Lagrangian Transfer

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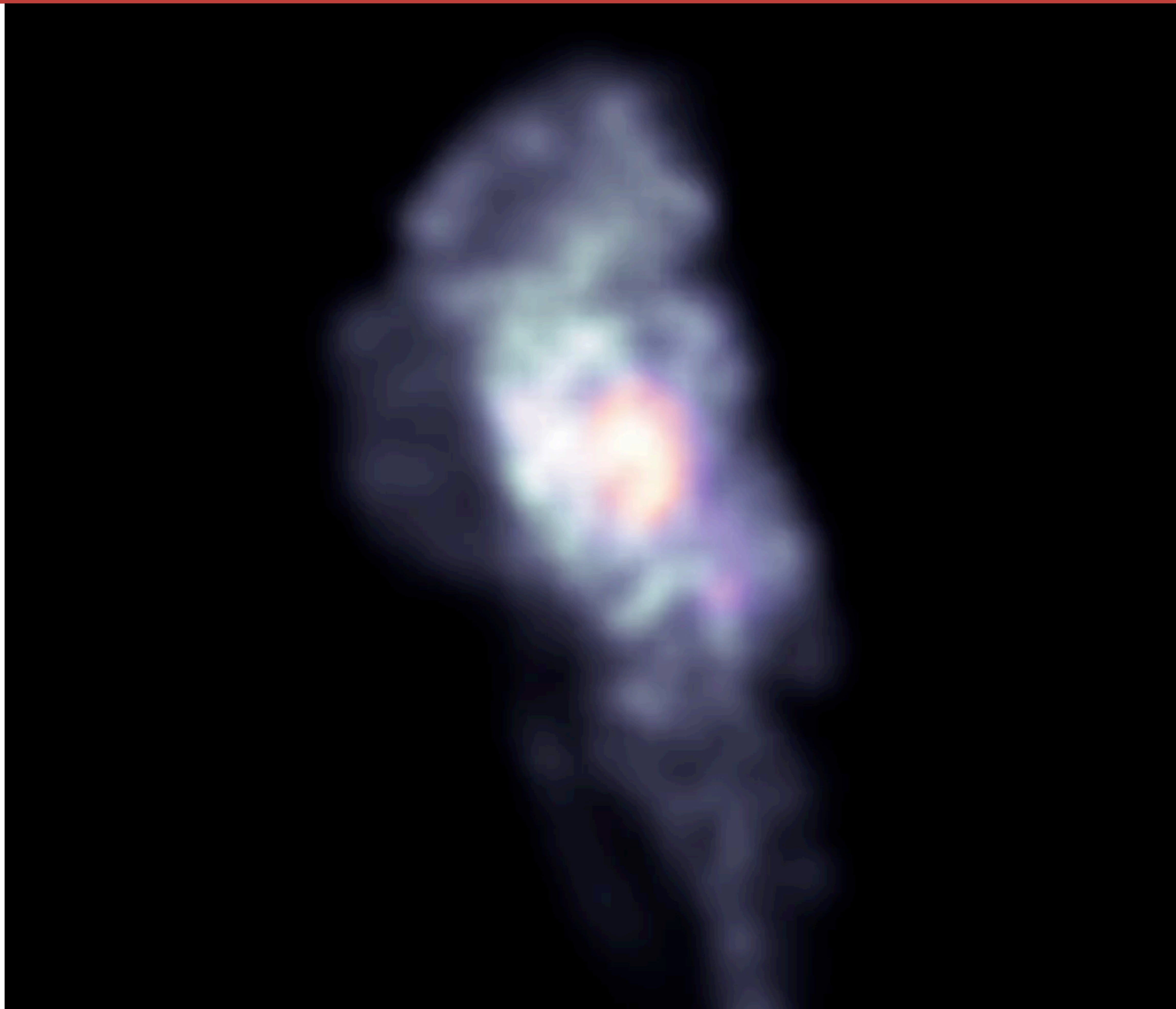
Overview

