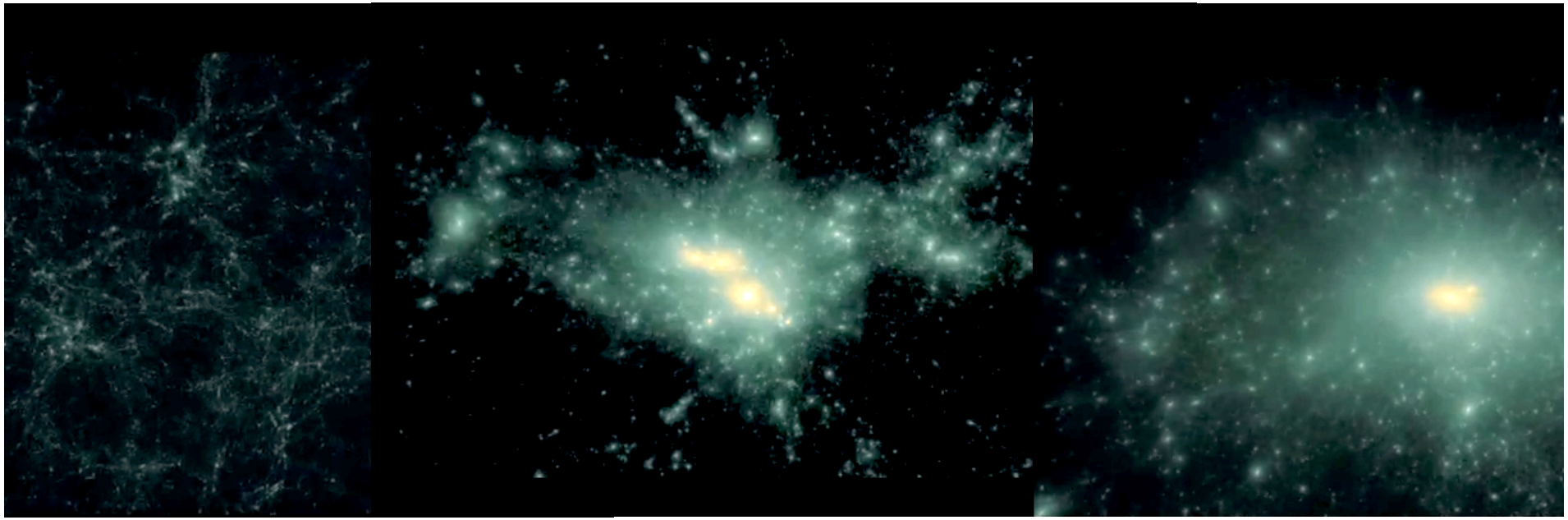
Measuring cluster relaxedness

Blythe Moreland
University of Michigan

Mentor: Risa Wechsler
Stanford University
SLAC National Accelerator Laboratory

Characterizing the structure of dark matter halos across time

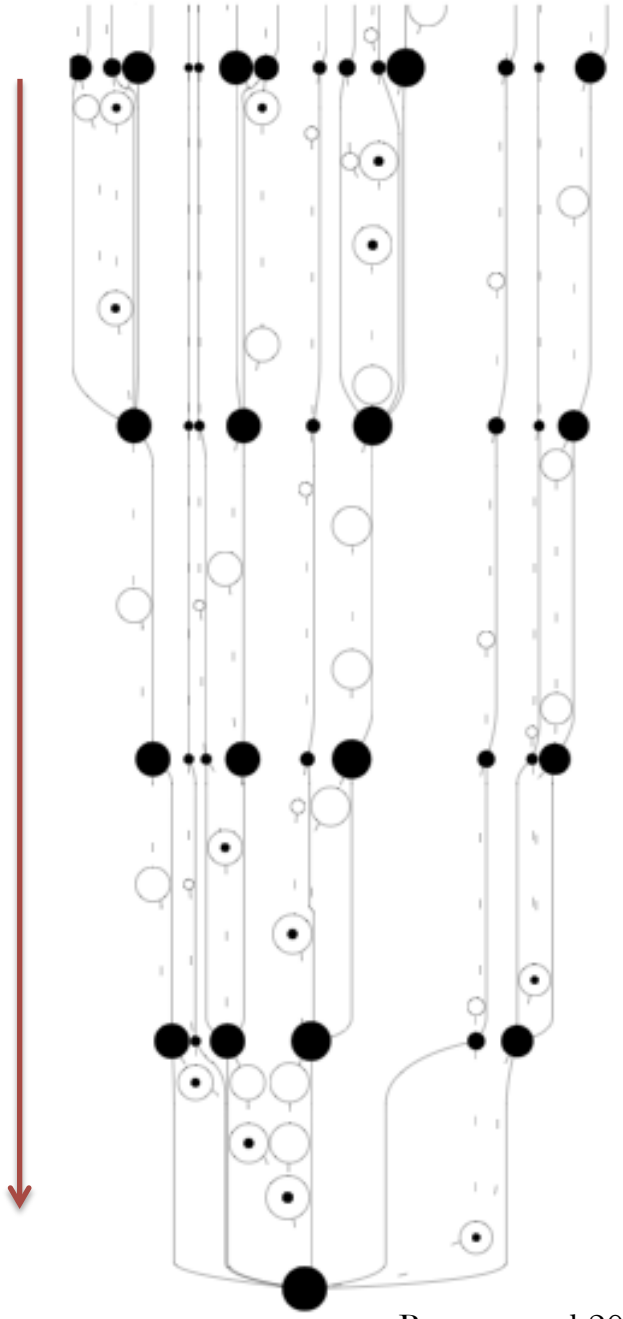


Increasing *a*
Decreasing *z*

Visualization: Ralf Kaehler
Simulation: Hao-Yi Wu, Oliver Hahn, and Risa Wechsler

