There and Back Again

Understanding the Critical Properties of Backsplash Galaxies

Josh Borrow

Mark Vogelsberger, Stephanie O'Neil, Mike McDonald, Aaron Smith

Massachusetts Institute of Technology

Virgo Meeting - Thu 14 July 2022

10^2
10^4
10^6
Projected Stellar Mass Density $\left[\frac{M_\odot}{kpc^3}\right]$
0.6
0.8
1.0
1.2
1.4
U-V Colour

10^2
10^4
10^6
Projected Stellar Mass Density $\left[\frac{M_\odot}{kpc^3}\right]$
0.6
0.8
1.0
1.2
1.4
U-V Colour
$R_{200,\,mean} = 3.70$ Mpc

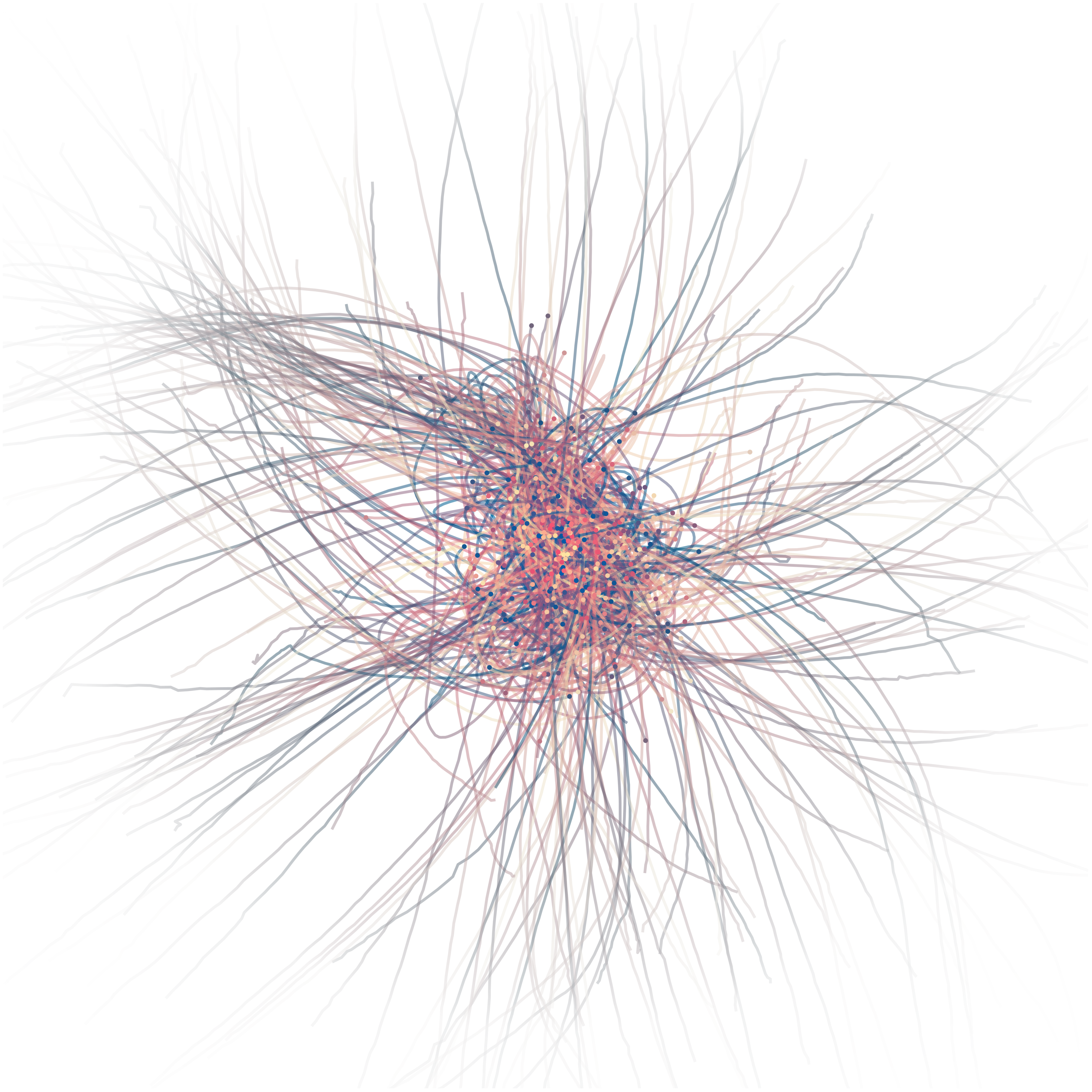
10^2 10^4 10^6
Projected Stellar Mass Density $\left[\frac{M_\odot}{kpc^3}\right]$
0.6 0.8 1.0 1.2 1.4
U-V Colour
$R_{200,\,mean} = 3.70$ Mpc

10^2 10^4 10^6
Projected Stellar Mass Density $\left[\frac{M_\odot}{kpc^3}\right]$
0.6 0.8 1.0 1.2 1.4
U-V Colour
$R_{200,\,mean} = 3.70$ Mpc

