Inter-Lagrangian Baryon Transfer in the SIMBA Simulations

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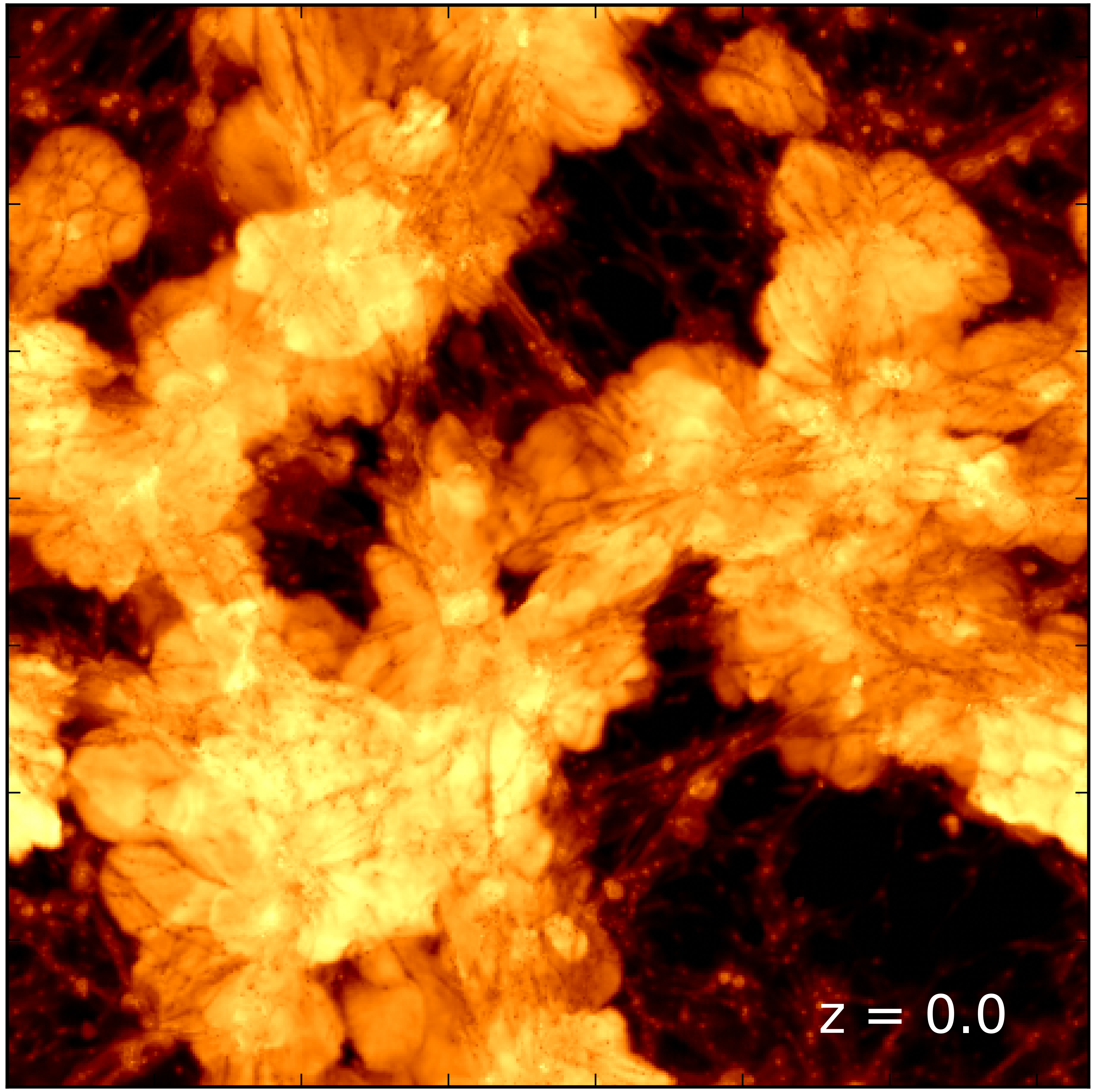
Overview

- The SIMBA simulation suite
- Feedback models
- Novel metrics for studying the movement of baryons
- What can we learn from transfer?
- Future work

SIMBA

- New cosmological simulation suite
- Sub-grid parameters based on scalings from FIRE (Hopkins+ 2018)
- Includes a sophisticated AGN feedback model



Temperature map (z=0) for the 50 Mpc/h SIMBA volume (Dave+ 2019)

Feedback Models

- BH accretion uses torque model from Angles-Alcazar+ 2017.
- At low Eddington rations ($f_{edd} < 0.2$) jet modes are introduced into the AGN feedback model.
- These have a velocity cap at $f_{edd} = 0.02$ of 10^4 km/s.
- Jets are ejected perpendicular to the disk.

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Gravitational torque-driven black hole growth and feedback in cosmological simulations

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ABSTRACT
We investigate black hole–host galaxy scaling relations in cosmological simulations with a self-consistent black hole growth and feedback model. Our sub-grid accretion model captures the key scalings governing angular momentum transport by gravitational torques from galactic scales down to parsec scales, while our kinetic feedback implementation enables the injection of outflows with properties chosen to match observed nuclear outflows (star formation-driven winds are not included to isolate the effects of black hole feedback). We show that 'quasar mode' feedback can have a large impact on the thermal properties of the intergalactic medium and the growth of galaxies and massive black holes for kinetic feedback efficiencies as low as 0.1 per cent relative to the bolometric luminosity. None the less, our simulations indicate that the black hole–host scaling relations are only weakly dependent on the effects of black hole feedback on galactic scales, since black hole feedback suppresses the growth of galaxies and massive black holes by a similar amount. In contrast, the rate at which gravitational torques feed the central black hole relative to the host galaxy star formation rate governs the slope and normalization of the black hole–host correlations. Our results suggest that a common gas supply regulated by gravitational torques is the primary driver of the observed co-evolution of black holes and galaxies.

Key words: galaxies: active – galaxies: evolution – galaxies: formation – intergalactic medium – quasars: supermassive black holes – cosmology: theory.

1 INTRODUCTION

The energy released by accretion on to supermassive black holes may have a profound effect on the evolution of galaxies (Silk & Rees 1998; Somerville et al. 2008; Cattaneo et al. 2009). Indeed, contemporary models of galaxy formation appear to require feedback from active galactic nuclei (AGN) to suppress star formation in galaxies at high masses (Somerville & Davé 2015). Recent years have seen increasing observational evidence for AGN feedback, from radio-emitting jets powered by slowly accreting black holes to powerful winds driven by quasars (Fabian 2012; Heckman & Best 2014). While the overall effect is still unclear, the energy and momentum inferred from observed fast nuclear outflows (e.g. Tombesi et al. 2013; Nardini et al. 2015) and galaxy-scale winds (e.g. Feruglio et al. 2010; Rupke & Veilleux 2011; Sturm et al. 2011; Greene, Zakamska & Smith 2012; Maiolino et al. 2012; Liu et al. 2013; Cicone et al. 2014; Harrison et al. 2014) suggest that AGN feedback may have a significant impact on the evolution of massive black holes as well, particularly during phases of rapid growth where most black hole mass is believed to assemble (Soltan 1982; Yu & Tremaine 2002).

The observed correlations between the mass of central supermassive black holes and various stellar properties of their host galaxies (e.g. Häring & Rix 2004; Hopkins et al. 2007b; Gültekin et al. 2009; Graham & Scott 2013; McConnell & Ma 2013; Woo et al. 2013; van den Bosch 2016) are often interpreted as indirect evidence for the effects of feedback from black hole accretion on galactic scales.