Examining a halo's history

- A halo finder gives an initial number of bound substructures.
- A **merger tree** tracks the hierarchical formation of a dark matter halo as these substructures merge and particles accrete onto the halos.

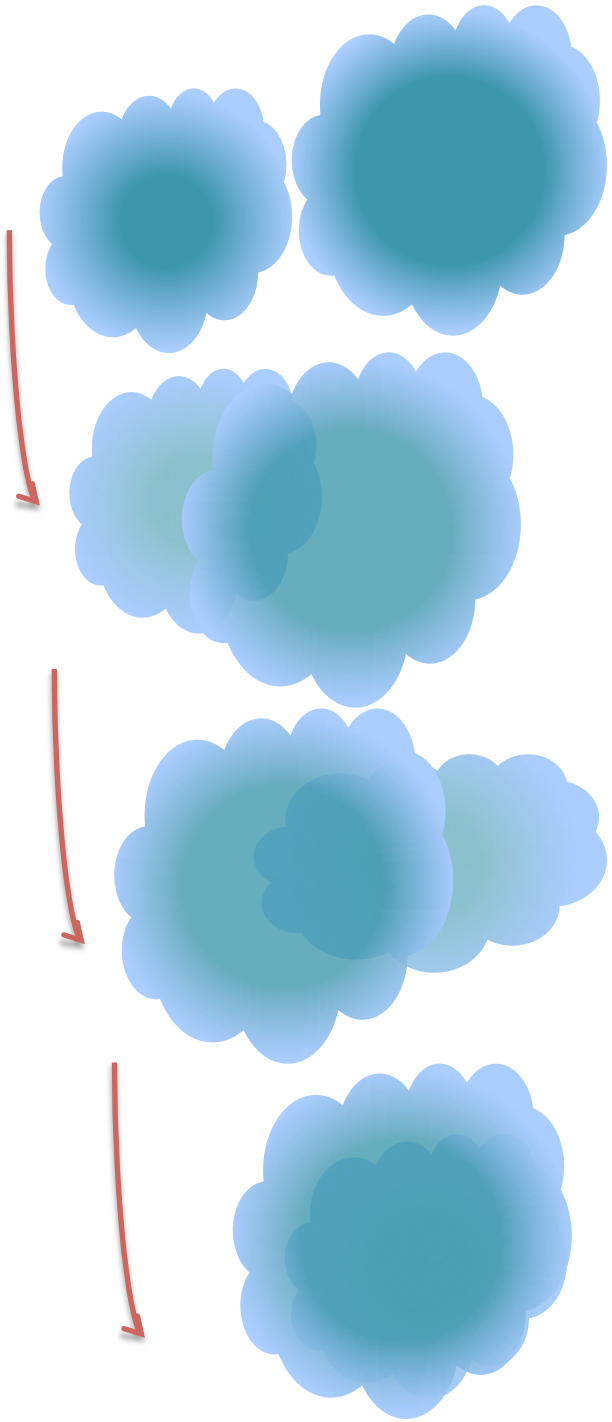


Benson et al 2011

Major mergers and structural change

•A **major merger** occurs when two structures of comparable size merge.