10^2
10^4
10^6
Projected Stellar Mass Density $\left[\frac{M_\odot}{kpc^3}\right]$
0.6
0.8
1.0
1.2
1.4
U-V Colour
$R_{200,\,mean} = 3.70$ Mpc

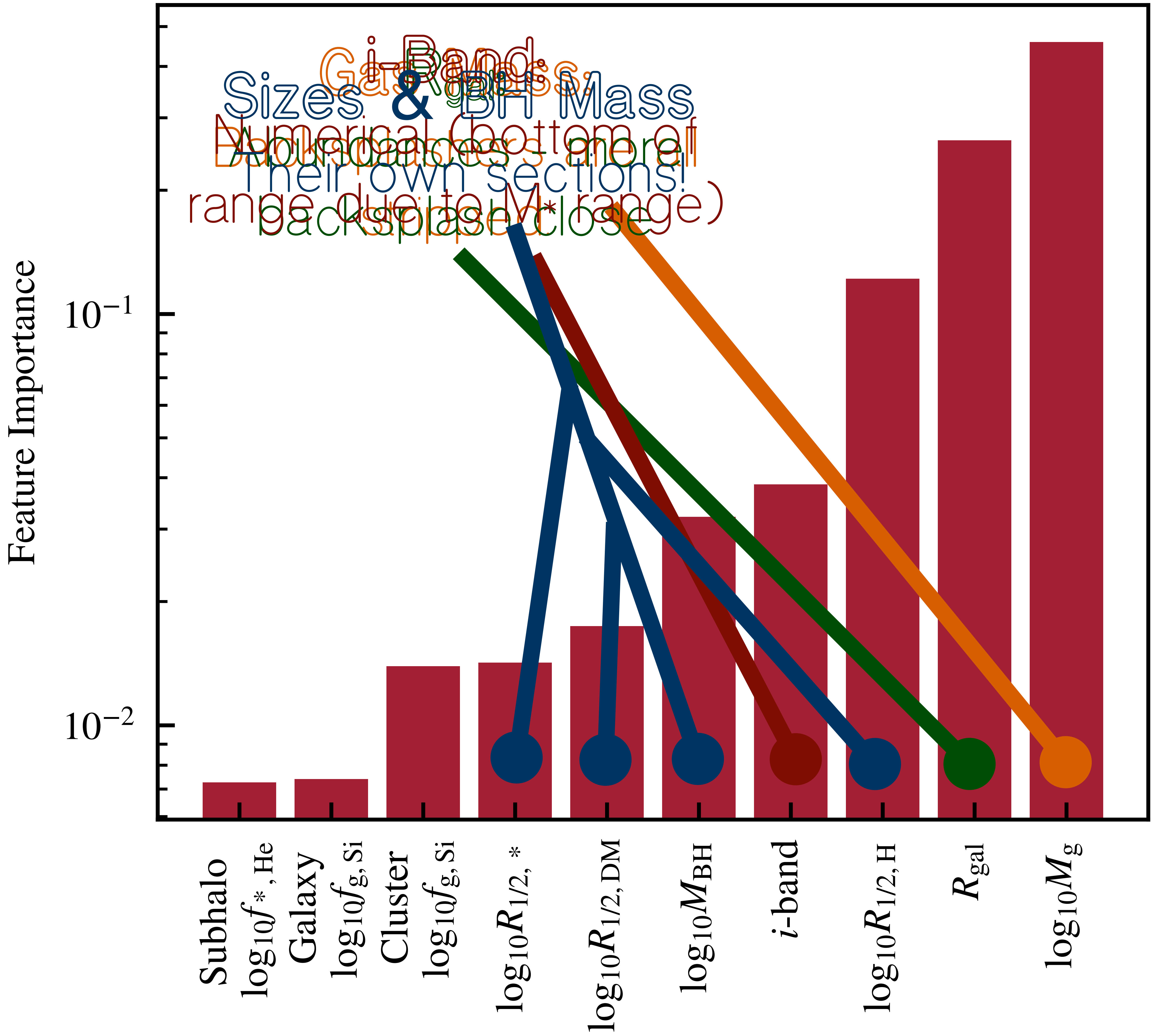
Cluster Selection

- Clusters with mass 10^{13} $M_\odot$ or greater are selected.
- Use a strict isolation criteria; must be the most massive cluster within 10 $R_{200,mean}$.
- Same sample selection as O'Neil+ 2021 and 2022, but includes additional constraint that BCGs must be traceable.
- L-HaloTree merger trees track all galaxies with $M_* > 10^8$ $M_\odot$



