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Characterizing the assembly of dark matter halos with **protohalo size histories**

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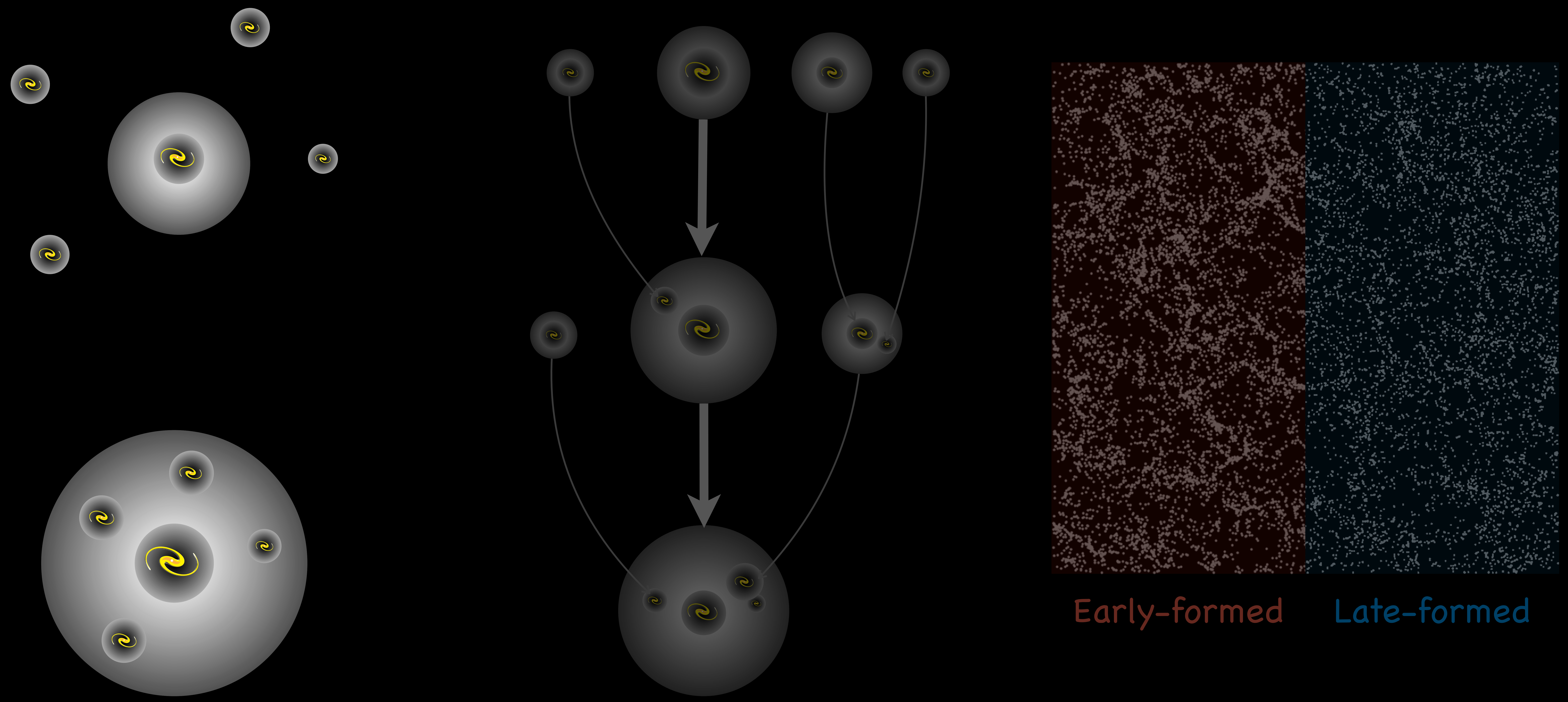
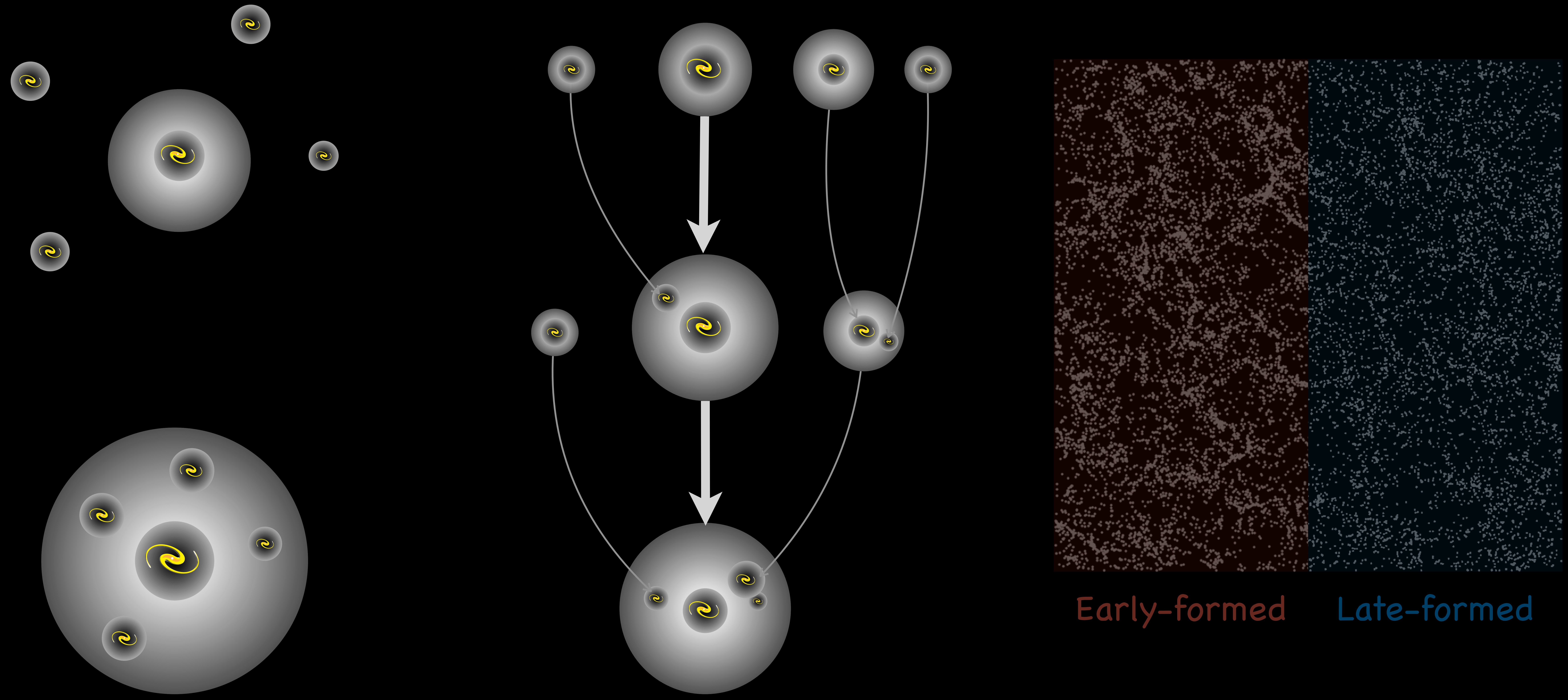
Halo Assembly Bias