• It is around these events that we wish to look at measures of a halo's **relaxedness** (or, most interestingly, unrelaxedness)



Model behavior

• A classic model for the spatial mass distribution of a dark matter halo in dynamic equilibrium is the NFW profile:

$$\rho(r) = \frac{\rho_0}{\frac{r}{R_s}\left(1 + \frac{r}{R_s}\right)^2}$$

• **Concentration =** $C_{vir} = r_{vir} / r_s$

A personality test for halos

• Relaxedness is not a well-defined concept but there are proxies one can reasonably motivate :

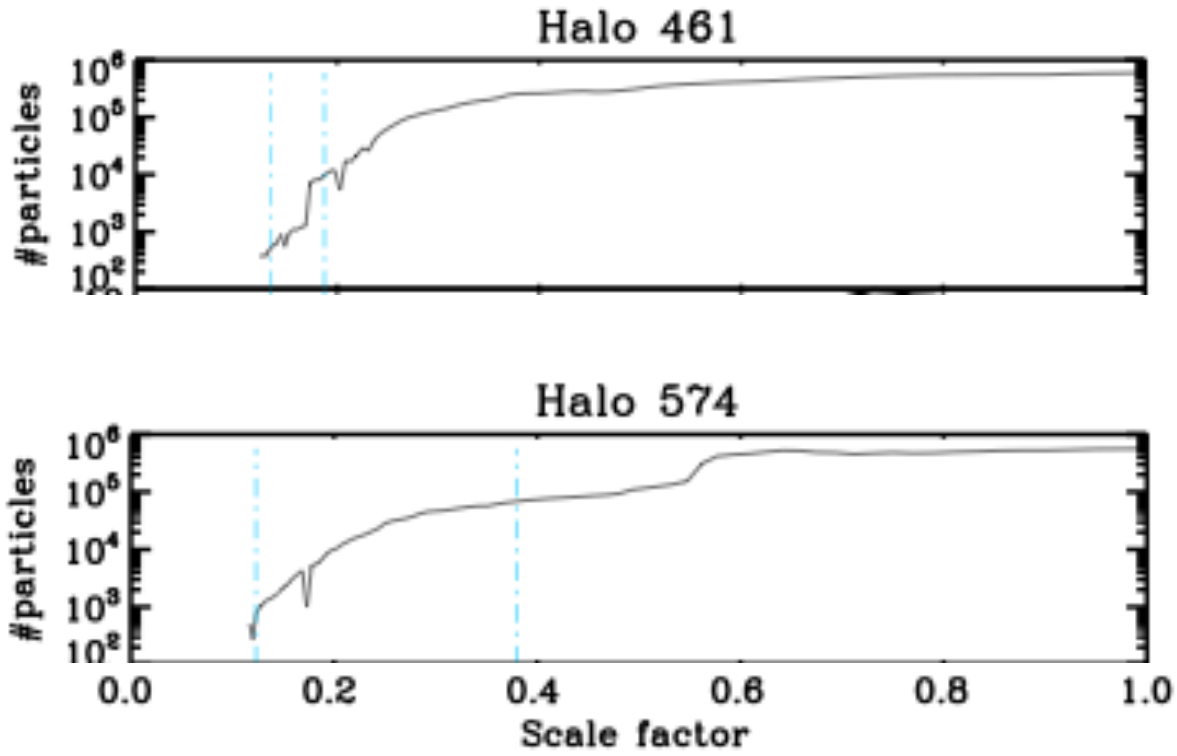
NFW Fit:	The χ^2 error on the NFW profile fit
Center of mass displacement:	$s = \frac{\lvert r_c - r_{cm} \rvert}{r_{vir}}$
Virial ratio:	$2T/\lvert U \rvert$
f_{sub}:	The fraction of mass within subhalos

The simulation setup

- Resolve subhalos → **high resolution**
- Interesting substructure → **massive clusters**
- Statistically significant results → **large number of halos**