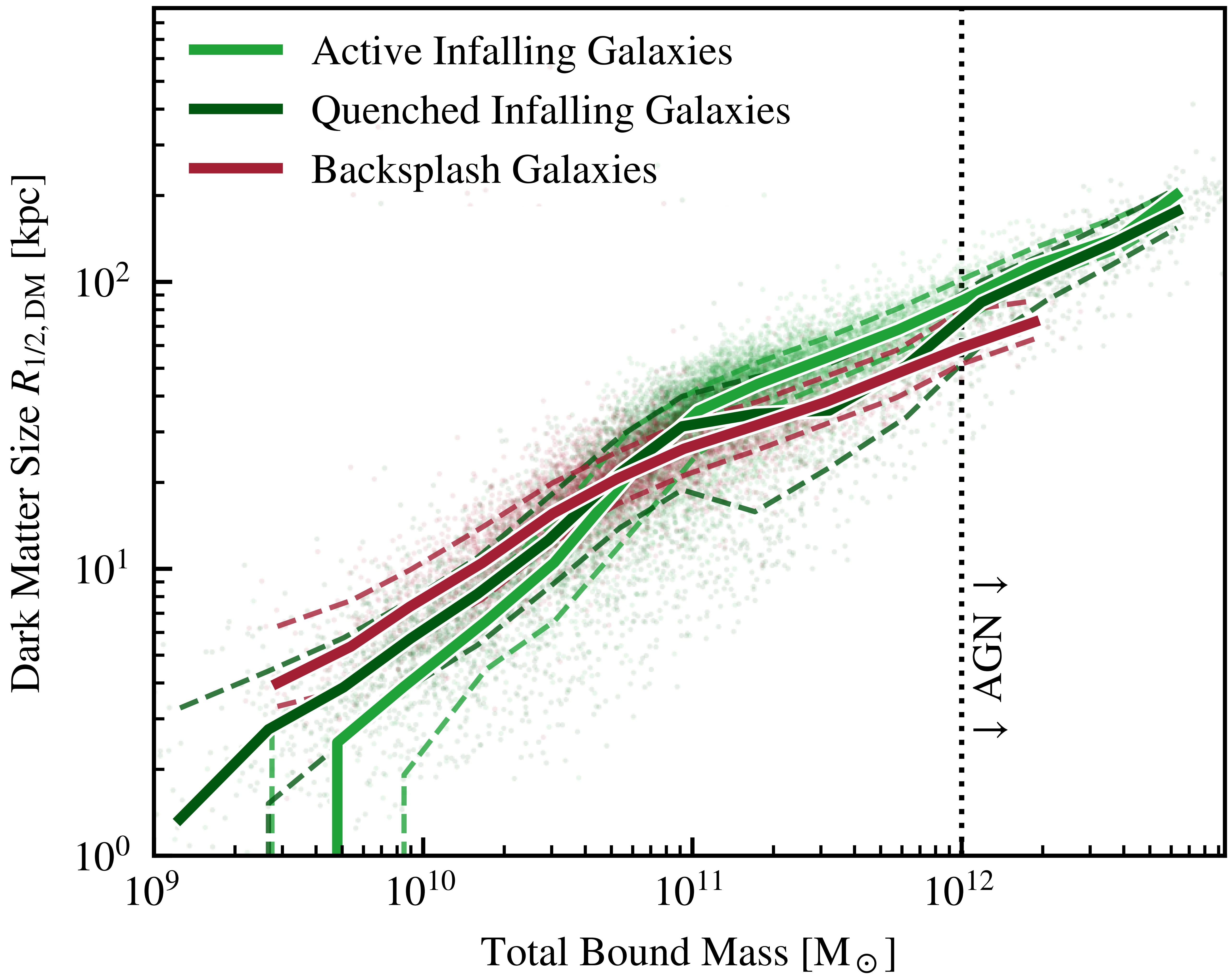
What Makes Backsplash Galaxies Special?

- Train a decision tree classifier on all galaxy properties, and properties of the host clusters in the TNG SubFind catalogues.
- Two additional items - distance from cluster center (R_{gal}) and U-V and g-r colours.
- Right - Feature importances from the decision tree (higher importance means 'cleaner' cut between infalling and backsplash populations)



