A systematic search for galaxy protocluster cores at the transition epoch of star formation activity

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Protocluster core

✦ Protocluster (PC)

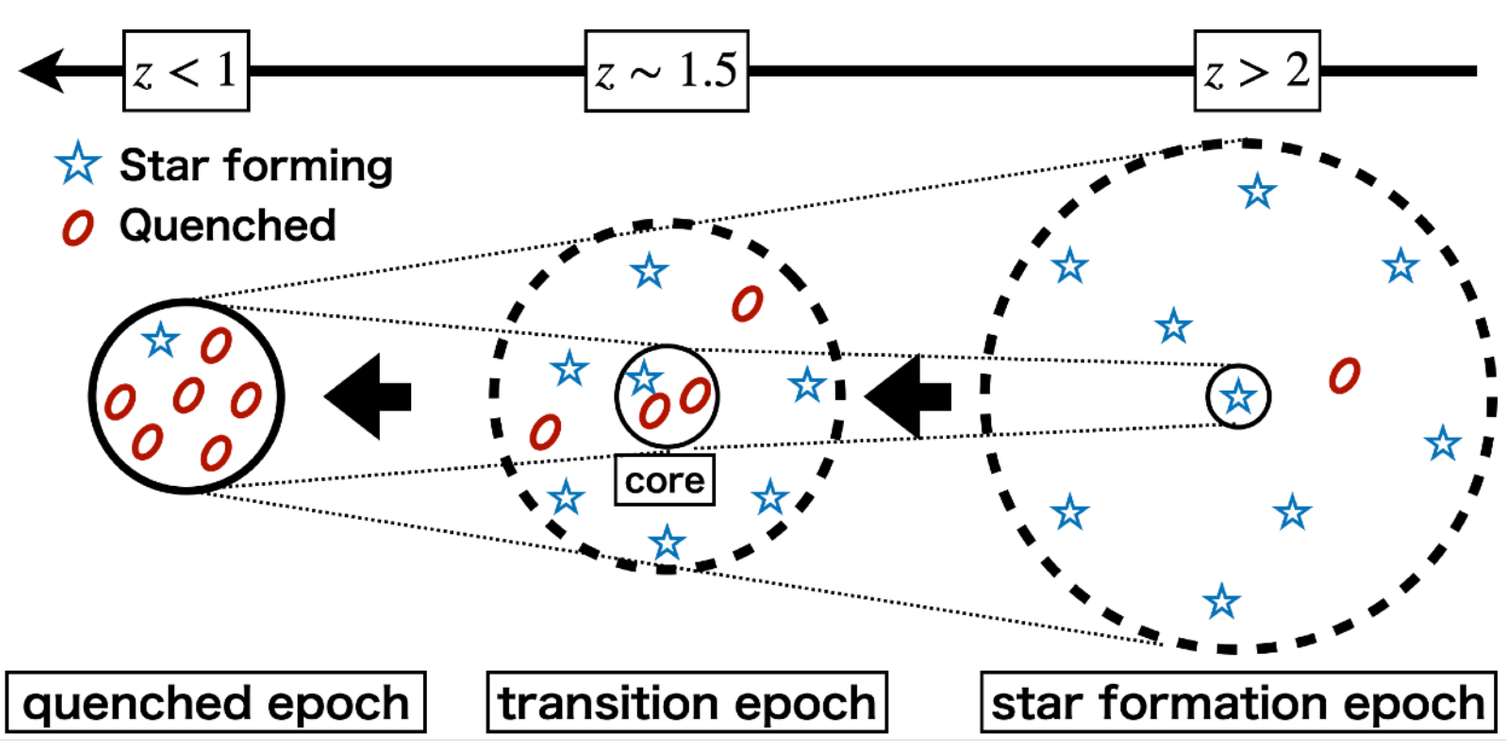
- active star formation at $z > 2$ (e.g. Shimakawa+18), quenching at $z < 1$ (e.g. van der Burg+18)
- $z \sim 1.5$ is the “transition epoch” of star formation activity

➡ When and how the star formation quenching occurs in (proto)cluster

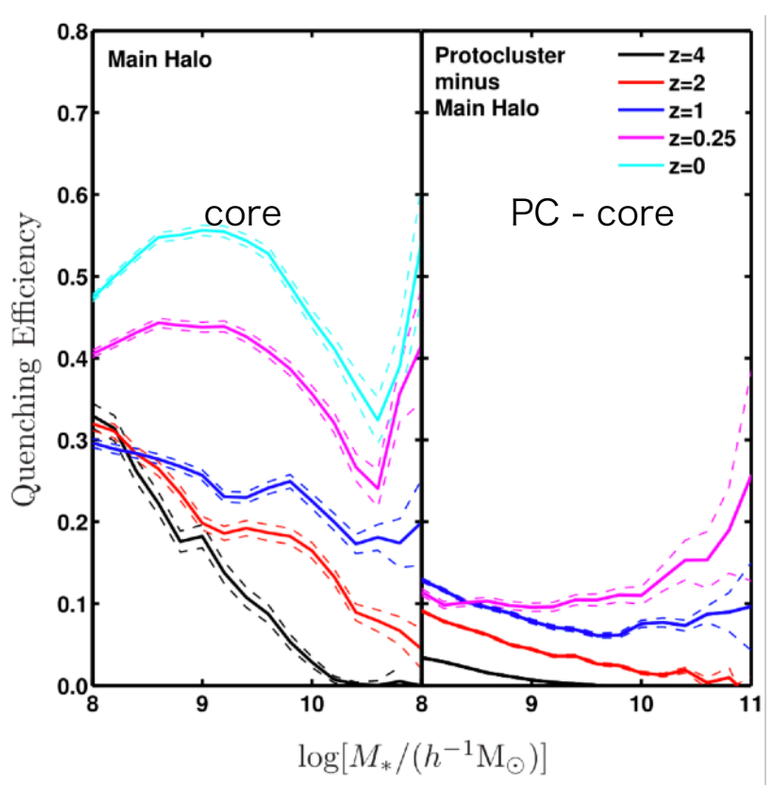
✦ PC “core”: most massive halos in PCs

- strong environmental effect (Muldrew+18)

➡ conduct a search for PC cores at $1 < z < 1.5$



Muldrew+18



Data

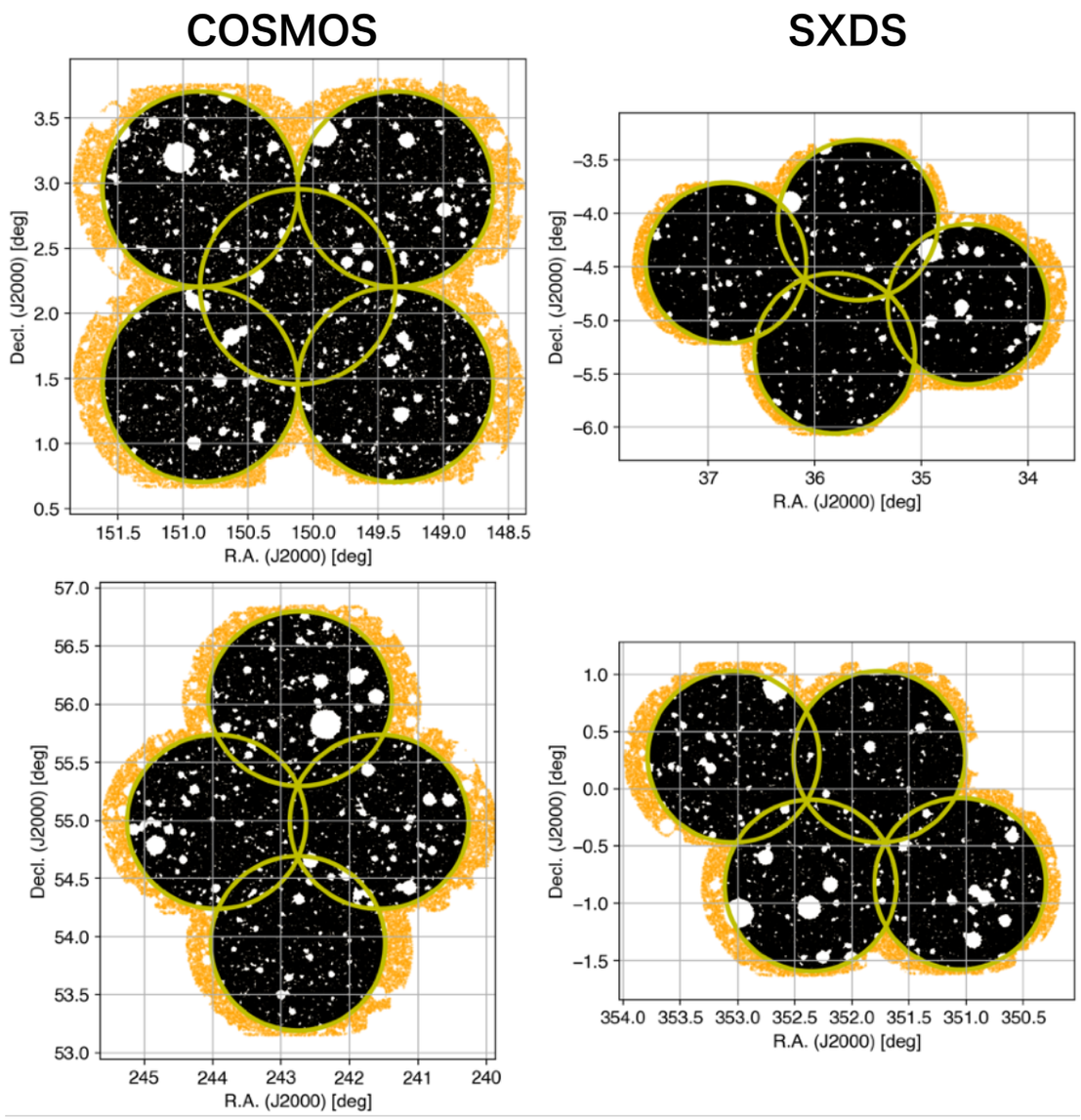
✦ HSC-SSP S19a (Aihara+19); 4 DUD fields