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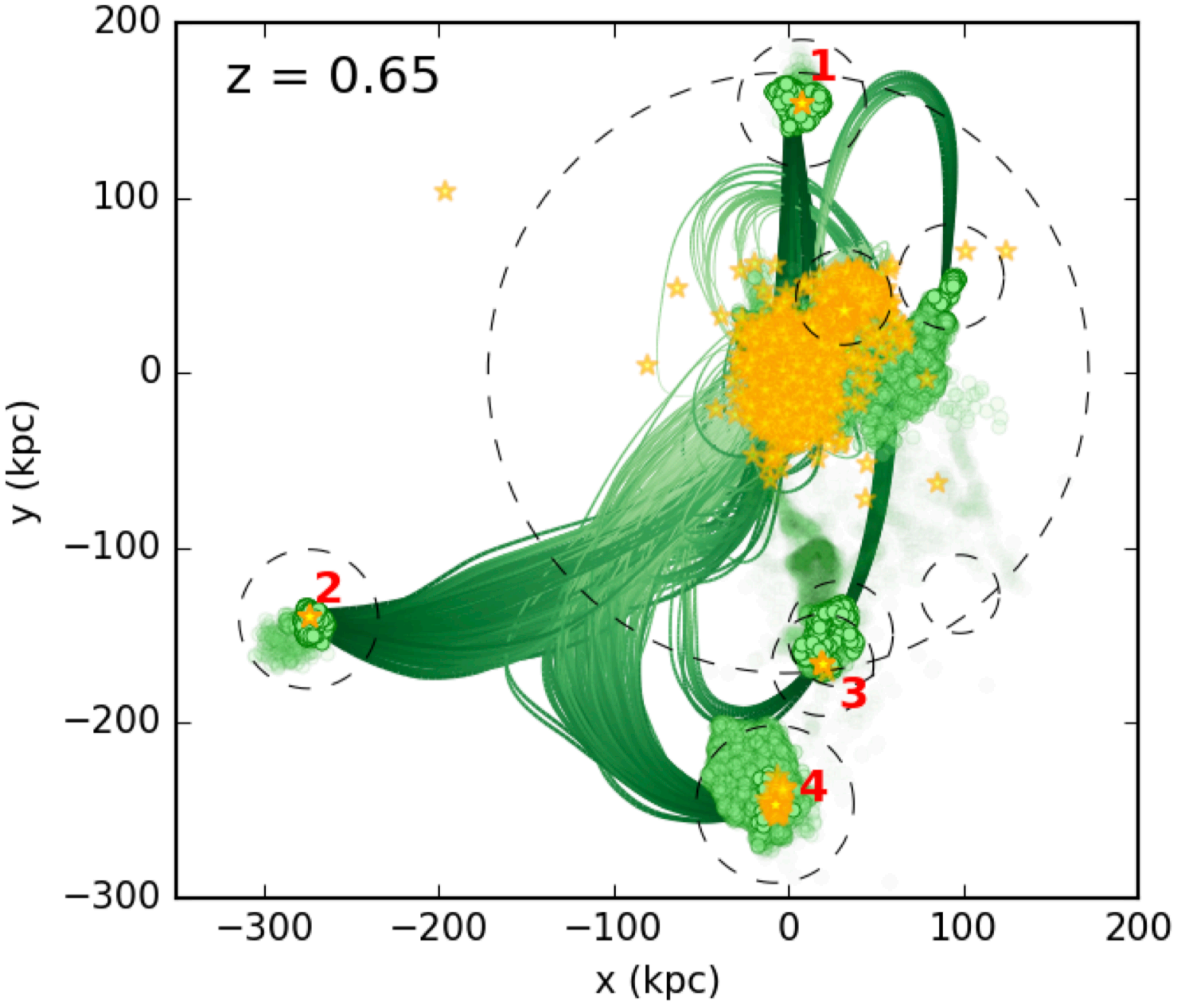
Physical Motivation

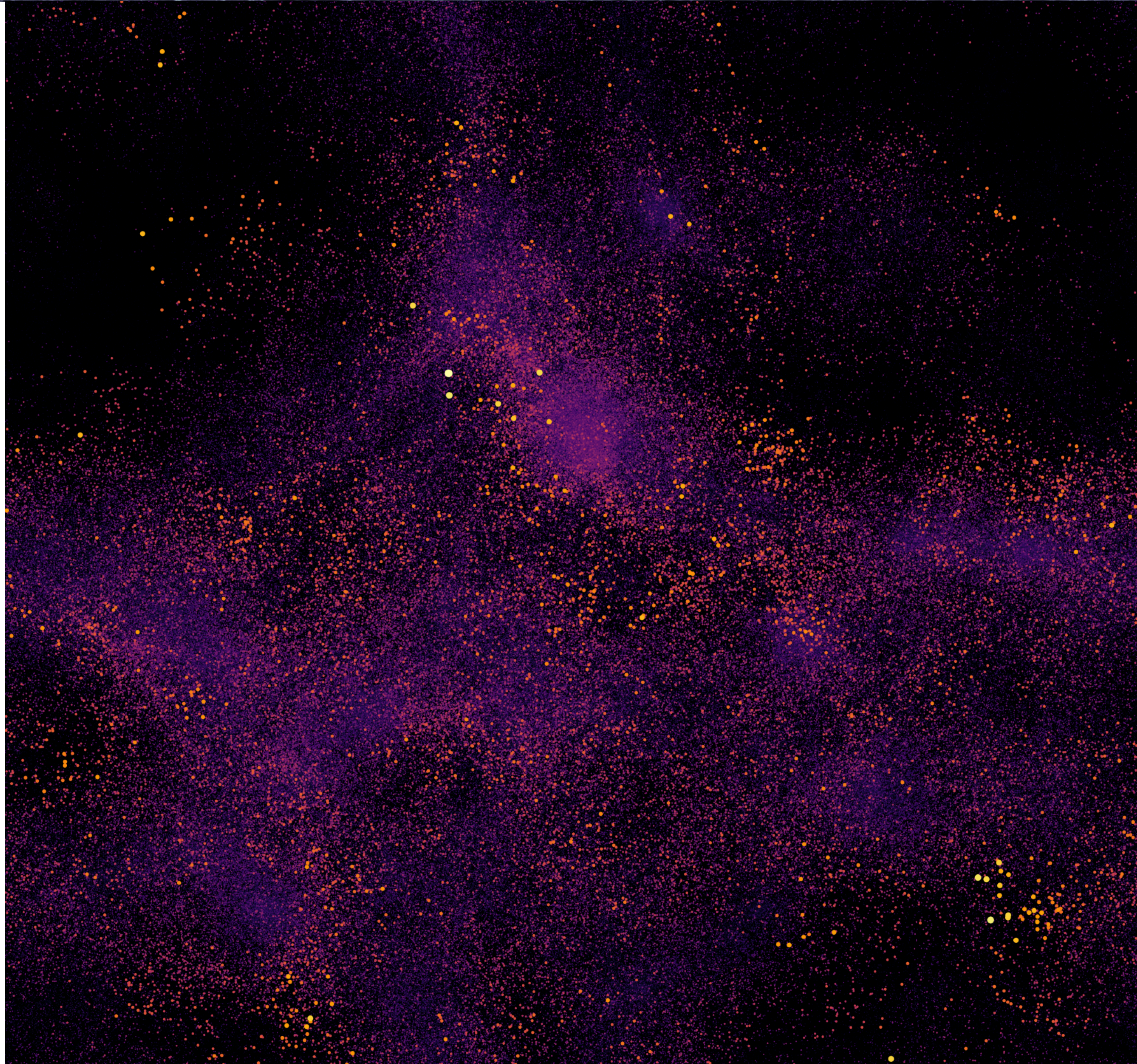
- Feedback causes gas to be blown out of galaxies
- This is especially true in simulations that include AGN feedback
- Where does that gas go?