Halo Assembly Bias



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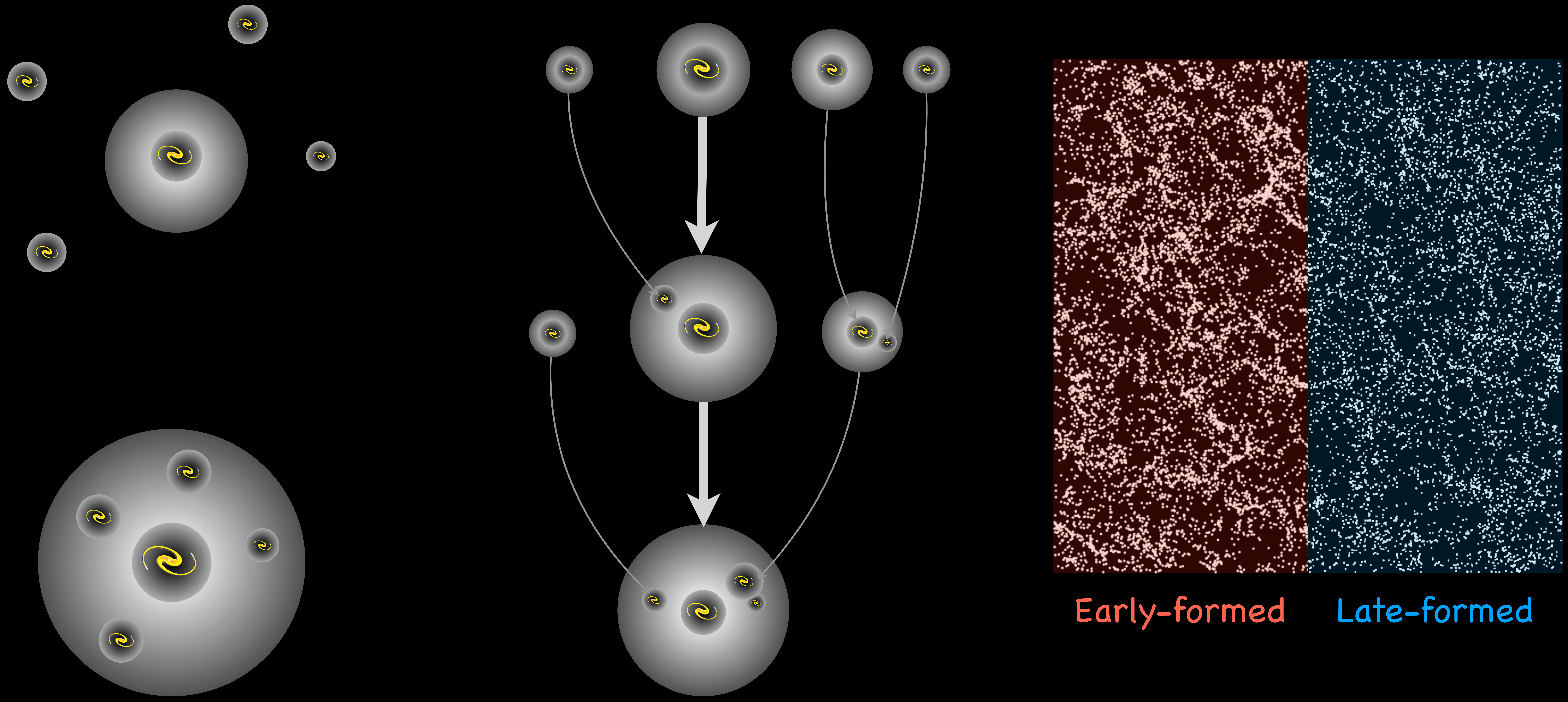
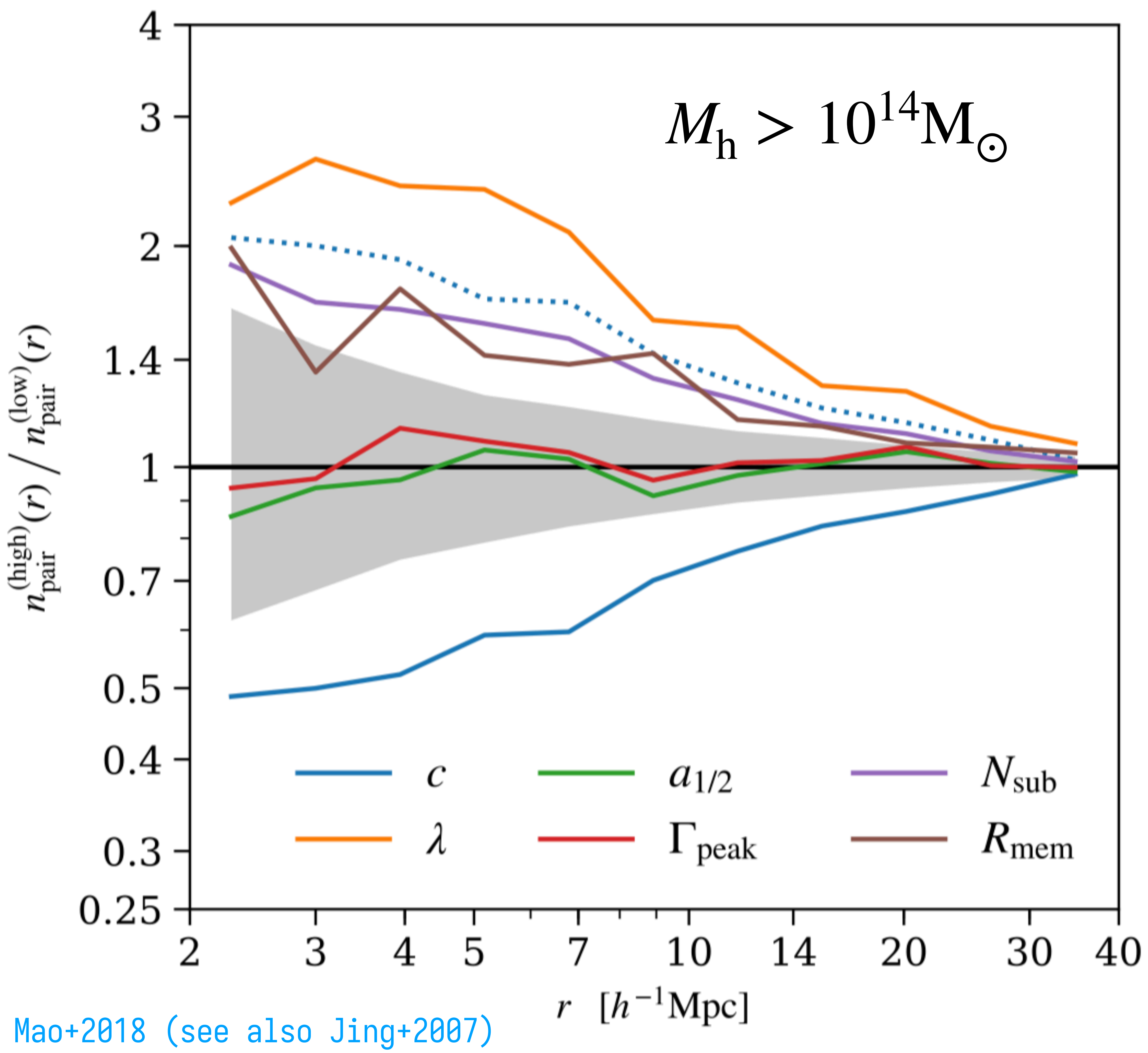


Halo Assembly bias

- At fixed halo mass, the clustering of dark matter halos depends on secondary halo properties. (Wechsler & Tinker 2018)
- The entanglement of secondary halo properties and their large-scale environments. (Wang+2023)



Mao+2018 (see also Jing+2007)

Why interested in halo assembly bias?

- Build secondary galaxy-halo connections
- Understand halo formation
- Mitigate impact on cosmological constraints

Take-away message

For cluster-size halos, the halo assembly bias effect is
- strong for halo structural parameters,
- weak for halo assembly parameters.

If

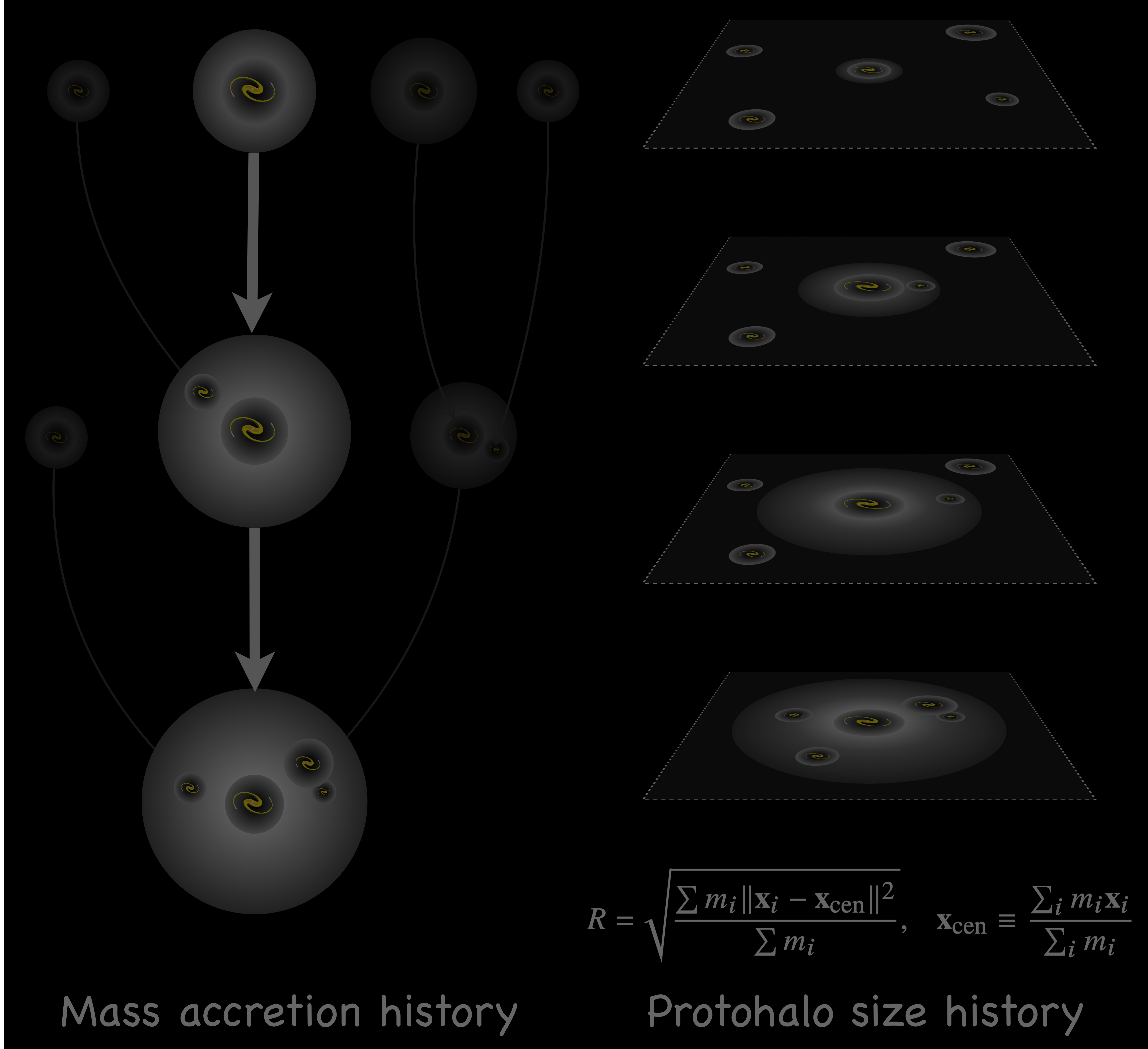
halo assembly history determines halo structure,

then

how the halo structure knows its environment without the assembly history knowing it?