✦ sample selection
- photo-z catalog (called “Mizuki”)
- $0.85 < z_{\rm phot} < 1.65$
- $\log(M_*/M_\odot) > 9$

✦ Galaxy classification
- red galaxy: $g - i > 2.1$
- blue galaxy: $g - i < 2.1$
  - $\sim 80\,\%$ completeness for quenched galaxy
  - $\sim 20\,\%$ contamination (dusty SFG)

  (comparison with COSMOS2015 catalog)

~22 deg^2 in total (black areas)



Protocluster core search

✦ search for PC cores

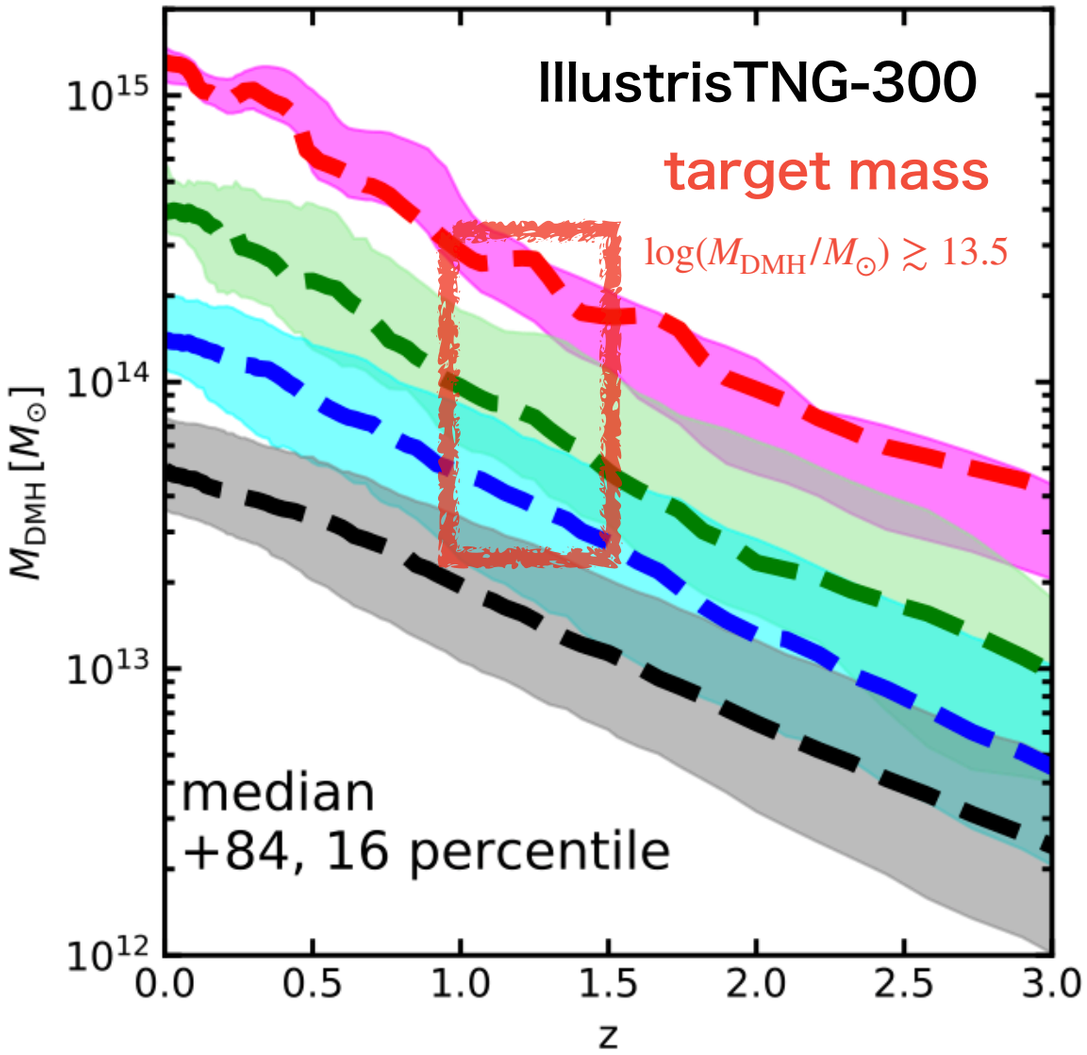
1) massive massive galaxies as PC core centrals

- $\log(M_*/M_\odot) \sim 11,\ 1 < z < 1.5$

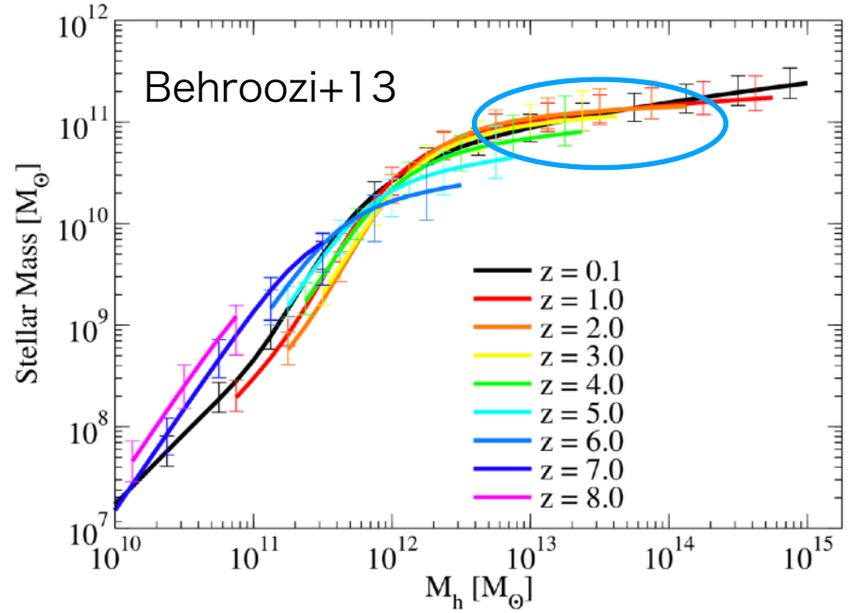
2) halo mass estimate based on clustering analysis