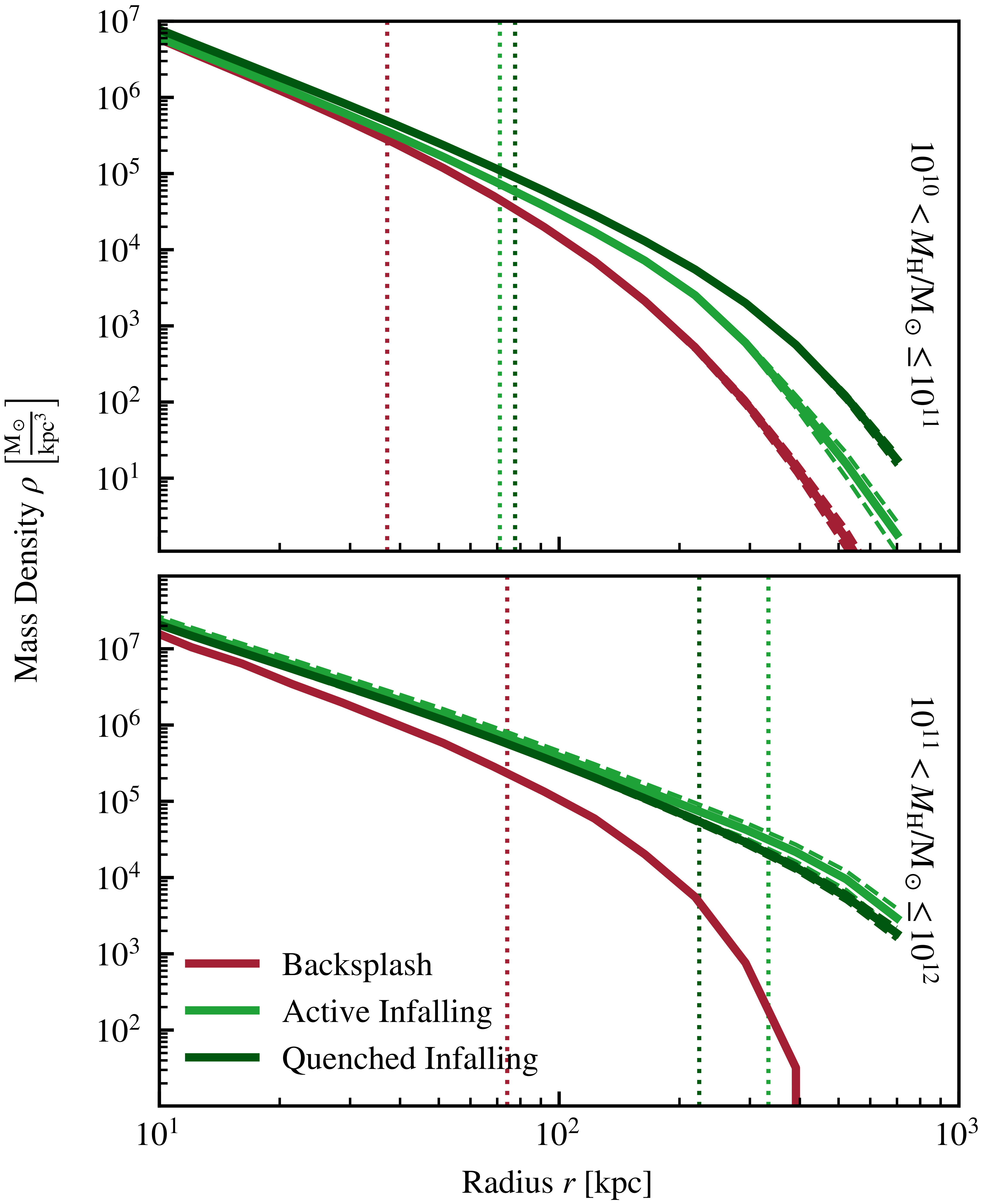
Dark Matter Sizes

- More massive backsplash galaxies have significantly smaller sizes than their infalling counterparts.
- At lower masses, the trend reverses, with again backsplash galaxies having larger sizes than their infalling counterparts (in a similar way to the stellar sizes).
- Both the smaller and larger sizes of backsplash galaxies can be explained through their tidal interactions with the cluster.