Halo assembly history cannot determine halo structure.

Halo assembly history knows it. Mass accretion history doesn't.



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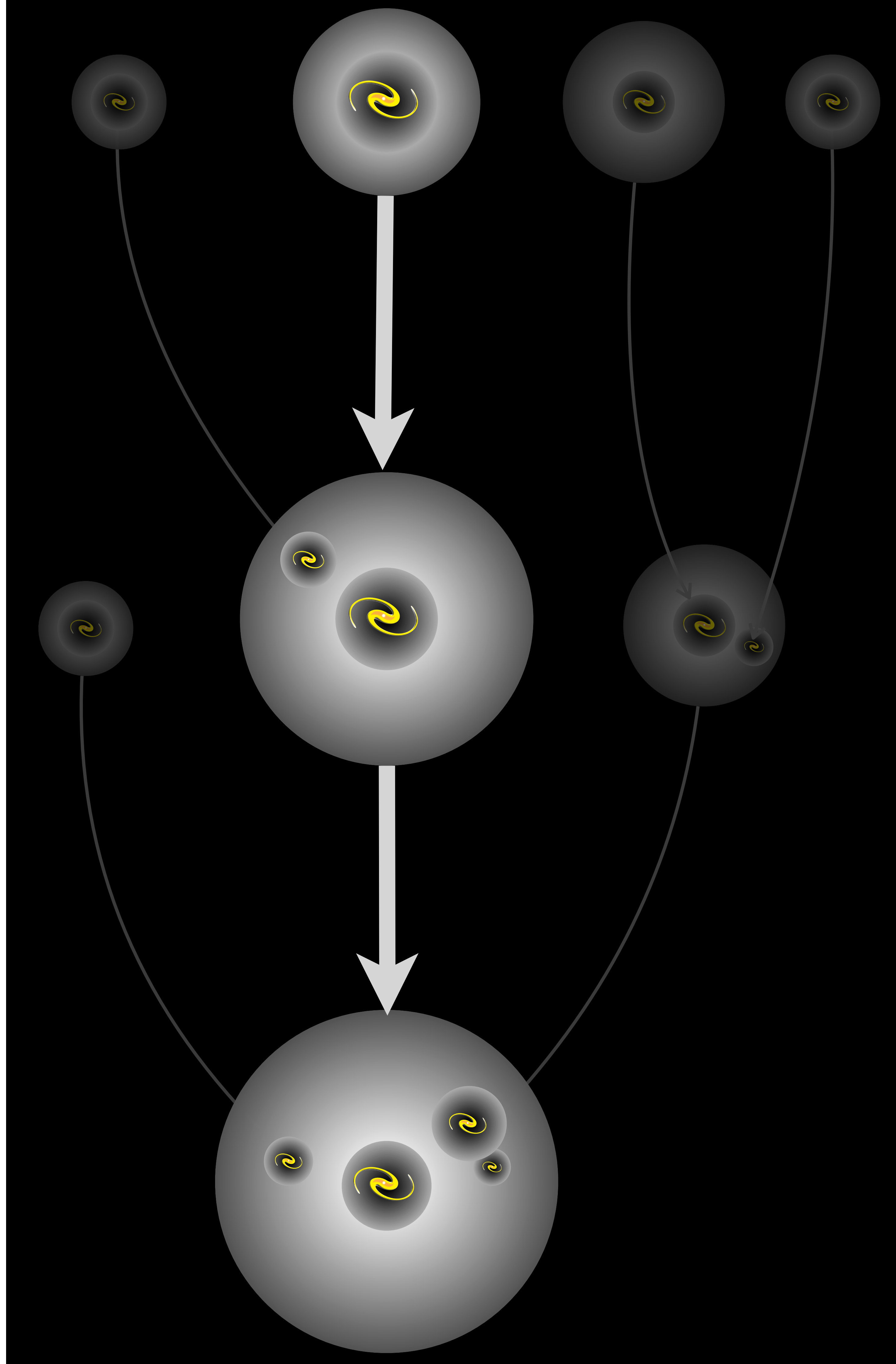
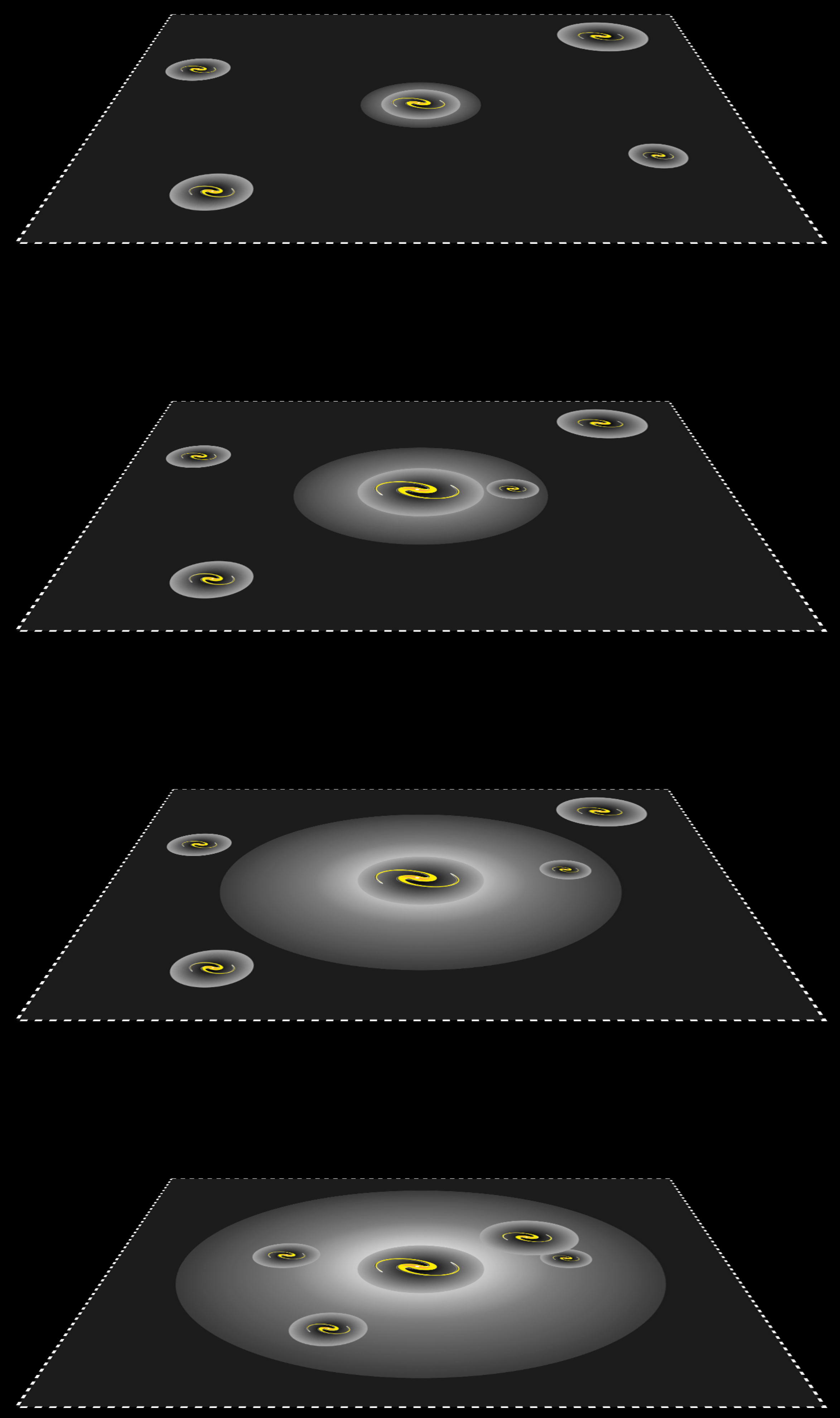


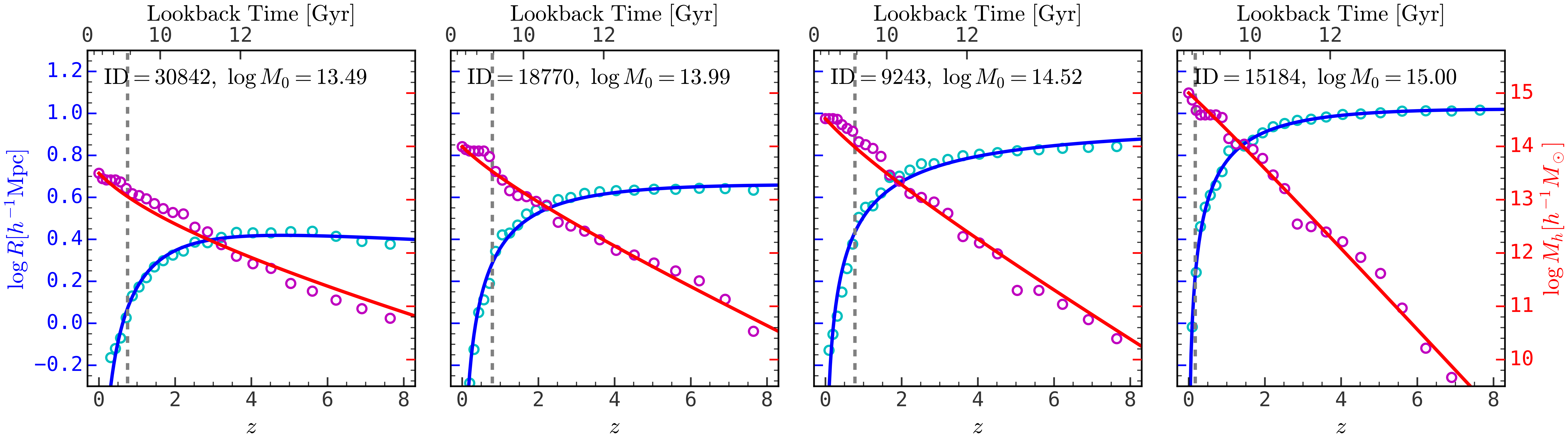


$$R = \sqrt{\frac{\sum m_i \|\mathbf{x}_i - \mathbf{x}_{\text{cen}}\|^2}{\sum m_i}}, \quad \mathbf{x}_{\text{cen}} \equiv \frac{\sum_i m_i \mathbf{x}_i}{\sum_i m_i}$$

