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Mass Segregation with Galaxy Analogues

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Introduction

Galaxy populations in groups and clusters are characterized by redder colours, lower star formation rates (SFR's) and more elliptical morphologies compared to field galaxies. Segregation in galaxy properties with halo-centric radius within large halos could help determine the dominant processes driving galaxy evolution.

Studies have found segregation in properties such as luminosity, colour, SFRs, quenched fractions etc.[e.g. 1,2,3,4] These trends in observed properties may be driven primarily by baryonic processes. The segregation of galaxies by mass however is still a topic of debate[e.g. 5,6,7,8,9], and could arise purely through gravitational interactions. We aim to understand mass segregation in dark-matter-only simulations using a simple method to select a sample of galaxy analogues.

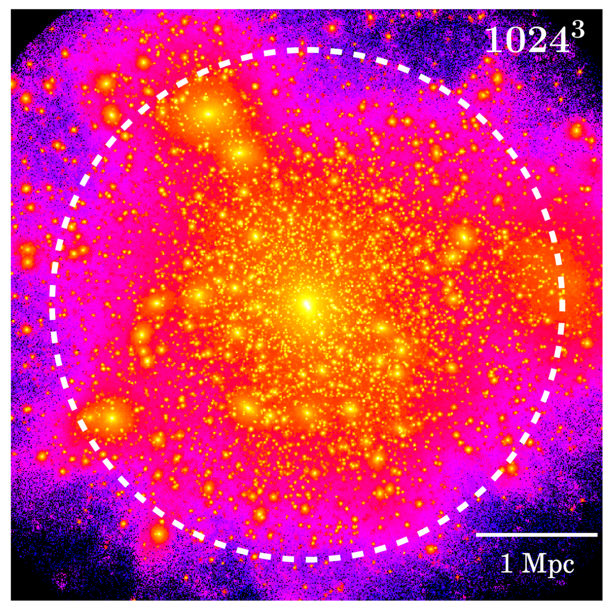


Fig. 1: Density plot of most massive cluster at highest resolution. Dashed line indicated virial radius

Simulation

N-body simulation of a cosmological volume using the SPH code ChaNGa[10]

- Initial conditions created using MUSIC[11]
- 100 Mpc box; highest resolution contains 1024^3 particles, $m_{part} = 3.7\times10^7\,M_\odot$
- Halo finding using
  - → AHF[12]: spherical overdensity algorithm
  - → ROCKSTAR[13]: phase-space FOF algorithm

Selecting Galaxy Analogues

Galaxy analogues are identified in the dark matter simulation at z=0, starting with each distinct halo and applying the following criteria:

- **If $M_{vir}<10^{10}\,M_\odot$:** halo and subsequent branches are eliminated
- **If $M_{vir}>10^{12.5}\,M_\odot$:** halo is eliminated, but each subhalo is considered as candidate
- **If $10^{10}<M_{vir}<10^{12.5}\,M_\odot$ and halo has no subhalos with $M_{vir}>10^{10}\,M_\odot$:** halo is included as galaxy analogue and subsequent branches are eliminated
- **If $10^{10}<M_{vir}<10^{12.5}\,M_\odot$ and halo has at least one subhalo with $M_{vir}>10^{10}\,M_\odot$:** we calculate (M_{halo}-$\Sigma M_{subhalo}$); if residual mass is also within $10^{10}<M_{vir}<10^{12.5}\,M_\odot$, halo is included as analogue and each subhalo is also considered as candidate

A schematic of the selection process is shown in Fig. 2.

