YZiCS: On the Mass Segregation of Galaxies in Clusters

Published in ApJ (Kim et al. 2020)
Doi: 10.3847/1538-4357/abbfa6

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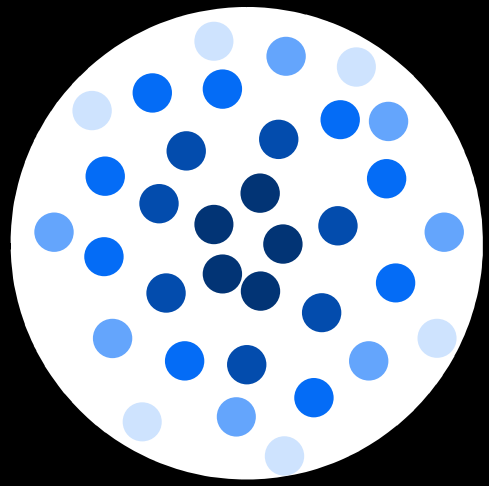
Mass Segregation in Galaxy Clusters

- Various environmental mechanisms result in the radial segregation of different properties of galaxies.

  (morphology, color, SFR, etc.)

- **Mass Segregation (MS)**: The tendency of more massive galaxies being distributed closer to the cluster center.
- This is assumed to happen because of the dynamical friction.



A cluster, 1 R_{vir}

Theoretical Background of MS

- **Dynamical friction**

: A drag force being caused by the momentum exchange between a massive object moving within a sea of lighter background particles.

$$\frac{dv_{sat}}{dt} = -4\pi G^2 \, M_{sat} \, \rho \, \log(\Lambda) \, f(v_* < v_s) \, \frac{v_s}{{v_s}^3}$$

This causes the satellites to lose orbital energy and ultimately merge with the central galaxy.

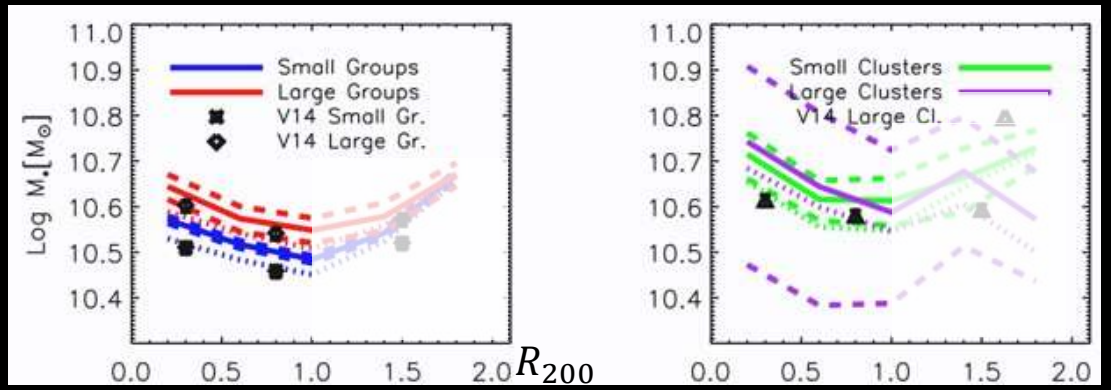
The merging timescale: $t_M \sim \frac{1}{2} \frac{f(\epsilon)}{C} \frac{V_{vir} \, R_{vir}^2}{G \, M_{sat} \, ln\Lambda}$ $\left(ln\Lambda = \frac{1}{1+M_{vir}/M_{sat}} \right)$

The merging timescale is shorter for massive galaxies → MS is ***expected*** to be shown.

The Controversy on the Visibility of Mass Segregation

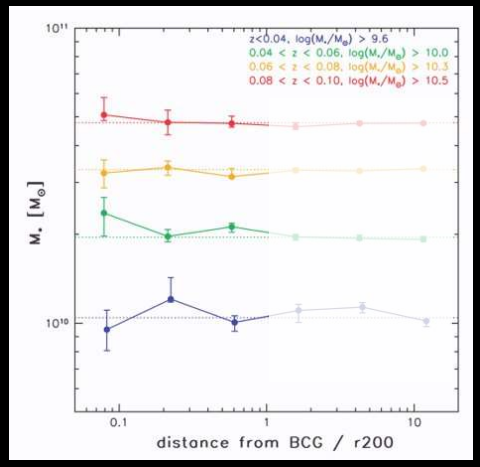
- Mass segregation does exist

  Contini & Kang (2015)



- Mass segregation does not exist

  von der Linden et al. (2010)



Data - YZiCS

- **YZiCS** (Yonsei Zoom-in Cluster Simulation) - Choi & Yi (2017)

  A set of cosmological zoom-in simulations performed with the AMR code RAMSES.