Mass accretion history

Protohalo size history

Mass accretion history v.s. Protohalo size history



Mass accretion history

- Modeling (McBride+2009)

$$M(z) = M_0 (1+z)^{\gamma} e^{-\delta z}$$

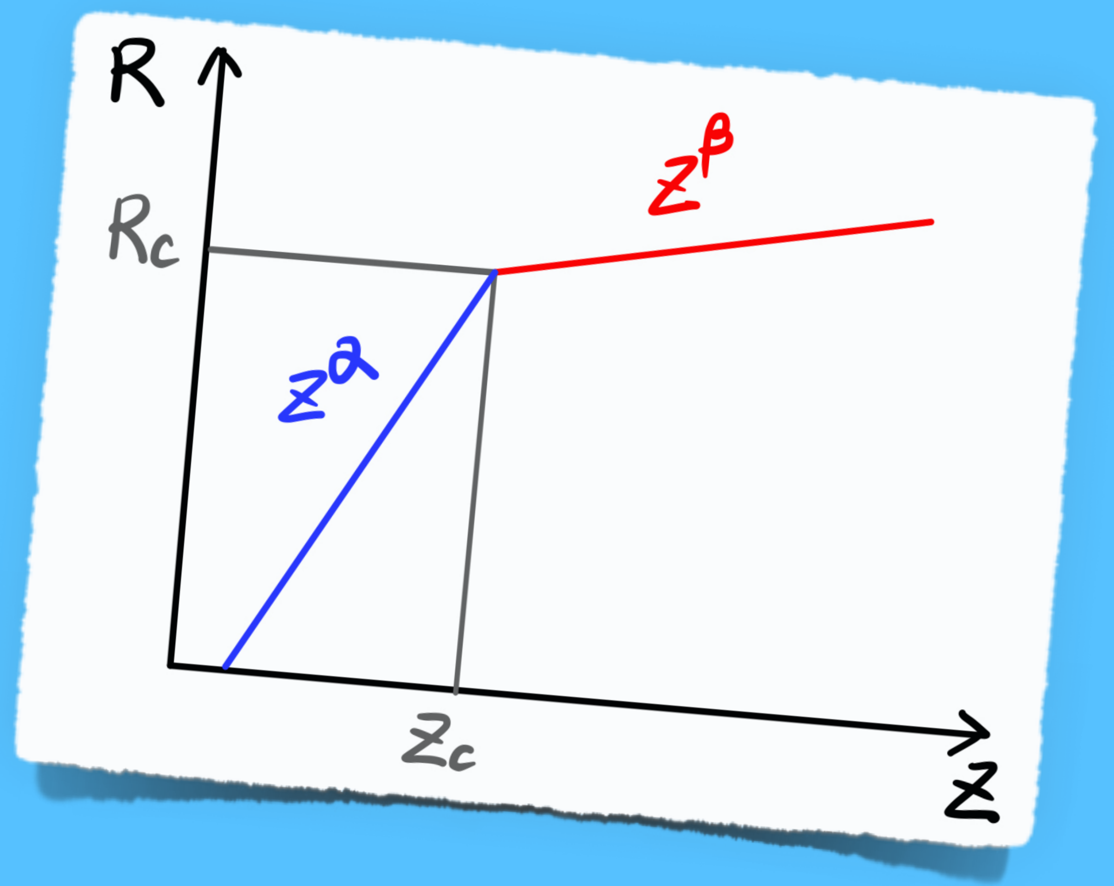
- Bumpy
- Halo formation time: $z_{\rm half}$

Protohalo size history

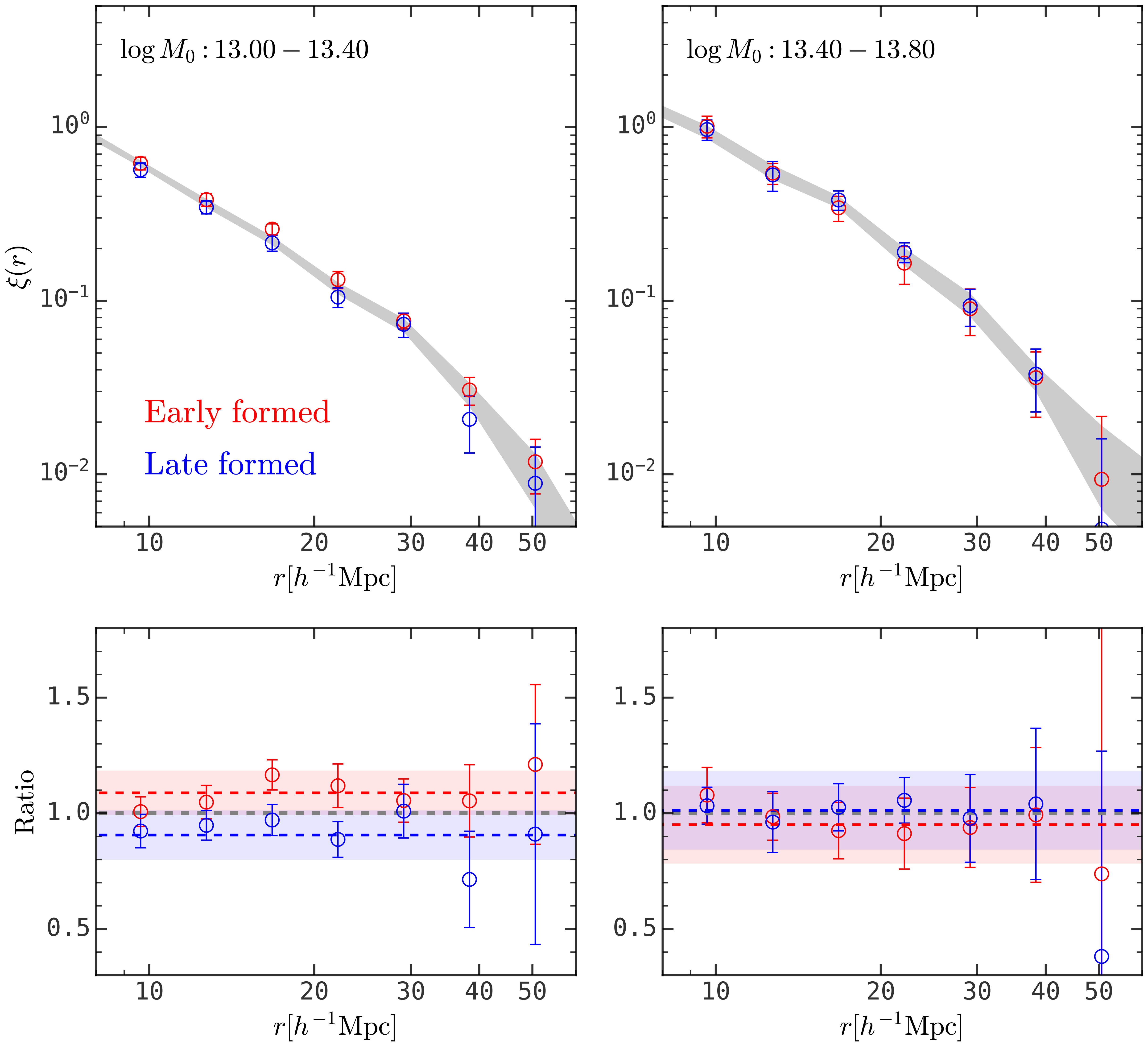
- Modeling (Wang+2023)

$$R(z) = \frac{2R_c}{\left(\frac{z}{z_c}\right)^{-\alpha} + \left(\frac{z}{z_c}\right)^{-\beta}}$$