Angles-Alcazar+, Baryon Cycling and Galaxy Assembly on FIRE, 2017

Let's talk about metrics

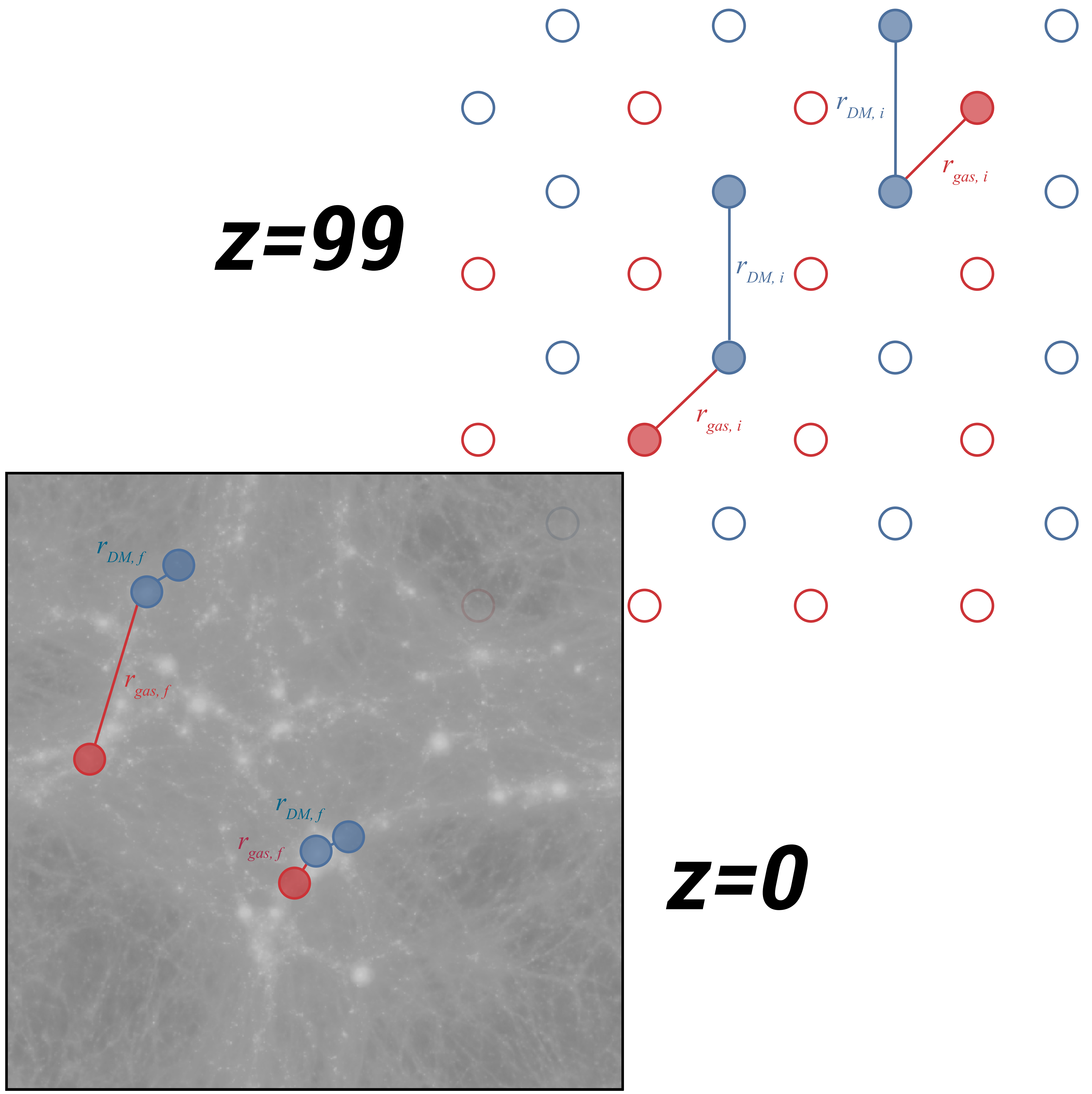
- The effect of feedback itself is hard to quantify
- Can see effect on GSMF, etc. indirectly
- Very few direct metrics exist
- Have to run simulations with/out; these are usually invalid because of calibration.



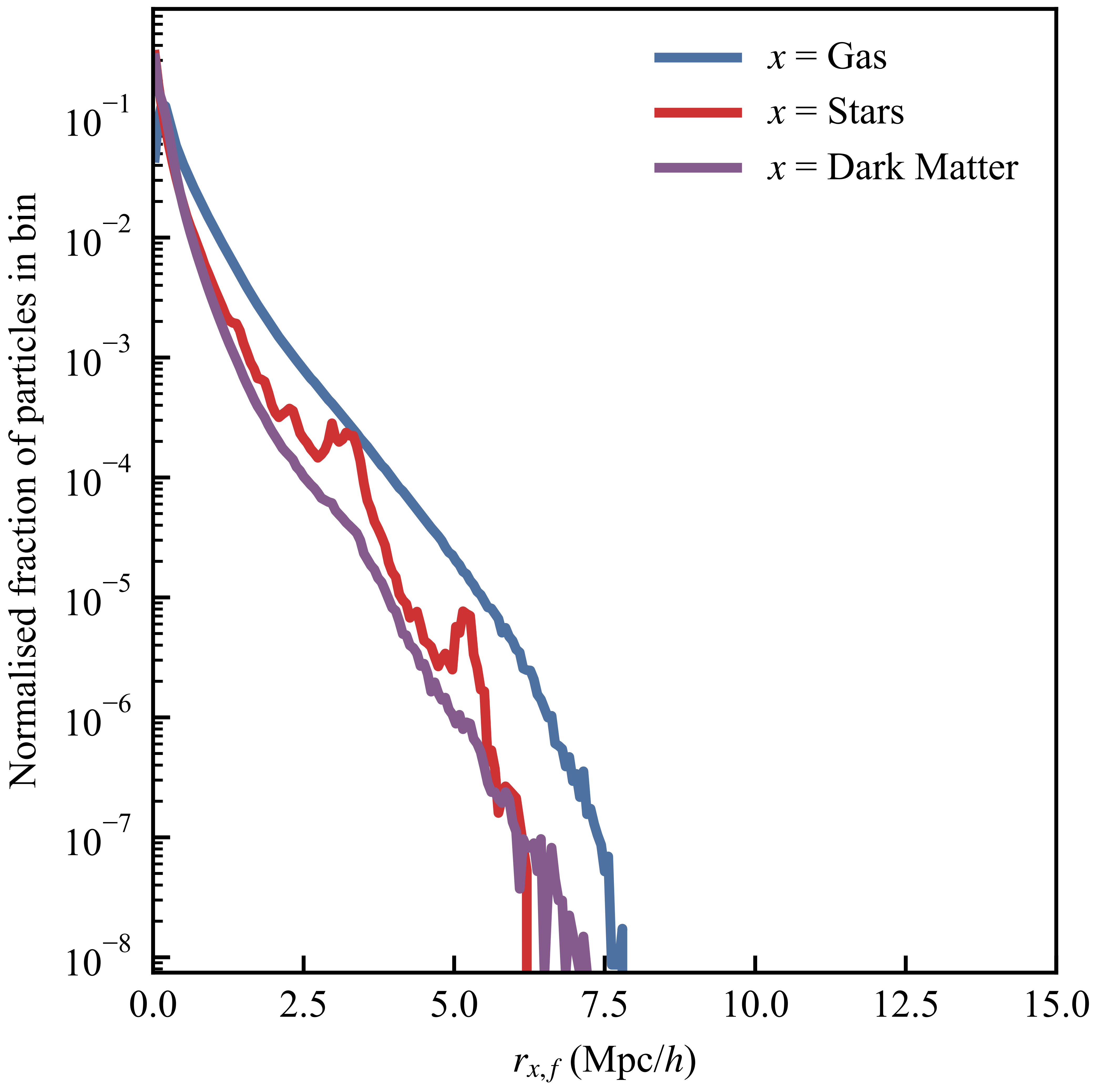
1/100th of particles in box, coloured by distance moved

