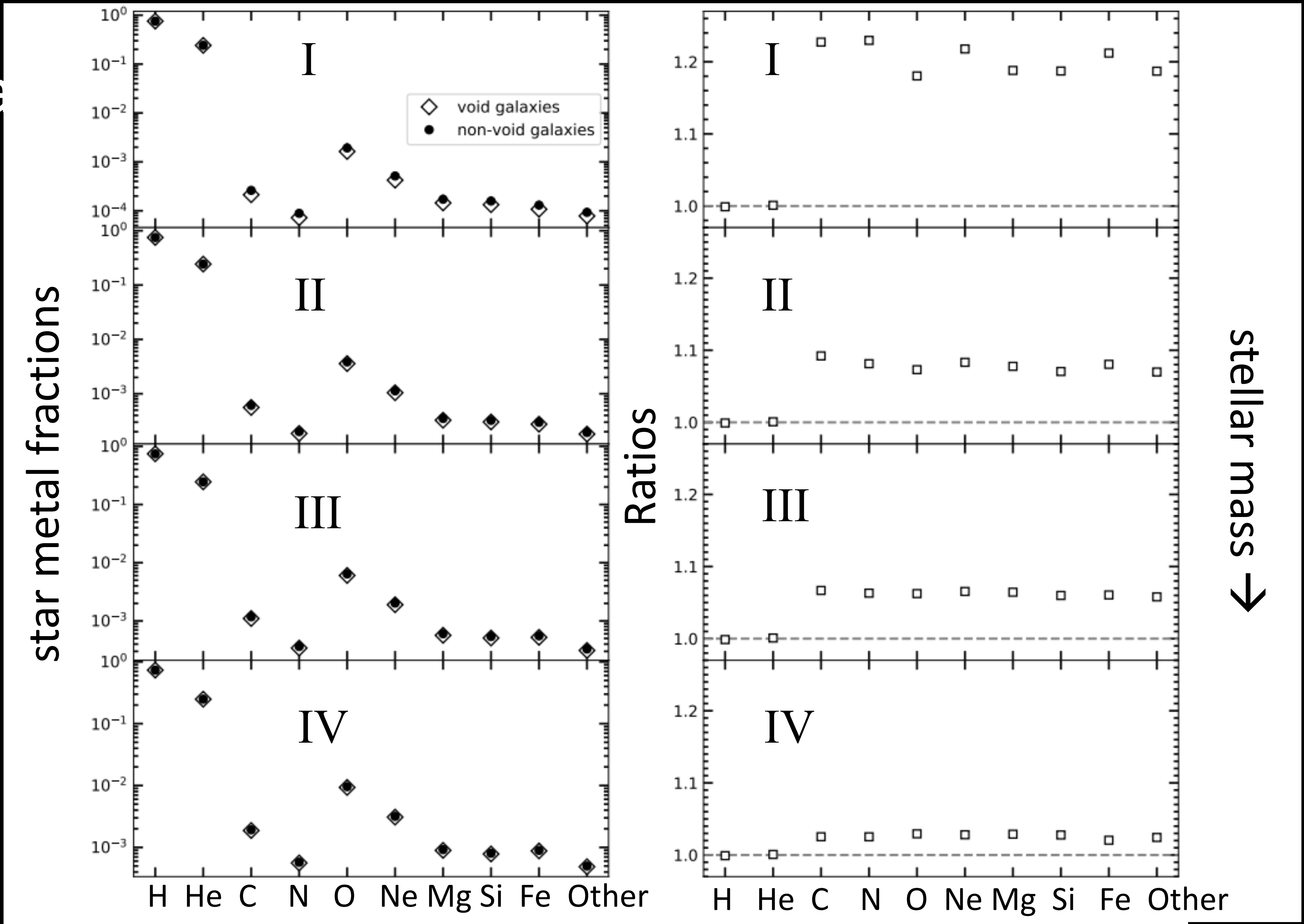
- Lowest stellar mass bin labelled as I and highest bin labelled as IV

IV. Star Metal Fractions



Curtis et al., in preparation

IV. Sta



star metal fractions
Ratios
stellar mass ↓
I
II
III
IV
void galaxies
non-void galaxies
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1.0
1.1
1.2
H He C N O Ne Mg Si Fe Other