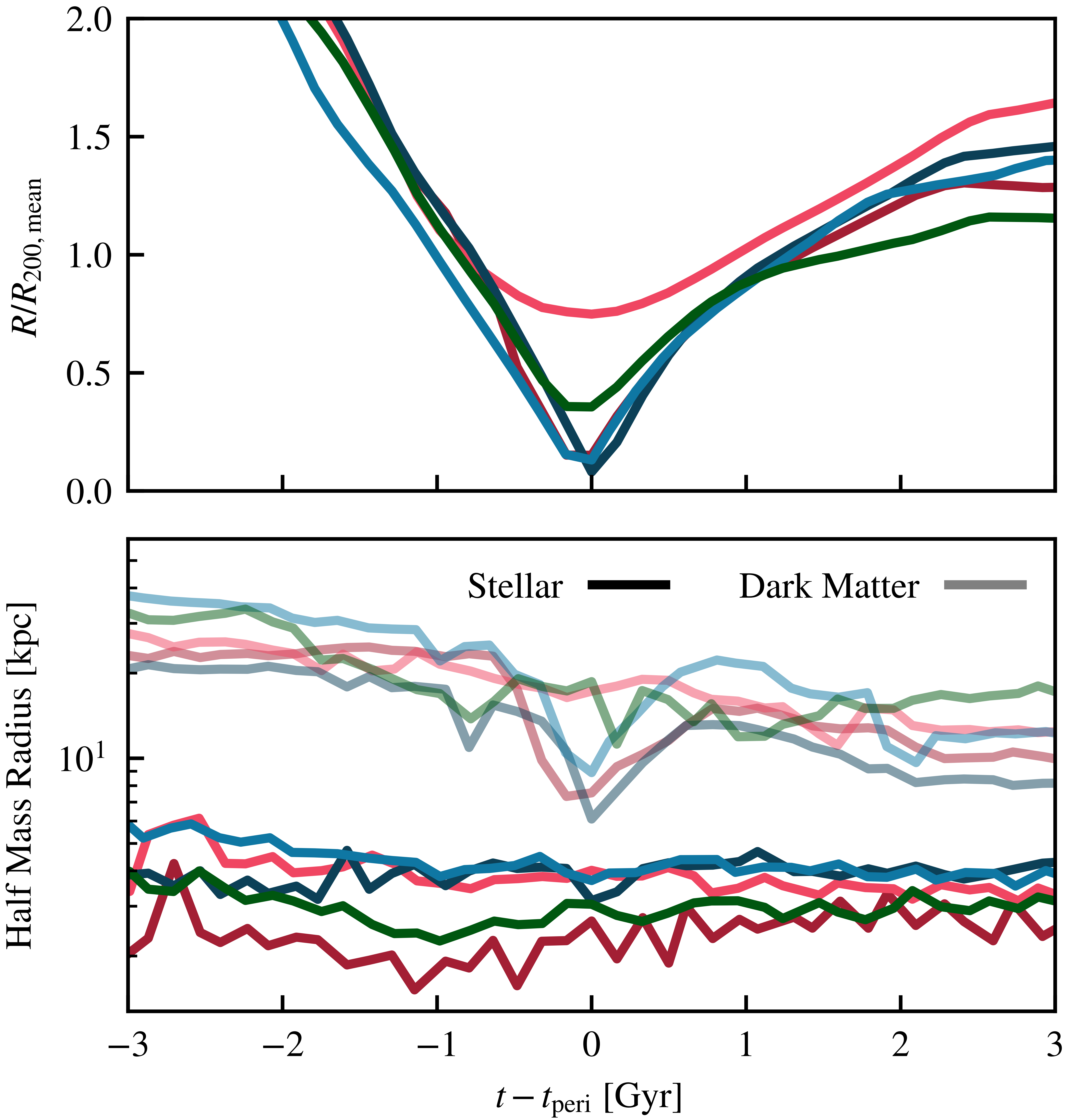
Dark Matter Profiles

- The outskirts of backsplash galaxies are subject to significant tidal stripping, with densities reduced by multiple orders of magnitude outside of the half-mass radius.
- The strength of the stripping depends strongly on the mass of the galaxy, and hence its initial density.
- As these processes occur at much larger radii, and on a single crossing timescale (~1-2 Gyr), they are reliable even given tidal disruption issues.