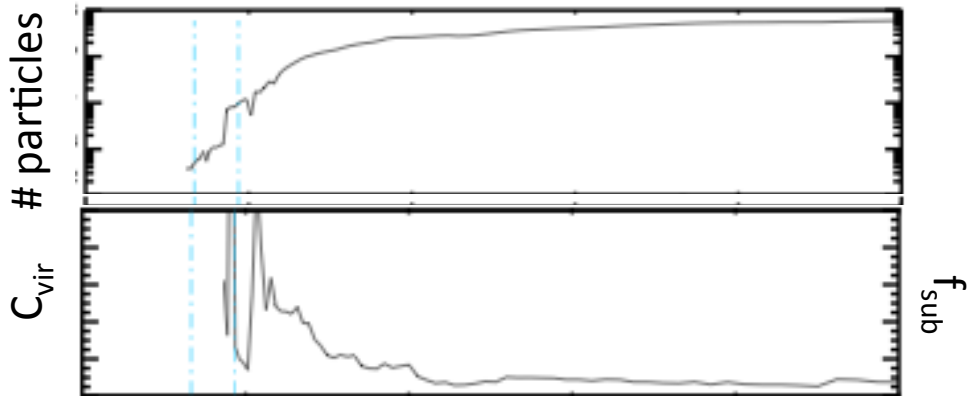
- The *Rhapsody* catalog created by Dr. Wu resimulates isolated massive clusters for high resolution, such that we have resolution of **6.7 kpc**, halo mass on the order of $\mathbf{10^{14}\ M_{\odot}}$ and **110** such halos.

What can relaxedness measures tell us about two very different pasts?