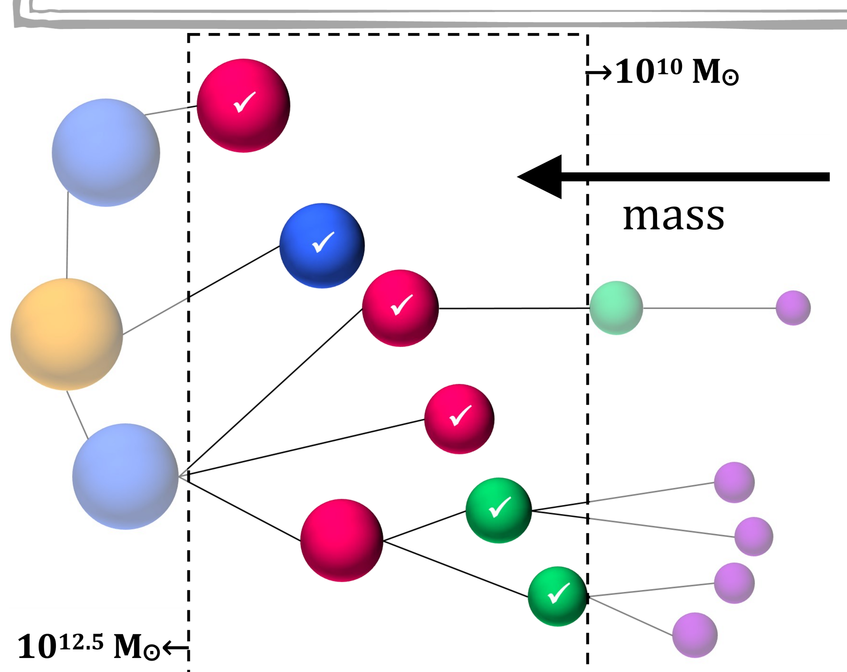


Fig. 2: Schematic showing the selection of galaxy analogues from the subhalo hierarchy. Colours indicate different levels in the subhalo hierarchy, the size of the halos as well as their horizontal position is proportional to $\log(M_{vir})$. The dashed box indicates the galaxy analogue mass range while the white tick marks show which halos were accepted as galaxy analogues.

Results

The radial distribution of galaxy analogues by number as well as by mass fractions are shown in the top panels of Fig. 3. The results from the two halo finders agree well outside 0.5 R_{vir}, although there are significant differences within 0.5 R_{vir}. The bottom panels of Fig. 3 show the significantly different levels within the subhalo hierarchy of the galaxy analogues detected by the two halo finders.

These differences at small radii can also be seen in more detail in Fig. 4, which shows an example group halo and its substructure. The results highlight the need for velocity information (as used by ROCKSTAR) in identifying galaxy analogues in the inner regions of halos, in agreement with previous work.[e.g. 14]