  Baryon physics recipe is based on the Horizon-AGN simulation (Dubois et al. 2014).

  Mass resolution: 8 x $10^7 M_\odot$; Spatial resolution: 0.76 h^{-1} kpc

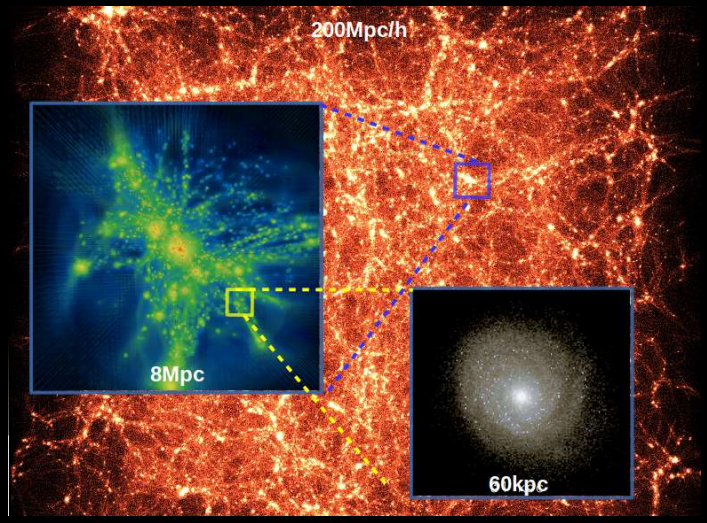
DM only simulation run within a cubic volume 200 h^{-1} Mpc

↓

16 dense regions were chosen as clusters

↓

Hydro zoom-in simulation for the backtraced volume of the clusters



Data - KYDISC

- **KYDISC** (KASI-Yonsei Deep Imaging Survey of Clusters - Oh et al. (2018)

  Target: 14 Abell clusters at 0.015 < z < 0.144

  <Photometry> - u, g, r band

  -Magellan Baade telescope – IMACS

  -Canada-France-Hawaii Telescope – MegaCam

  <Follow-up spectroscopy>

  -Magellan Baade telescope – IMACS

  -du Pont 2.5m telescope –WFCCD

  -WIYN 3.5m telescope – Hydra

  Result: 1409 cluster galaxies brighter than -19.8 (r-band)