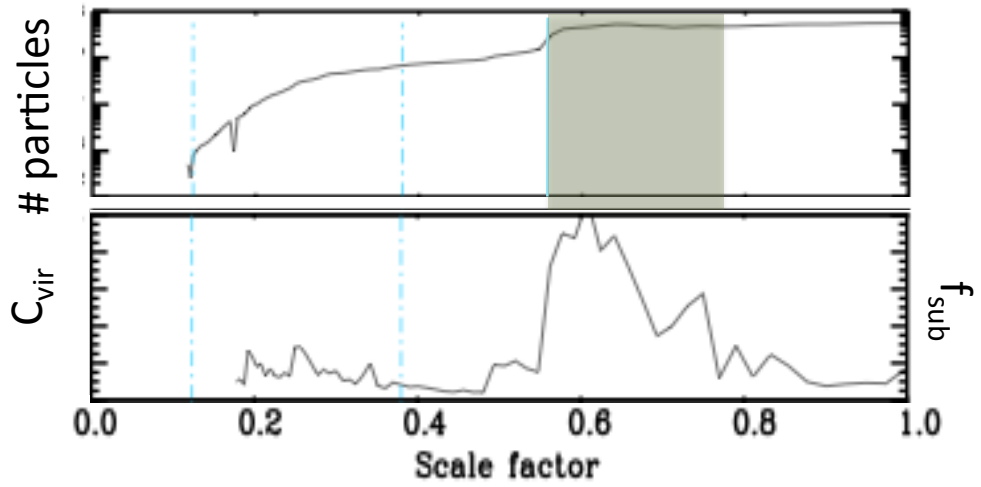


Example: A tale of two halos

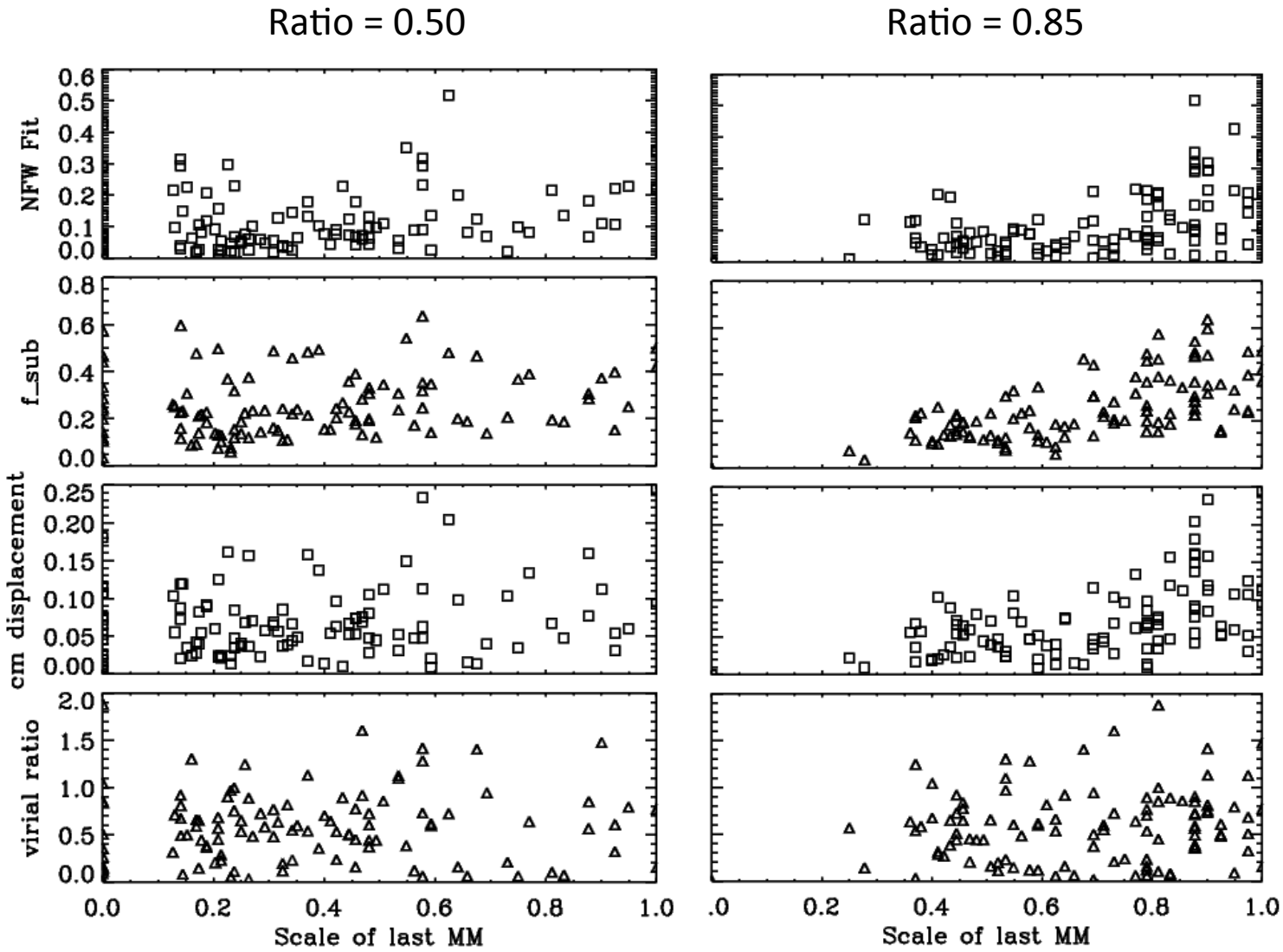
Halo 461



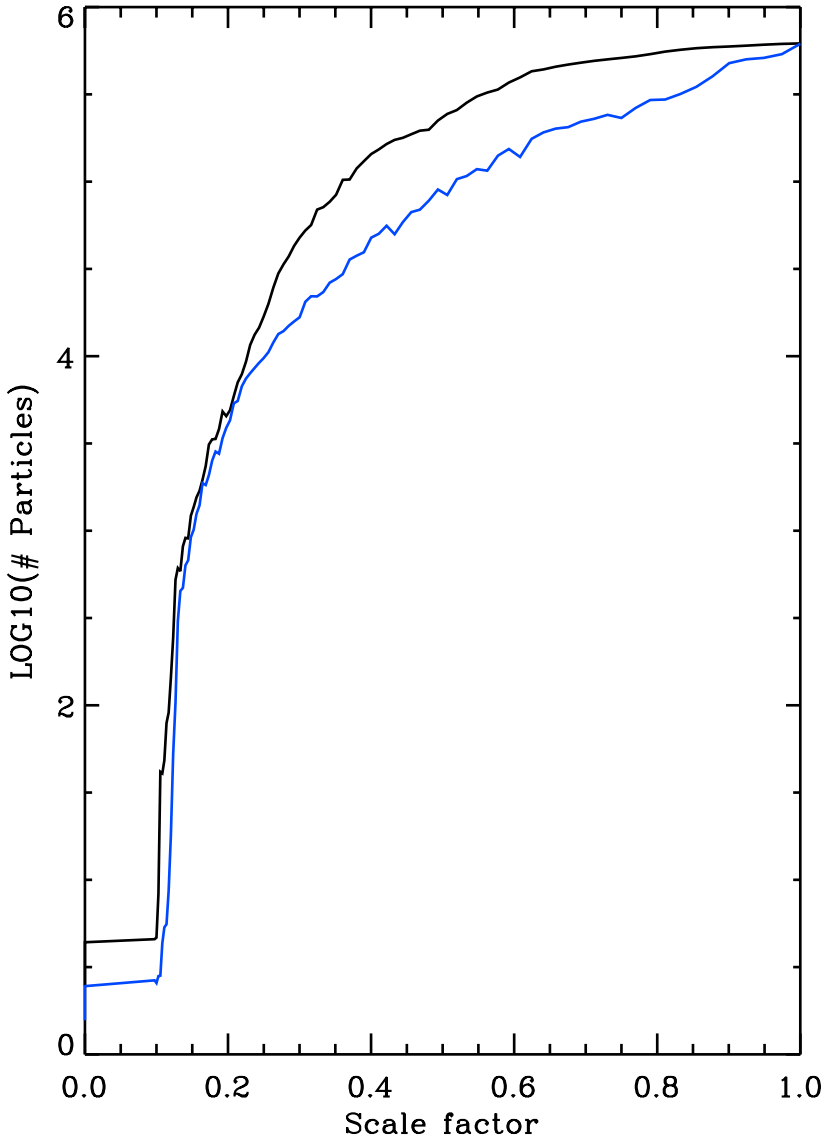
Halo 574



Let’s start at $z = 0$. Does the current relaxedness indicate the time lapse from a major merger?


Ratio = 0.50
Ratio = 0.85
NFW Fit
f_sub
cm displacement
virial ratio
Scale of last MM
Scale of last MM

Can the current relaxedness measure indicate different accretion histories in general?



- Unrelaxed (blue), Relaxed (black)
- Rank the halos by f_{sub} at *z=0* and choose top and bottom 10%.

Relaxedness and centering

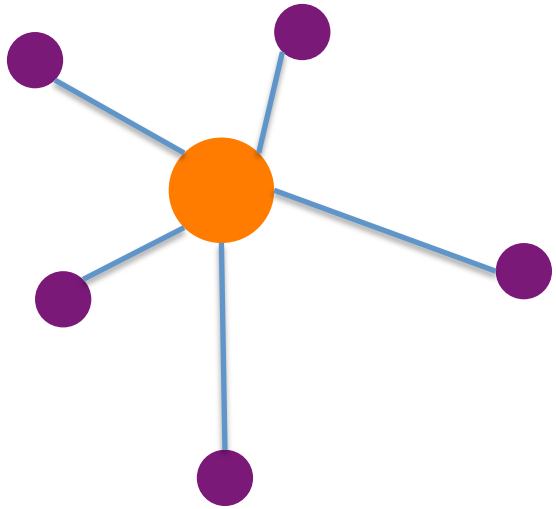