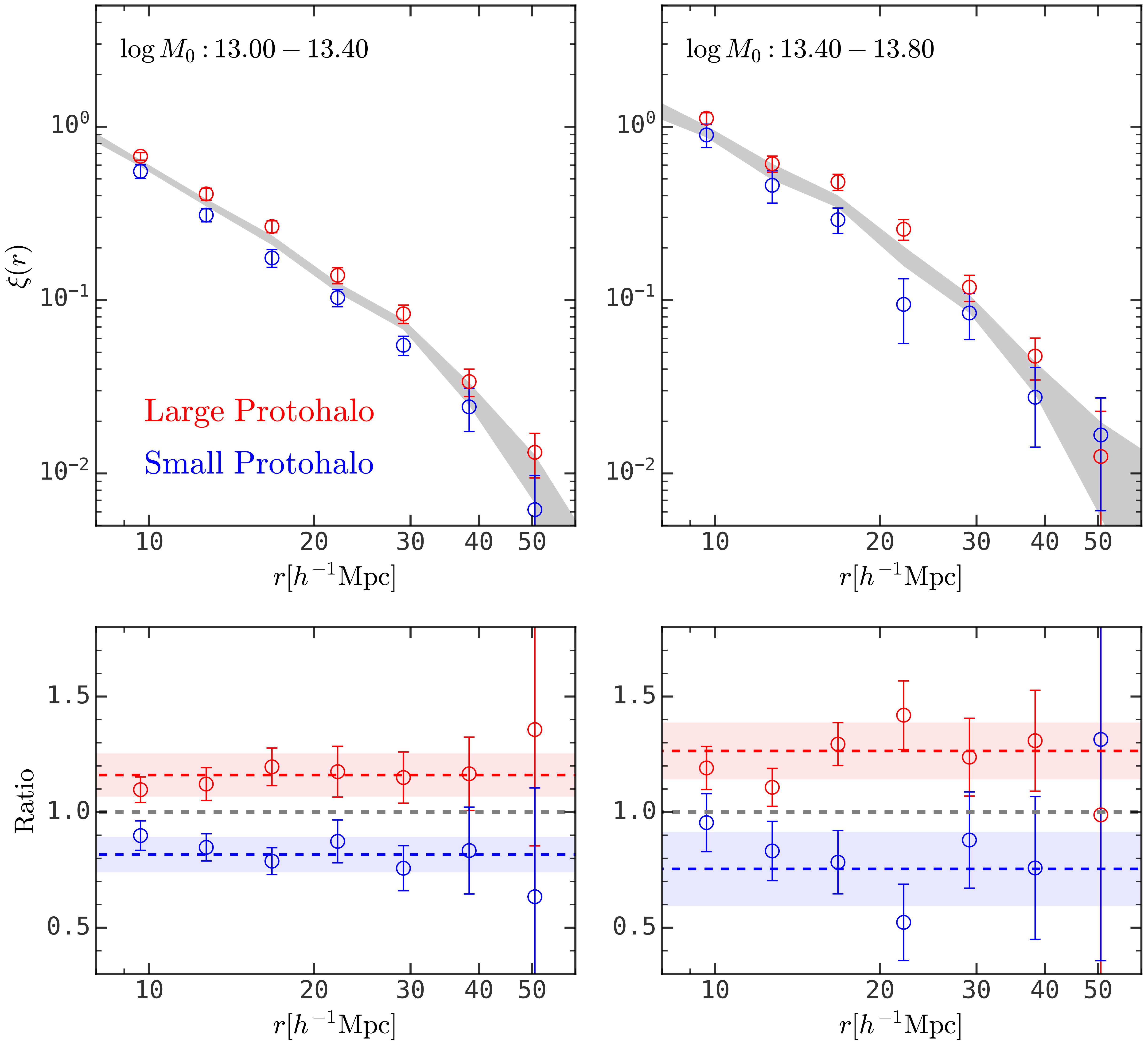
- Smooth
- Protohalo size: R_c



• Halo Assembly Bias manifested by correlation function

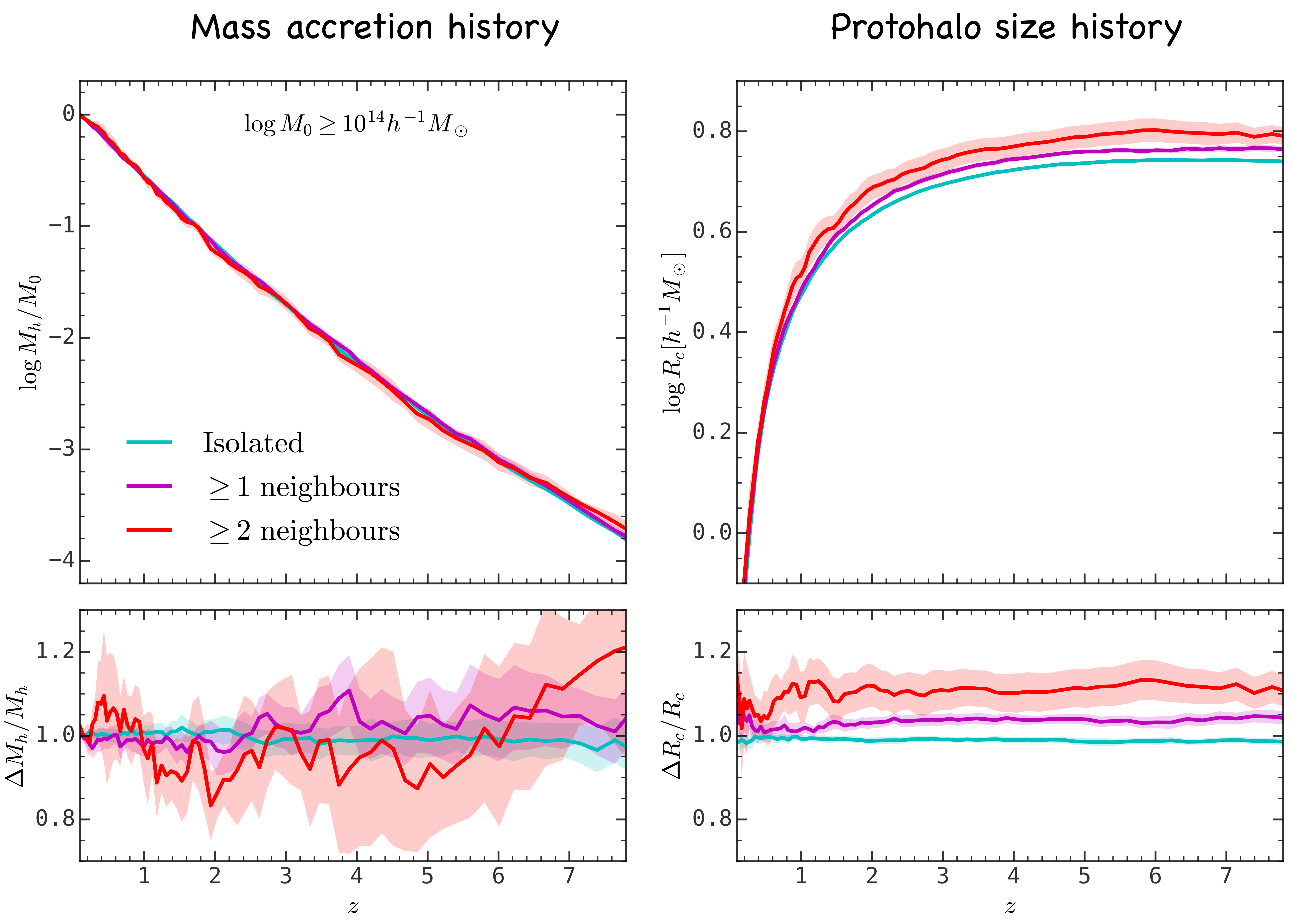


Mass accretion history



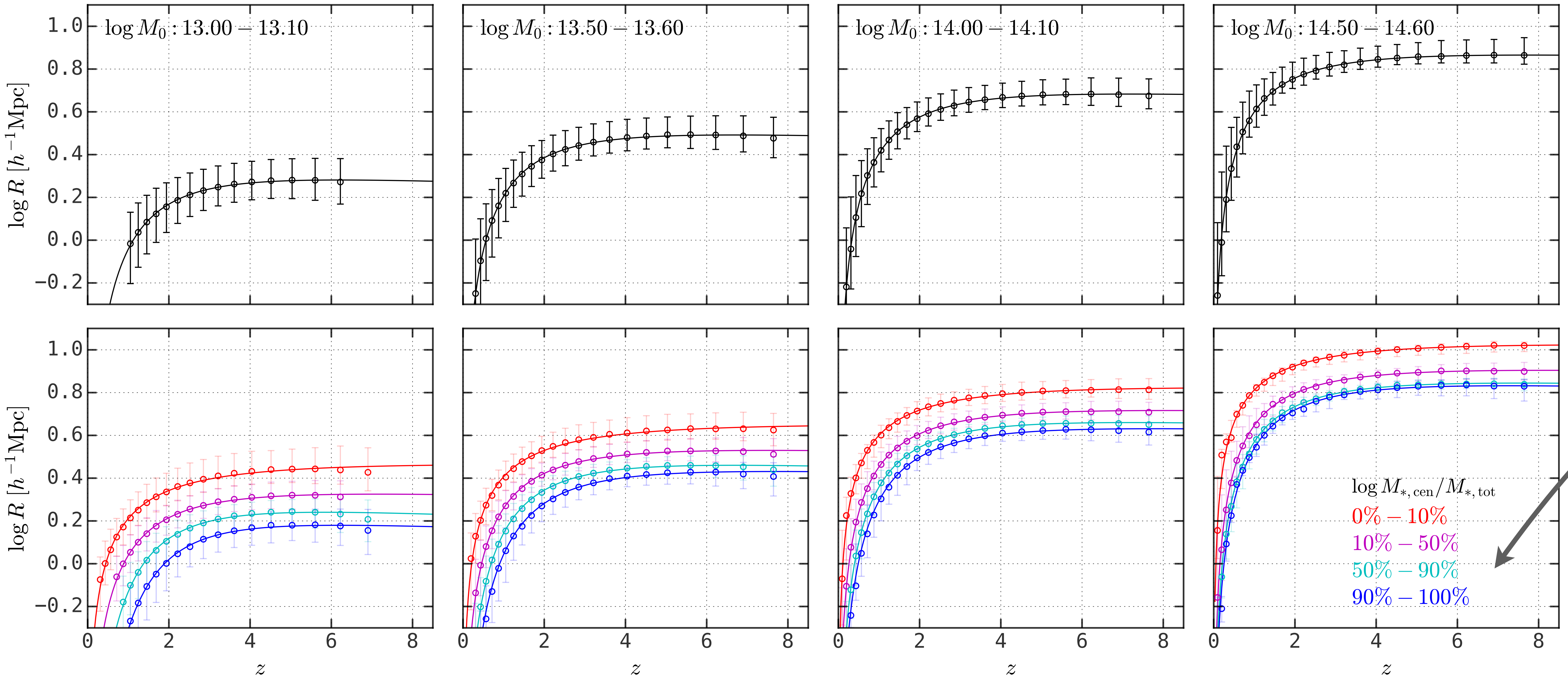
Protohalo size history

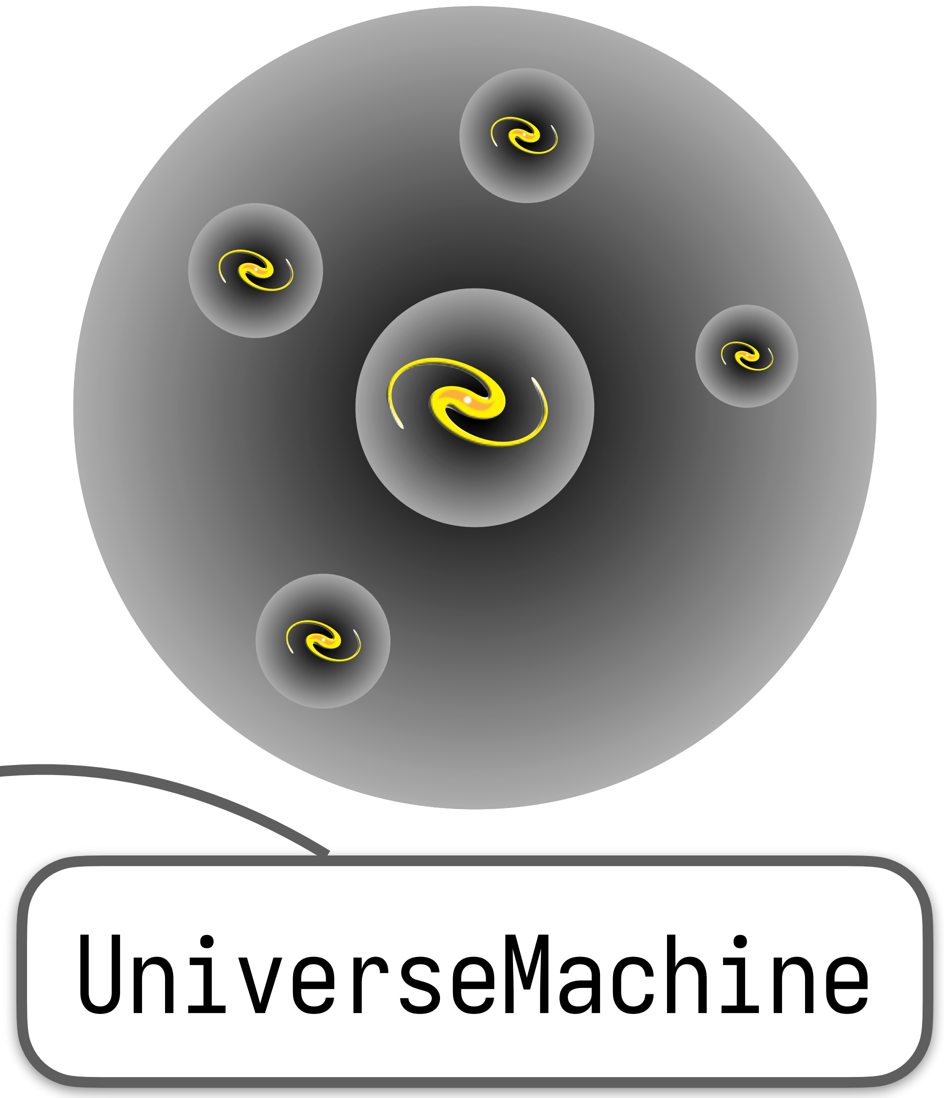
● Halo Assembly Bias manifested by environment-dependent history