3) confirm their halo mass is consistent with PC core

$(\log(M_{\rm DMH}/M_\odot) \gtrsim 13.5)$



central M_*



$M_{\rm DMH}$

✦ halo mass at z=0

Coma: $\log(M_{\rm h}/M_\odot) > 15.0$

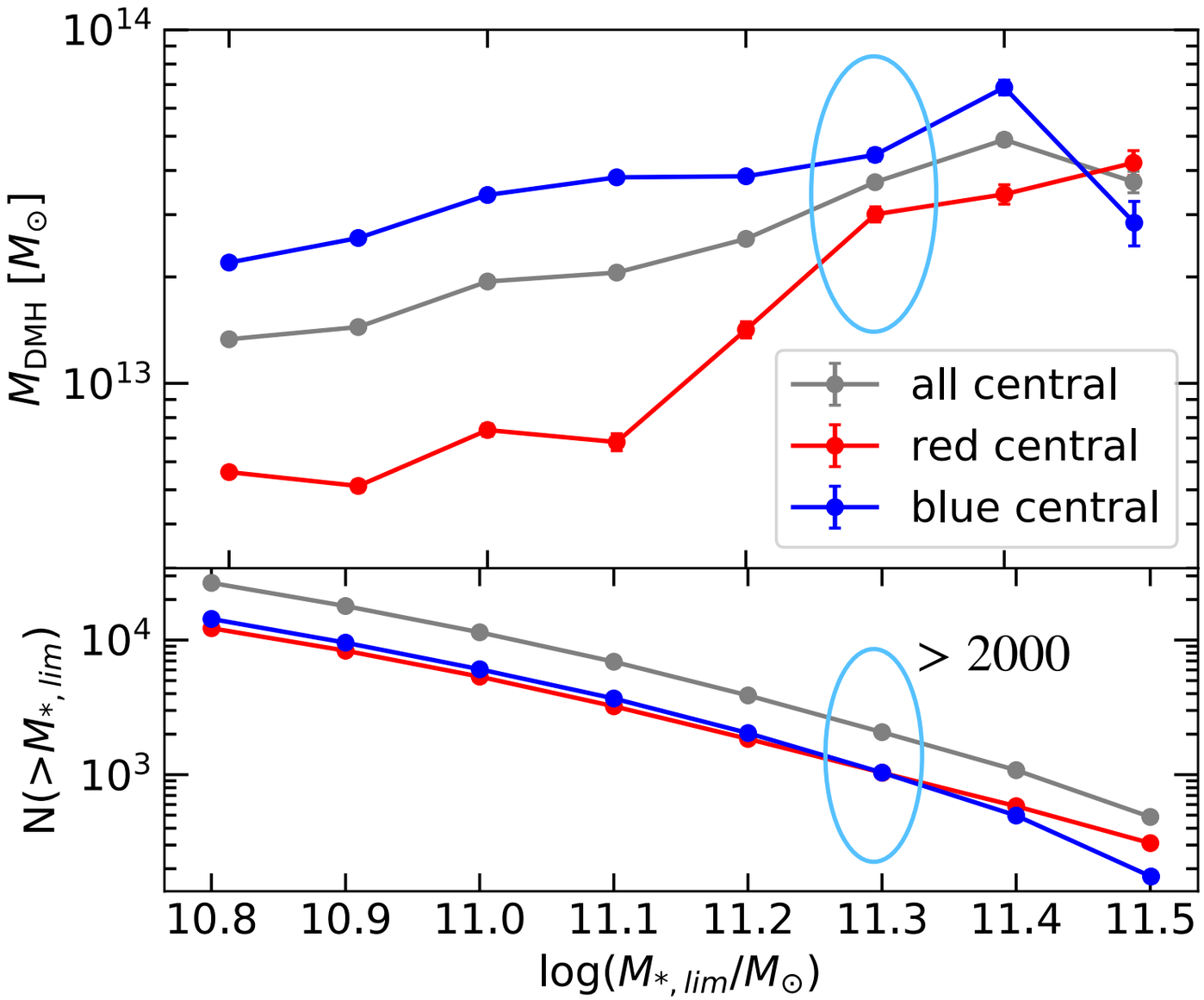
Virgo: $14.5 < \log(M_{\rm h}/M_\odot) < 15.0$

Fornax: $14.0 < \log(M_{\rm h}/M_\odot) < 14.5$

Group: $13.5 < \log(M_{\rm h}/M_\odot) < 14.0$

Result 1: Halo mass estimate

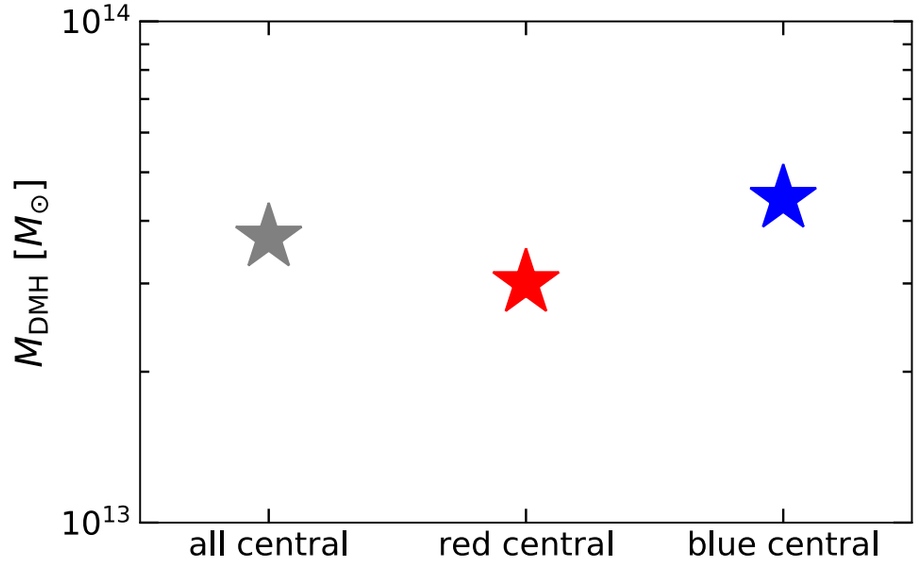
- halo mass of massive galaxies ($> M_{*,\mathrm{lim}}$)
  - cross-correlation w/ less massive galaxies
  - host halos of galaxies w/ $\log(M_*/M_\odot) > 11.3$



Result 1: Halo mass estimate

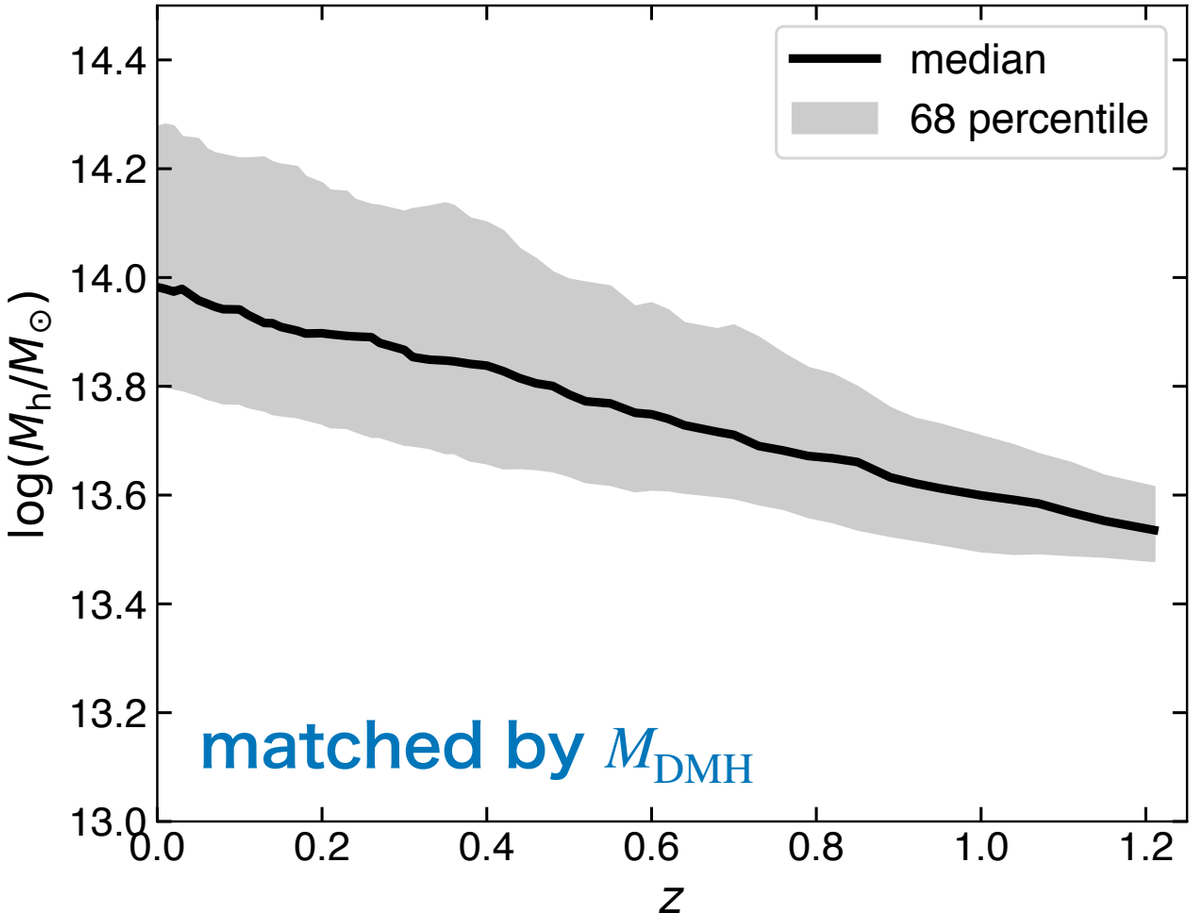
✦ Comparison with IllustrisTNG-300

- select DMH at $z = 1.25$ with similar $M_{\rm DMH}$ or $M_{*,\rm lim}$
- massive enough to evolve into cluster by z=0