`Traditional' Method of Showing MS

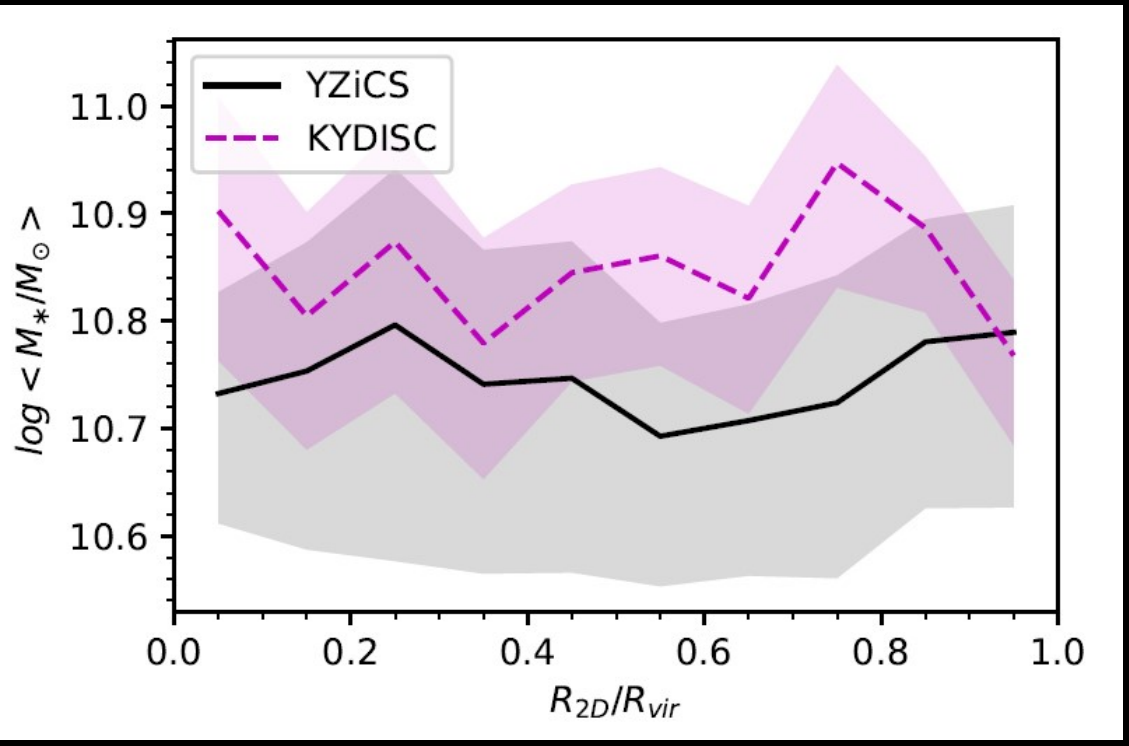
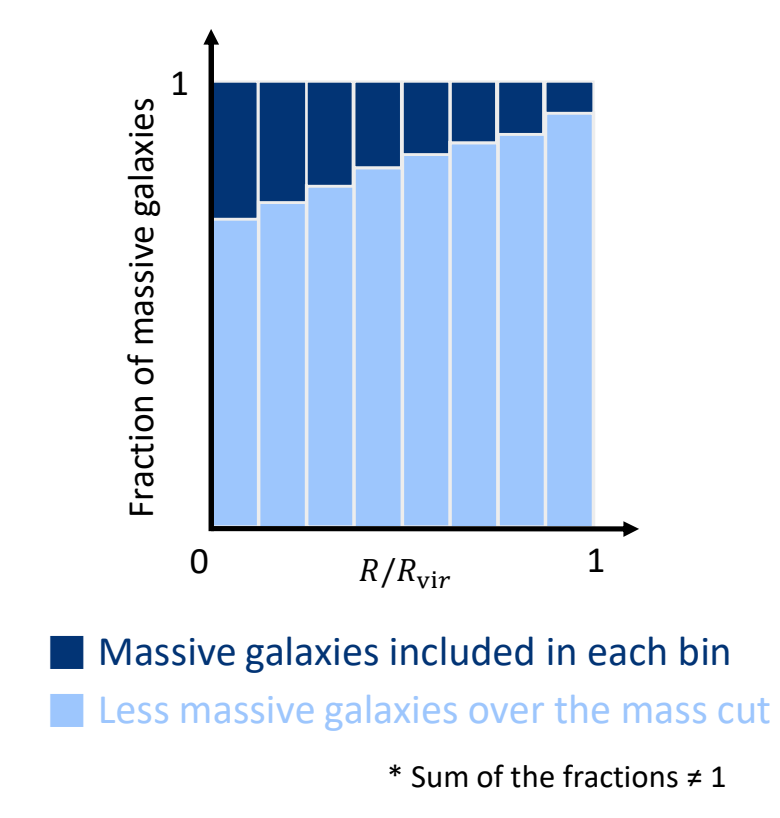


Figure 1.

- No MS is seen.
- This methodology fails to consider the different galaxy mass distributions of clusters of different mass.

Fractional Analysis

- To normalize the mass functions of galaxies in different clusters, the use of fractions is needed.
- Massive galaxies = Galaxies that are more massive than N% of the galaxies in a cluster
- Fraction = $\frac{\text{\# of massive galaxies included in a bin}}{\text{total \# of galaxies in a bin}}$