- Another way to think about relaxedness is through the issue of **centering**. The center of a halo is the most gravitationally bound particle.
- Centering a galaxy cluster is an important task in observational data.
- An ambiguity in centering may mean that a rightful center cannot be chosen (as when there's major merger).

Centering method: Gravitational potential proxy

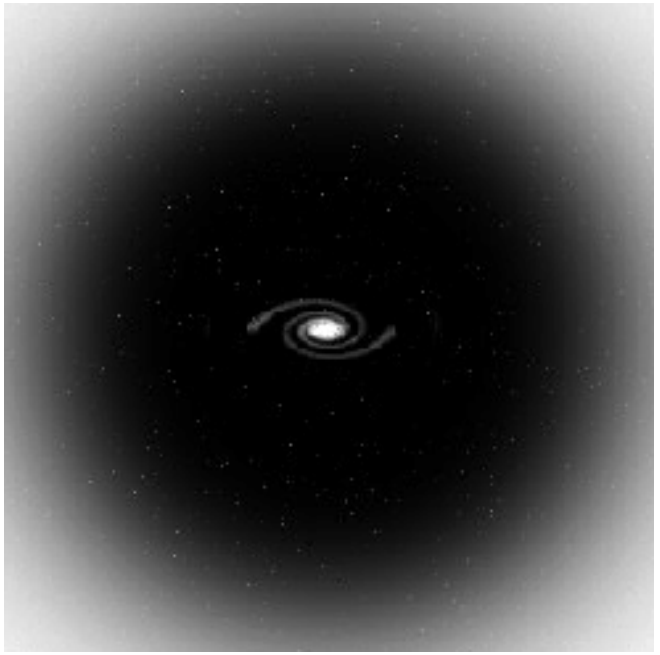
• Using the mass to light ratio, we can use observables to create a gravitational potential proxy:

$$w_{ij} = \frac{L_i L_j}{r}$$

• And assign a strength to each galaxy based on the sum of these weights:



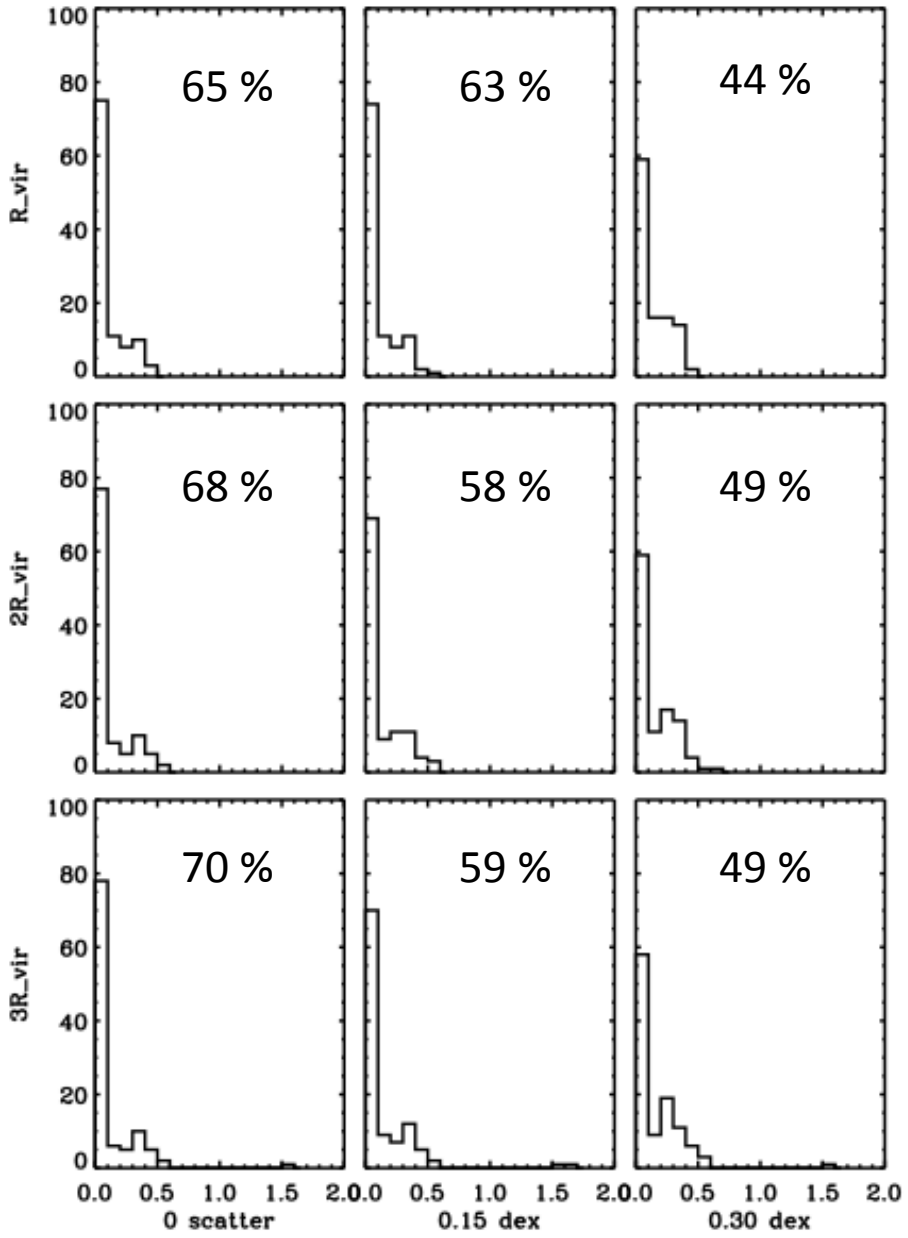
• Under the assumption that a galaxy would sit inside a resolved subhalo (and $v_{peak} > 130$ *km/s*), we relate this galaxy centering method to a halo centering one.