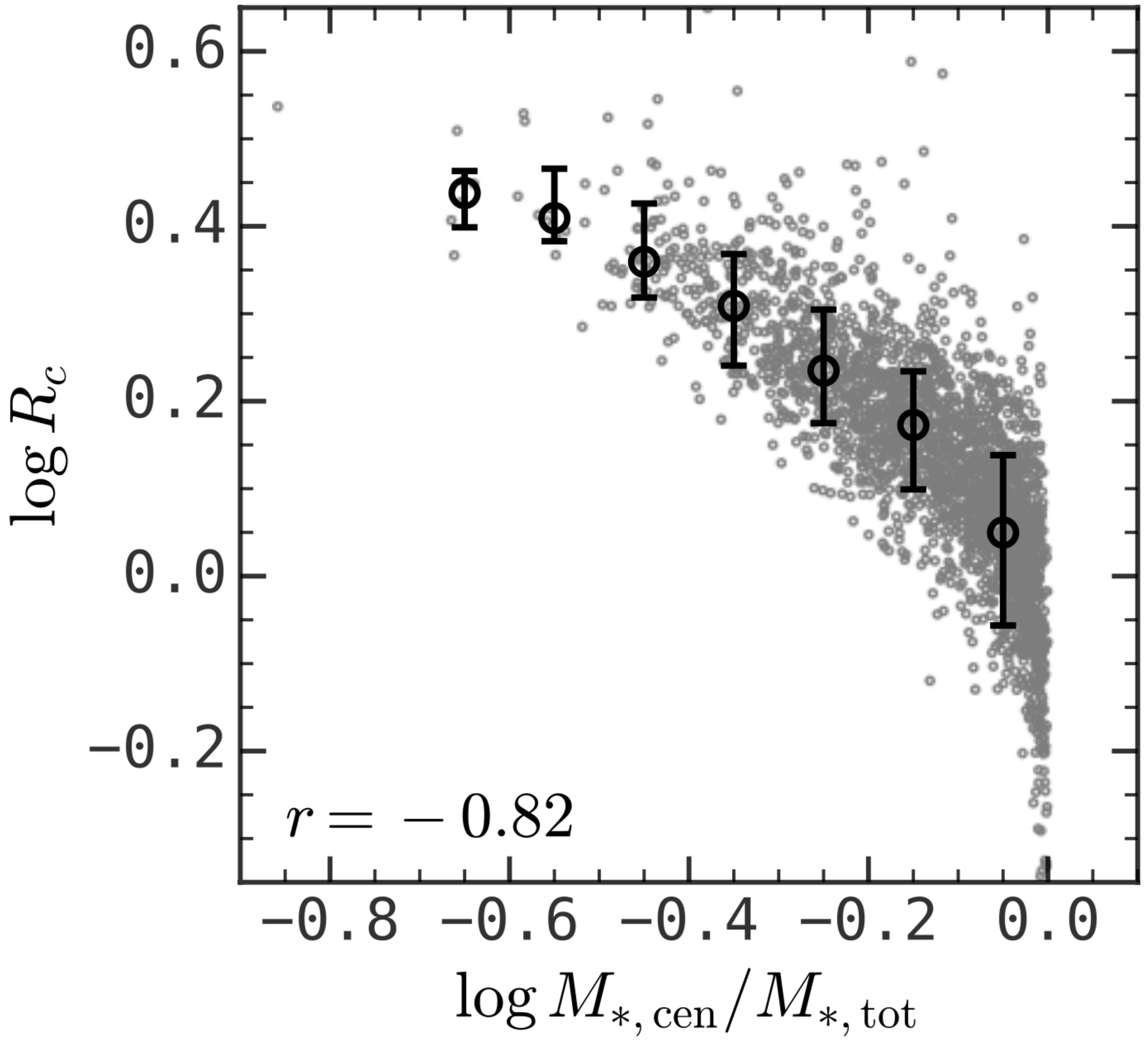


see also Mao+2018

• Protohalo size & descendant central-to-total stellar mass ratio



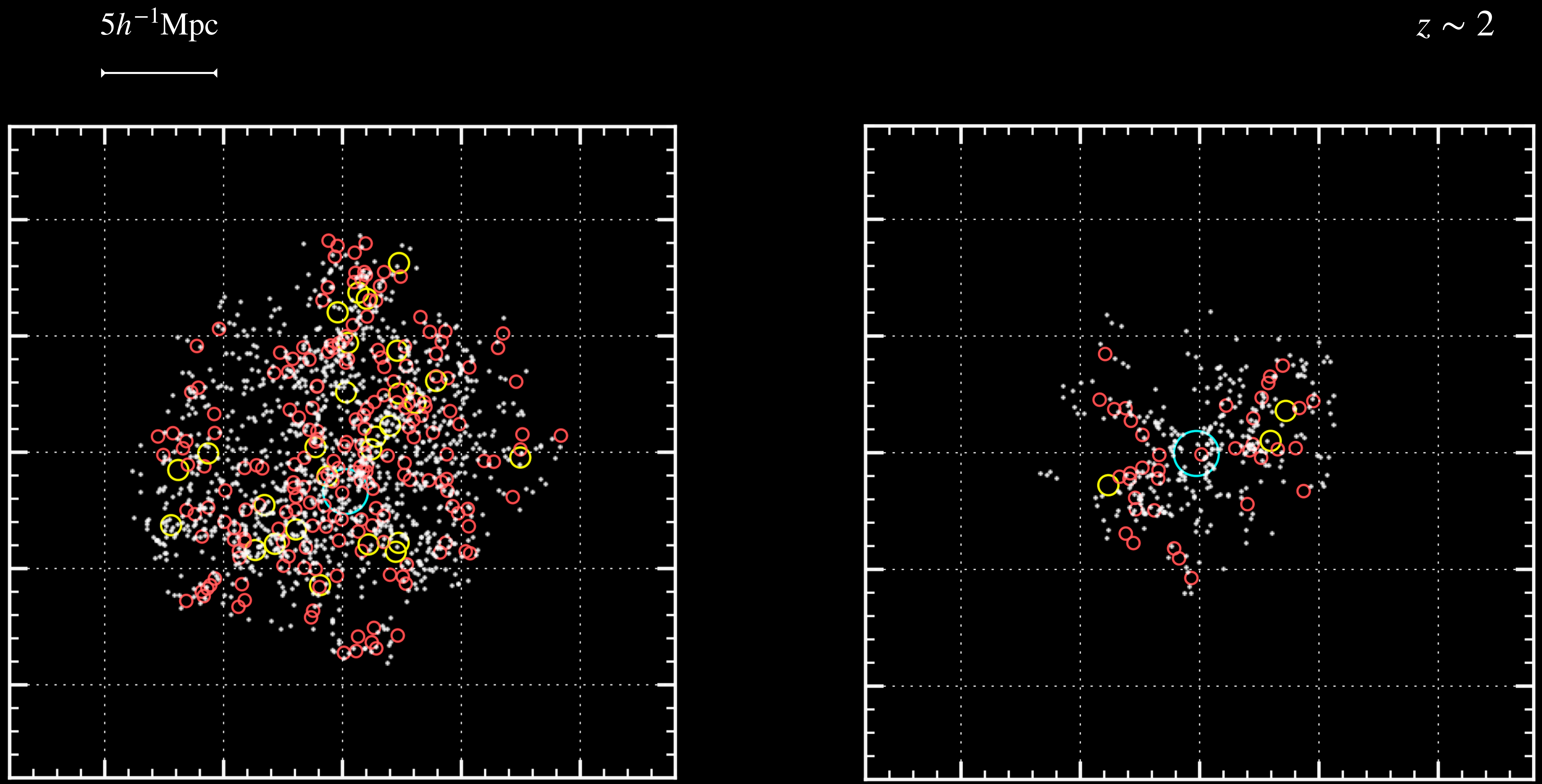




At fixed mass, halos with

- more substructures
- less-dominating central galaxy