Fractional Analysis

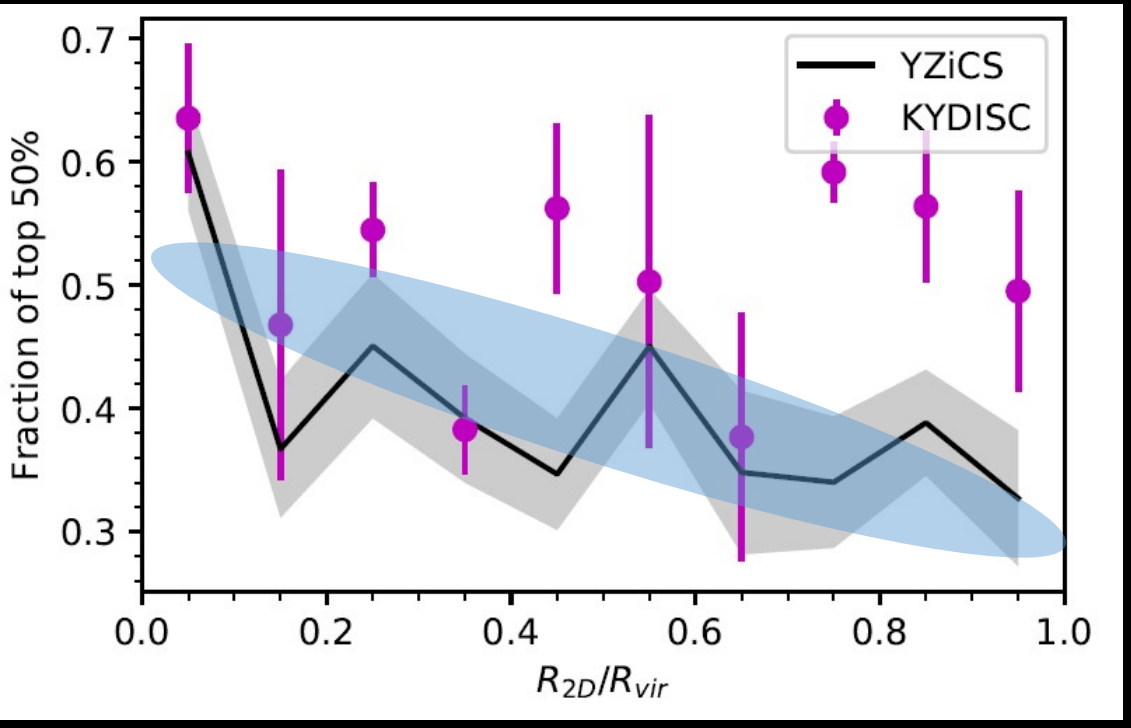


Figure 2.

- Is it safe to choose an `arbitrary' percentage cut?

Fractional Analysis – Using Different %

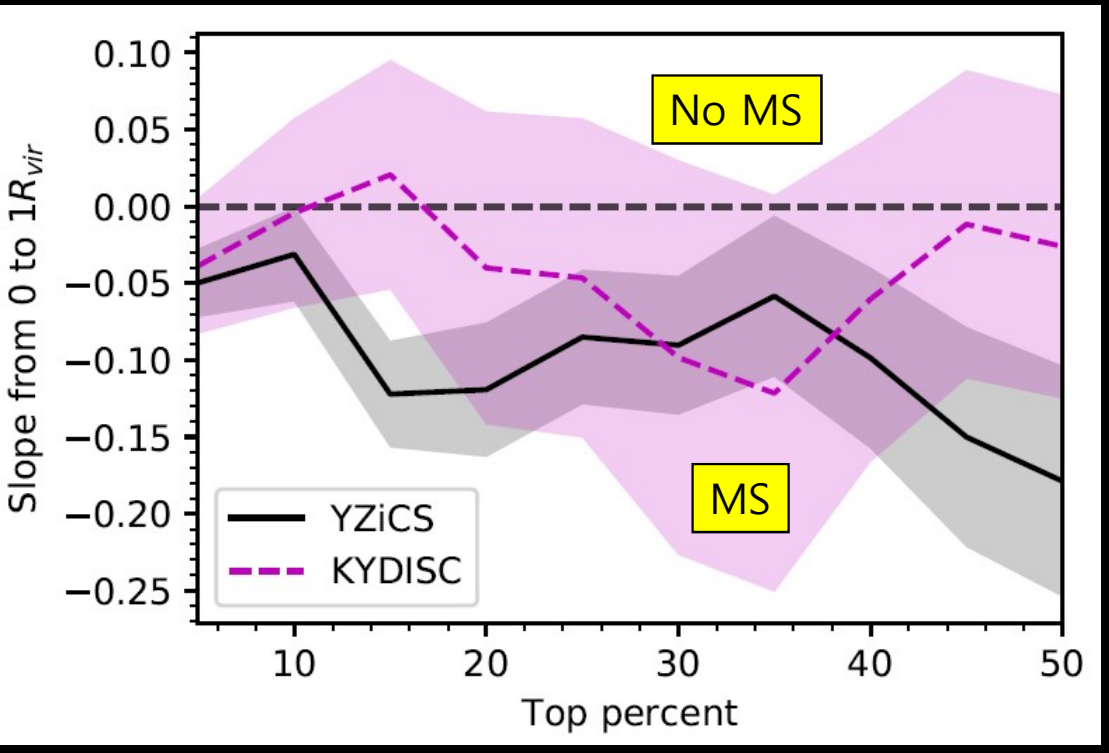
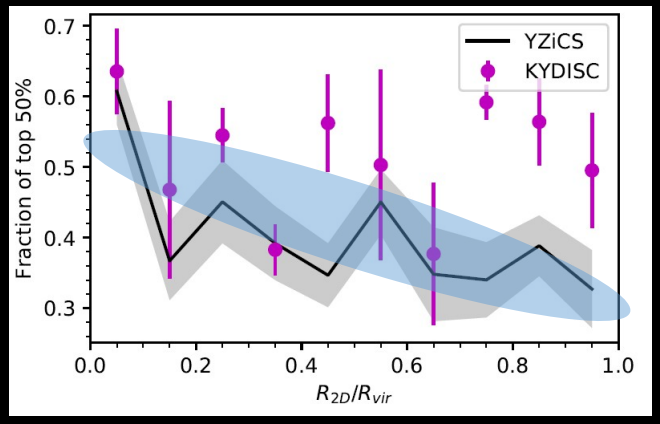