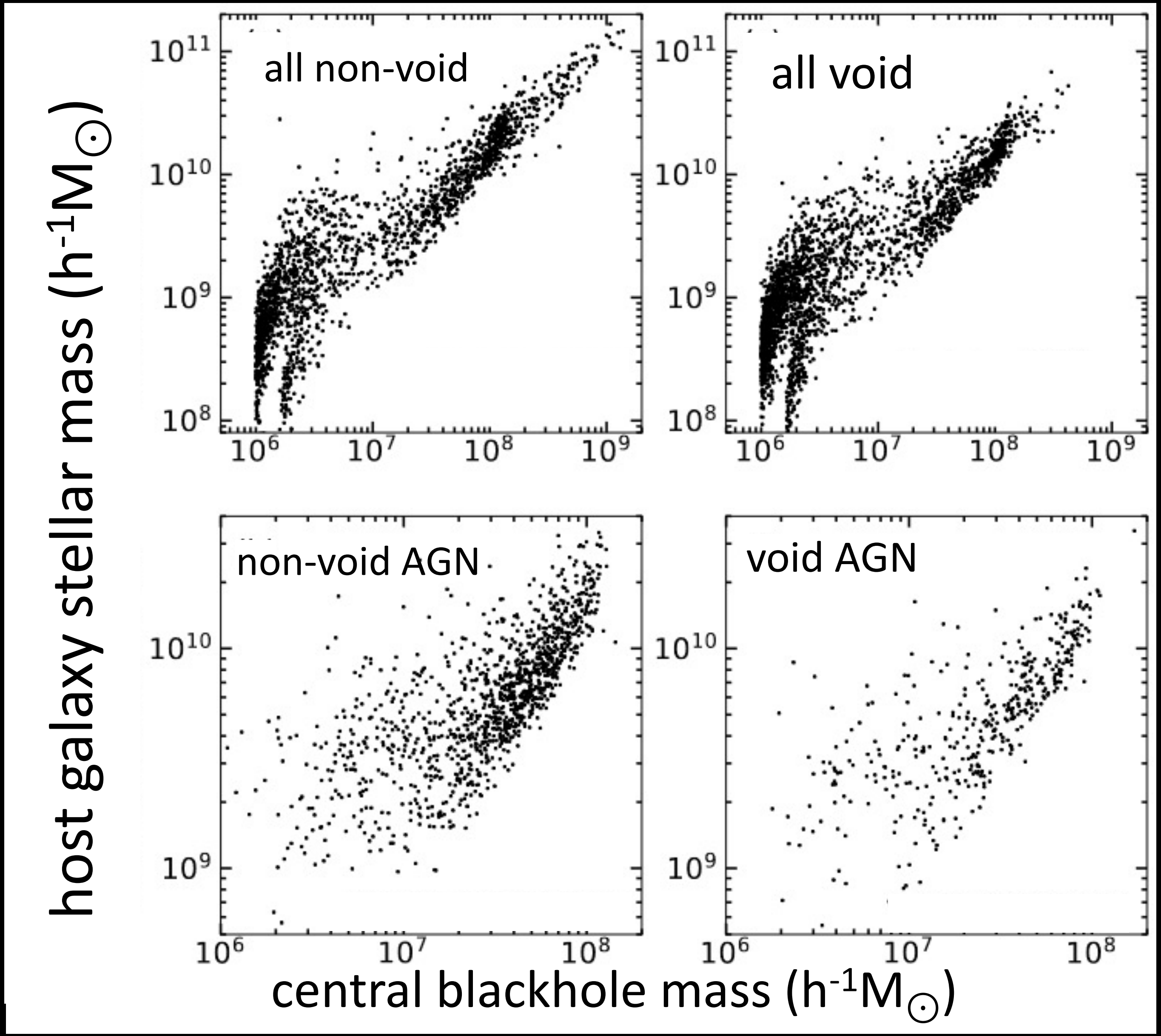
IV. Star Metal Fractions

- These results agree with ΛCDM theory that says dark matter halos in lower density regions of the universe should form later in the history of the universe.

- That is, on average a void galaxy should be younger than their non-void counterparts.

- <u>Median Luminosity Weighted Ages</u>
  Void: 9.217±0.002 Gyr
  Non-void: 9.364±0.001 Gyr

V. Active Galactic Nuclei AGN



- Both populations of galaxies exhibit the $M_{BH} - M_*$ relation that we see in supermassive blackholes in the real universe..
- 5.83% of non-void galaxies and 5.77% of void galaxies contained active galactic nuclei.
- No relation between the triggering of the AGN phenomenon and local matter density.

Conclusions

- The effects that differences in local matter environment have on non-void and void field galaxies is poorly constrained at present.

- Here, we explored the extent to which void galaxies in the TNG300 simulation differ from their non-void counterparts at z=0. We find:

  1. Void galaxies are bluer, younger, and less metal enriched on average.

  2. Luminosity functions of void galaxies more closely follow a Schechter function than non-void galaxies.

  3. No difference between AGN activity or abundance between the two populations.

Contact: Olivia Curtis | Boston University | amcurtis@bu.edu