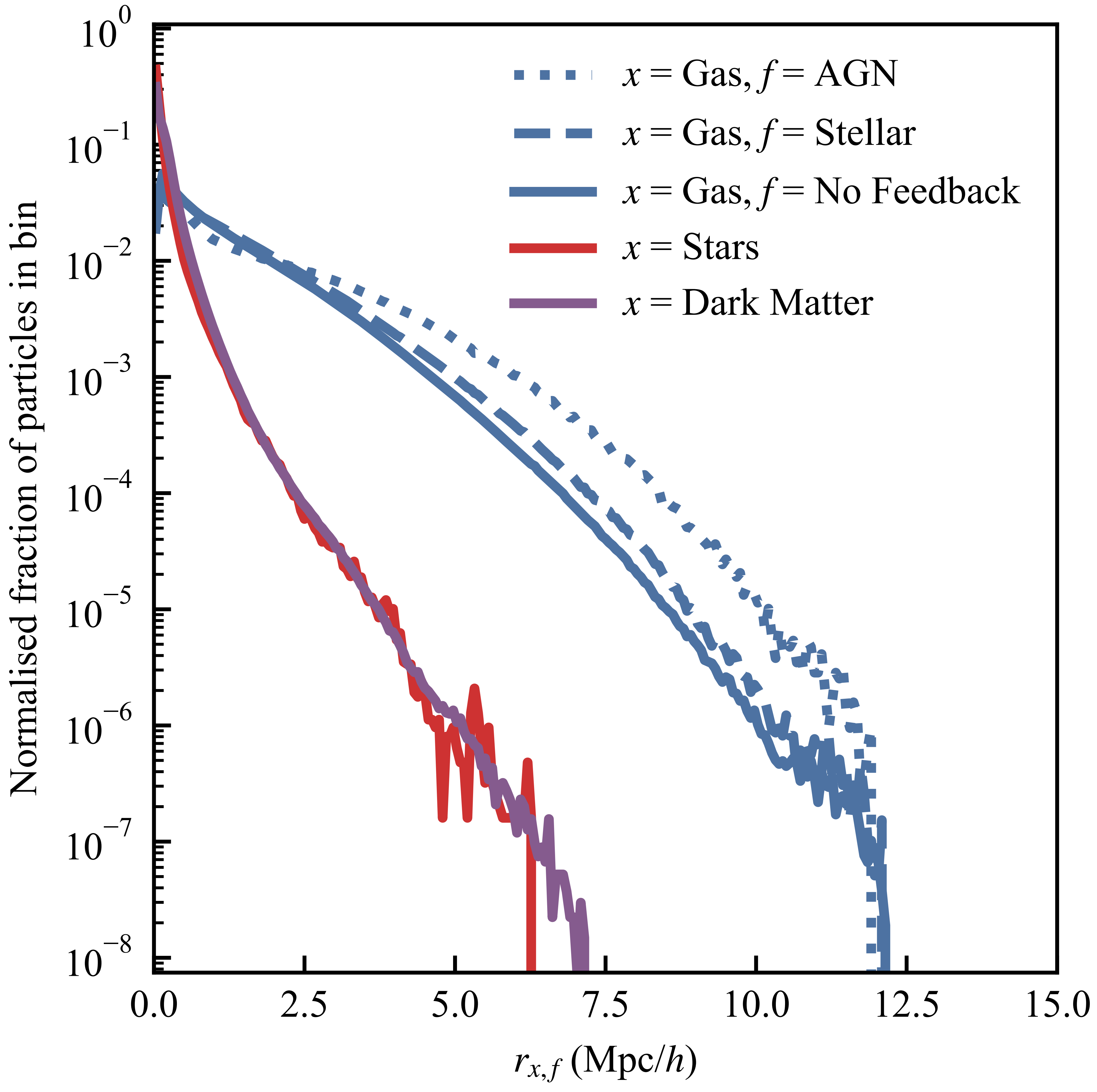
The spread metric

- For every particle *i* in the initial conditions, find the nearest dark matter neighbour *j*.
- In the final conditions, match all remaining baryonic particles with their initial conditions progenitor (in this case, stars are matched with their gas progenitor).
- In the final conditions, find the distance r_{ij}, i.e. the distance between the original neighbours.



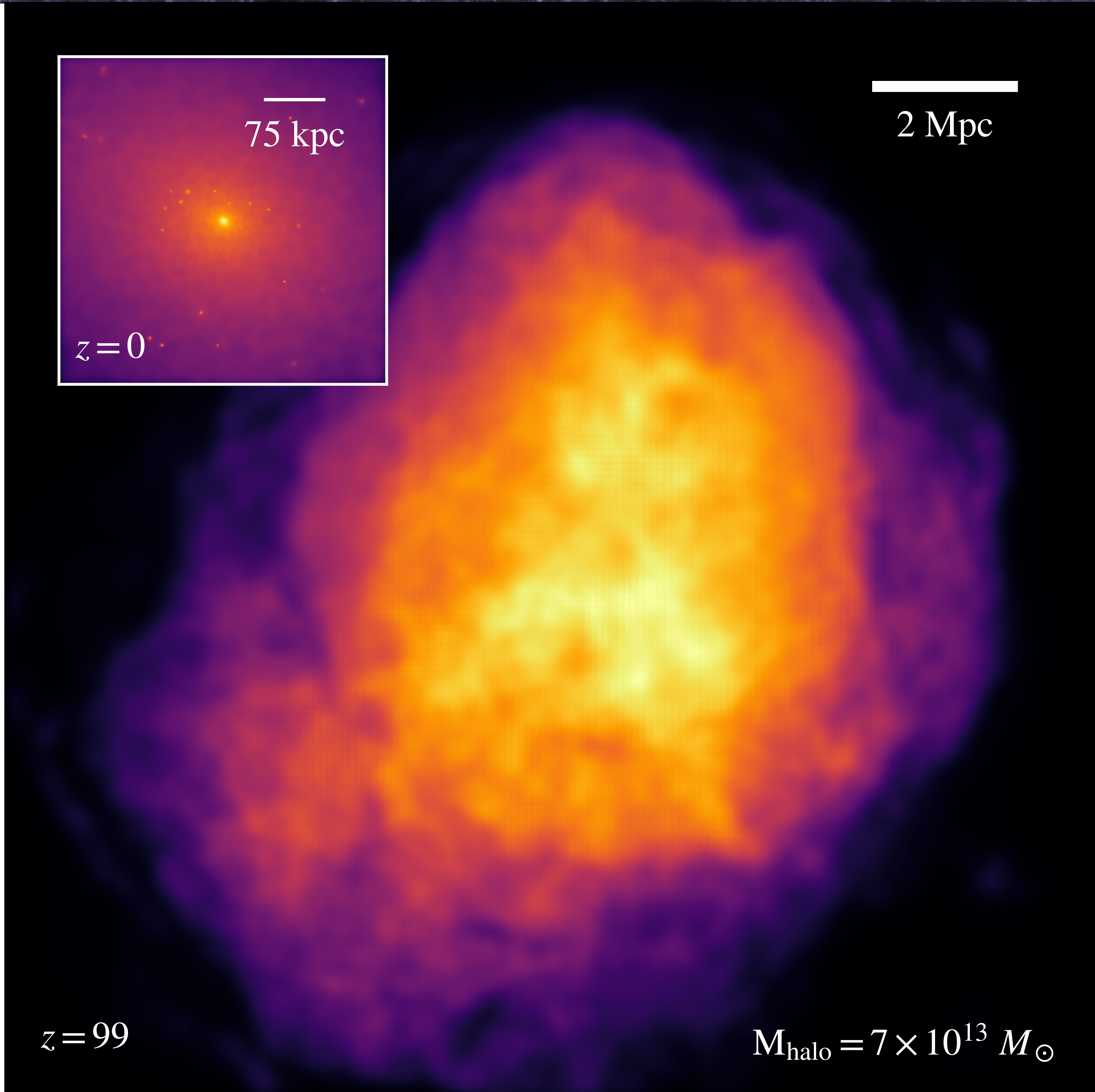
NoJet (L) v.s. full model (R)