Figure 3.

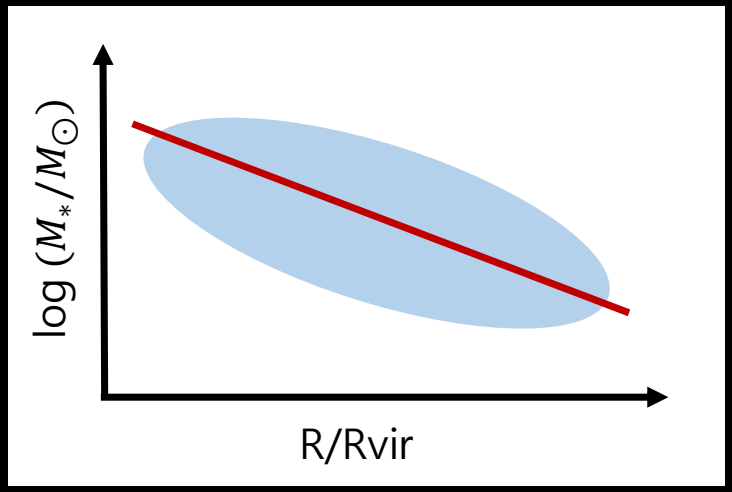
- The slopes of the `fraction' plots are fitted.
- The analysis is stable against the choice as long as a reasonable value is used.



Previous plot

Halo Mass Dependence of MS

- Clear halo mass dependence of MS is seen.
- Why is there a difference in the degree of MS for different clusters?