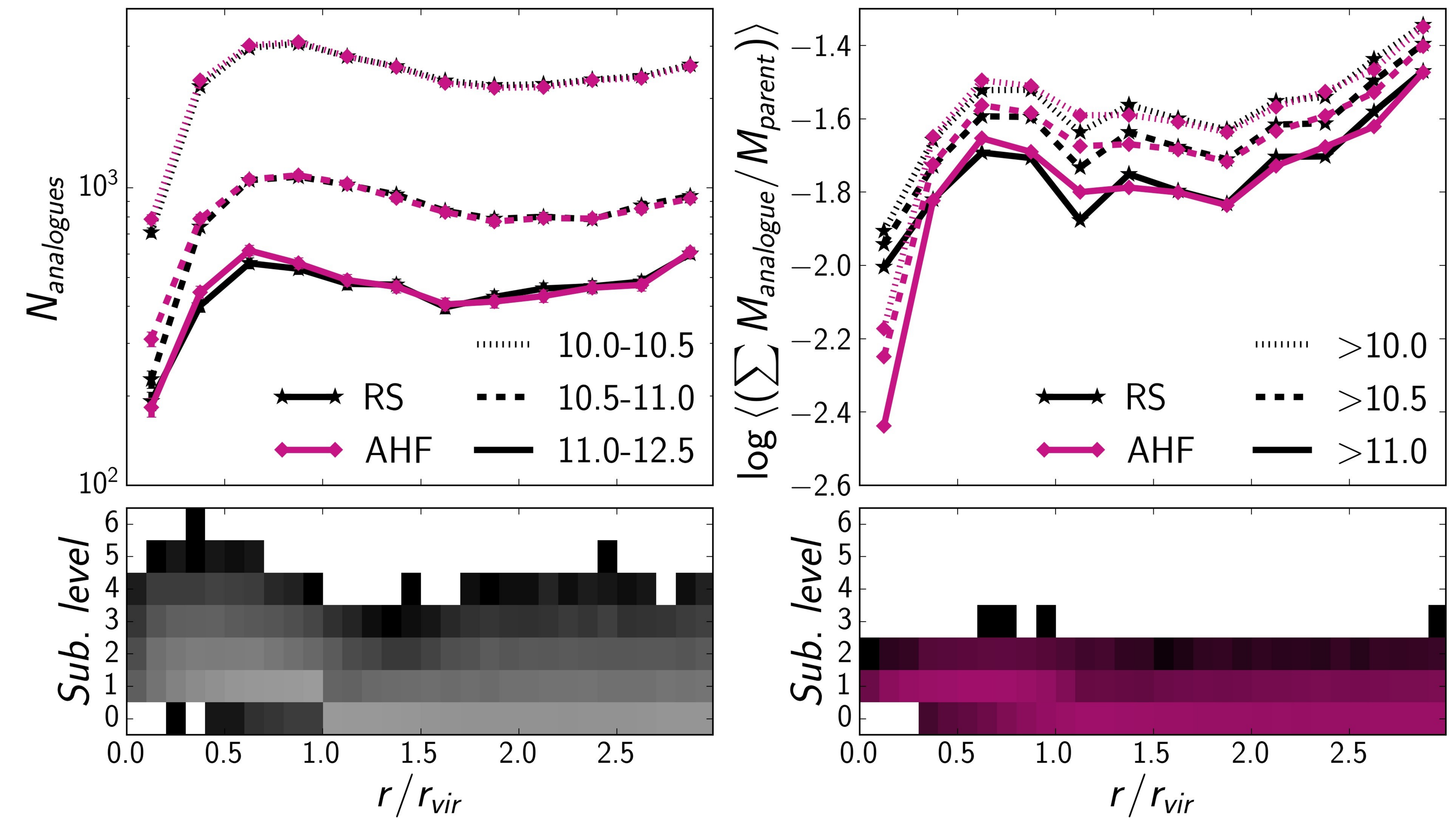


Fig. 3: Radial distributions of numbers of galaxy analogues (*top left*) and their mass fractions (*top right*). Linestyles indicate bins of $\log(M_{vir})$. (*Bottom*) 2D histograms of radius and subhalo level (distinct halos are level 0, subhalos level 1, subsubhalos level 2 etc.). The colour map is logarithmic; black corresponds to a single analogue, while the brightest grey and pink correspond to 1675 and 1680 analogues respectively.