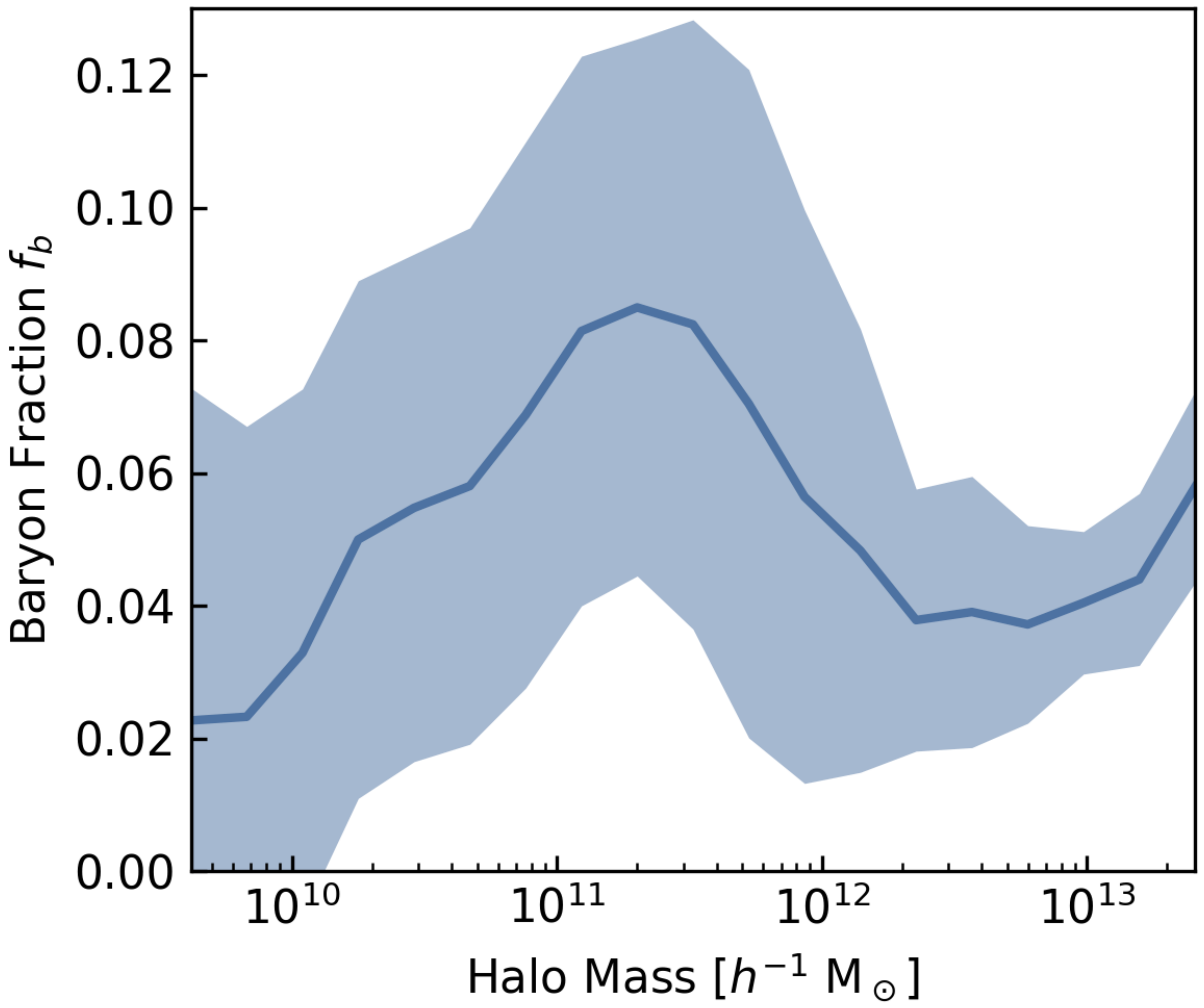
Lagrangian regions

- Define the "Lagrangian region" by the dark matter of a collapsed object at z=0
- Look at the spatial region those particles are spread over in the ICs
- Extend to gas using nearest neighbour searching

