Constraining galaxy assembly bias in redshift surveys

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Image from the Aemulus Project (ask me about that later).
/ˈaɐ̯.mu.lus/, [ˈaɐ̯.mʊ.ɬʊs] : (Latin) Striving to equal or exceed.

What is assembly bias?

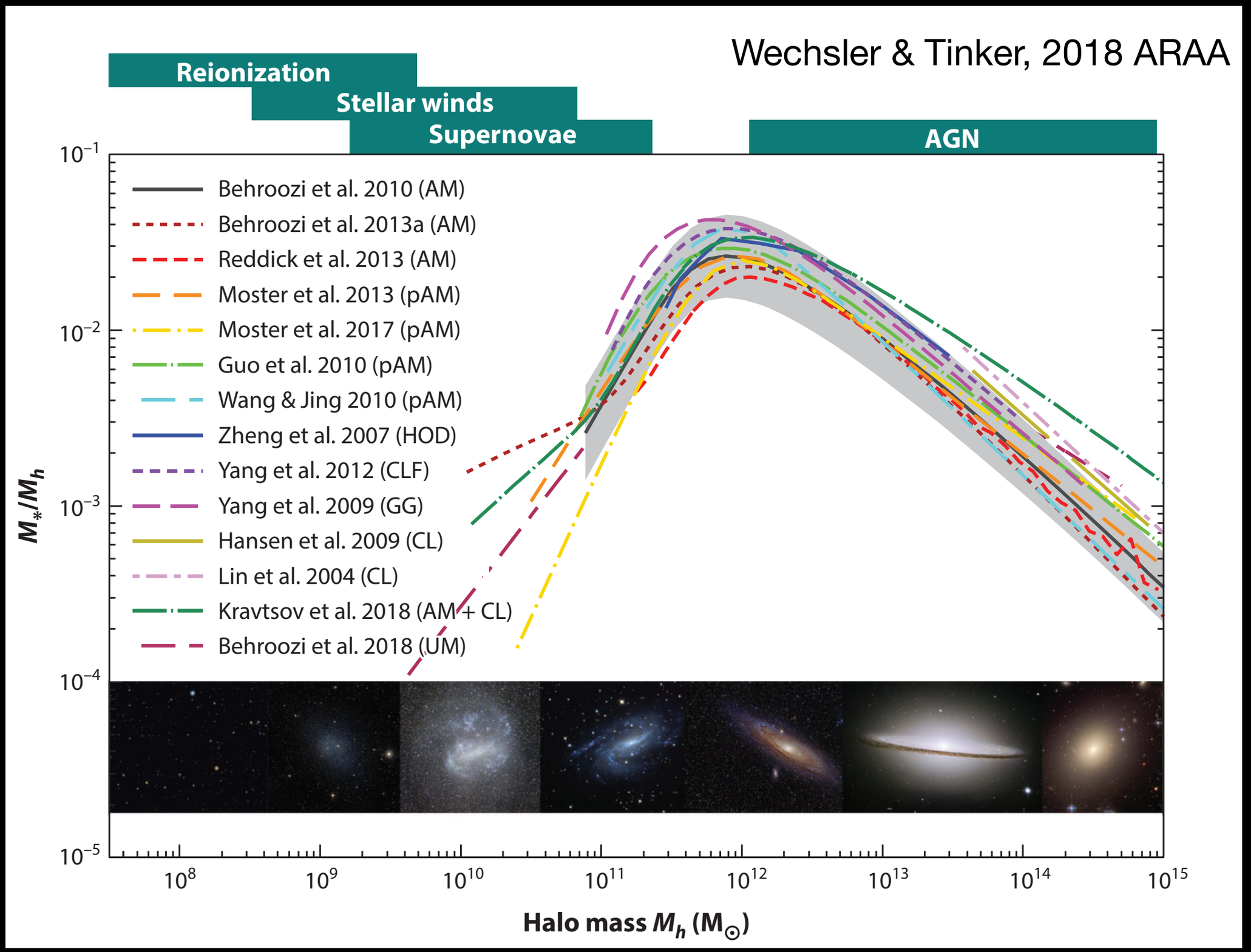
- Before we talk about galaxies, we first have to talk about halos.

- All galaxies live in halos.

- The most basic property of galaxies and halos is their mass. Total mass (mostly dark) for the halos, and stellar mass for the galaxies.

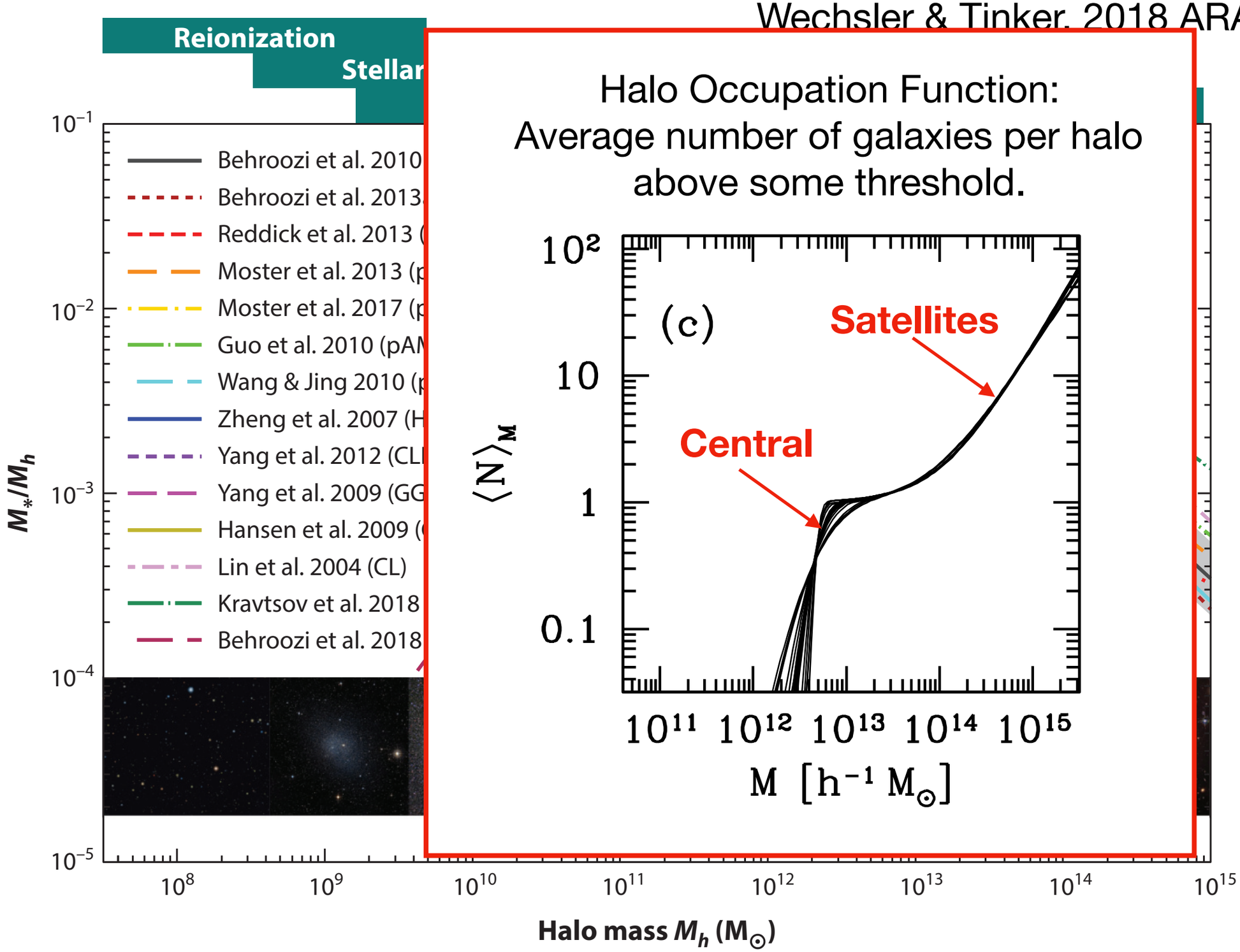
- Much attention has been put toward the relationship between these two properties.