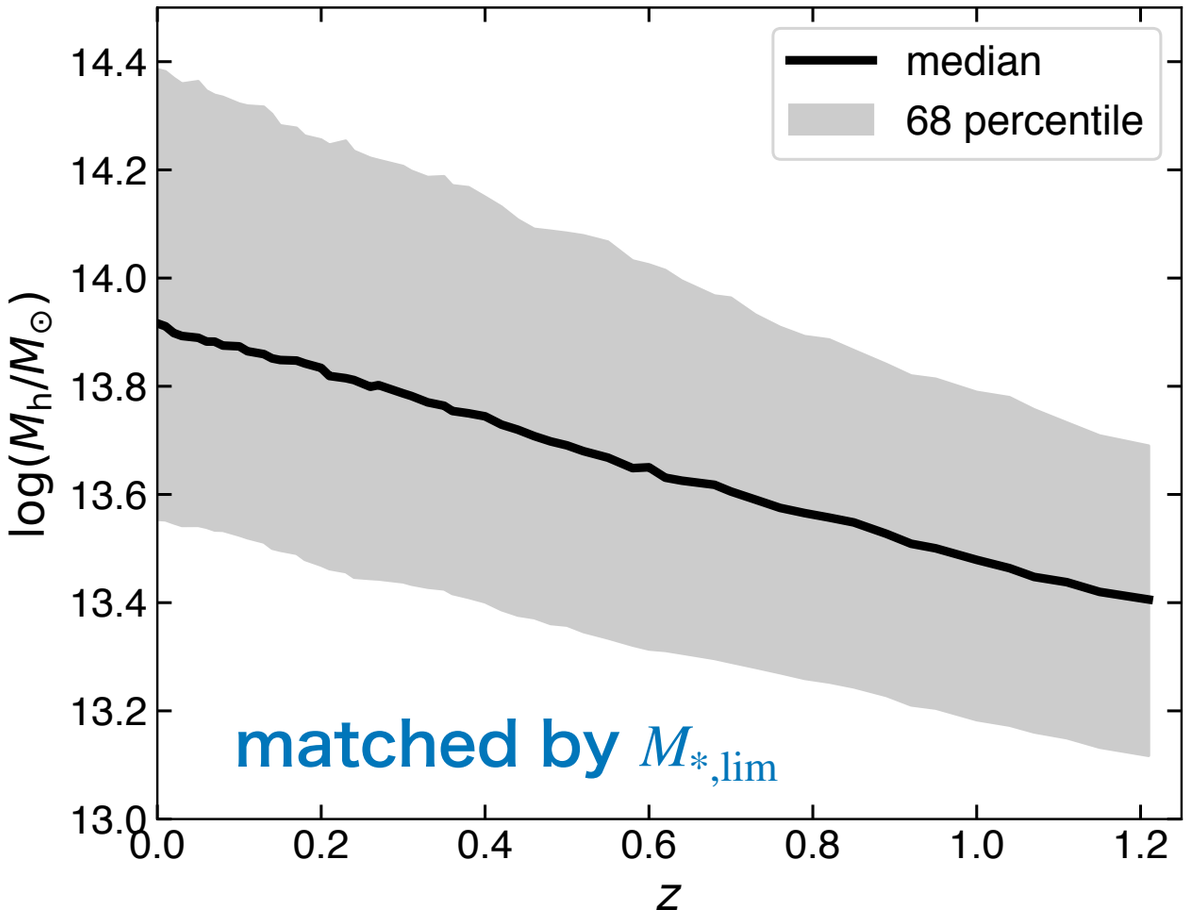


IllustrisTNG 300

$\log(M_{\rm h}/M_\odot) = 13.5 +/- 0.1$ at $z = 1.25$



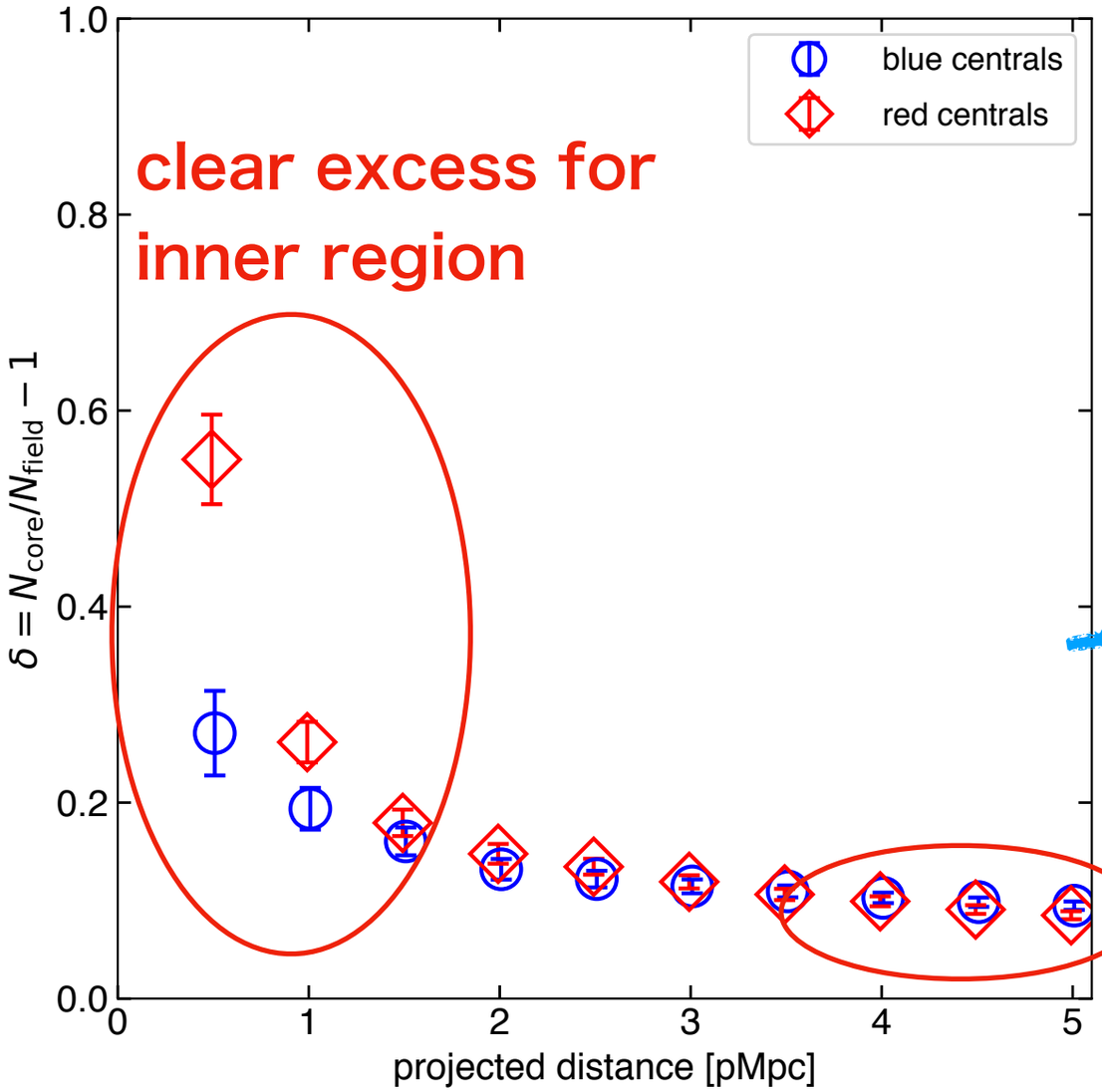
$\log(M_*/M_\odot) > 11.3$ at $z = 1.25$

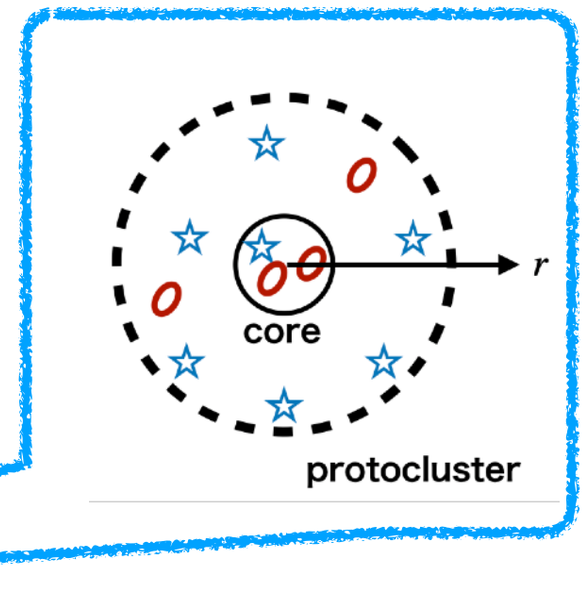


Result 2: Large scale overdensity

✦ Is there overdensity?