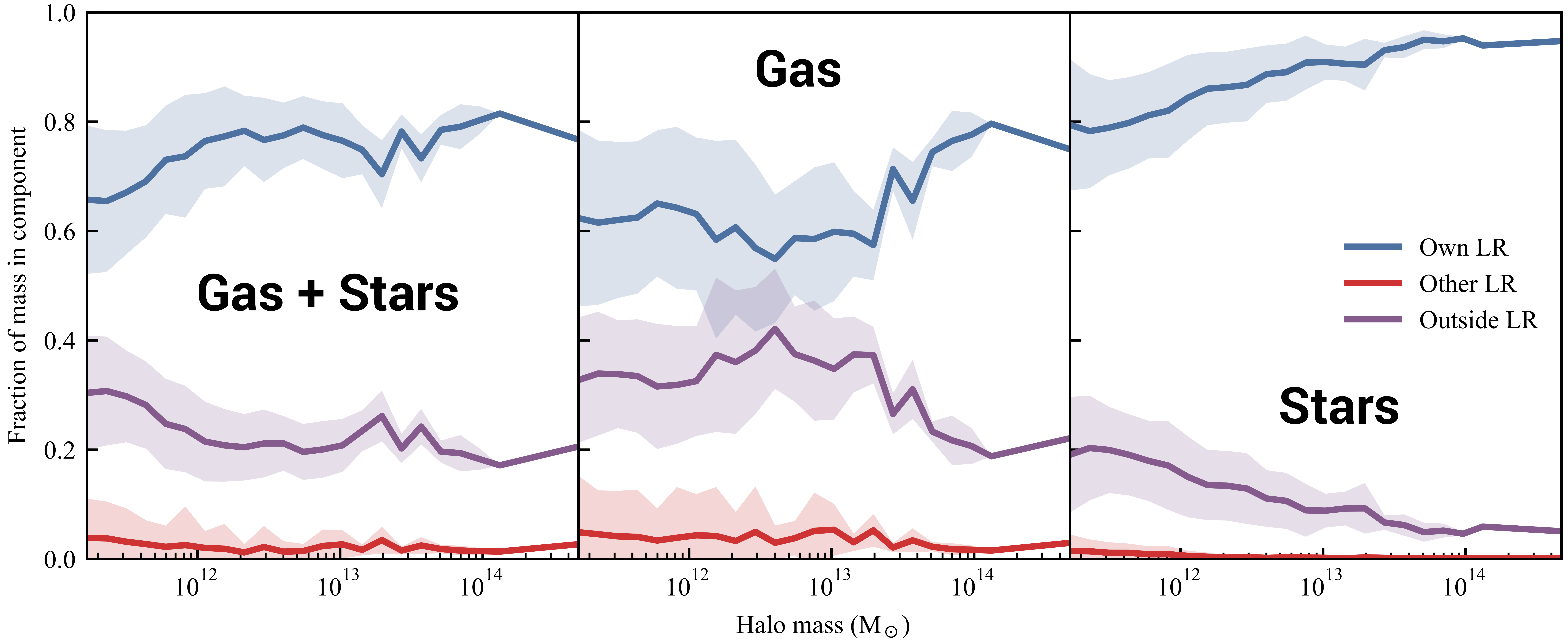


Defining inter-Lagrangian transfer

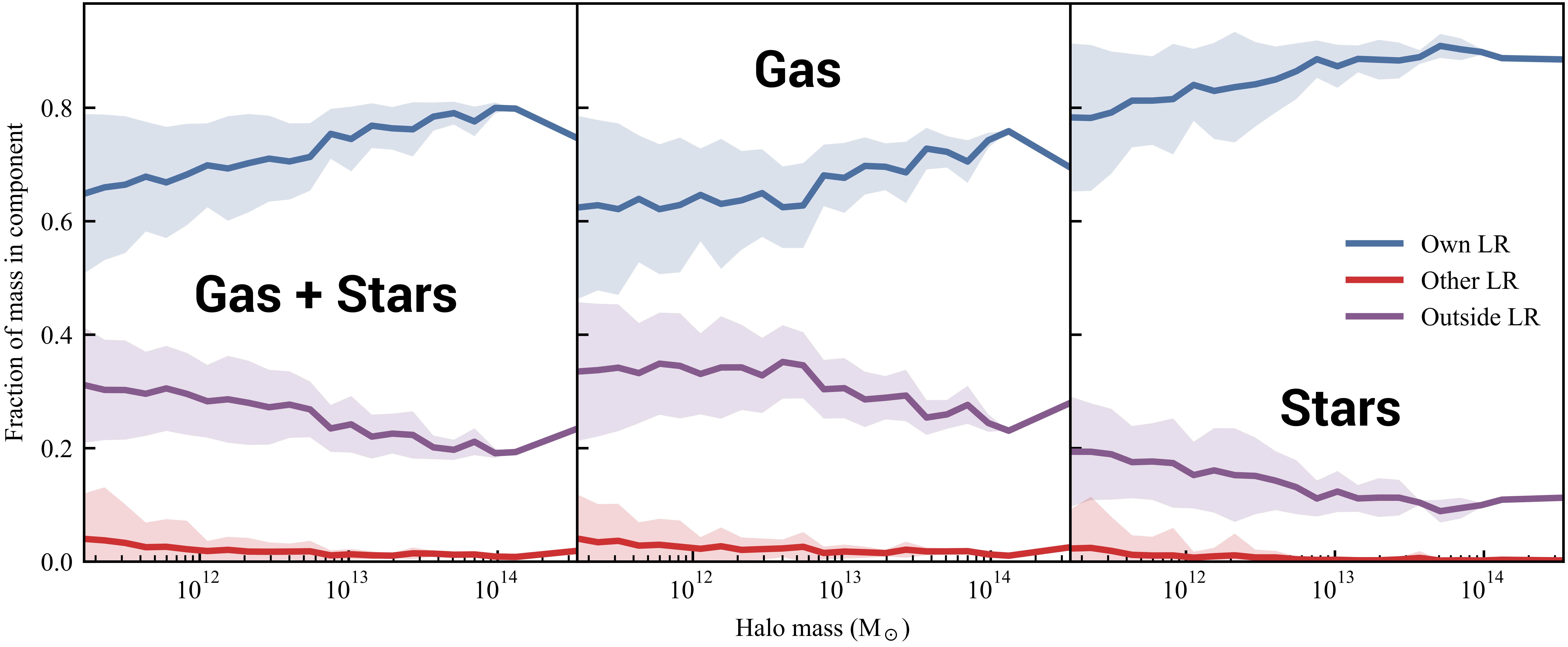
- Use VELOCIraptor (6D FoF) to define halos (variable linking length for 6D FoF, *b=0.2* for basic 3D initially)
- Particles are then tracked from initial conditions to final conditions through ID matching.



BTMF (Baryon Transfer Mass Functions)



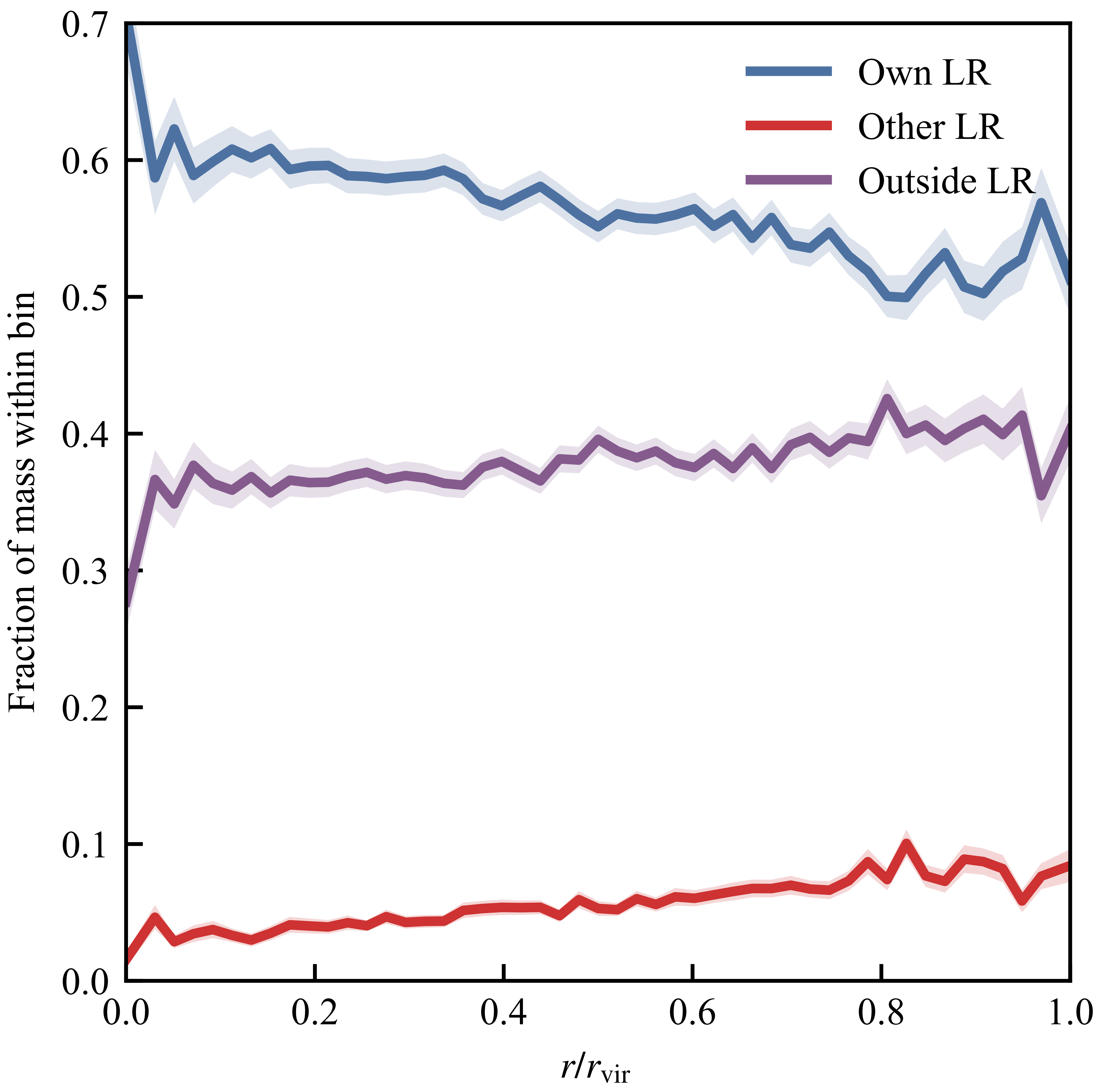
BTMF (NoJet)



Fraction of mass in component
0.0
0.2
0.4
0.6
0.8
Gas + Stars
Gas
Stars
Own LR
Other LR
Outside LR
10^{12}
10^{13}
10^{14}
Halo mass ($M_\odot$)