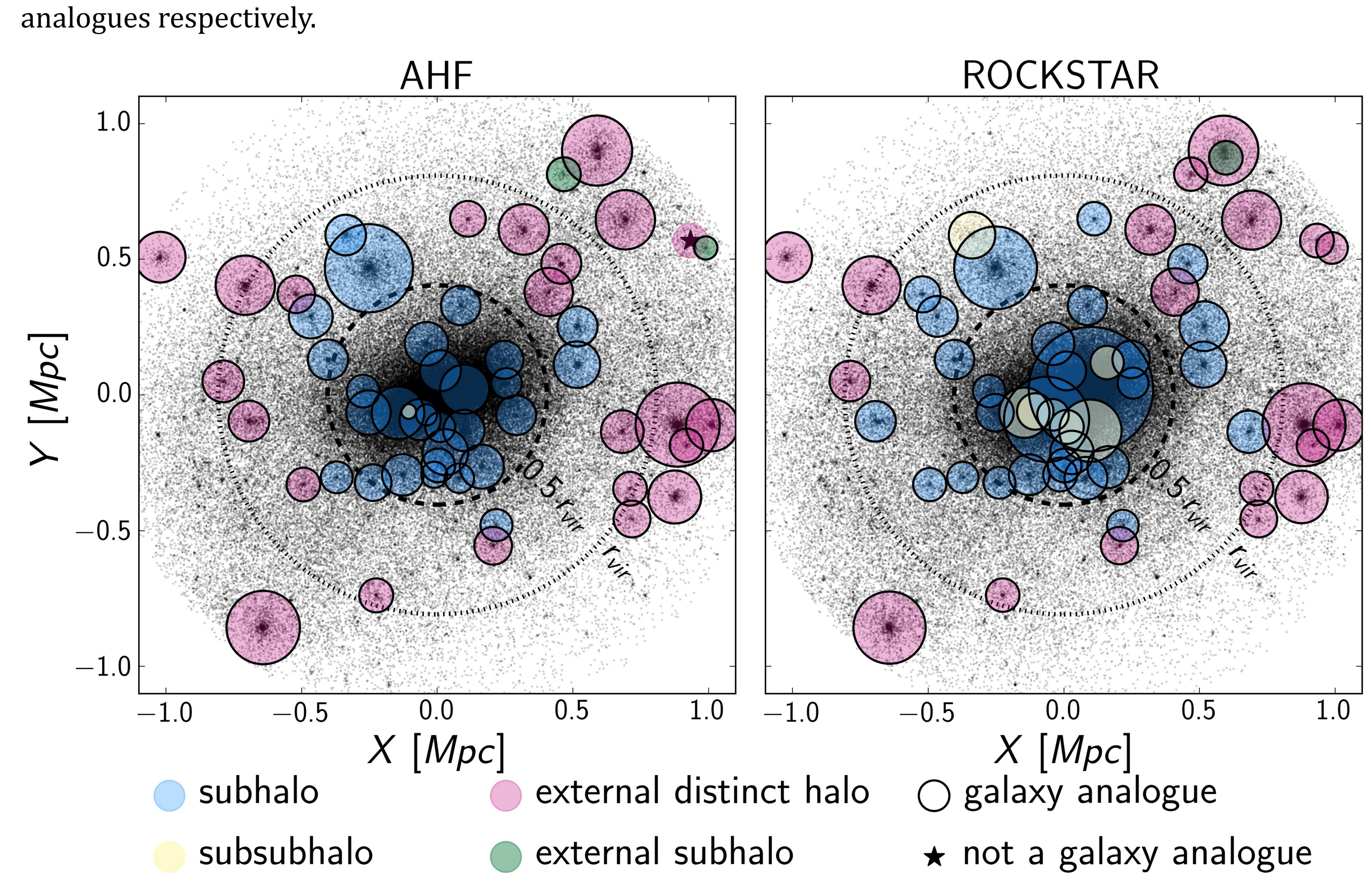


Fig. 4: Example system, with $M_{vir} = 2.9\times10^{13}\,M_\odot$, showing (sub)subhalos, external halos and galaxy analogues identified by AHF (*left*) and ROCKSTAR (*right*). Every 5th particle is plotted as a black dot. While the (sub)subhalo populations are different, the analogue populations are more consistent, although within 0.5 R_{vir}, even the analogue populations show significant differences.