- count galaxies with $10 < \log(M_*/M_\odot) < 11,\ \Delta z < 0.15$
- clear overdensity especially at small radii
- “offset” at large scale => core associated by large-scale structure

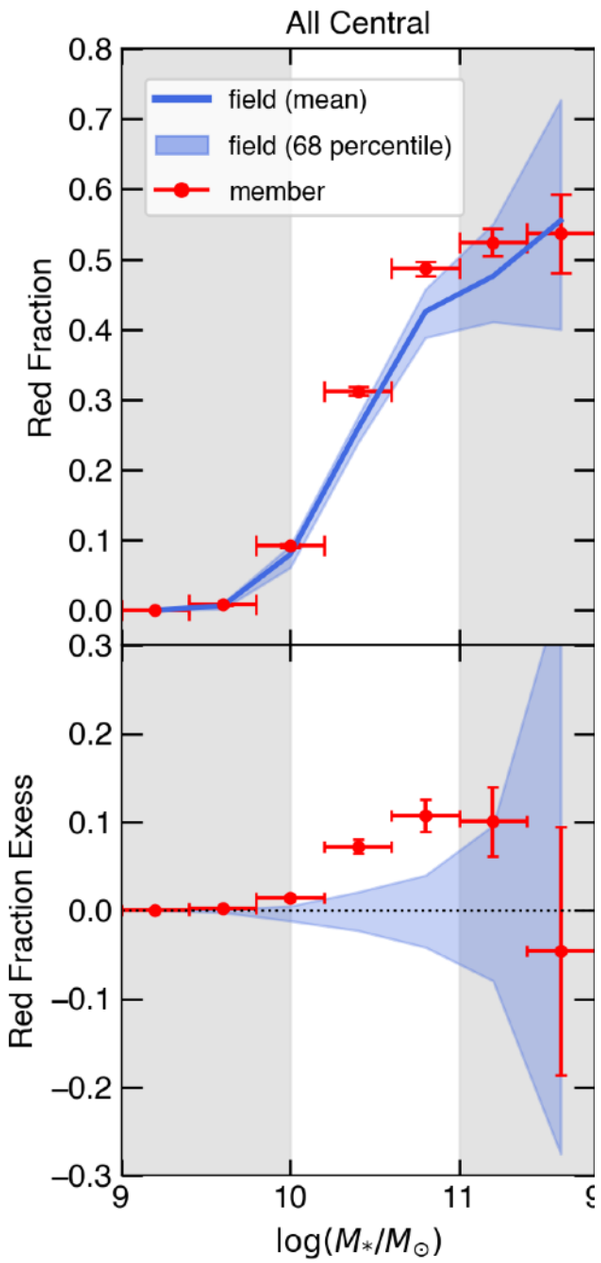




Result 3: Red fraction

✦ Red fraction

- $\Delta z < 0.15$, $\Delta r < 0.5\,\mathrm{pMpc}$, w/o centrals
- field galaxy subtraction



Red Fraction

$$f_{\mathrm{red}} = N_{\mathrm{red}}/(N_{\mathrm{red}} + N_{\mathrm{blue}})$$

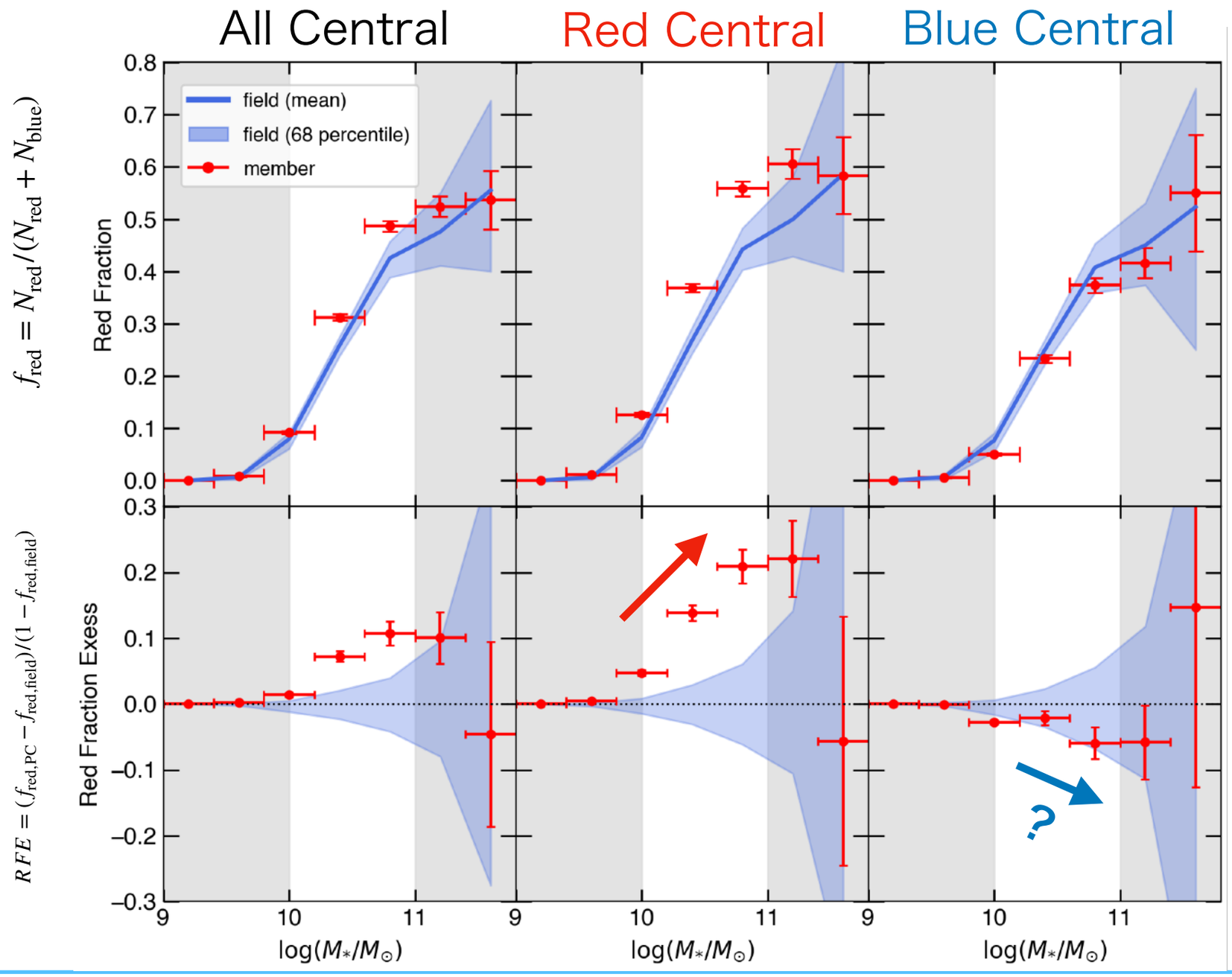
Red Fraction Excess

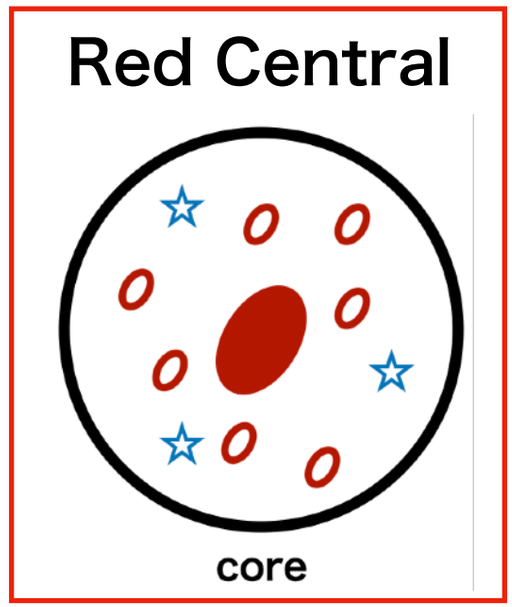
$$RFE = \frac{f_{\mathrm{red,PC}} - f_{\mathrm{red,field}}}{1 - f_{\mathrm{red,field}}} = 1 - \frac{f_{\mathrm{blue,PC}}}{f_{\mathrm{blue,field}}}$$

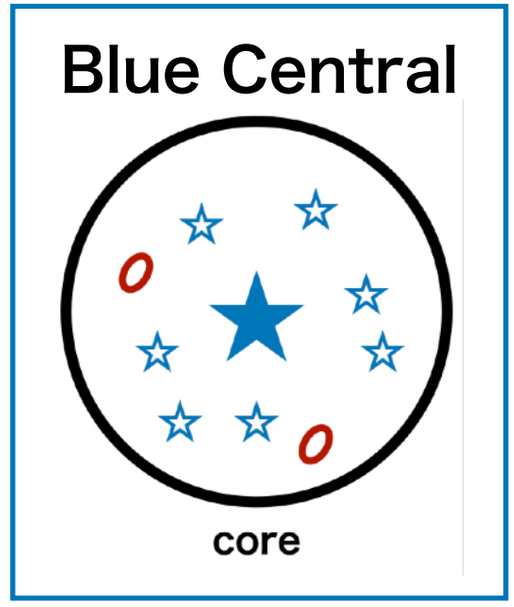
Result 3: Red fraction

✦ Red fraction

- clear **positive RFE** around **red** centrals
  - increasing trend of RFE against M_*
- marginal **negative RFE** around **blue** centrals