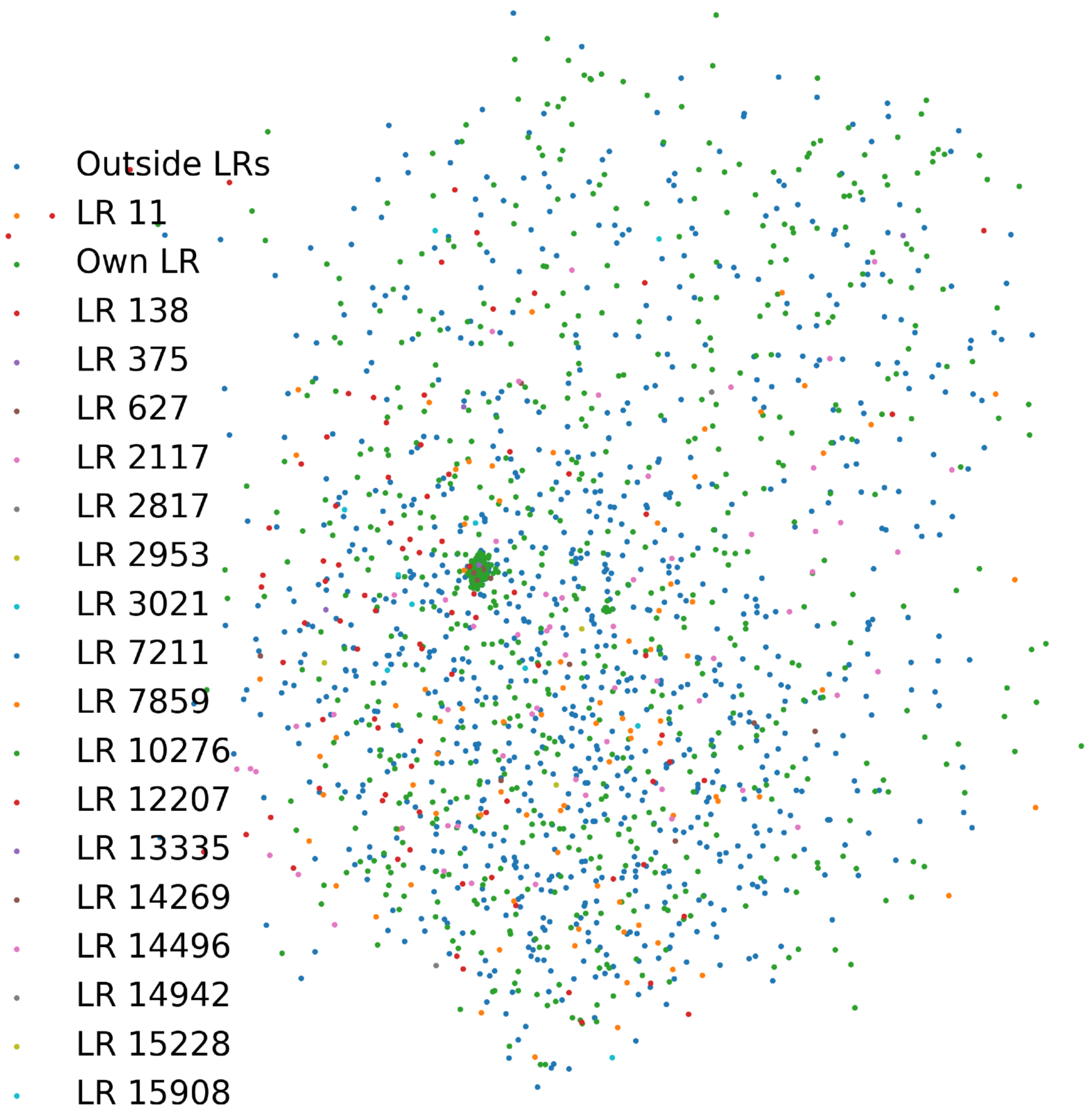
Stacking

- Take all halos with $10^{12} < M_H < 10^{13}$
- Stack their radial BTMF profiles
- Gas: solid lines
- Stars: dashed lines
- Shaded regions show scatter



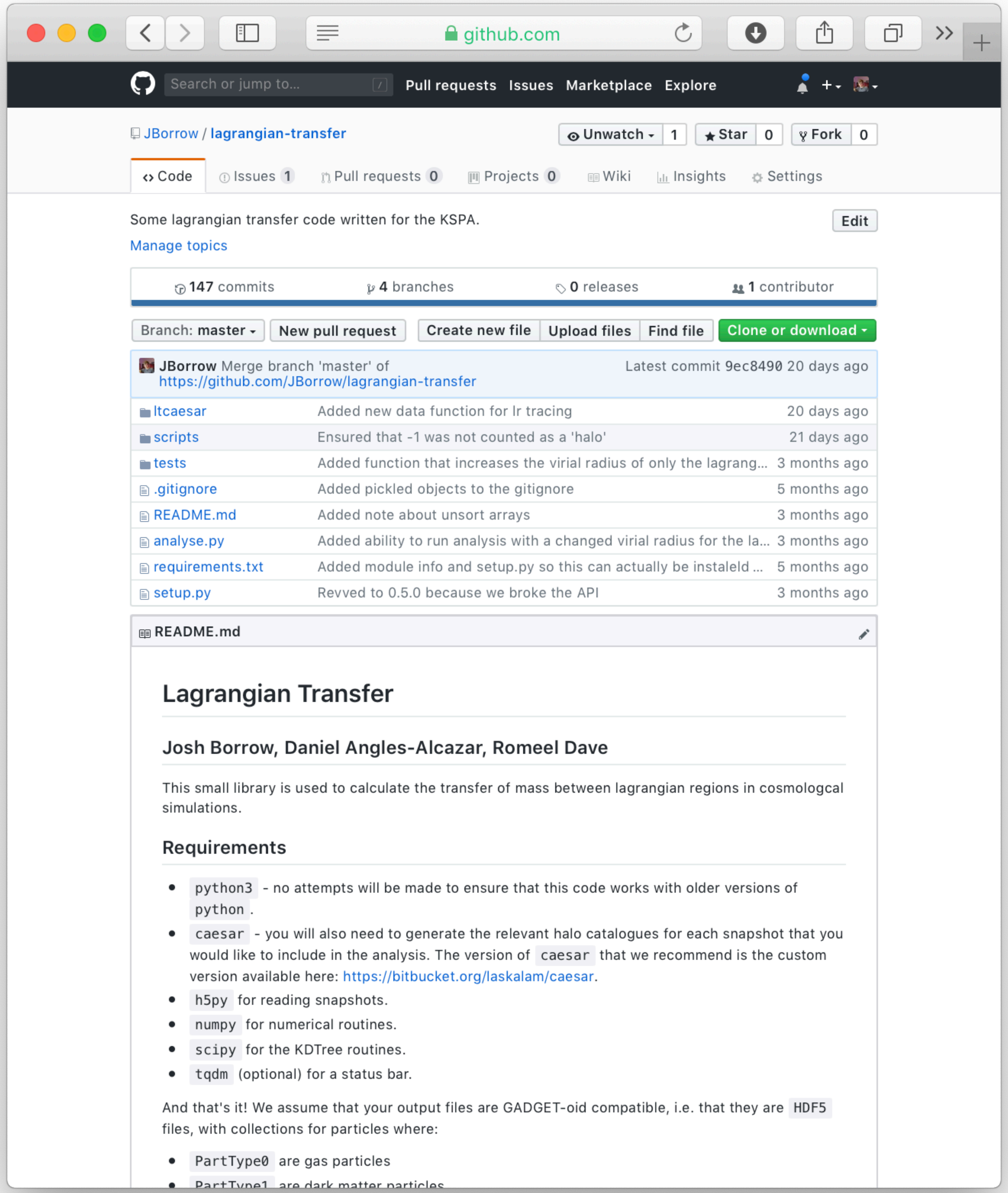
Where to go with this?

- Can use these metrics to put constraints on feedback models
- Of course, this is very difficult to measure in observations
- Can tie into metallicity measurements, etc.



LTCaesar

- LTCaesar, the code that does this matching, is fully open source and available
- We want to apply this to other simulation suites (next up EAGLE, Illustris, and maybe TNG?) so get in touch if you are interested!



Conclusions

- New feedback models include jet modes

- The impact these jet modes have is clear visually, but hard to quantify; can use the spread metric to visualise.