- lower central-to-total stellar mass ratio

have larger protohalo size.

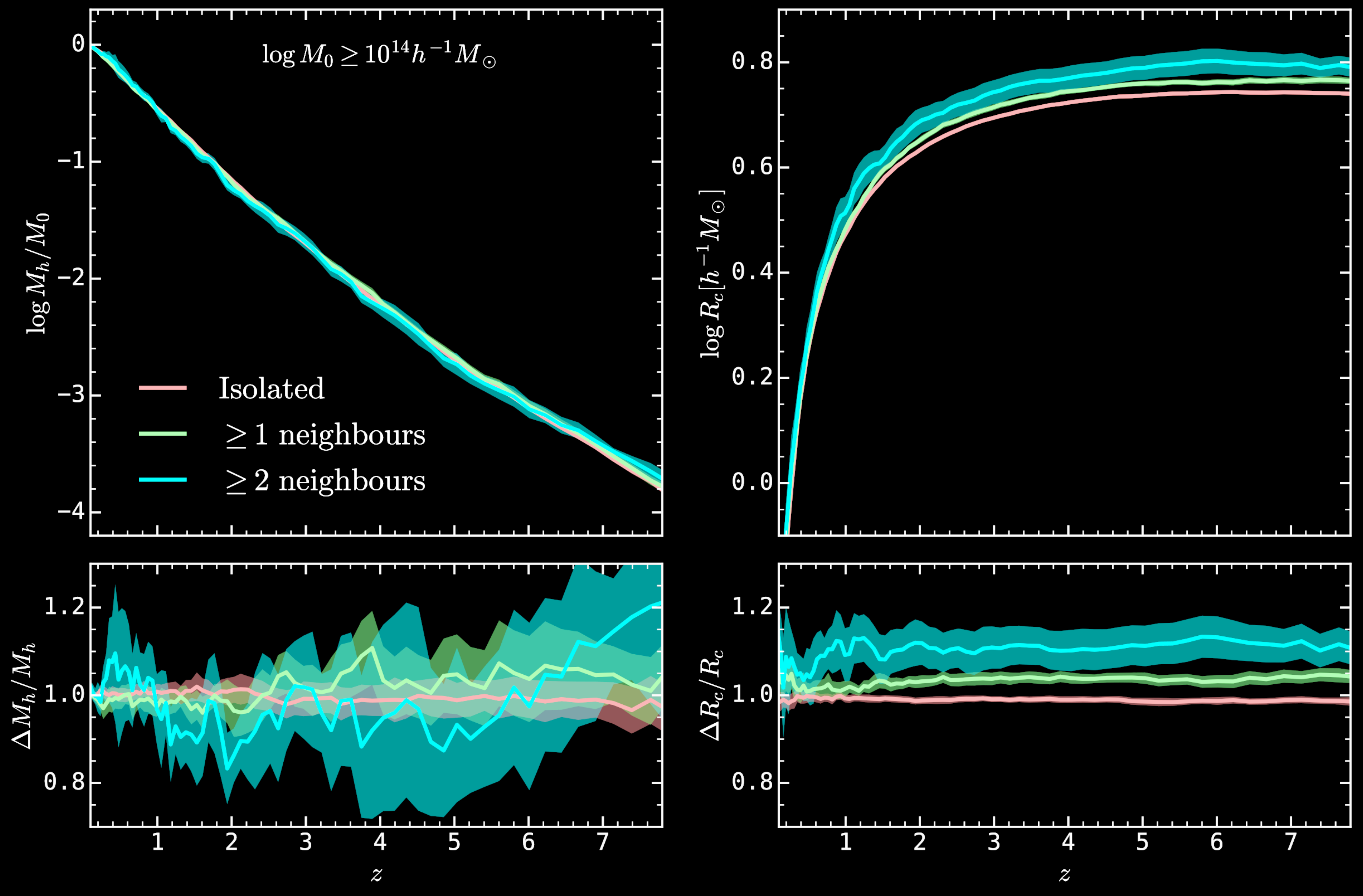


$M_{\mathrm{h},z=0} = 10^{14.07} h^{-1} \mathrm{M}_\odot$

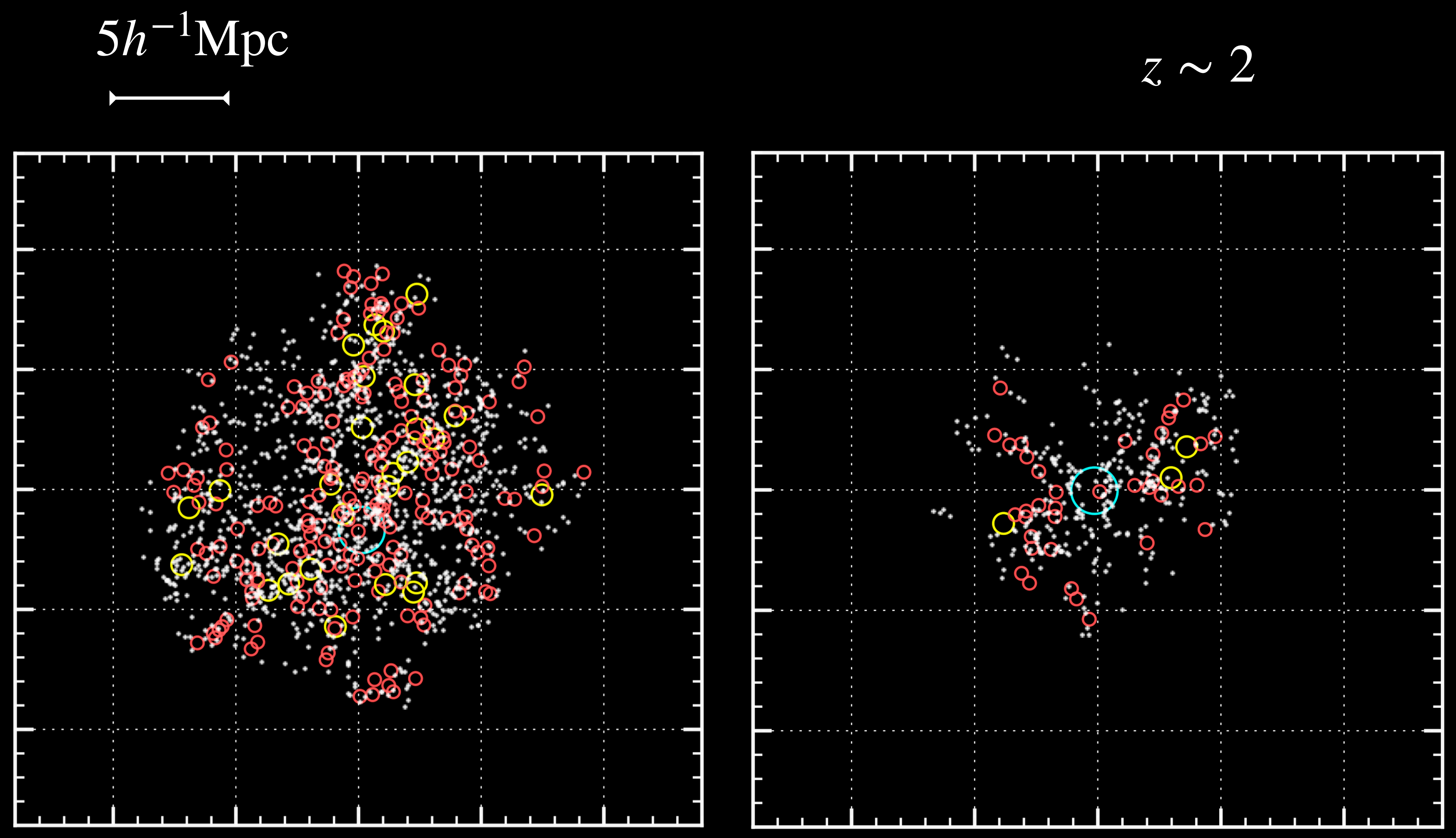
$M_{\mathrm{h},z=0} = 10^{14.08} h^{-1} \mathrm{M}_\odot$