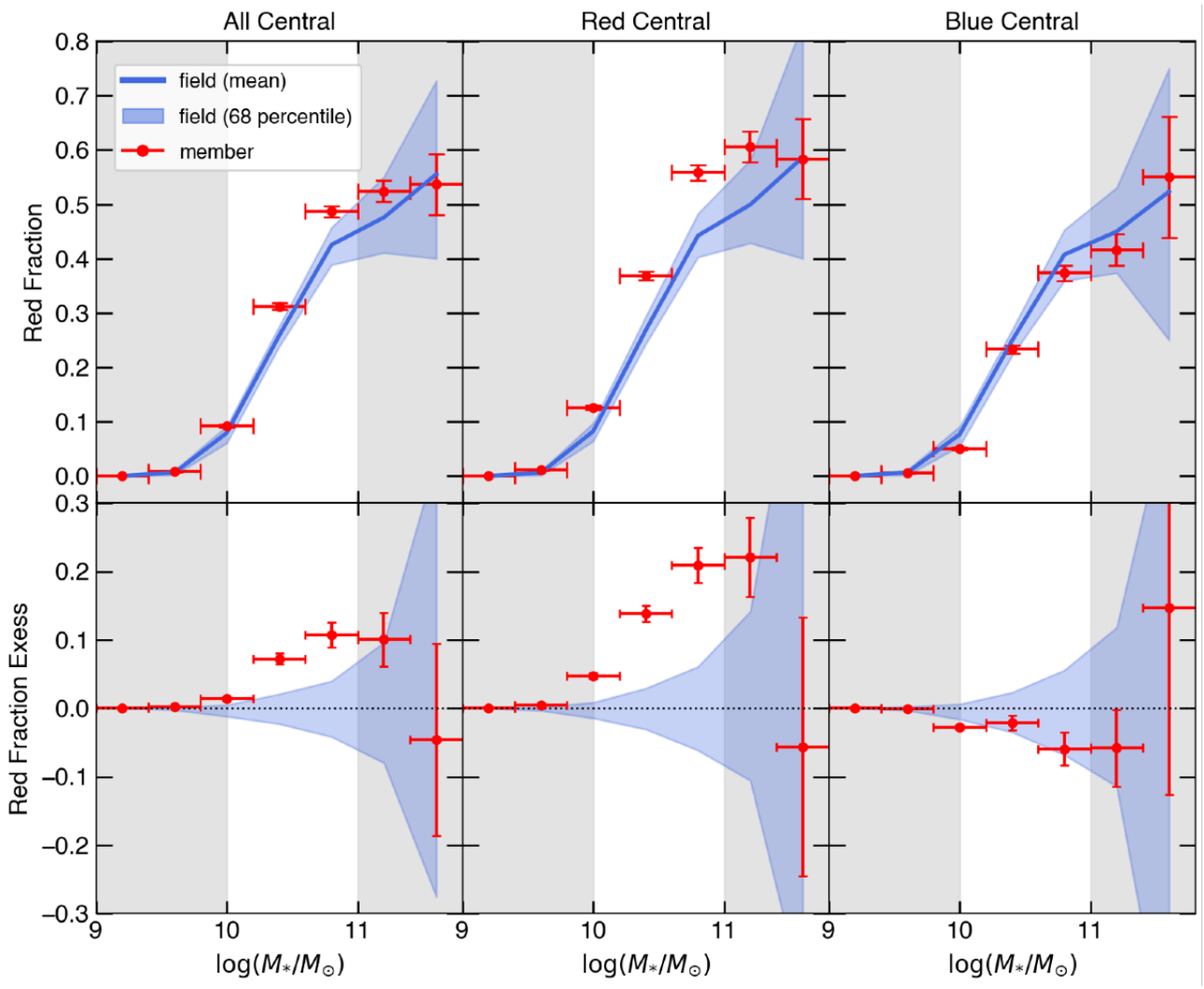


Result 3: Red fraction

✦ Literature comparison (group @$1 < z < 1.5$)

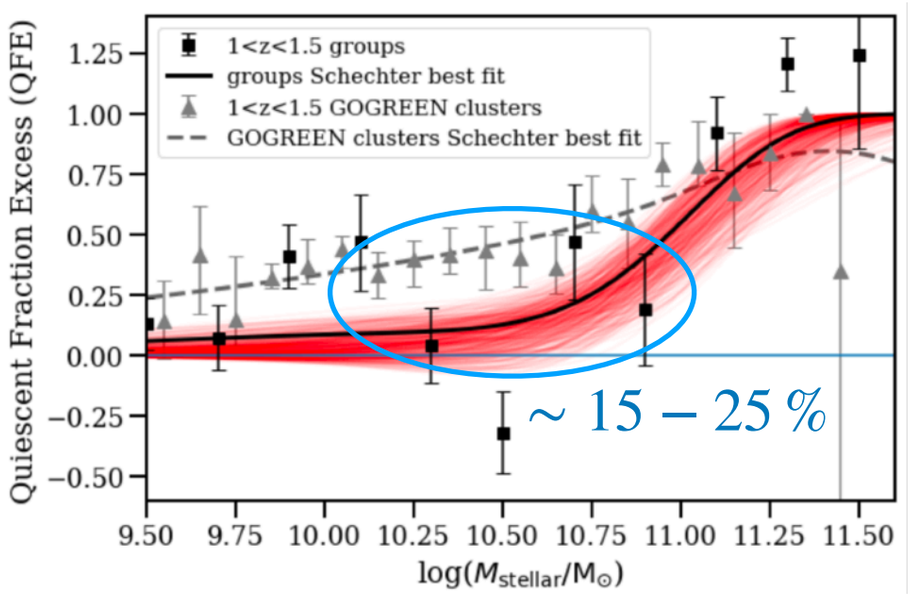
- similar RFE (<=> Quenched fraction excess based on rest-UVJ)
- RFE increases as stellar mass becomes larger

➡At $z > 1$, environmental quenching depends on stellar mass



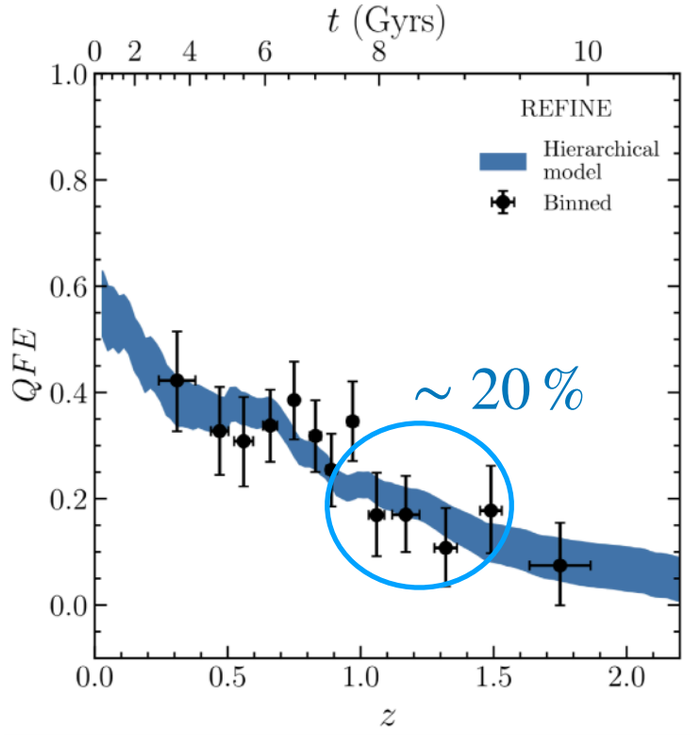
Reeves+21 (GOGREEN)

X-ray group, $\log(M_{\rm DMH}/M_\odot) \sim 13.8$



Saroon+21 (REFINE)