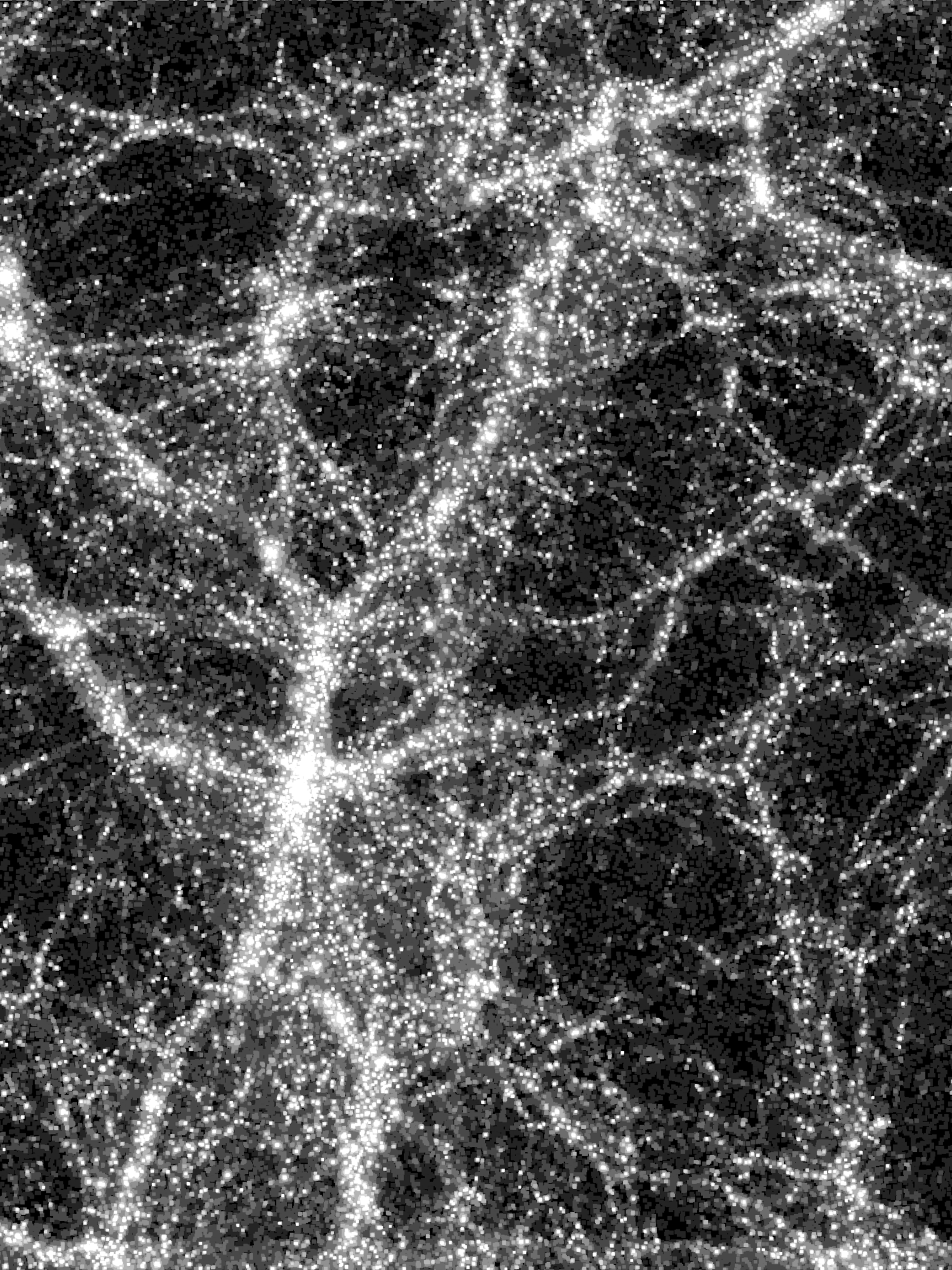
The Galaxy-Halo Connection

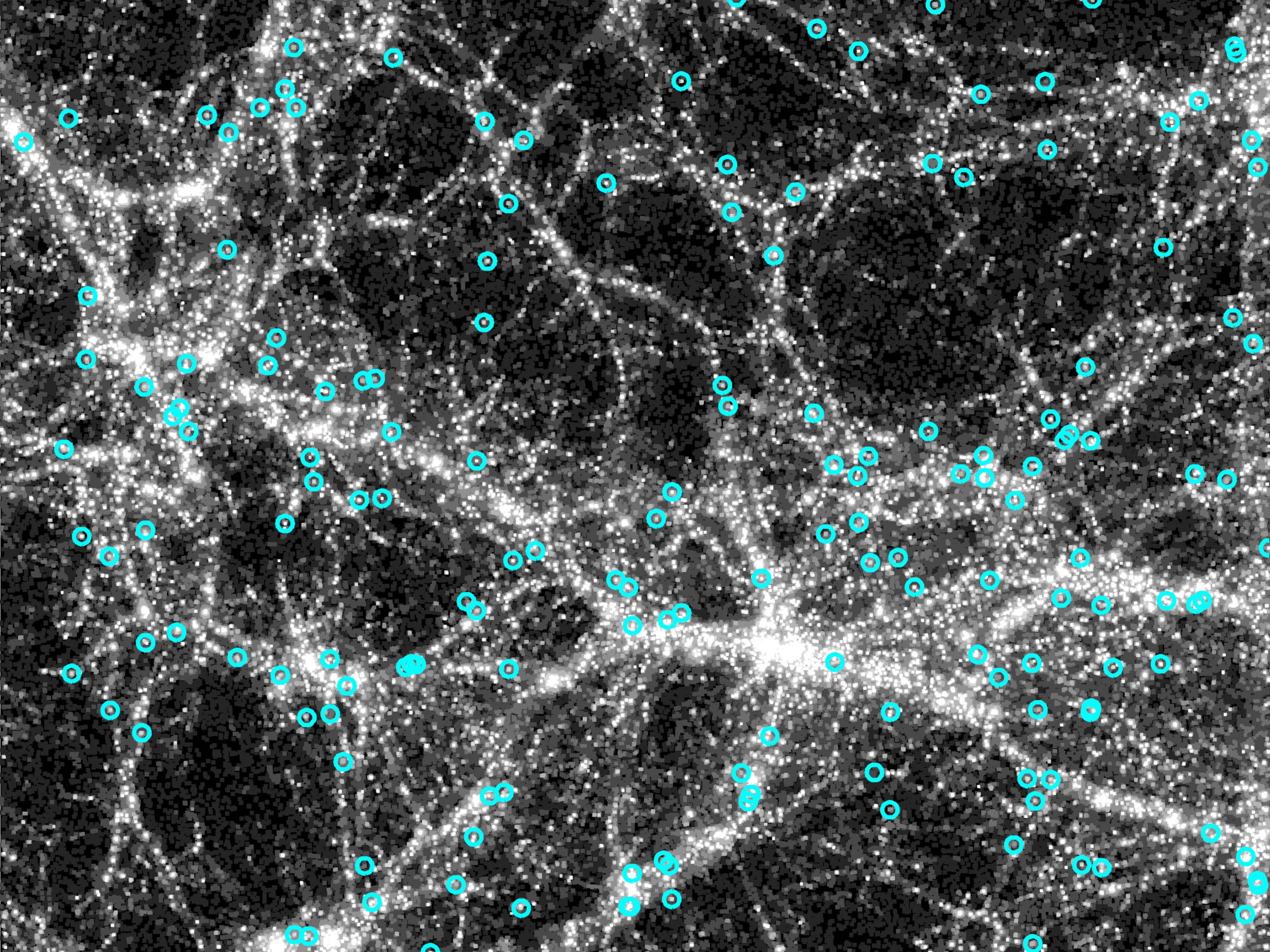


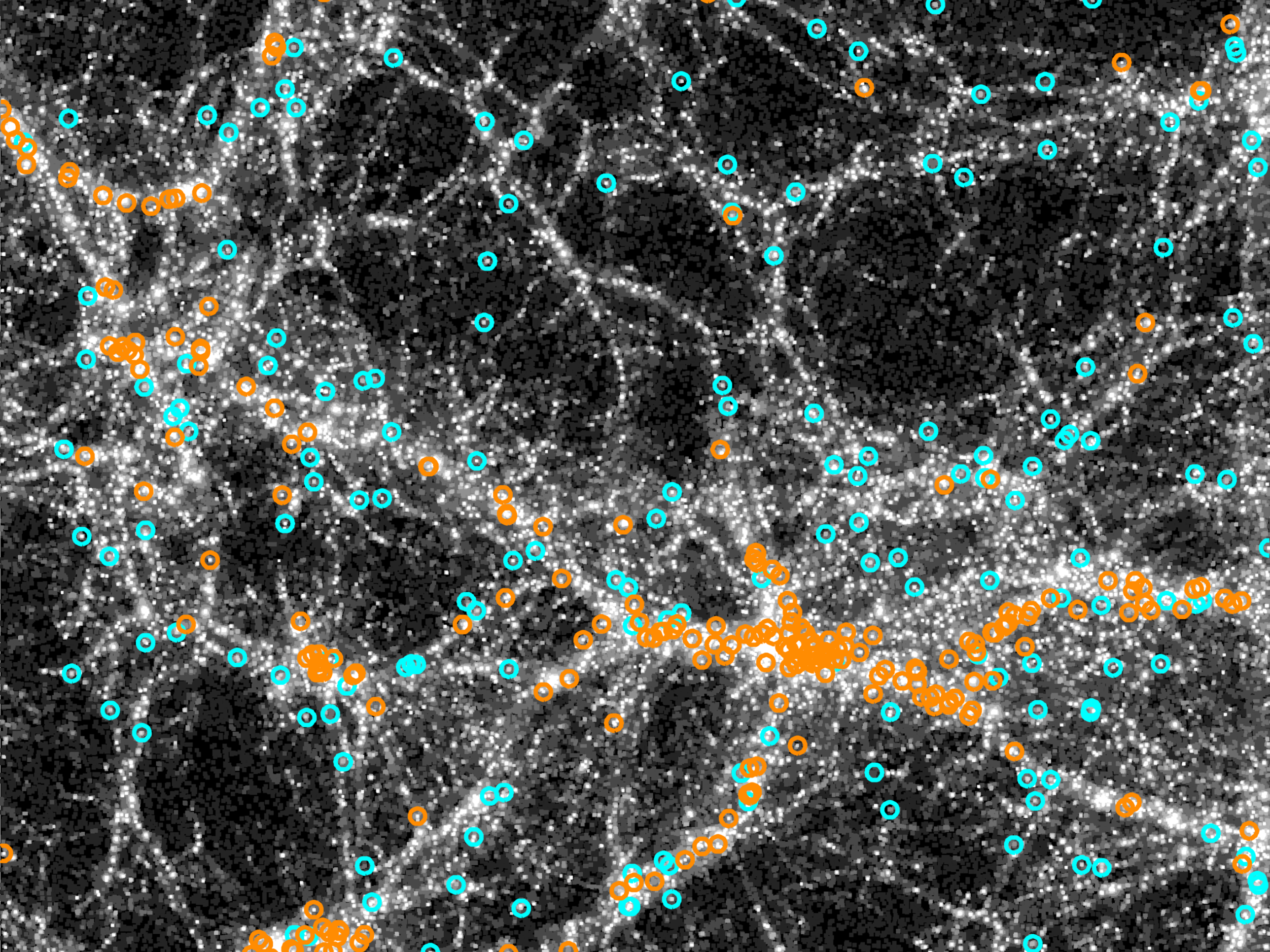
The Galaxy-Halo Connection

Wechsler & Tinker, 2018 ARAA



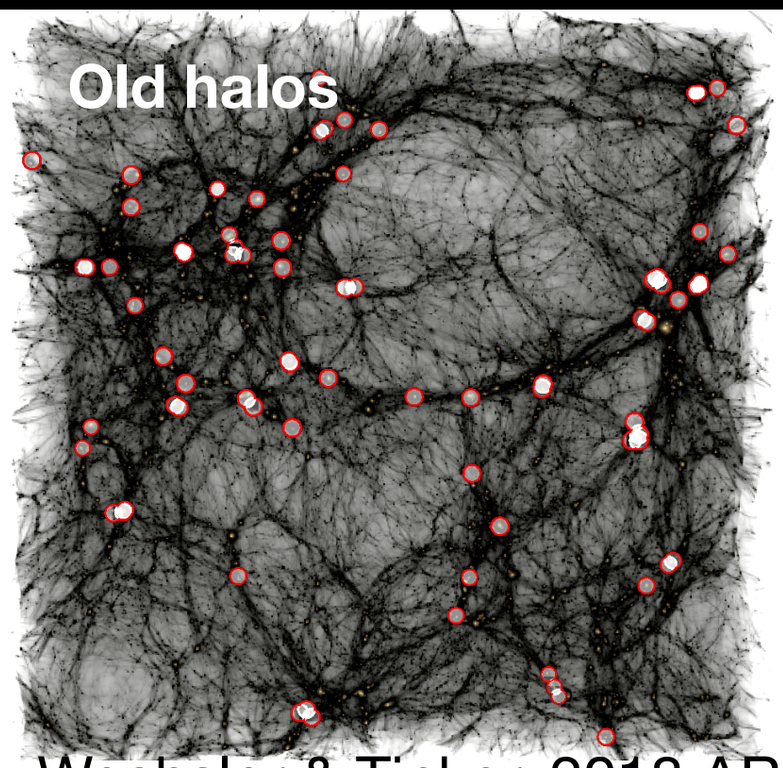


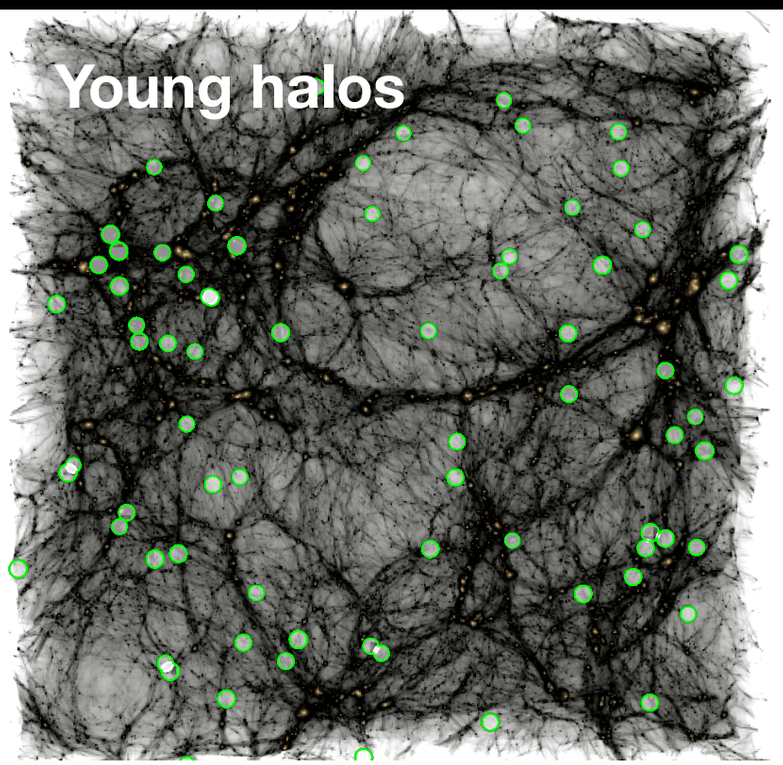




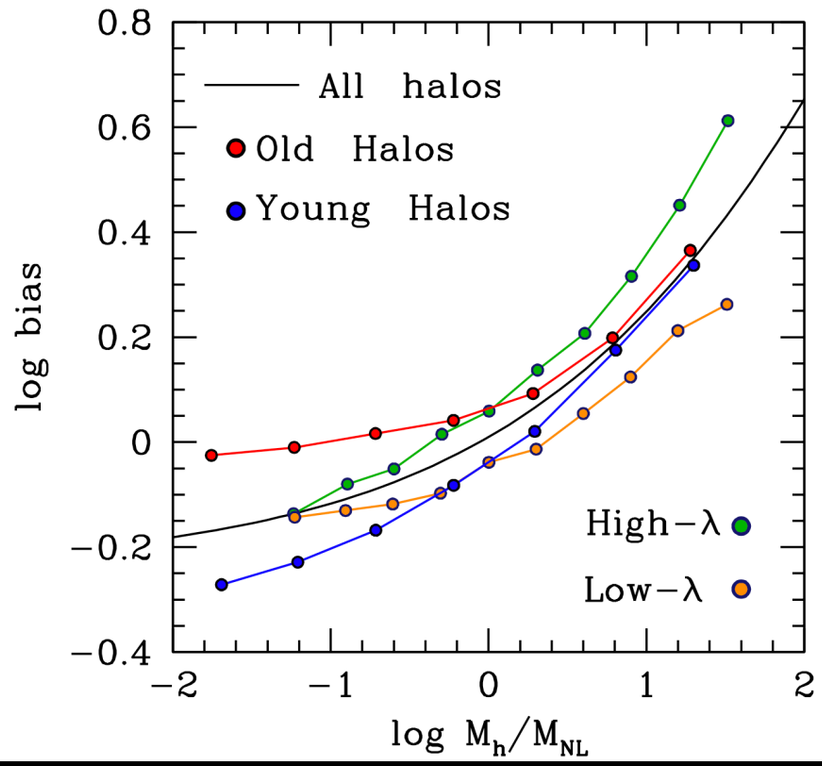
Halo Assembly Bias

Halo Assembly Bias or Secondary Bias: At fixed halo mass, the clustering of dark matter halos depends on secondary halo properties (which are generally correlated with the assembly history of the dark matter halo).