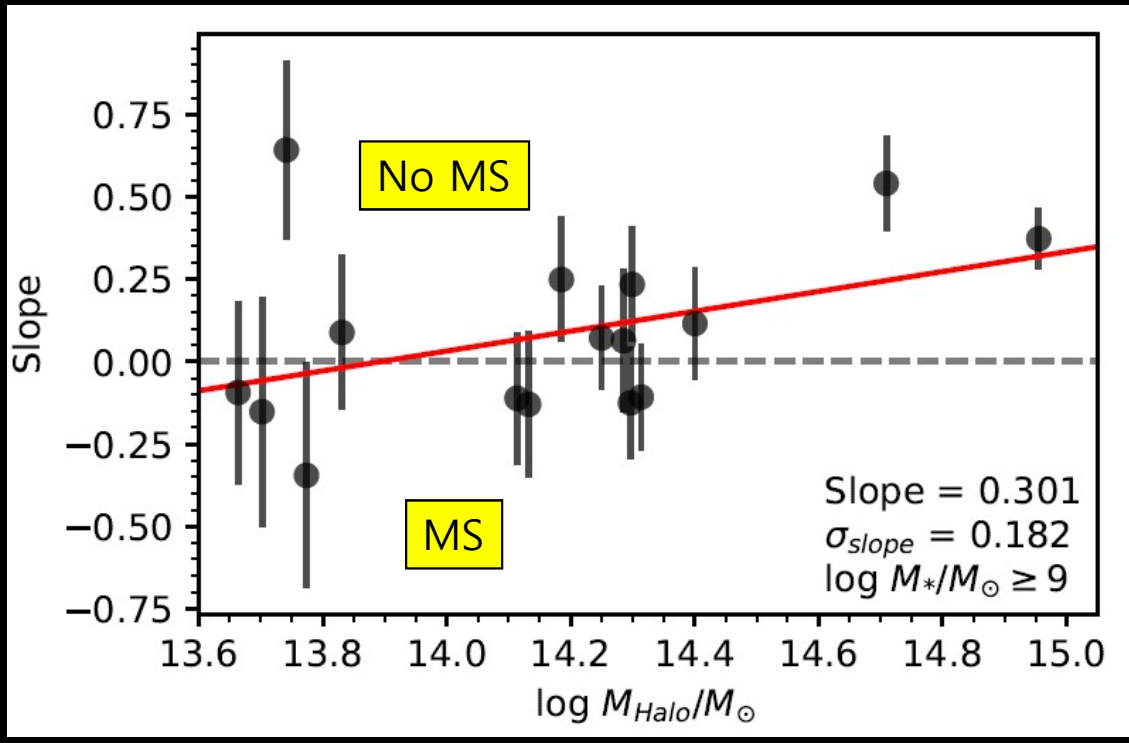
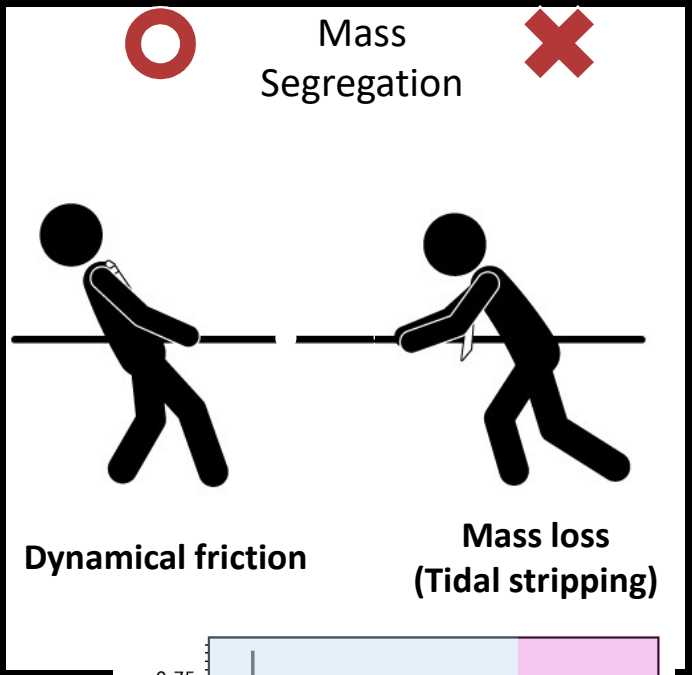


Figure 4.

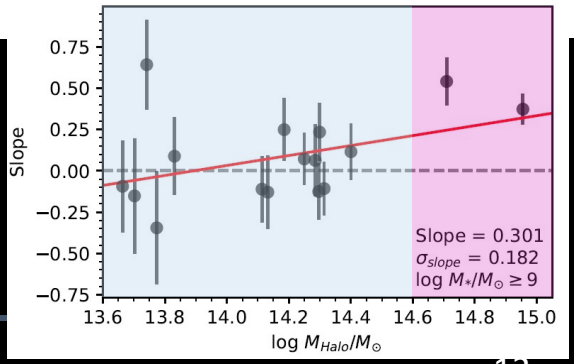
Halo Mass Dependence of MS

- MS may happen because of **dynamical friction**.
- However, mass stripping dilutes the trend.
- The most important of the mass stripping mechanism is **tidal stripping**.
- The degree of the MS is a result of the ``tug-of-war'' between dynamical friction and tidal stripping.
- MS is observed in low mass clusters because the effect of dynamical friction is stronger than that of tidal stripping.

Case of a low mass cluster



We divide the YZiCS clusters into two groups, using $10^{14.6} M_{\odot}$ as the mass cut.