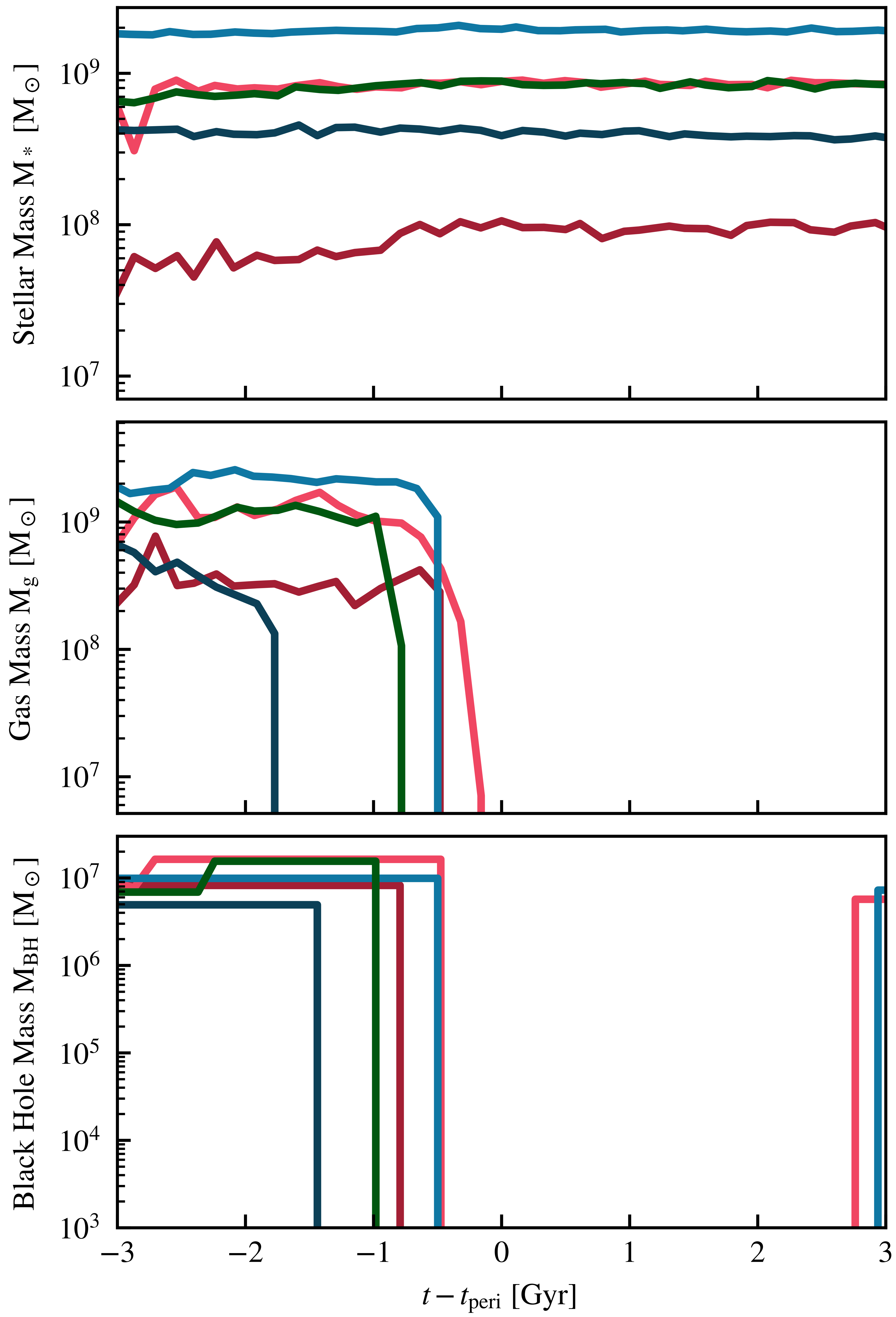
Galaxy Tracks

- Let's look at individual galaxies - 5 randomly sampled galaxies around the most massive cluster (10^{15} $M_{\odot}$).
- Re-organise them so t=0 overlaps (with t=0 set to be their pericenter time)
- DM sizes drop over time, as matter is tidally stripped, and stellar sizes increase for low mass (green and red).
- Confirms much of what we saw in profiles!



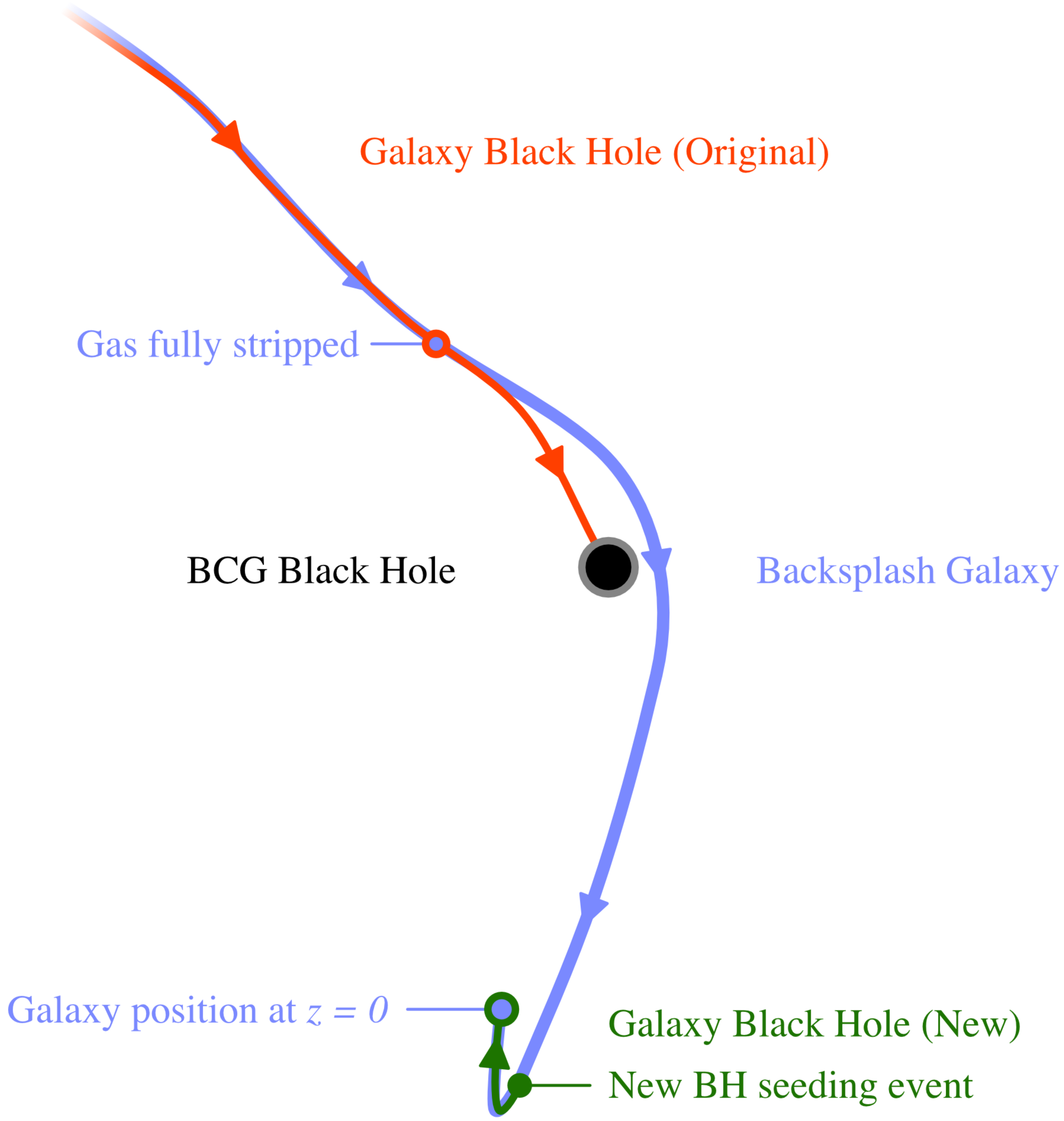
Mass Tracks

- Note - same axes, colours as before.
- Stellar mass stable, as this is centrally concentrated and as such not subject to tidal stripping.
- All backsplash galaxies have a gas fraction of 0, reached just before pericenter passage. Indicates ram pressure stripping significant in this environment.
- Notable oddity - backsplash galaxies lose black holes, and then re-gain them at turnaround (origin of high M_{BH} importance).