Gnedin et al 2004

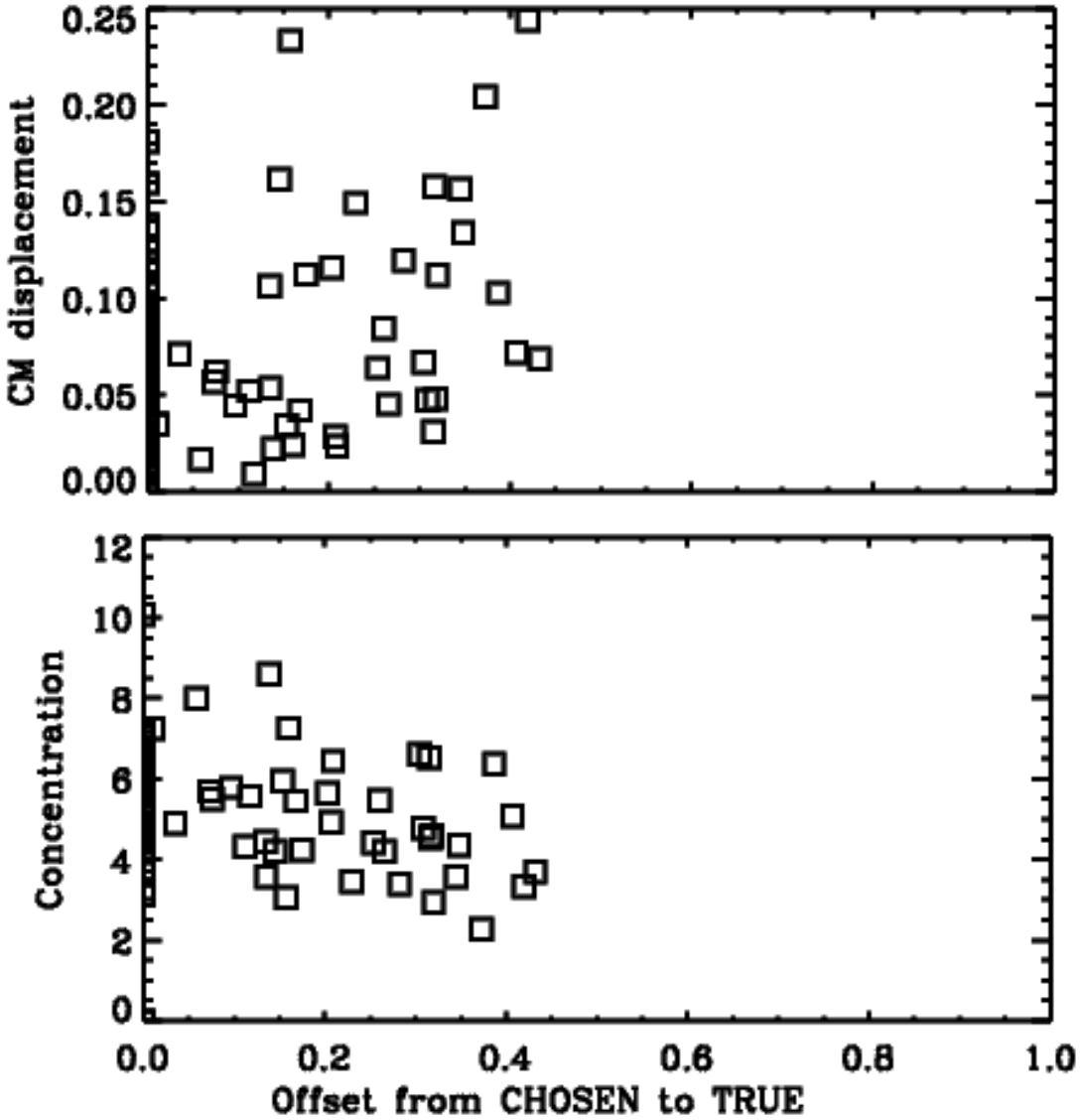
Will a mis-centering correspond to unrelaxedness?

Offset from the chosen center to the real center



- Even given the cleanest scenario, 35% of the halo centers aren't found…

Properties of mis-centered halos



• What properties of the subahalos (our stand-in galaxies) might contribute to this?

Work-in-progress/Future work

- How does scaling with the time of the last major merger change at other redshifts? As in, what are the time scales for relaxedness measures to restabilize? How does this time scale relate to the size of the major merger?

- How do current relaxedness measures relate to the trajectory of the mass accretion history?

- How robust is this centering method at other redshifts in terms of what it says about relaxedness?

Acknowledgements

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