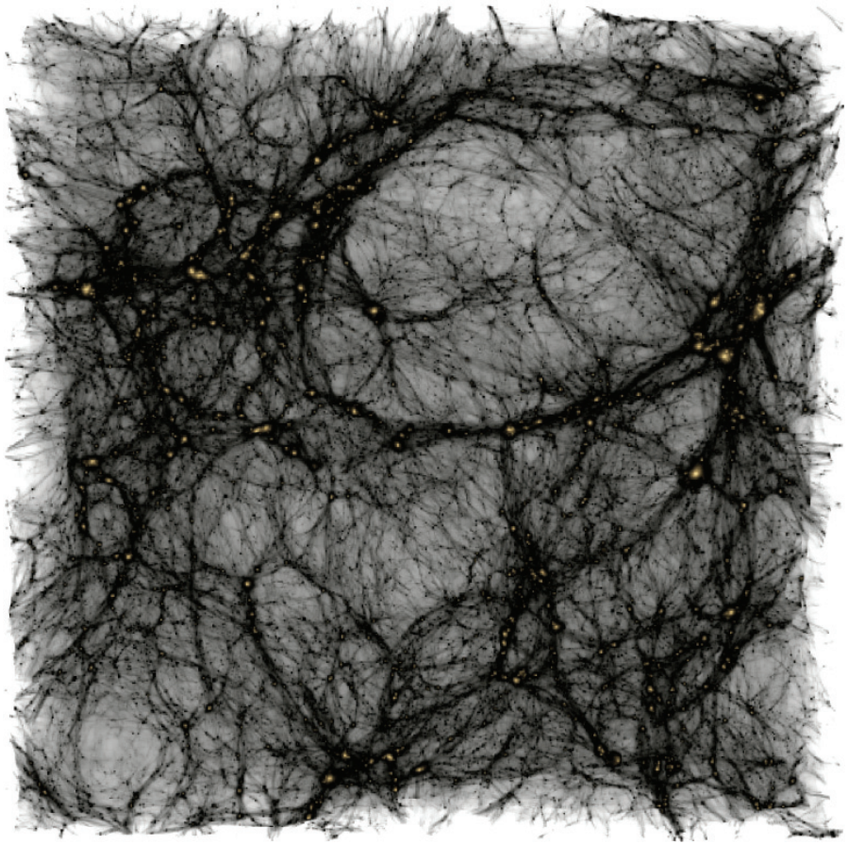


Wechsler & Tinker, 2018 ARAA

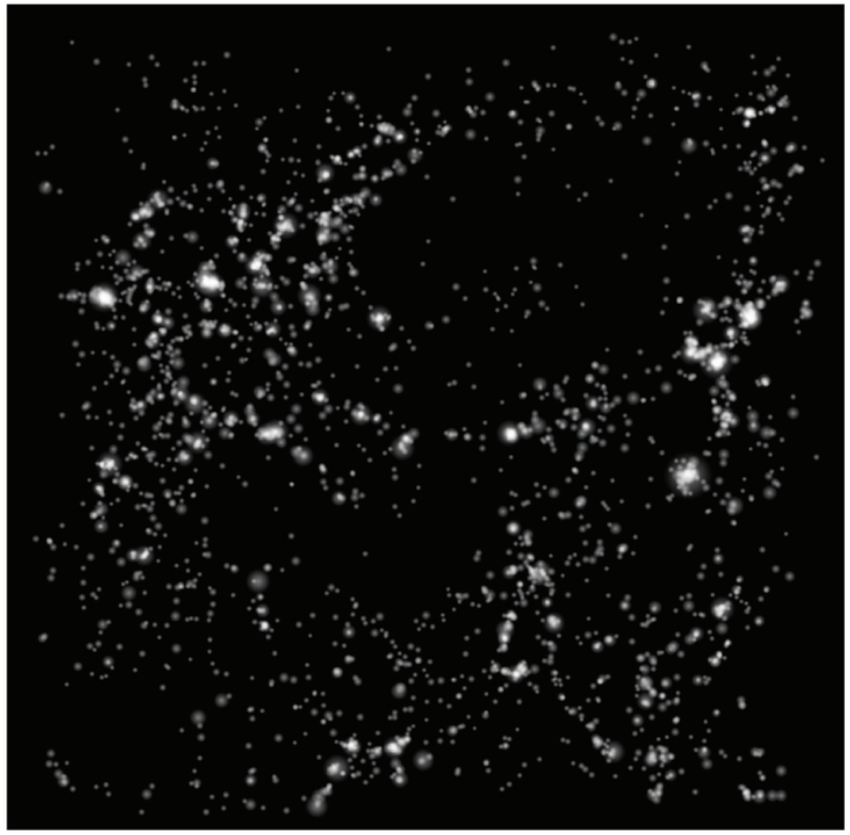


- Signal at low masses: formation time, concentration.
- Signal at high masses: spin, amount of substructure.

Do halo properties other than mass enter here?



Galaxy–halo connection



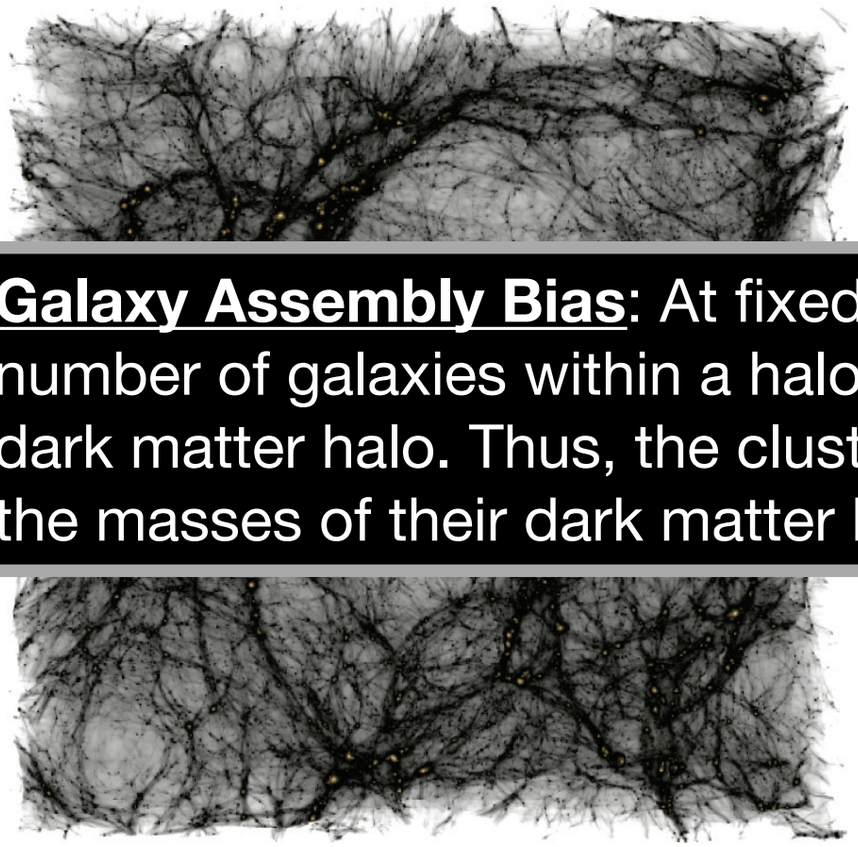
Approaches to modeling the galaxy–halo connection

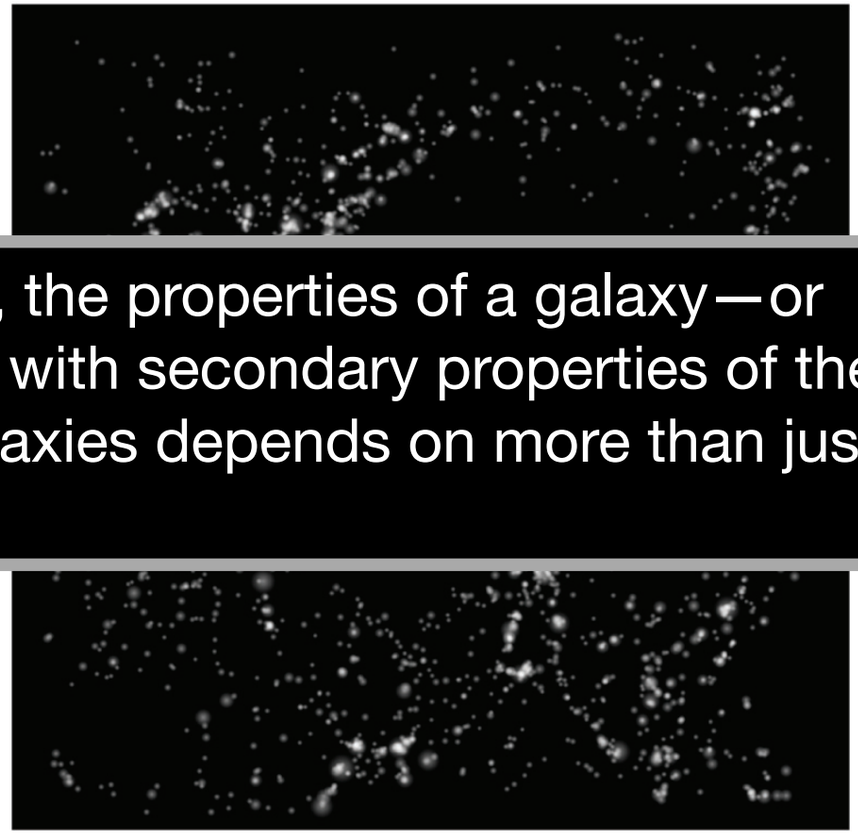
← Physical models — Empirical models →

Hydrodynamical simulations	Semianalytic models	Empirical forward modeling	Subhalo abundance modeling	Halo occupation models
Simulate halos and gas; star formation and feedback recipes	Evolution of density peaks plus recipes for gas cooling, star formation, feedback	Evolution of density peaks plus parameterized star formation rates	Density peaks (halos and subhalos) plus assumptions about galaxy–(sub)halo connection	Collapsed objects (halos) plus model for distribution of galaxy number given host halo properties

Wechsler & Tinker, 2018 ARAA

Do halo properties other than mass enter here?





<u>Galaxy Assembly Bias</u>: At fixed halo mass, the properties of a galaxy—or number of galaxies within a halo—correlate with secondary properties of the dark matter halo. Thus, the clustering of galaxies depends on more than just the masses of their dark matter halos.

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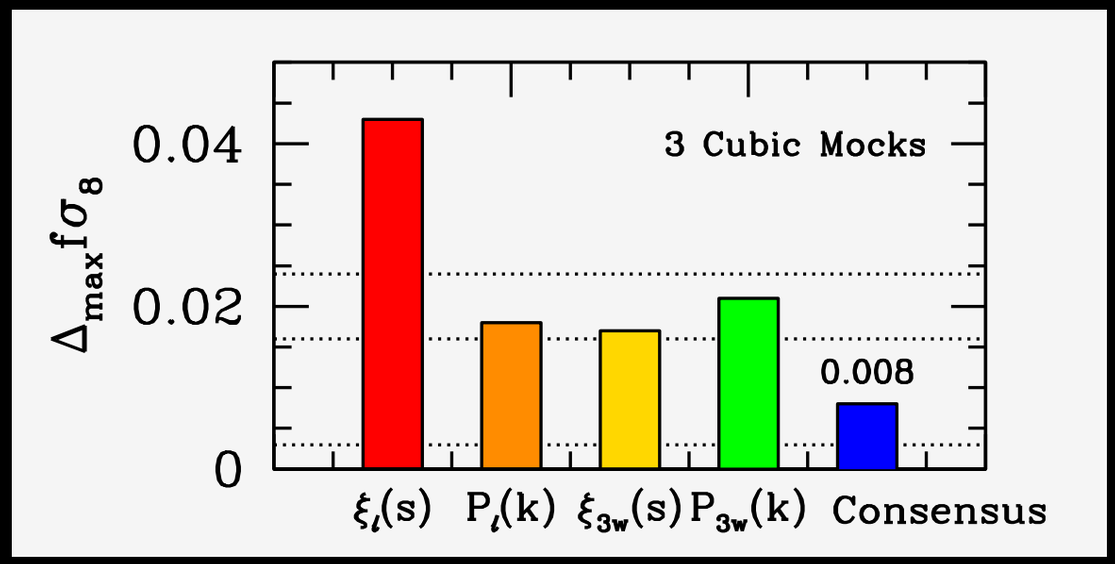
Wechsler & Tinker, 2018 ARAA

Why should you care?

- **Galaxy formation**: A key question in how galaxies are made within dark matter halos, and what causes the diversity in the galaxy population.

- **Cosmology**: The observed clustering bias of galaxies is not just a function of the masses of the halos they occupy, but a more complicated multi-parameter function.

Taken from Alam et al 2017, the BOSS DR12 cosmological analysis



Difference in $f\sigma_8$ values obtained from mock BOSS surveys built on the same dark matter distribution, but different bias models mapping galaxies onto the dark matter.

Do old and young galaxies live in old and young halos?