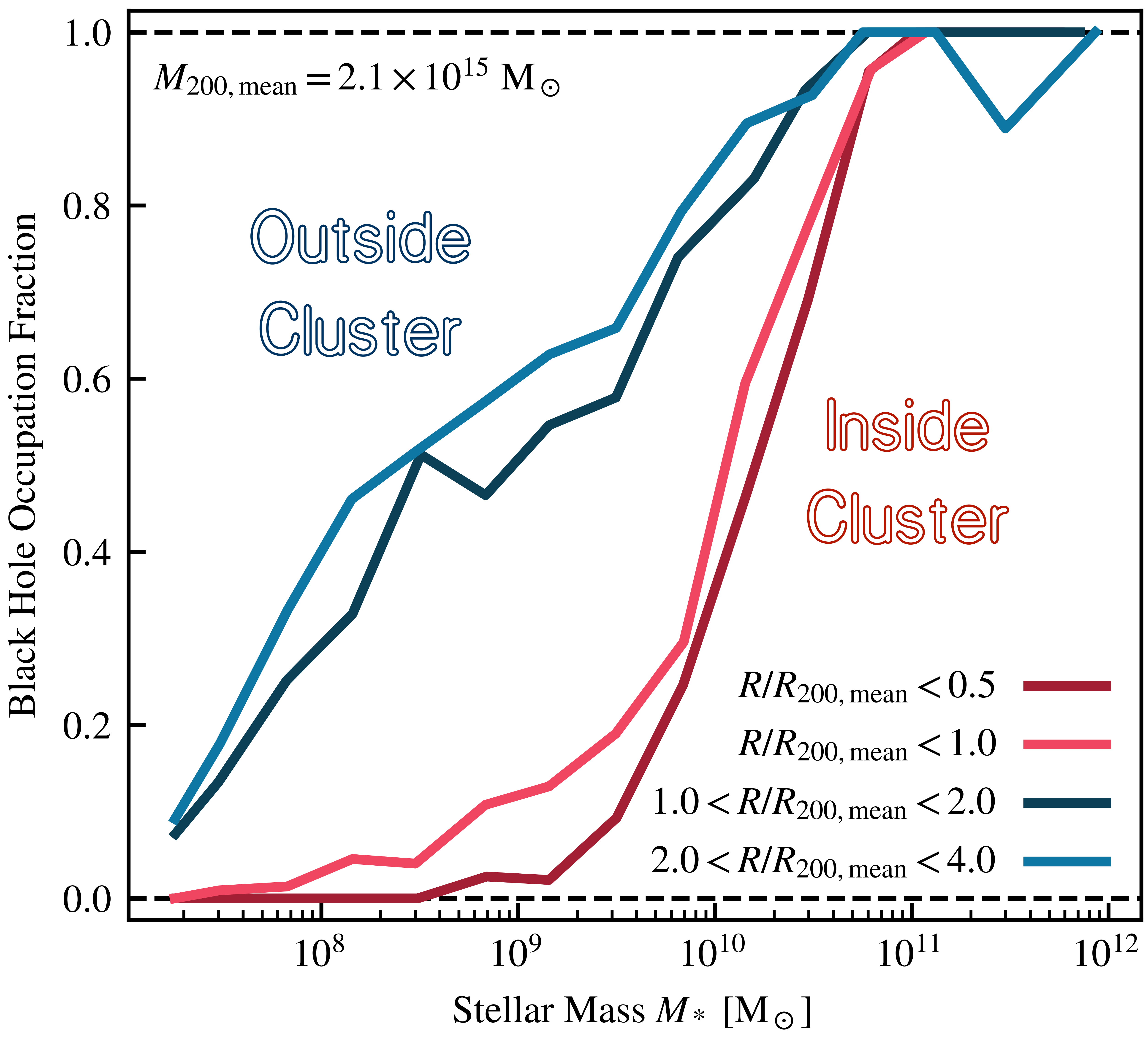
Black Holes?

- Black holes are being stripped when galaxies reach a gas fraction of zero.
- This is a consequence of the respositioning scheme used in all large-volume cosmological simulations.
- BHs are moved on top of (including velocity) a nearby particle with the lowest potential.
- As galaxies are stripped, or kinematically distinct particles are used, BHs are lost!
- At turnaround, galaxies are re-seeded with a new BH.



How Common is This?

- In our testing, almost all post-pericenter galaxies have no black hole, unless they have been re-seeded. This can be seen in the occupation fractions.
- However - TNG & other simulations that use BH seeding don't actually predict BH occupation fractions.
- AGN in cluster galaxies not significant as they have gas fractions of zero (?).
- BH growth is set by calibrated parameters (e.g. alpha in Bondi formula), so extra growth from this has been 'calibrated out' (?).