Take-home messages

- Halo assembly bias for cluster-size halos
  - No signal in the mass accretion history
  - Strong signal in the protohalo size history



- Connect structures across cosmic time
  - Large diversity of high-z protoclusters
  - Protohalo size as secondary property



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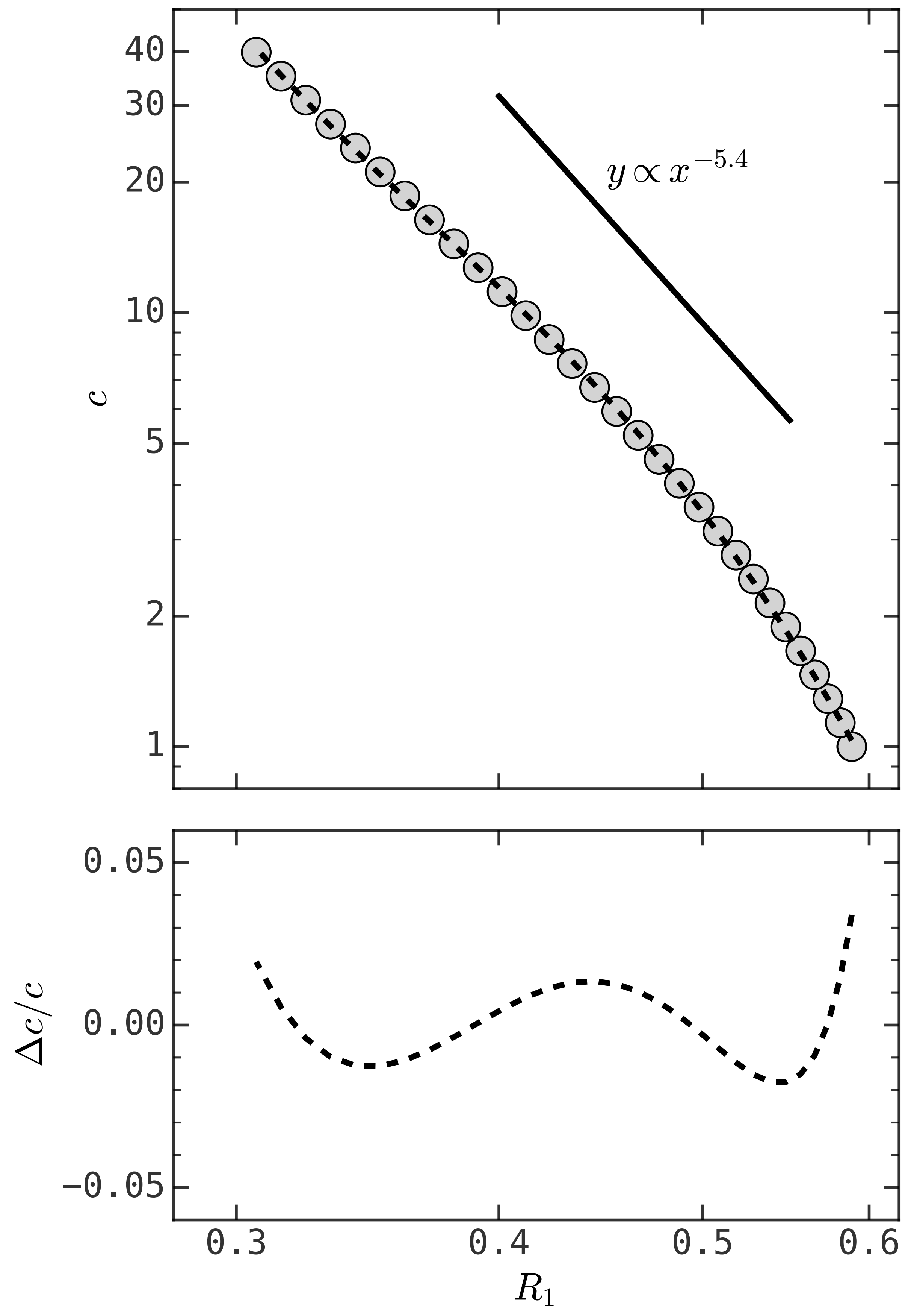


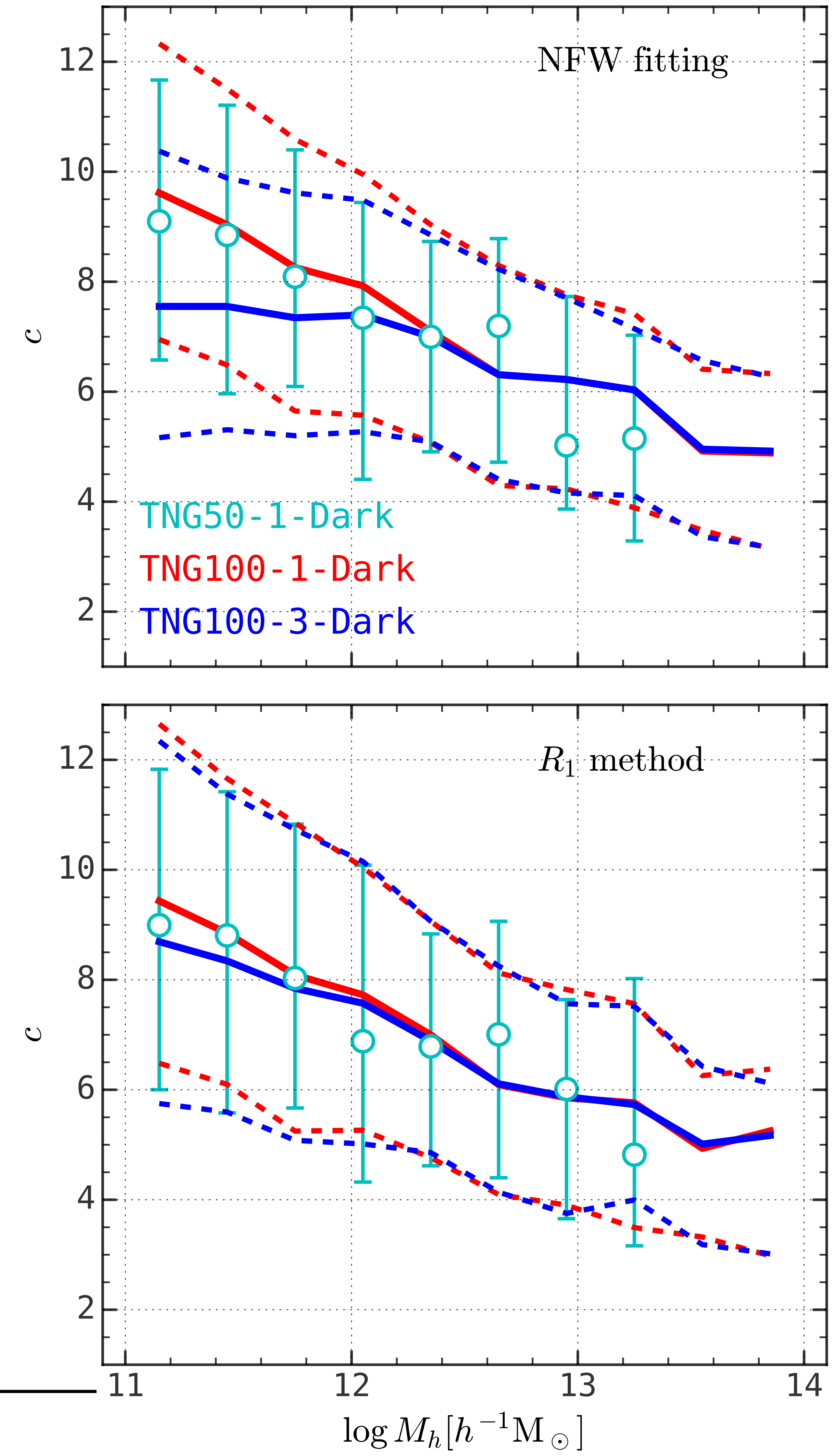

```
double m_vir = 0;
double r1 = 0;
for (auto &p: particles){
  d = calc_dist(p, halo);
  if (d < r_vir){
    ++m_vir;
    r1 += d;
  }
}
r1 /= m_vir * r_vir;
```

$$M_{\rm vir} = \int_0^{r_{\rm vir}} 4\pi r^2 \rho(r) dr$$

$$R_1 = \frac{1}{M_{\rm vir} r_{\rm vir}} \int_0^{r_{\rm vir}} 4\pi r^3 \rho(r) dr$$

$$R_1 = \frac{c - 2\ln(1+c) + c/(1+c)}{c[\ln(1+c) - c/(1+c)]}$$

~**260** DM particles
in TNG100-3-Dark



Kai Wang, H.J. Mo, Yangyao Chen, Joop Schaye 2023 (arXiv: 2310.00200)