A “young” galaxy

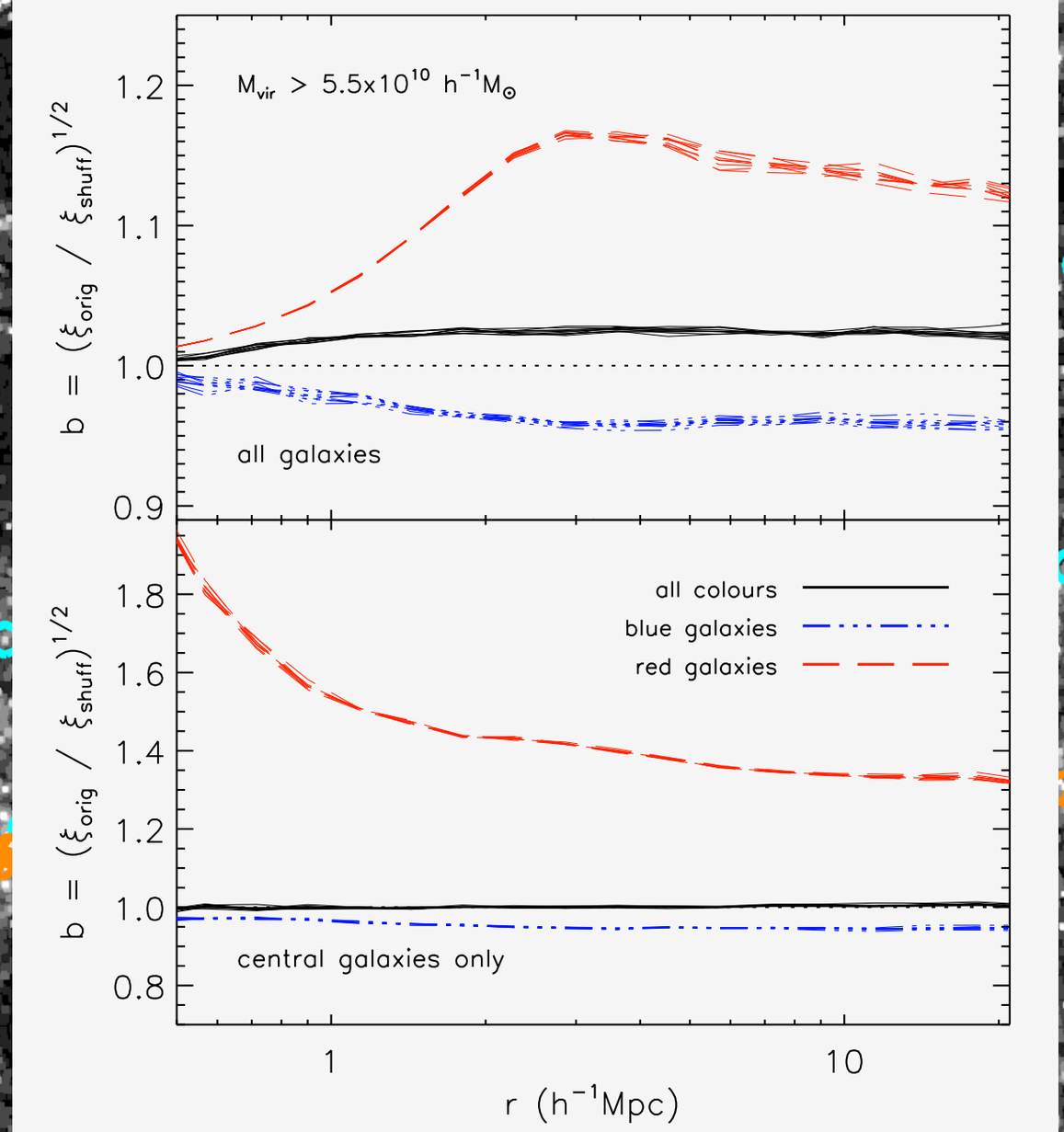
Active star formation…
Emission lines…
Selected as ELG.

An “old” galaxy

Old stellar population…
red colors…
Selected as LRG.

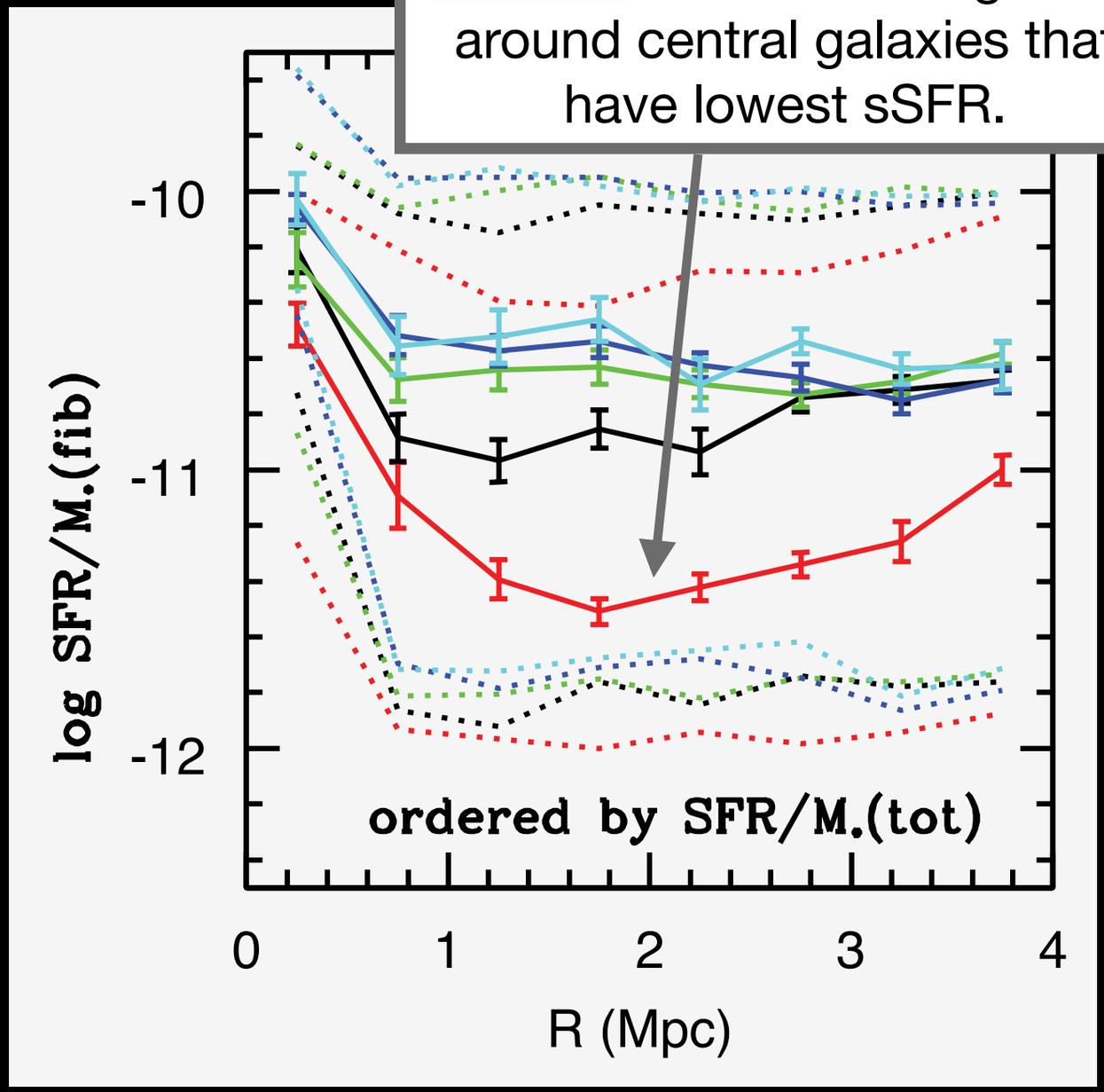
- **Found in semi-analytic models of galaxy formation!**
- **The "shuffle test" means taking all galaxies at fixed halo mass, and re-assigning them randomly to other halos of the same mass ("shuffling") .**
- **Any correlation with halo formation history is now removed. See if the clustering has changed.**
- **…. and boy it did.**

Croton, Gao, White 2007



Galactic Conformity

- The idea that galaxies will exhibit the same properties as their neighbors.
- If “old” galaxies live in old halos, then old galaxies will be spatially correlated.
- (More than what is generically expected from mass-only effects.)
- So if galaxy properties were a function of M_h only, these curves would all lie on top of each other.

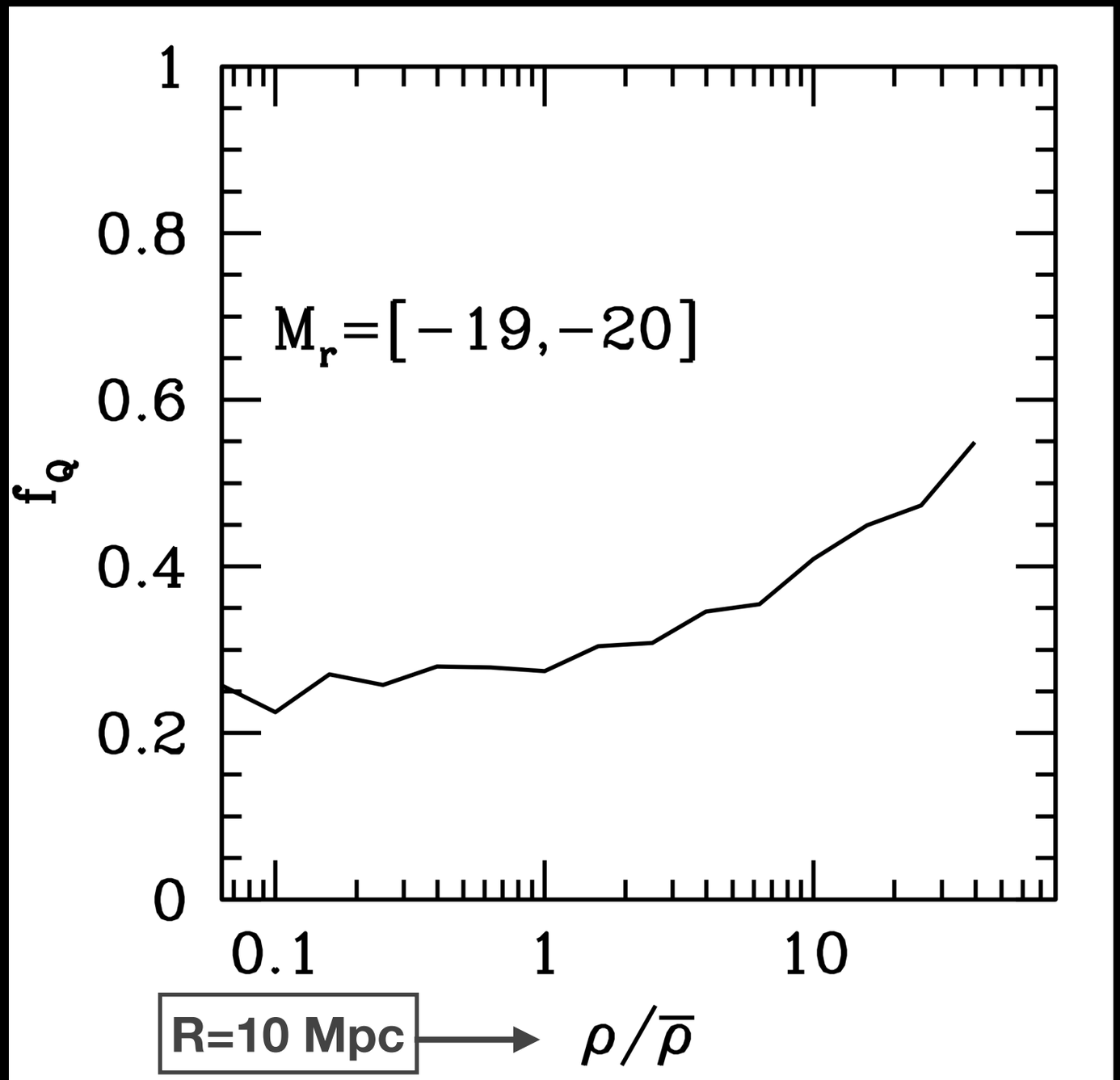


Detection of conformity in SDSS from Kauffmann et al 2013

Consistent with other data on galaxy bimodality?

- f_Q clearly depends on large-scale environment.
- *Qualitatively* consistent with the idea that old (quenched) galaxies preferentially reside in old (early-forming) halos.