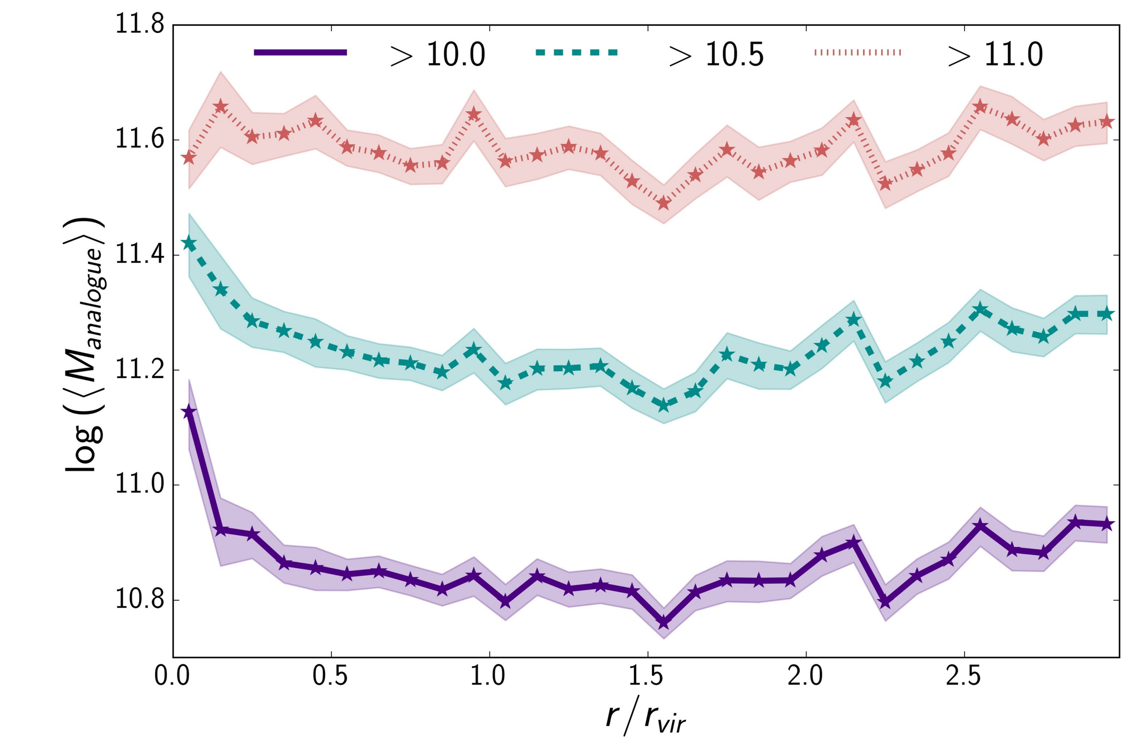
Mass Segregation

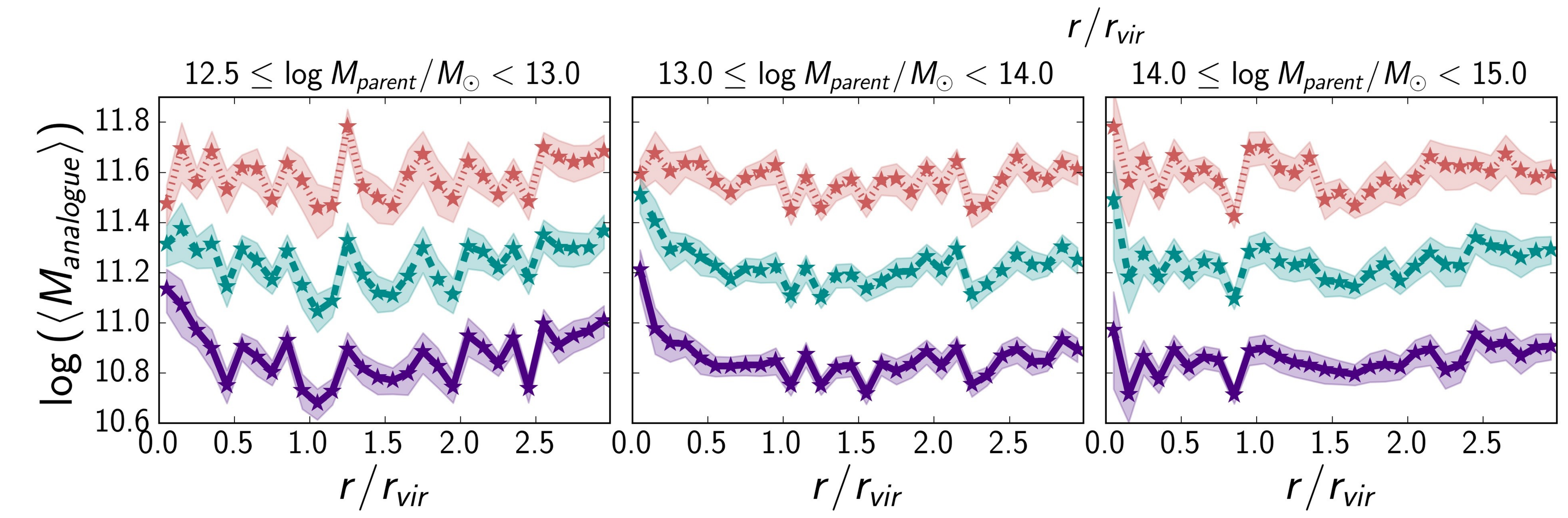
Using the galaxy analogues identified by ROCKSTAR, we study mass segregation.

- Fig. 5 shows average analogue mass as a function of halo-centric radius
  - → For the total sample (solid purple), a significant negative trend is found within 0.5 R_{vir} and a mild positive trend beyond R_{vir}.
  - → We examine the effect of excluding low mass halos (dashed green & dotted pink). The trends are similar with a lower mass limit of $10^{10.5}\,M_\odot$, but no significant trend is detected for high-mass analogues ($M_{analogue}>10^{11}\,M_\odot$)
- The results were also examined in bins of parent halo mass, as shown in Fig. 6. Mass segregation results are strongest in small and large groups with nearly no trend seen in massive clusters.

Fig. 5 (Right): Average galaxy analogue mass as a function of halo-centric radius. Colours and linestyles represent different lower mass cuts in $\log(M_{vir})$ to show the effect of excluding low mass galaxy analogues.

Fig. 6 (Below): Average mass vs. radius, as in Fig. 5, in bins of parent halo mass.





Summary

We find significant mass segregation in the inner regions of group-massed halos and the trends are stronger when considering low-mass analogues. Since dynamical friction is expected to be more efficient for more massive analogues, our results suggest that it is not the dominant factor at work. Instead, the results are likely driven by the accretion histories of the galaxy analogues and their host halos.

We are following up this work by examining segregation in mass at accretion and peak analogue mass, as well as with zoom-in hydrodynamical simulations to study in detail the various processes affecting galaxy evolution in galaxy groups.

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