The Degree of Mass Stripping

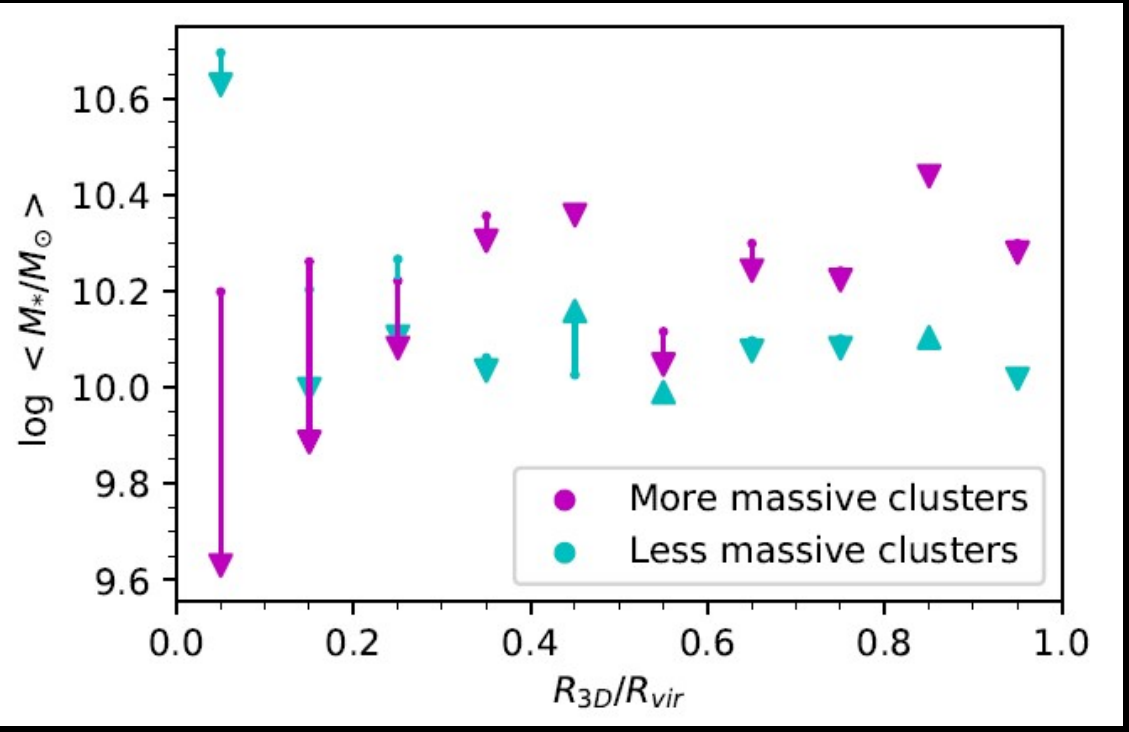


Figure 5.

- <Cluster mass range>
  $10^{14.6}\ M_\odot - 10^{15}\ M_\odot$
  $10^{13.6}\ M_\odot - 10^{14.4}\ M_\odot$
- The `infall' of a galaxy is defined as the most recent time it crosses 1.5 $R_{\rm vir}$.