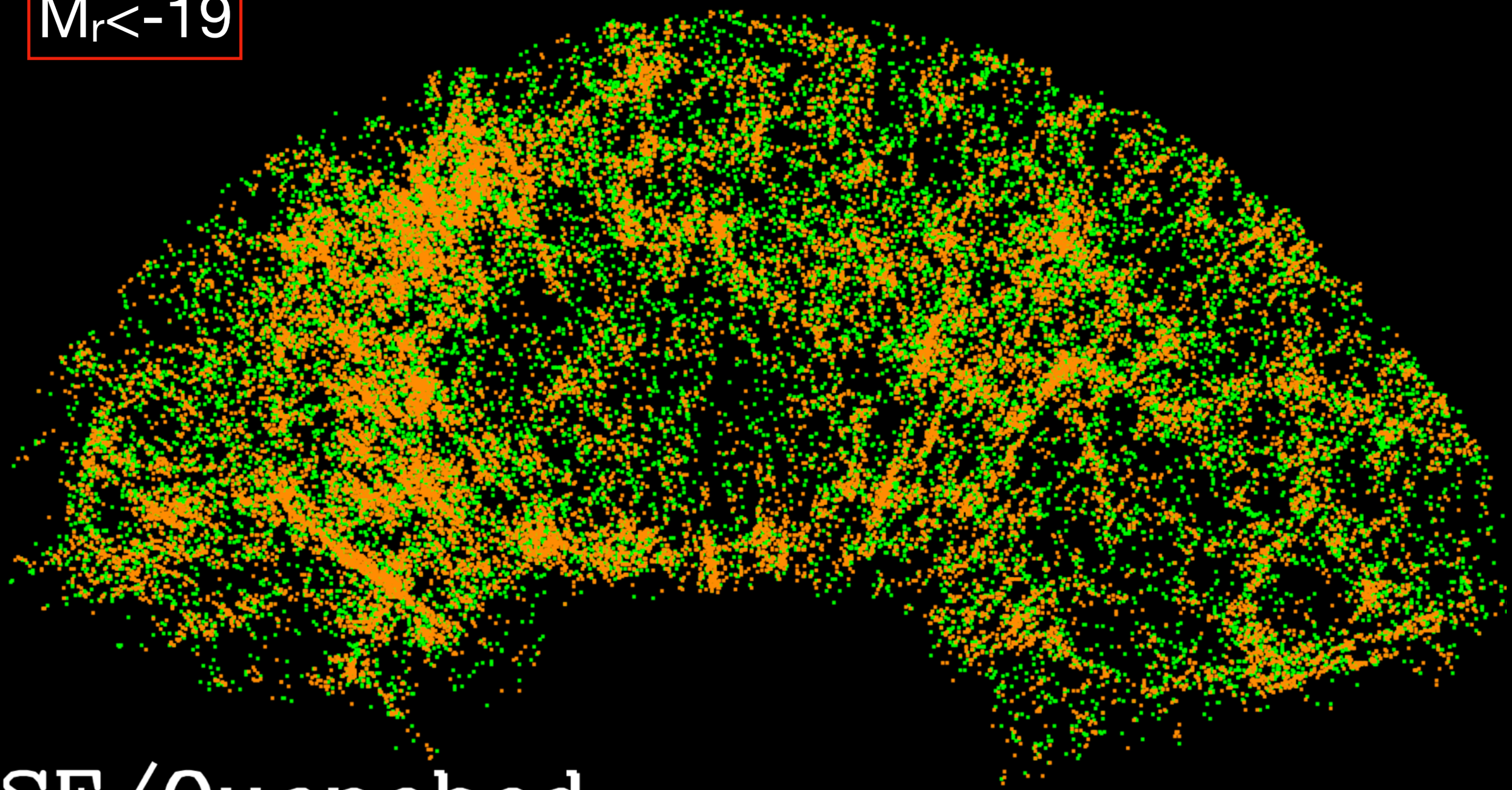
Tinker et al 2008, Peng et al 2010, Tinker et al 2017, 2018, Zu & Mandelbaum 2016, 2018, Wang et al 2018.



Tinker, Wetzel, Conroy 2011

Volume-limited 10^o slice through SDSS-MGS

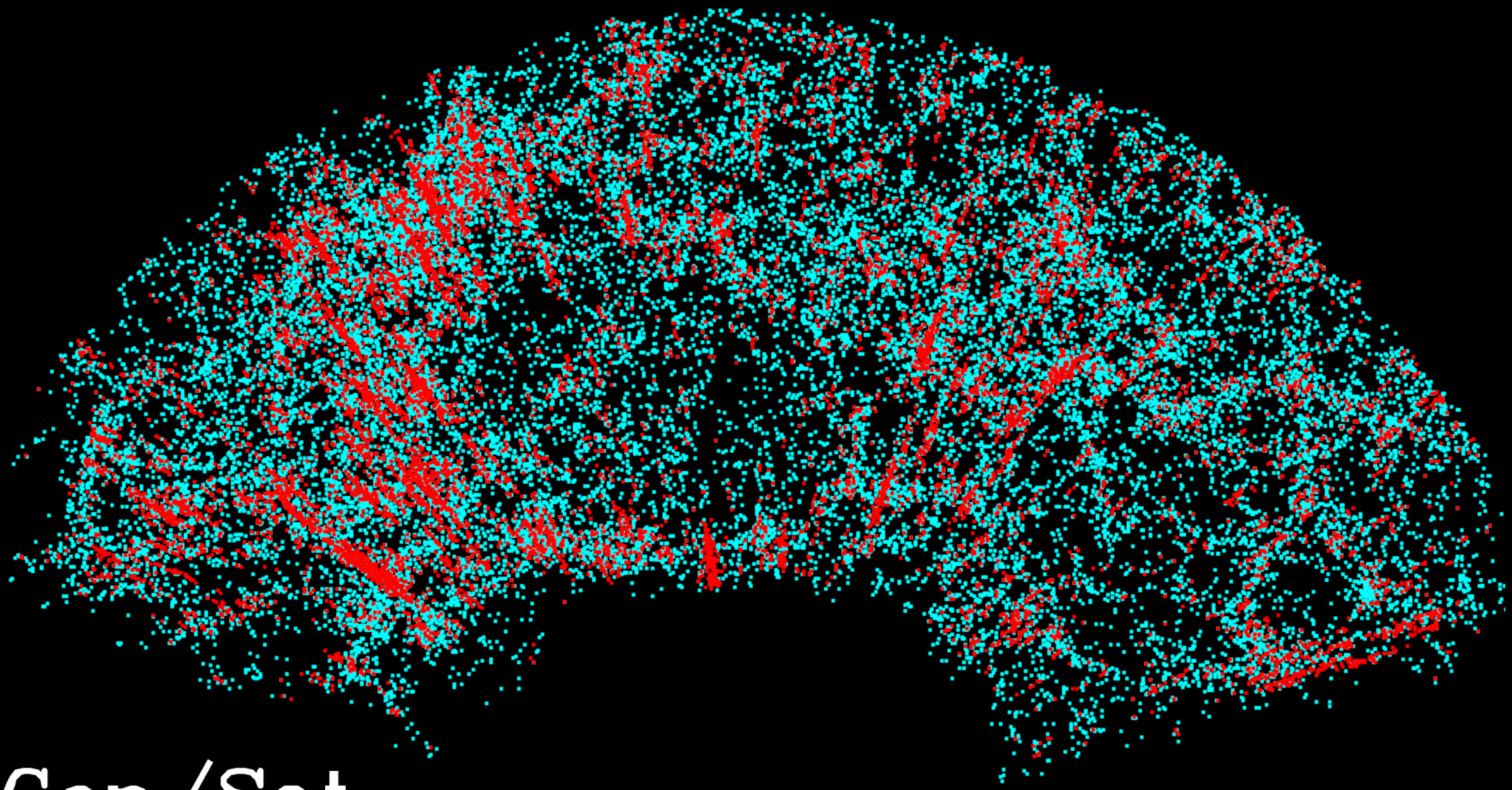
M_r<-19



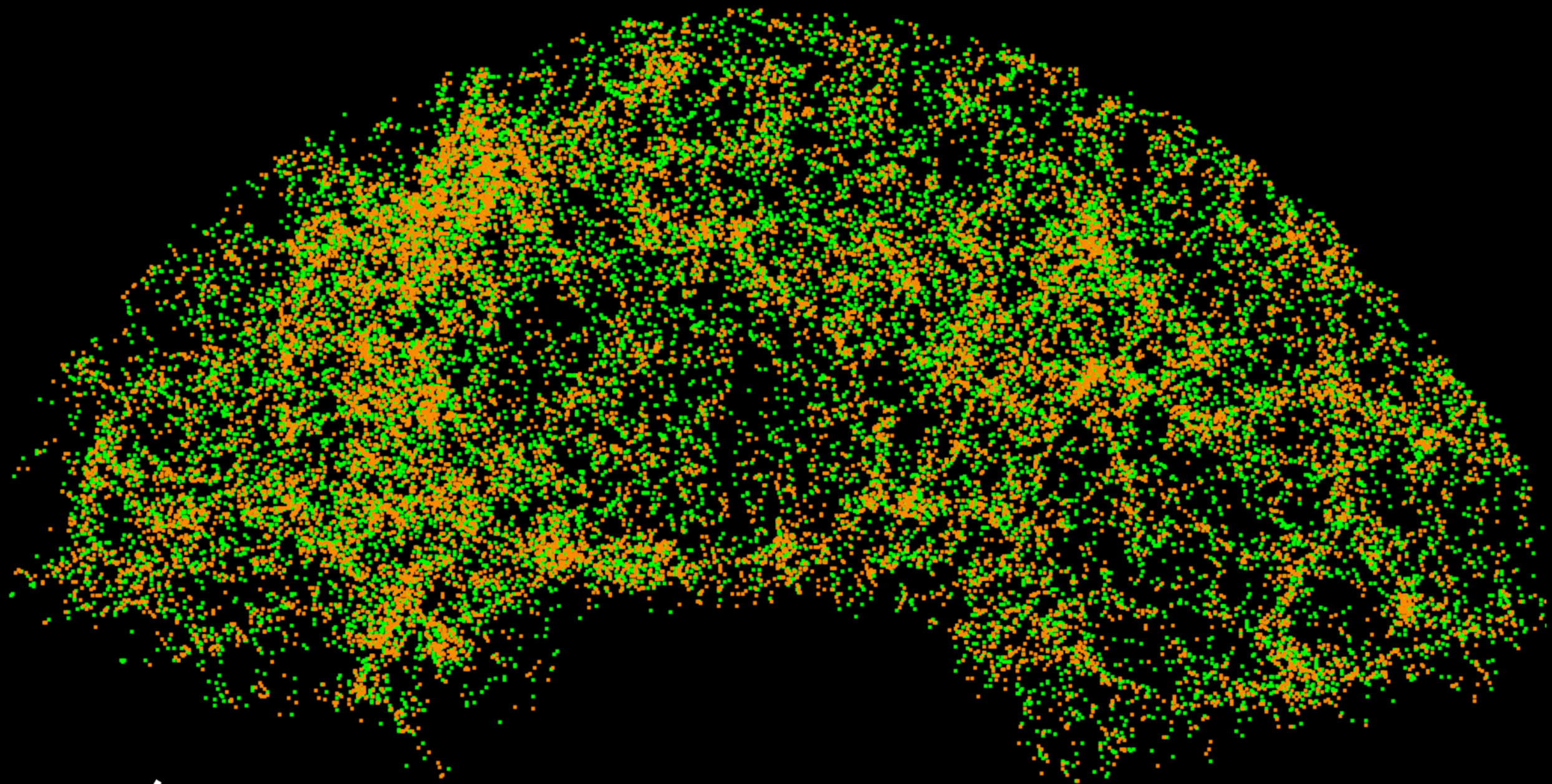
SF/Quenched

Tinker, Wetzel, Conroy, Mao 2017 arXiv:1609.03388

Applying the group finder to this slice.



Tinker, Wetzel, Conroy, Mao 2017 arXiv:1609.03388



SF/Quenched: Centrals

Tinker, Wetzel, Conroy, Mao 2017 arXiv:1609.03388

Consistent with other data on galaxy bimodality?

- f_Q clearly depends on large-scale environment.
- Deconvolving the contributions of centrals and satellites shows driven by satellites.
- Not consistent with central quenching being correlated with halo formation history.