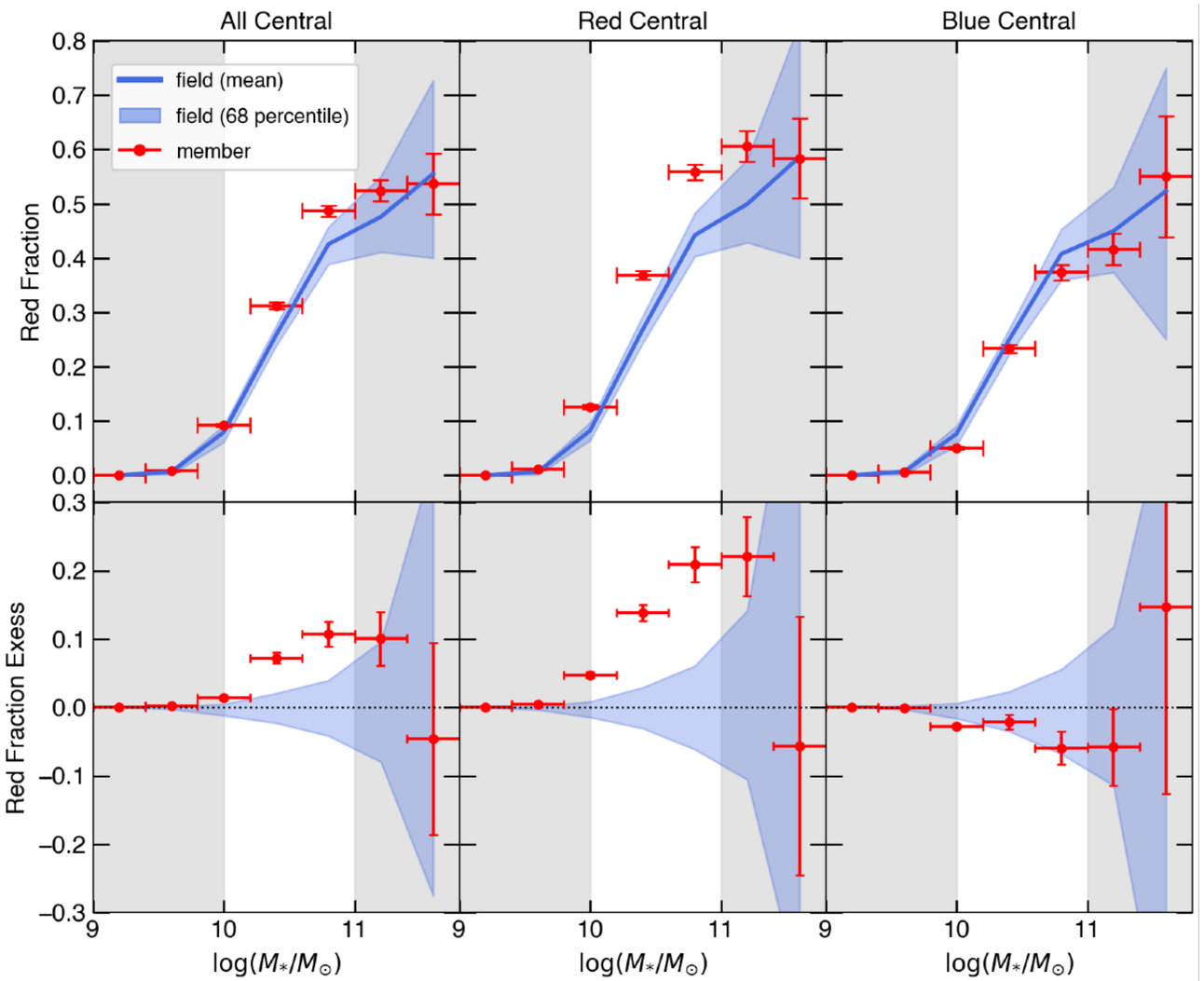
overdensity as group, $\log(M_{\rm DMH}/M_\odot) \sim 13.7$

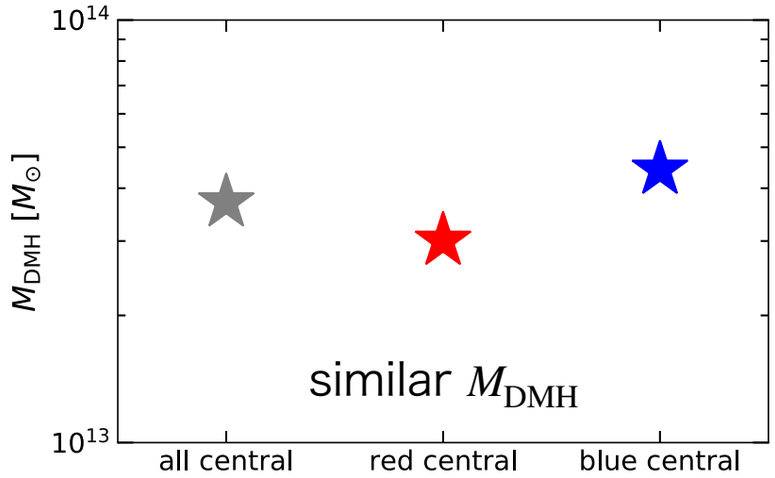


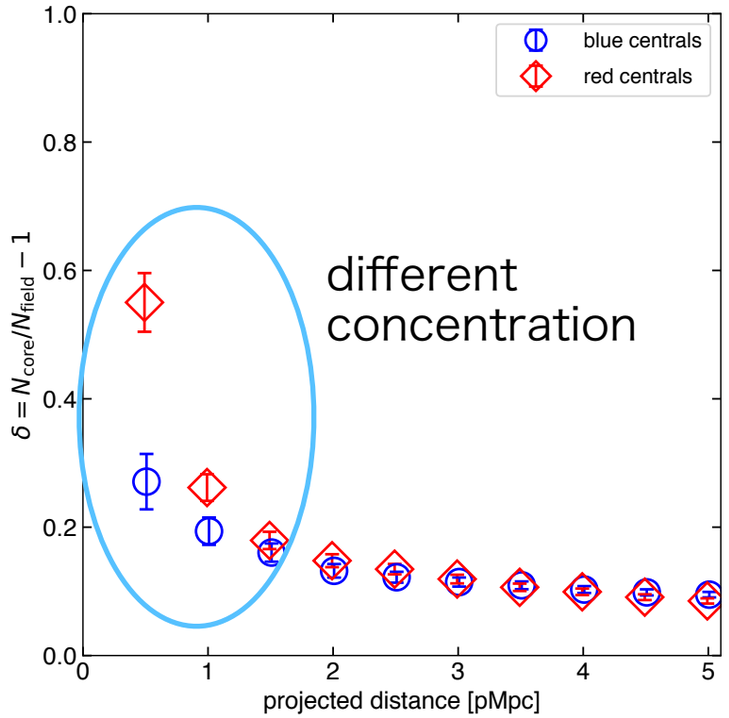
Result 3: Red fraction

✦ Galactic conformity

- red centrals - red satellites / blue centrals - blue satellites
- well known at local universe, some reports at $z > 1$ (Weinmann+06; Hartley+15)
- what is the cause conformity?
  - ✓ halo mass? ⋯ **No**
  - ✓ concentration? ⋯ more concentration around red centrals