- Feedback drives gas flow between halos; ~5-10% of the mass of a MW-like galaxy originates from another galaxy

KAVLI
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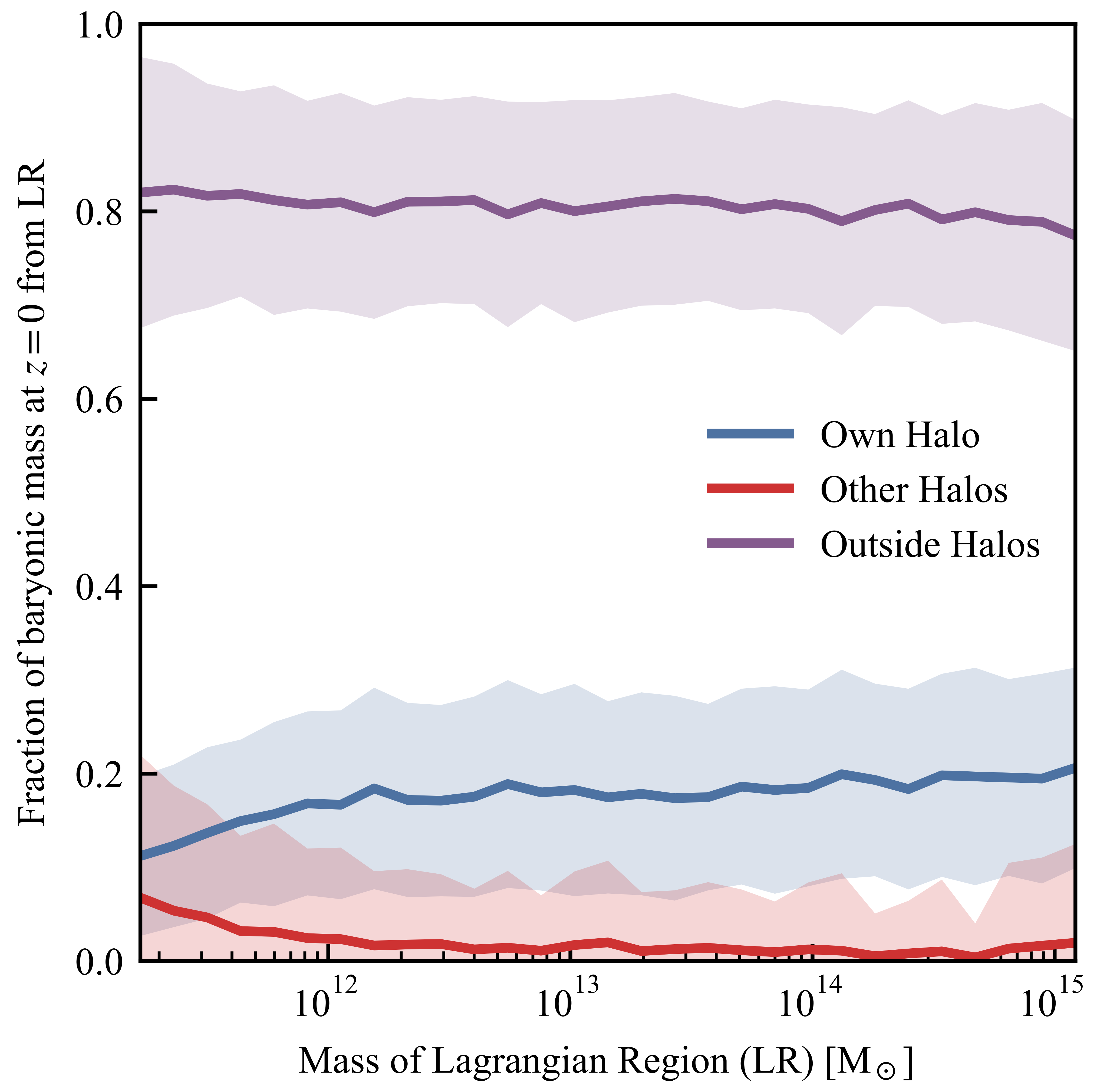
But where does it go?

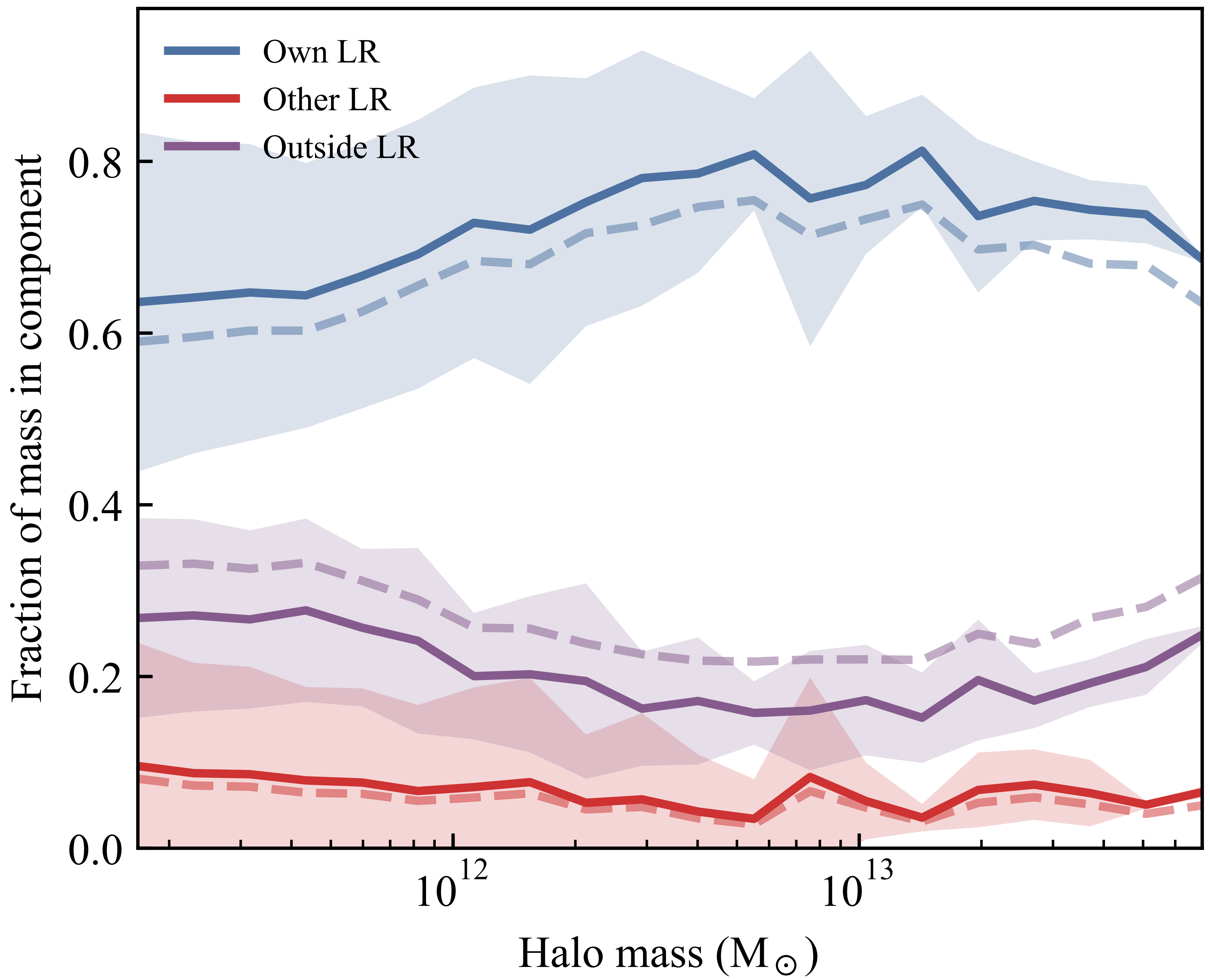
- Only 20% of the baryonic mass of a given Lagrangian region ends up in the final halo

- The rest ends up outside any LR: delayed infall and feedback out of galaxies.



Validation

Expanded r_{vir}



Smoothing LRs