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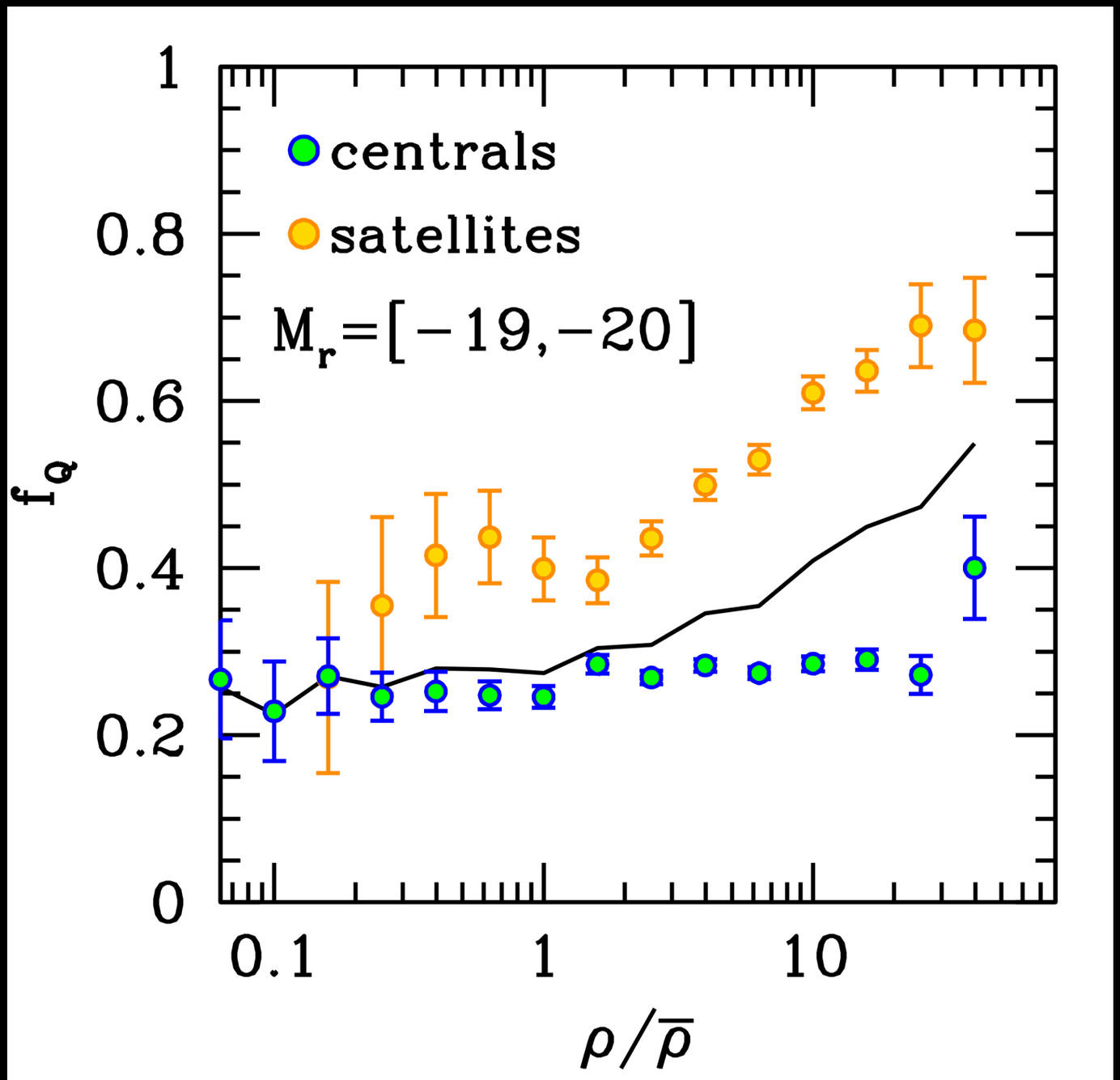

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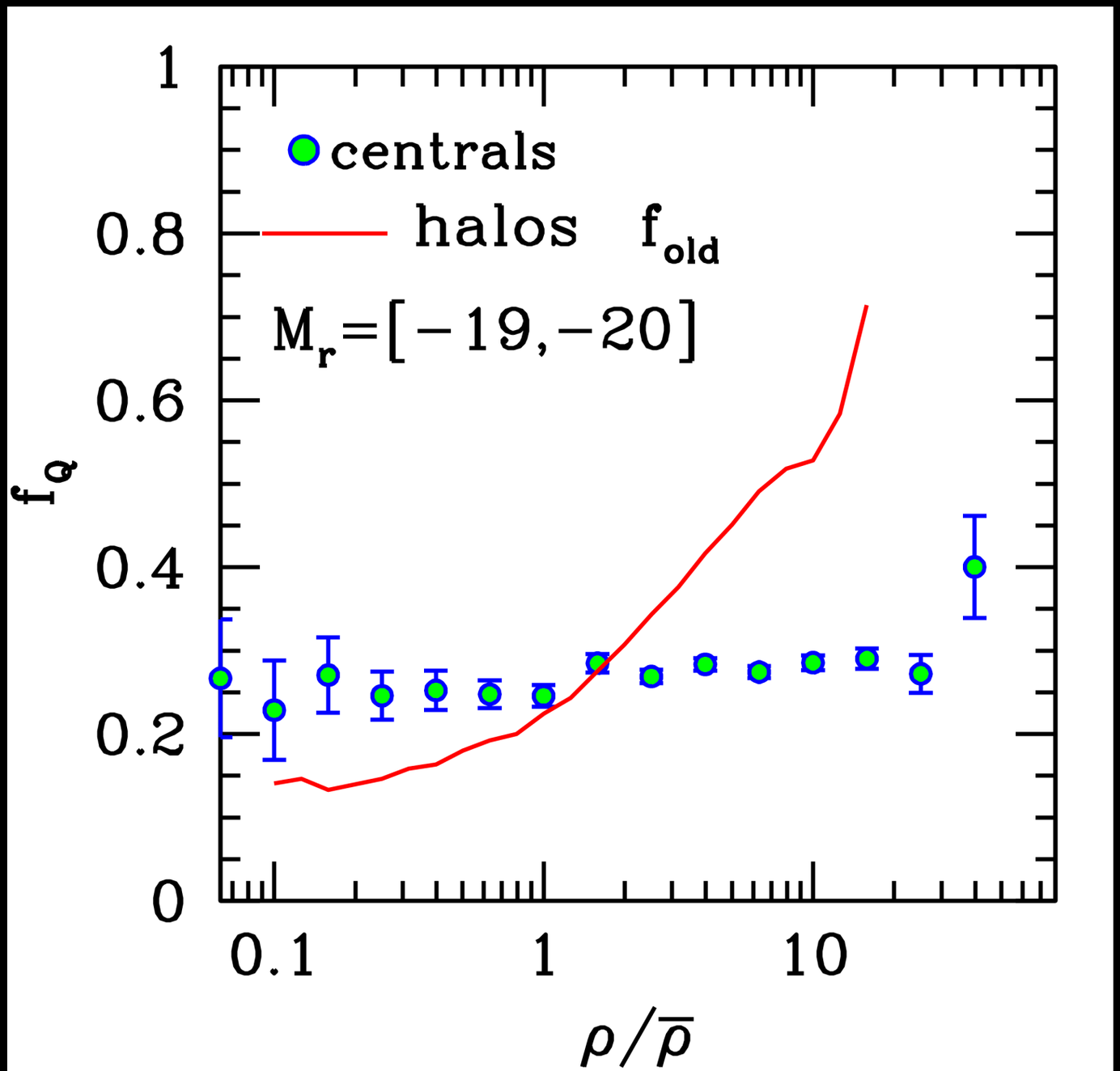
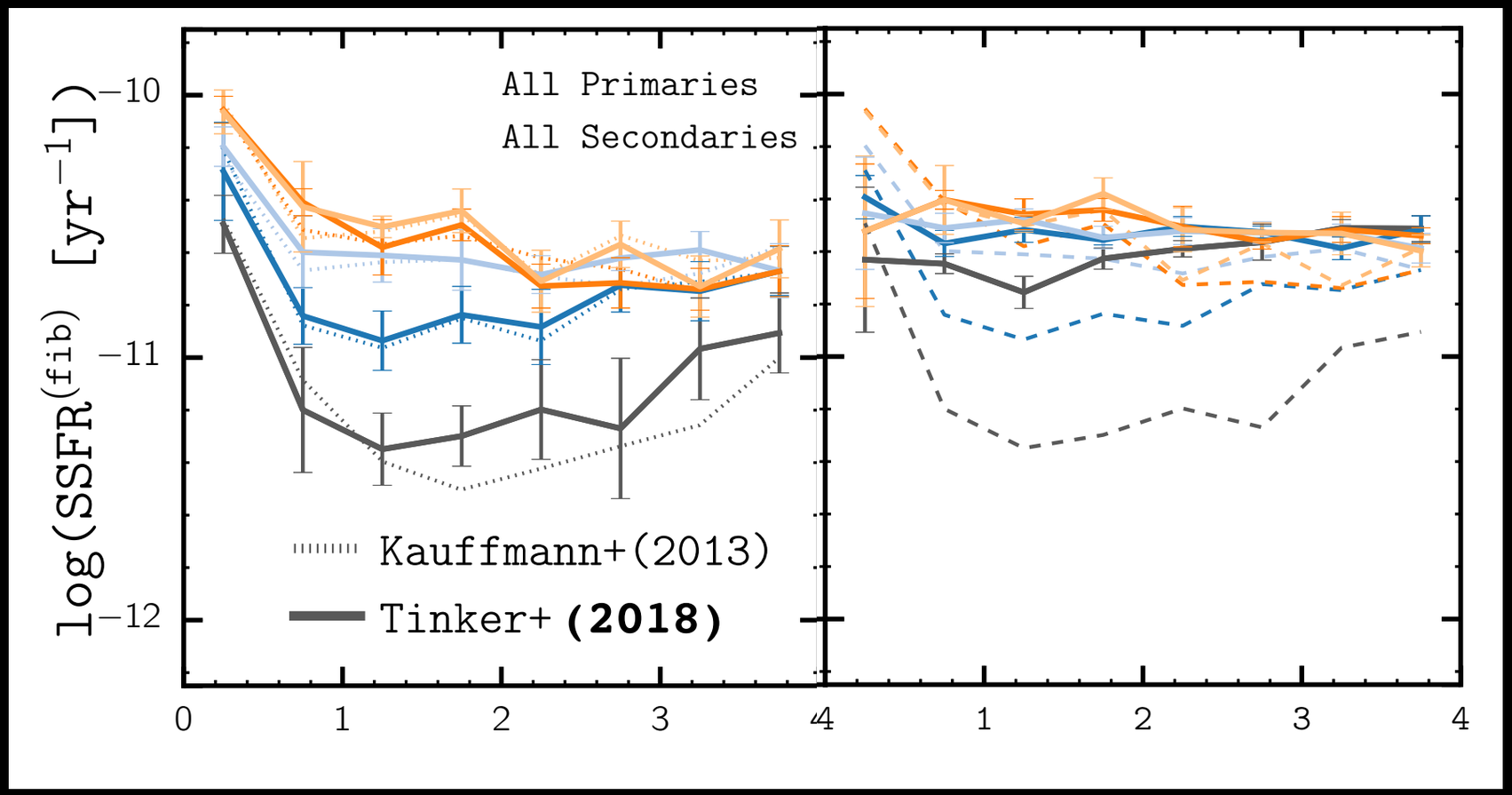


Tinker, Wetzel, Conroy 2011

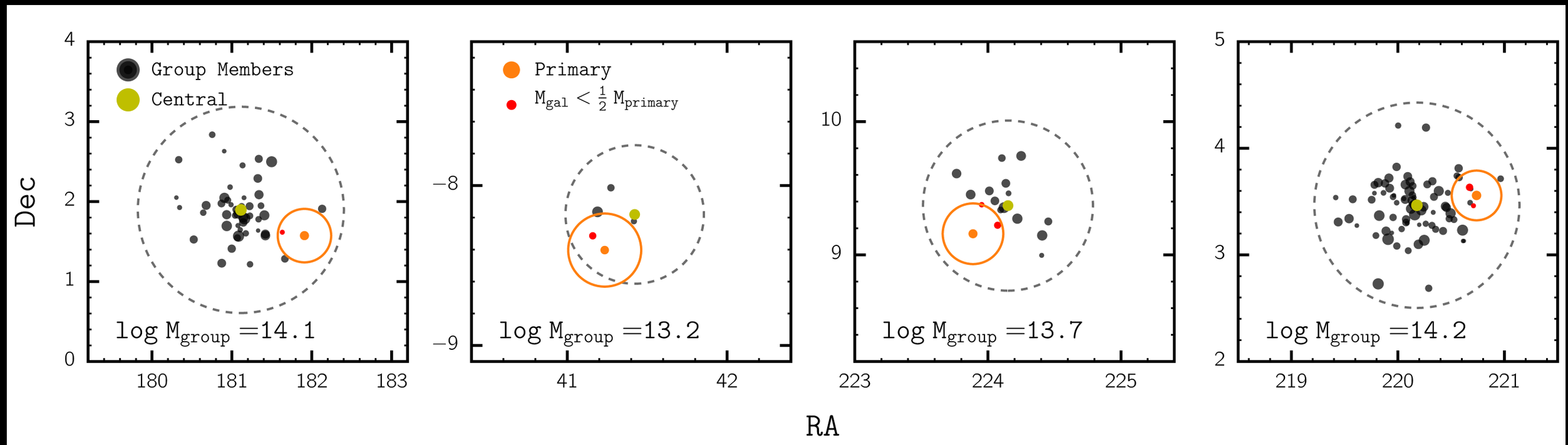
How to explain the galactic conformity detection?



- Left: Reproduction of the K13 conformity detection. Primary galaxies are found using isolation criterion.

- Right: Signal after removing “impurities” from the K13 sample of isolated galaxies.

- Examples of impurities in the Kauffmann et al sample,
- galaxies classified as “isolated” but the group finder labels them as satellites within high-mass halos.
- Source of the false conformity signal.