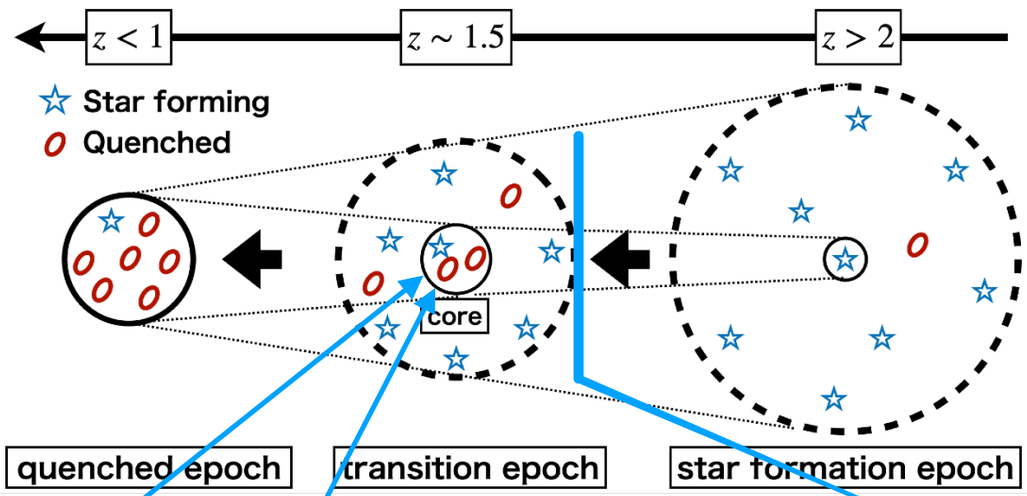


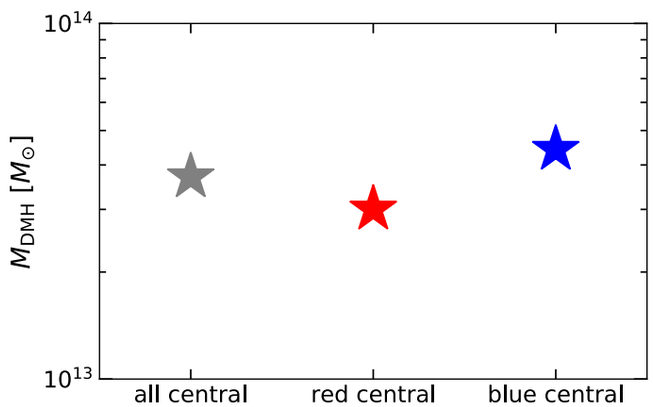


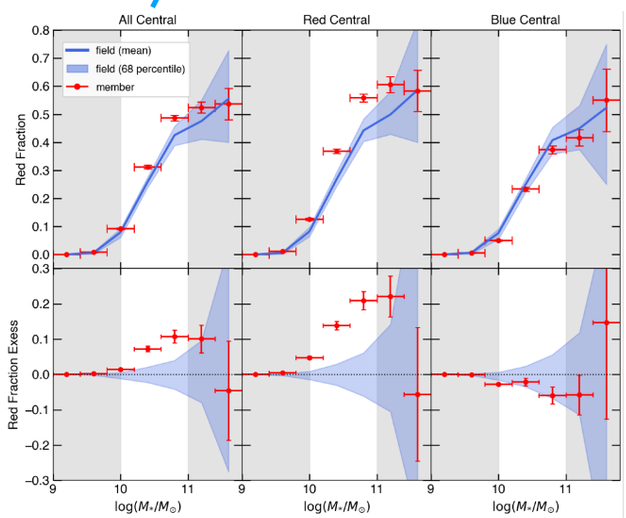


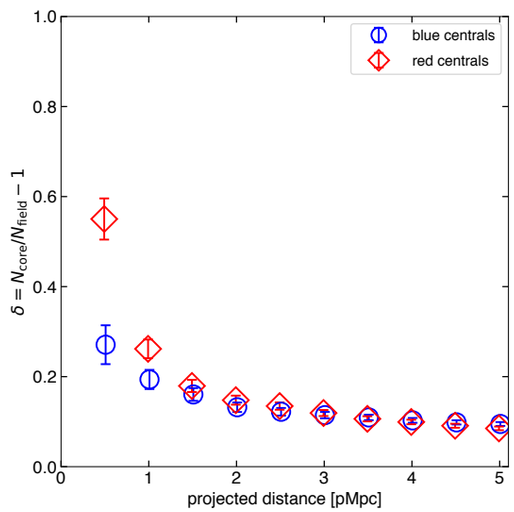
Summary

- ✦ We conduct a search for PC cores based on clustering analysis at $1 < z < 1.5$ with the HSC-SSP data
  - massive galaxies with $\log(M_*/M_\odot) > 11.3$ => ~ 2000 PC cores candidates with $\log(M_{\rm DMH}/M_\odot) \sim 13.5$
  - The core candidates are accompanied by overdensity both small and large scale
- ✦ Red fraction excess
  - increasing trend against M_*
  - galactic conformity



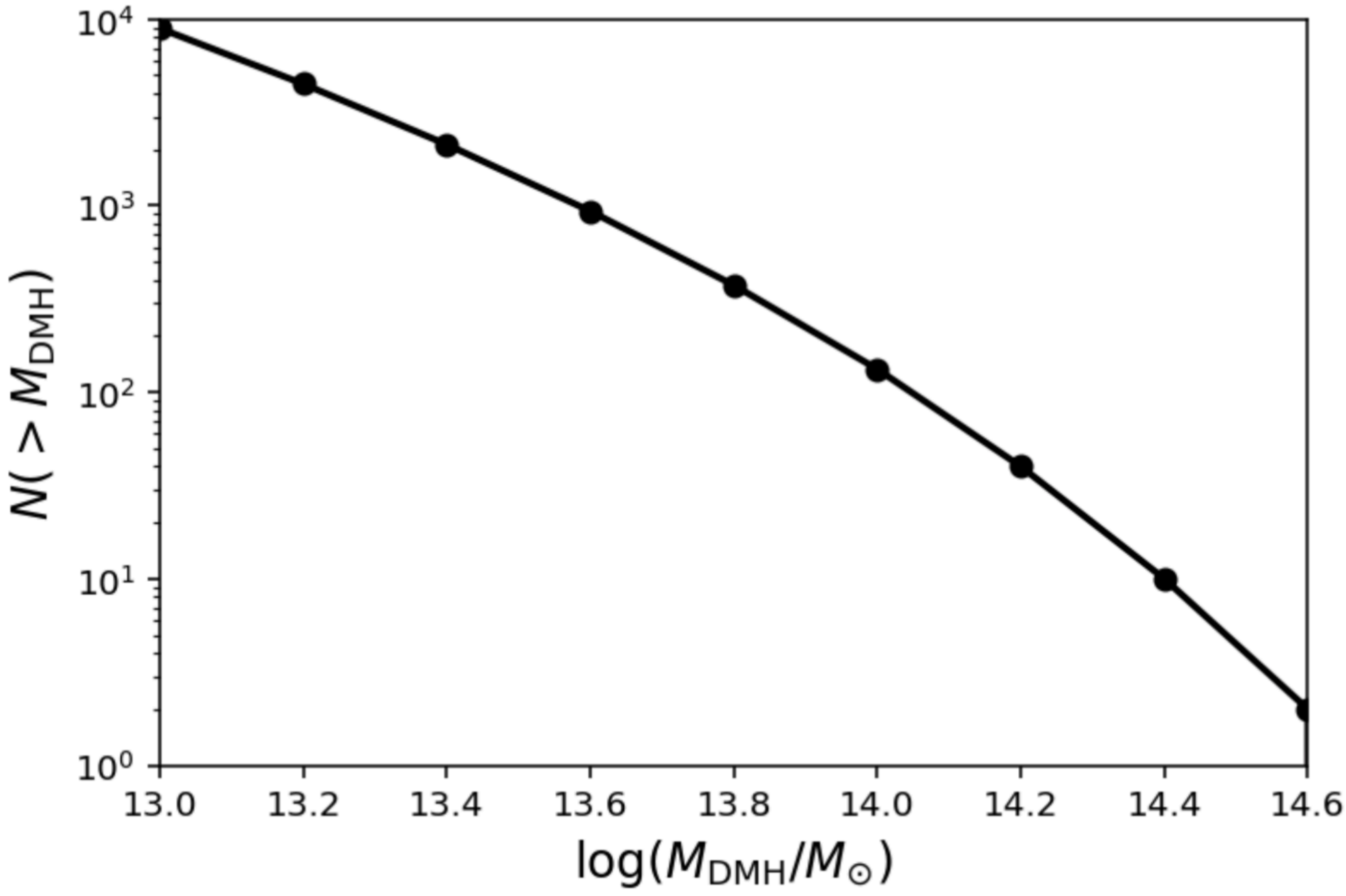






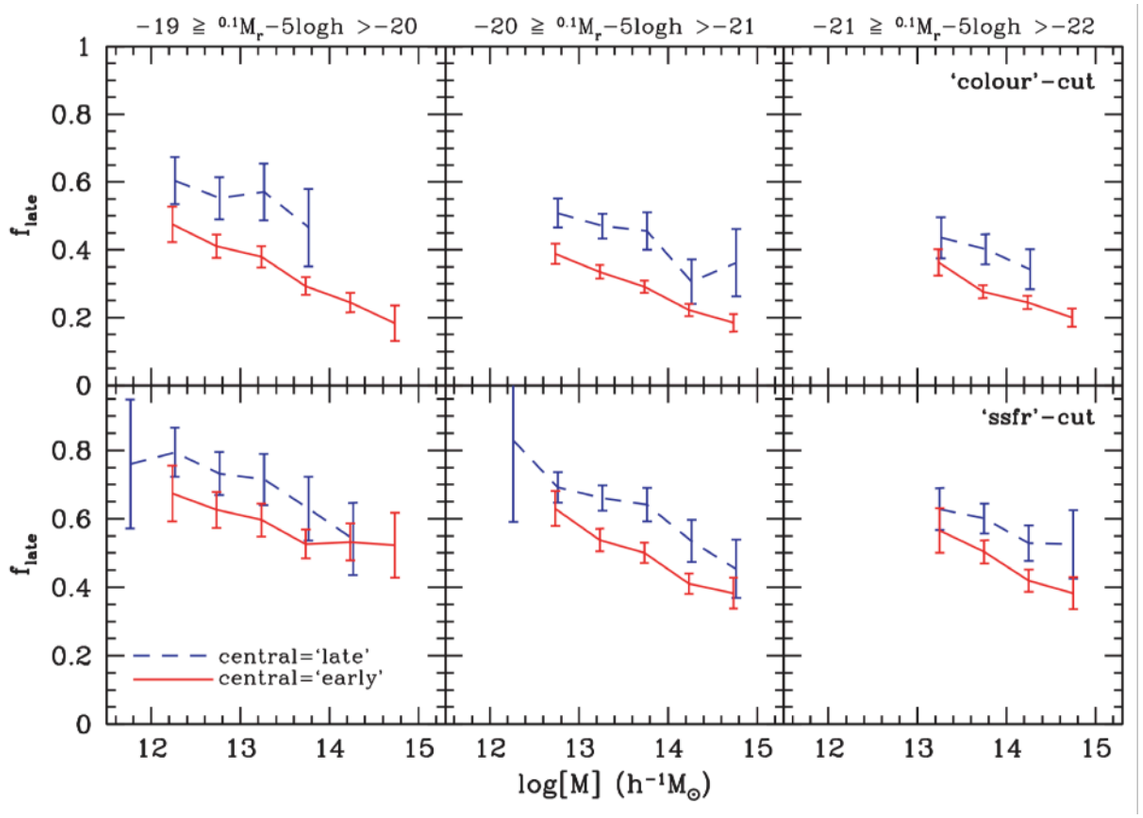
expected cumulative # of DMH v.s. halo mass
calculated by halo mass function (Sheth+99)

$\sim 22\,\mathrm{deg}^2$, $1 < z < 1.5$



conformity

Weinmann+06, SDSS local cluster



Hartlay+15, massive gal.