Redshift at Infall

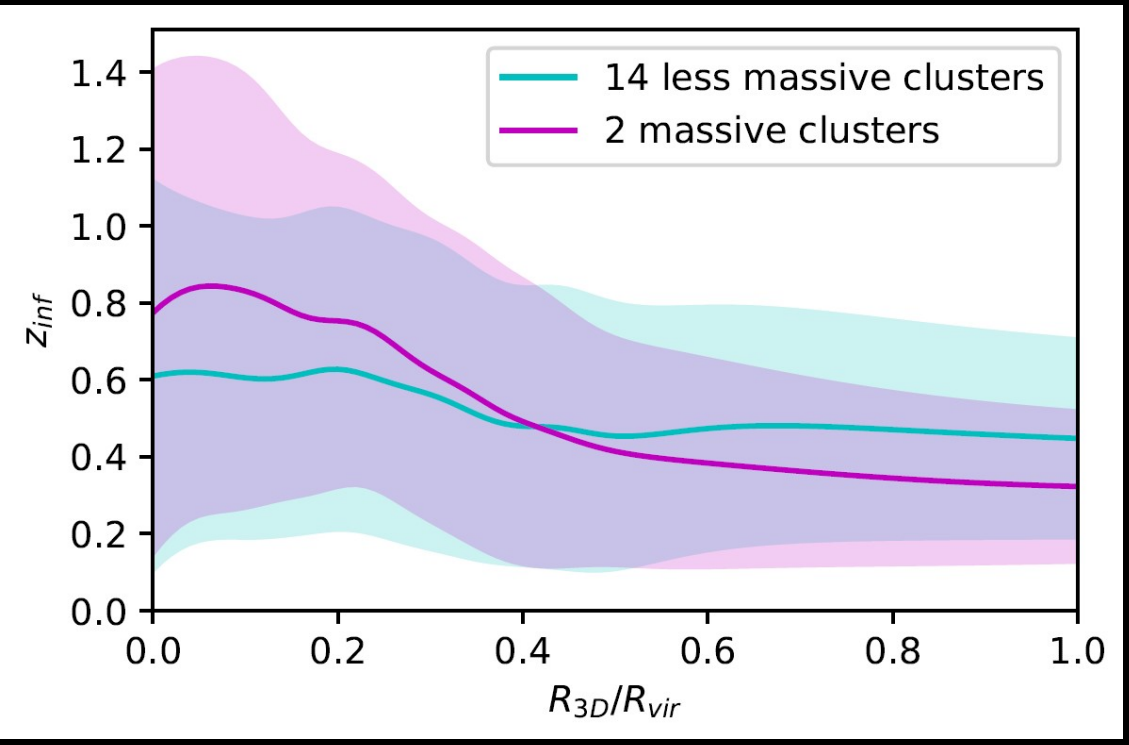


Figure 6.

- In the inner volume, redshift at the time of infall is marginally higher for more massive clusters.
- Less massive clusters:

  spent less time in the cluster → lost less mass → show MS

Cross-Check of the Scenario

- The dynamical evolution of a halo precedes that of the galaxy it contains.
- Therefore, what has been discussed in the previous slides should be visible in the dark matter haloes as well.
- The predicted results are shown.

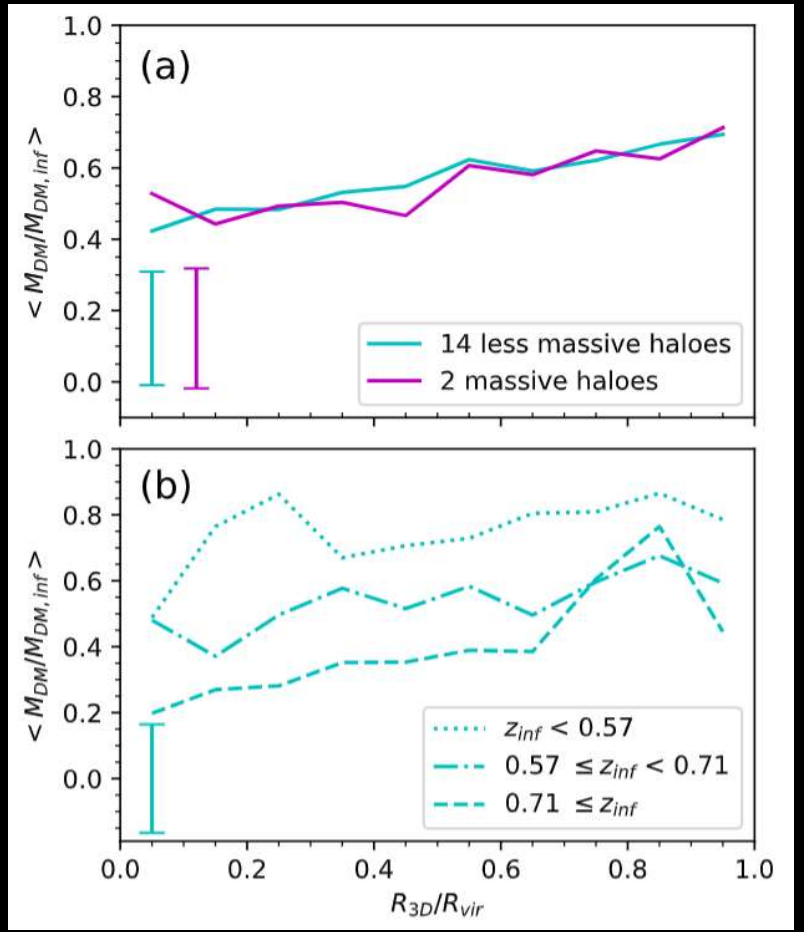


Figure 7.

Summary

- We examine the MS trend of galaxy clusters using a set of simulations and observation.

- Does MS exist in galaxy clusters? **It depends.**

  There is an inverse relationship between the MS trend and cluster mass.

- Tidal stripping acts as a competing effect to dynamical friction on MS.
- Galaxies in less massive clusters tend to lose less stellar mass because they have spent less time in the cluster than that of the massive clusters.

- Thus, the lack of consensus on MS in the literature is reconciled.

- For more information, refer to Kim et al. 2020.

doi: 10.3847/1538-4357/abbfa6

Thank you