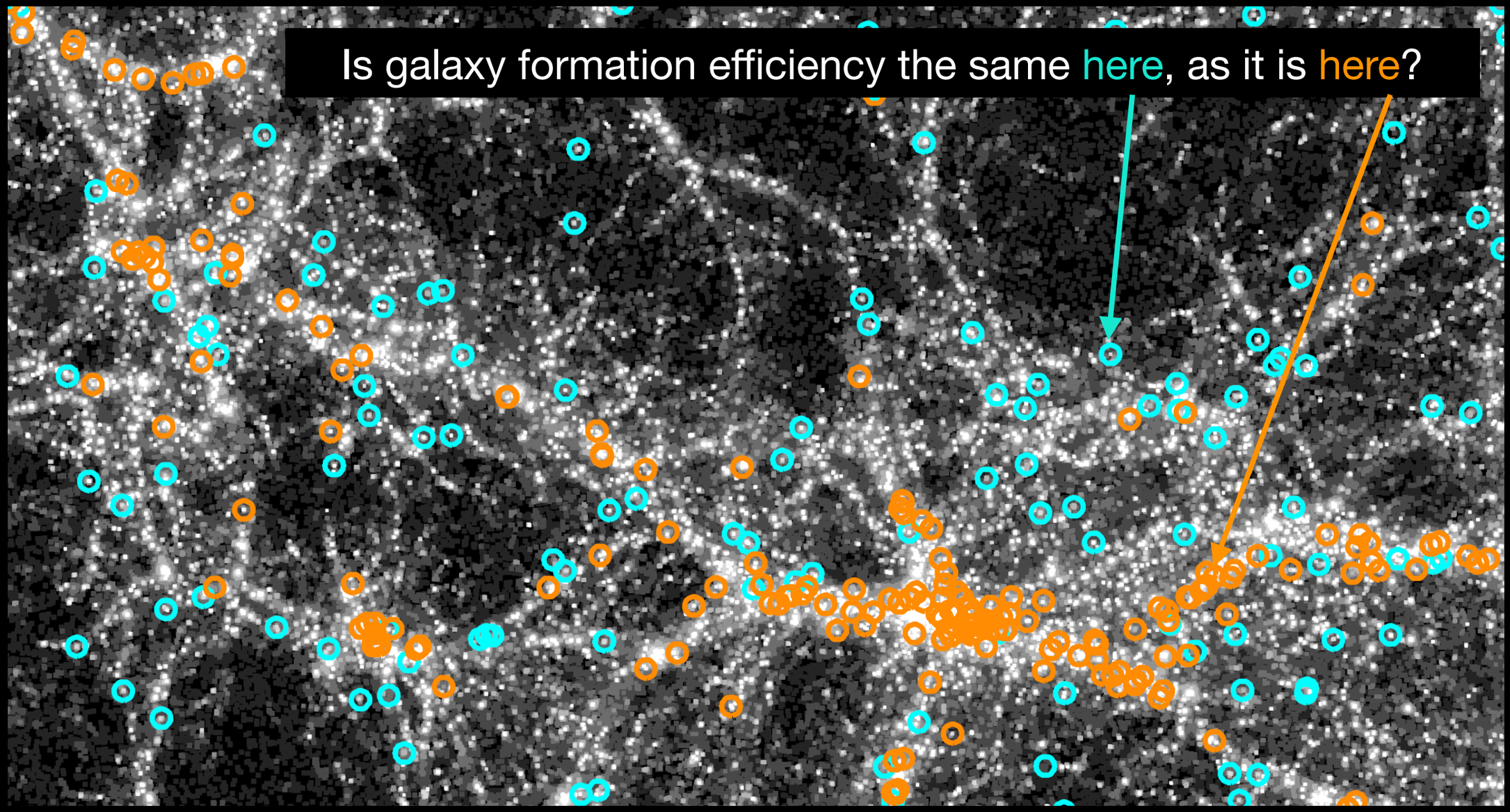


Orange circle: Kauffmann et al isolation radius

Grey dashed circle: Halo virial radius

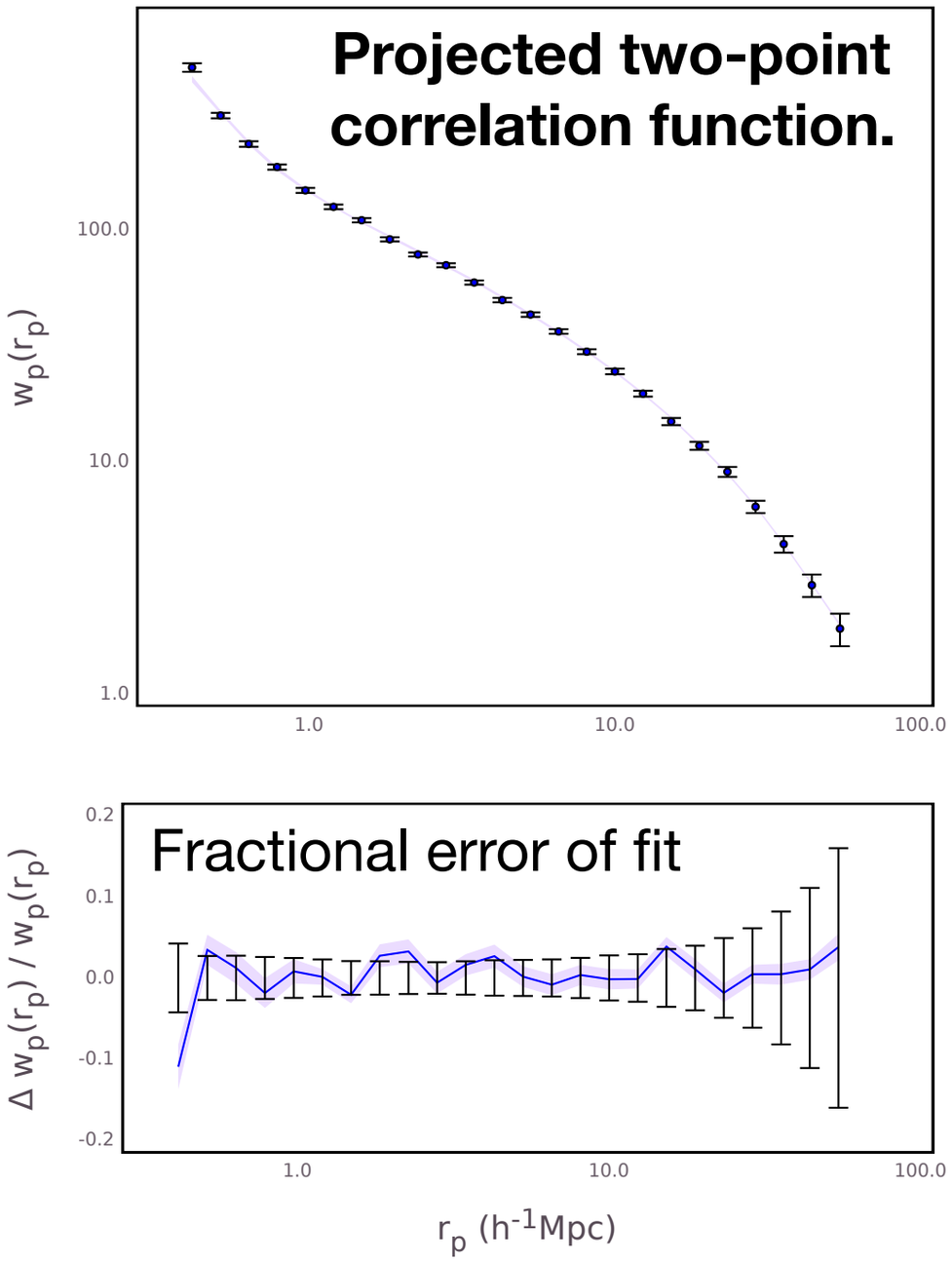
Sin et al 2017 found consistent conclusions when investigating the K13 detection.

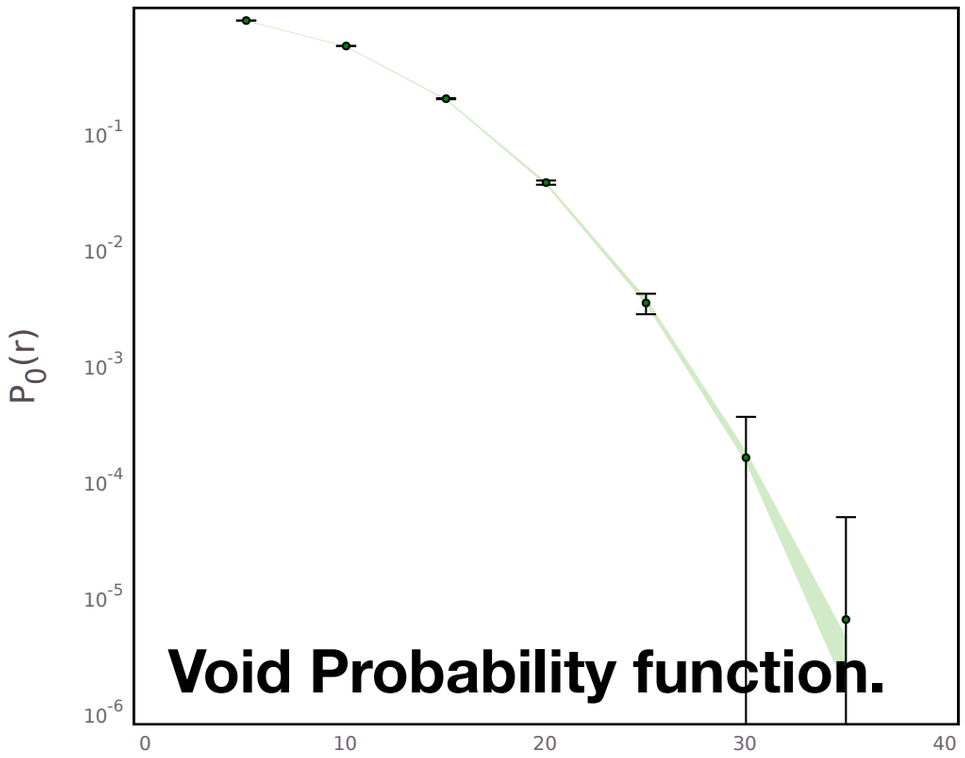
Voids as a critical test

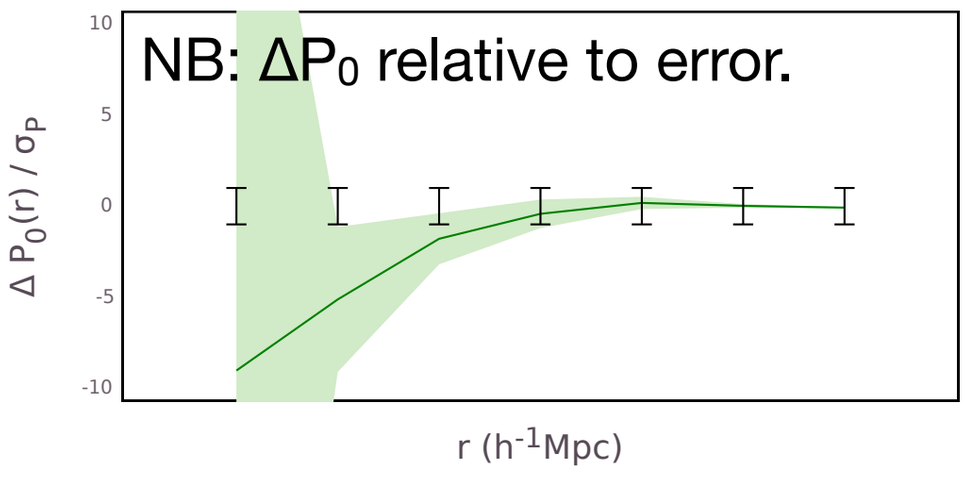


Can you simultaneously fit the two-point correlation function and the void probability function with a model where halo occupation is independent of large-scale environment?