Conclusions

- Backsplash galaxies are abundant in the universe, and the best place to look is galaxies in $1 < R / R_{200,mean} < 1.4$ of a cluster, and at galaxies with no detectable gas emission and red colours.
- These galaxies have interesting physical properties, mainly set by their interaction with the cluster - tidally heated cores, stripped outskirts, and are subject to ram pressure stripping. Simulations are known to have modeling errors with all of these, so backsplash galaxies are a great place to look for offsets between simulations and data.
- These findings were ‘suggested’ by a ML model, which also led us to investigate the black hole occupation of these galaxies, which is affected by numerical quirks. Suggests using ML classifiers as ‘truth’ is dangerous - equally likely to pick up on modeling quirks as they are physical properties (hopefully humans are better at this).

Weinberger+ 2018

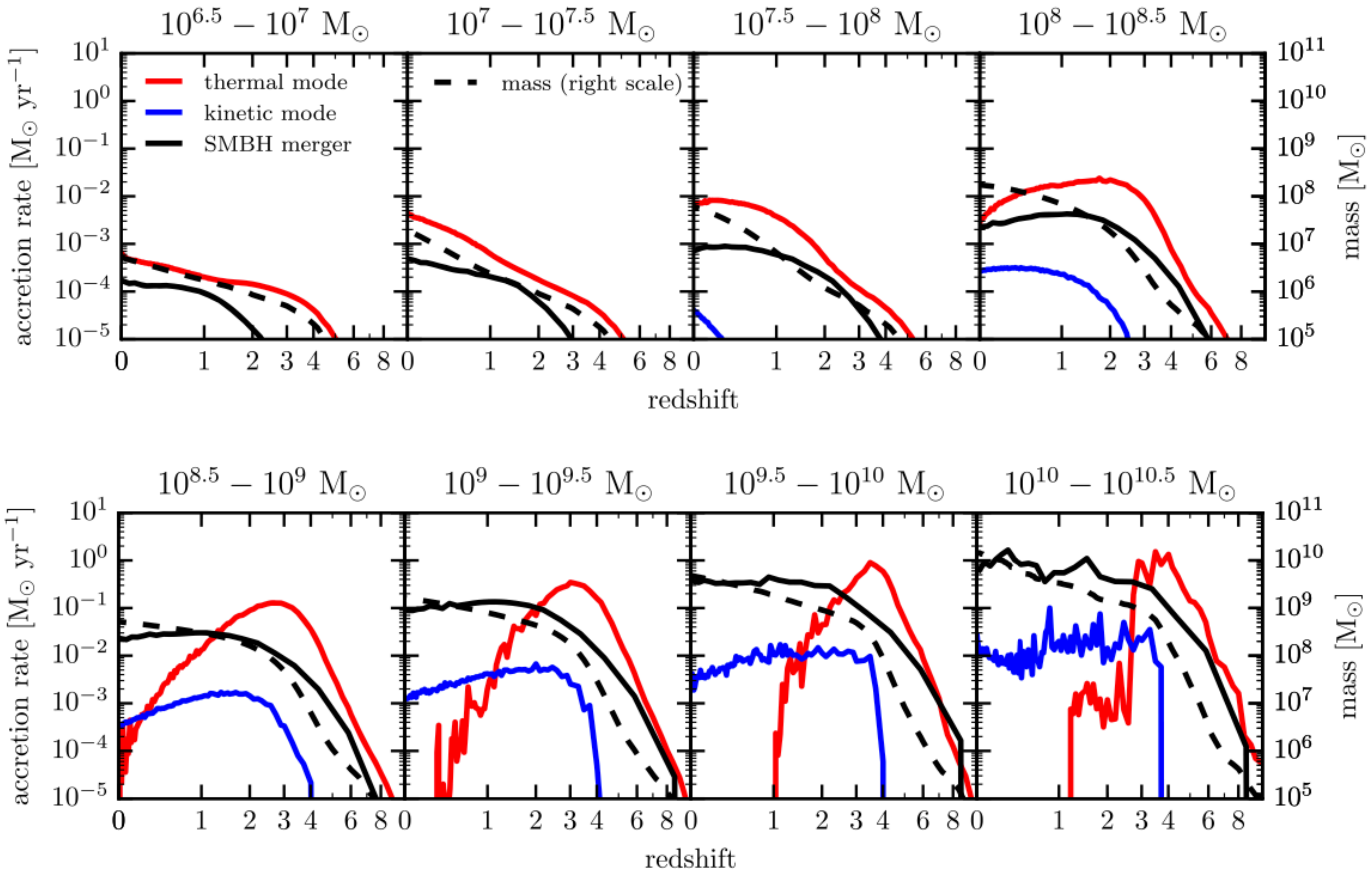


Figure 7. Mean mass growth history of SMBHs of different final masses, split up by gas accretion in thermal (red) and kinetic (blue) feedback modes, as well as via mergers with lower mass SMBHs (solid black). The more massive progenitor in an SMBH merger defines the main branch of an SMBH, while the less massive SMBH contributes to the merger (solid black) line. The dashed black lines indicate the average mass of the SMBHs at a given redshift. Low-mass black holes grow via accretion in the thermal mode, while high-mass black holes have a rapid accretion phase at high redshift, until they reach a mass of $\sim 10^{8.5}$ M$_\odot$, and build up most of their mass via mergers at later times.