Test applied to BOSS LRGs



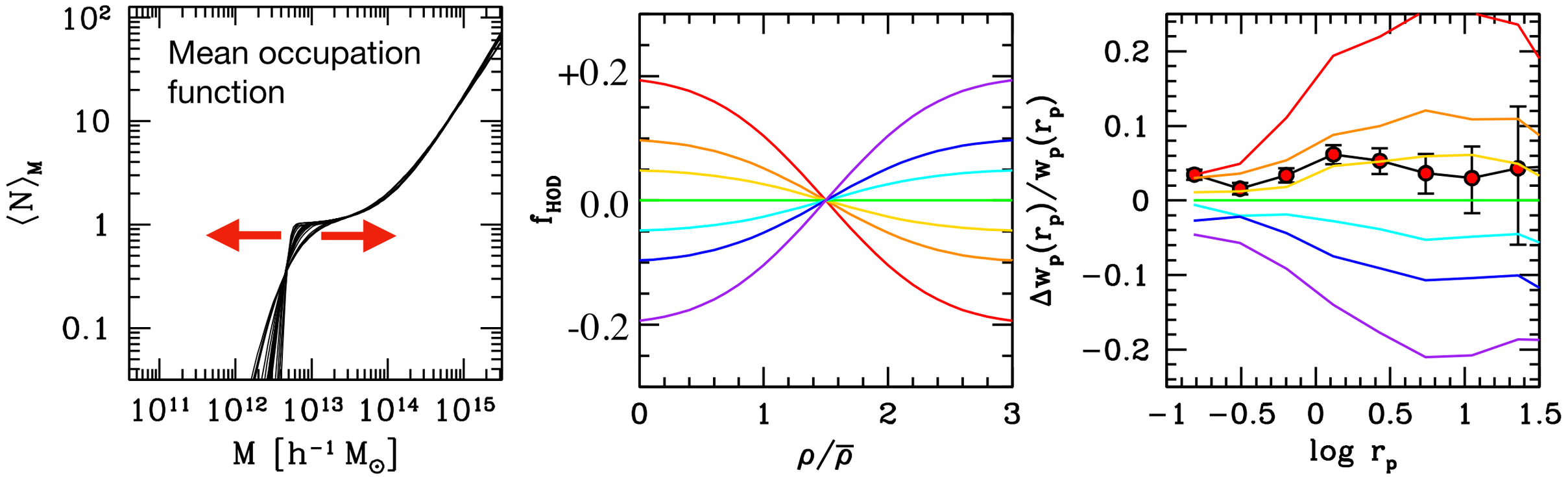




Walsh & Tinker 2019

This is a standard model: halo occupation only depends on halo mass.

Constraining Assembly Bias



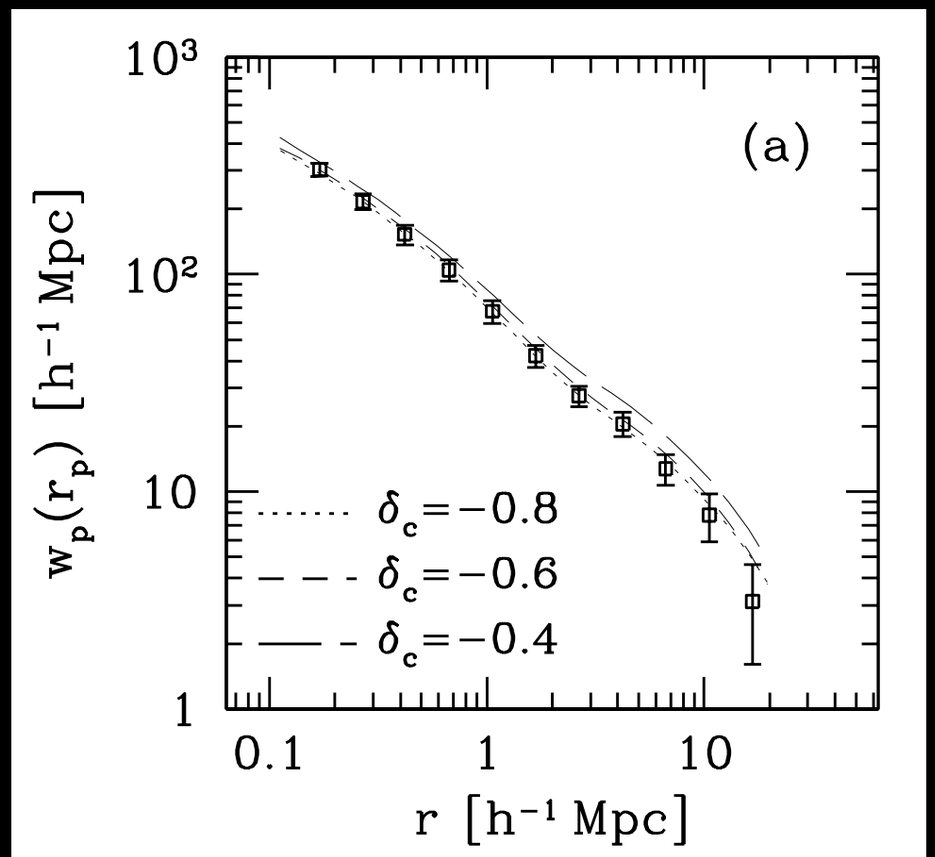
Shift the mass scale depending on the large-scale density

$$f_{\rm HOD} = \frac{f_\rho}{2}\left[1 + {\rm erf}\left(\frac{\log\rho_m - \log\rho_0}{\sigma_\rho}\right)\right]$$

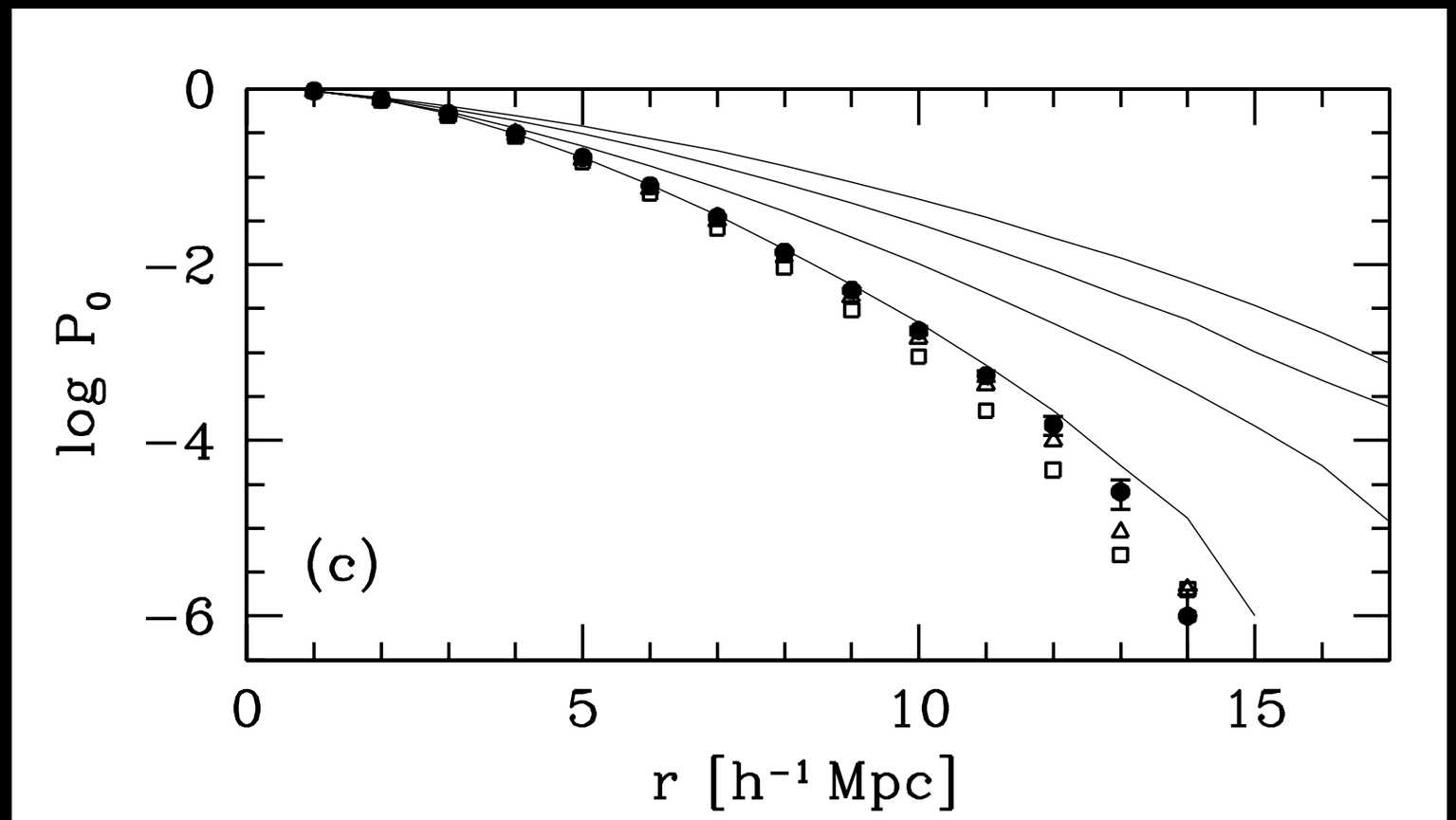
Red curve shifts galaxies from low densities to high densities

Purple curve shifts galaxies to high densities from low densities

Impact of assembly bias on correlation function



Impact of the same models on the void probability function.



Tinker, Weinberg, Warren 2006

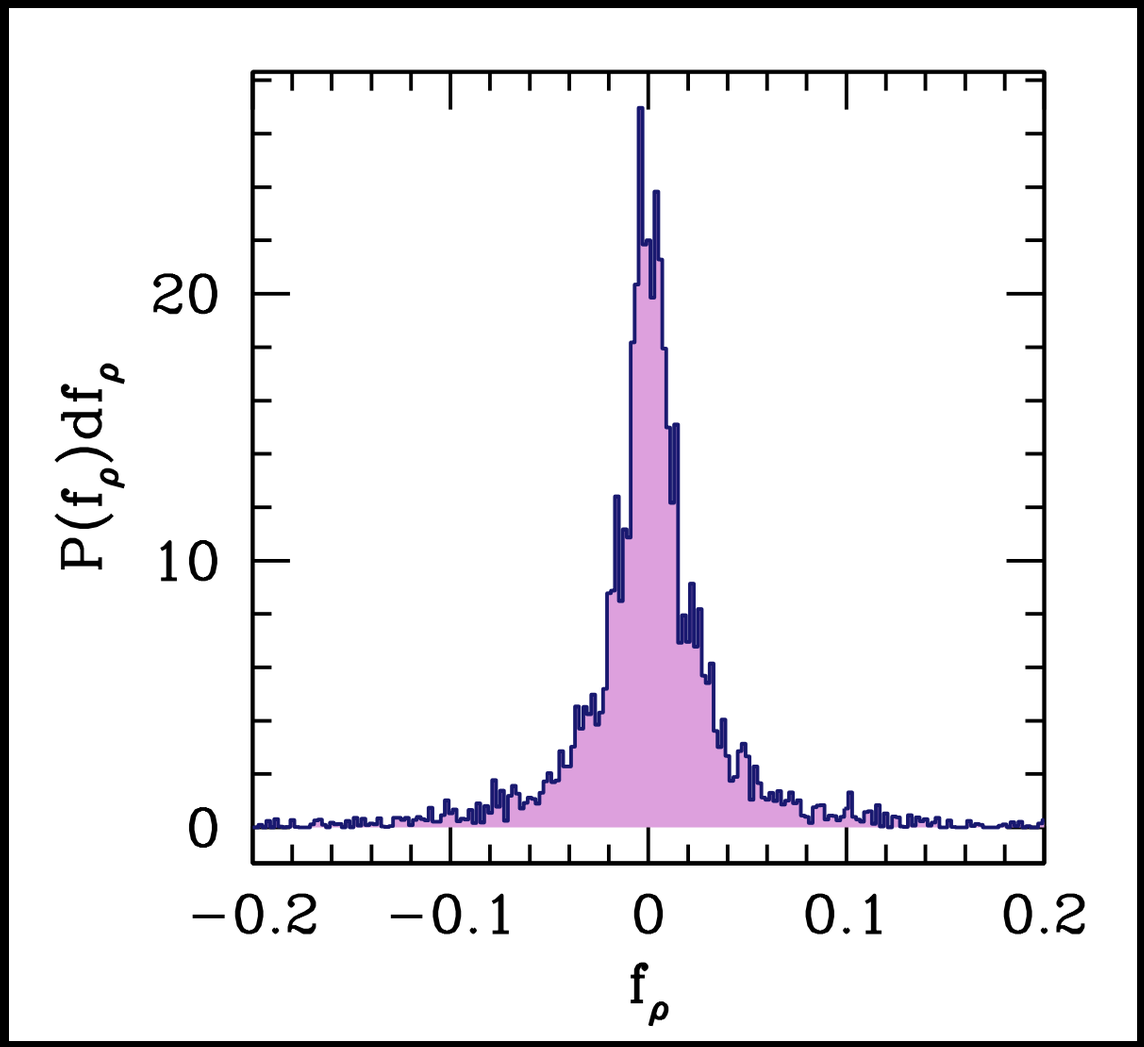
Constraints from BOSS

Recall the parameterization of assembly bias:

$$f_{\rm HOD} = \frac{f_\rho}{2}\left[1 + {\rm erf}\left(\frac{\log\rho_m - \log\rho_0}{\sigma_\rho}\right)\right]$$

- f_ρ is the key parameter for controlling the amplitude of the assembly bias.
- 68% confidence region of:

$$f_\rho = [-0.022, +0.026]$$



Conclusions

- Any assembly bias in BOSS LRGs must be very small—only impacting clustering by a couple percent.

- Assembly bias in galaxy color is minimal (or not detected) as well, including measurements of galactic conformity.

- However (#1) with DESI and future missions, “a couple percent” will be within the statistical errors.

- However (#2) assembly bias within the star-forming population needs to be looked at more closely: DESI, Euclid, WFIRST all target ELGs.