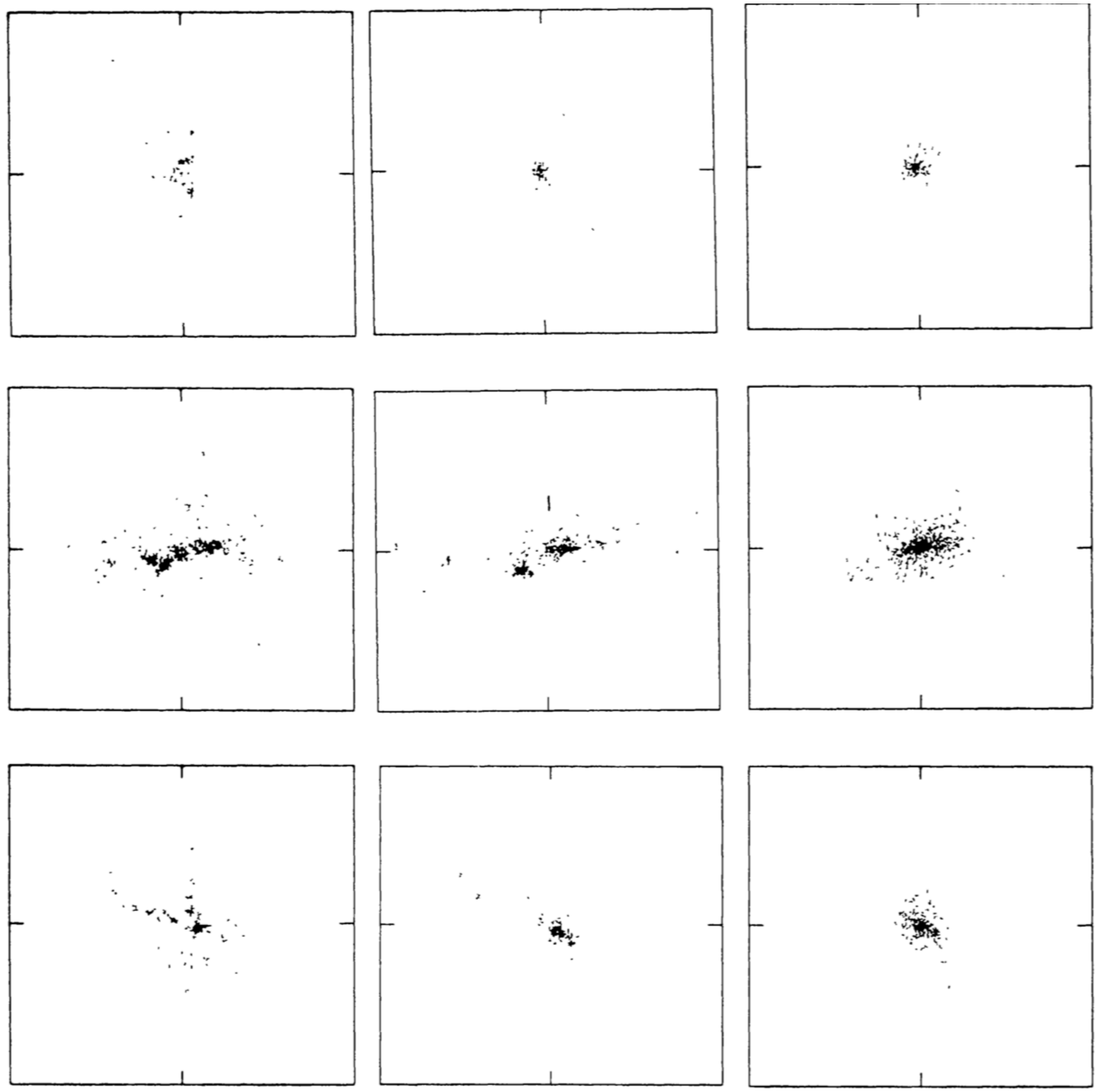
- Introduction; a short history of cosmological simulations
- Physical motivation
- What is a Lagrangian Region?
- Gas: where did it come from, where did it go?
- Conclusion



In white, the region where the gas comes from for a z=0, 10^{11} solar mass, halo. In red/purple, we see the Lagrangian region defined by the dark matter that will end up in the z=0 halo.

Back in the day...

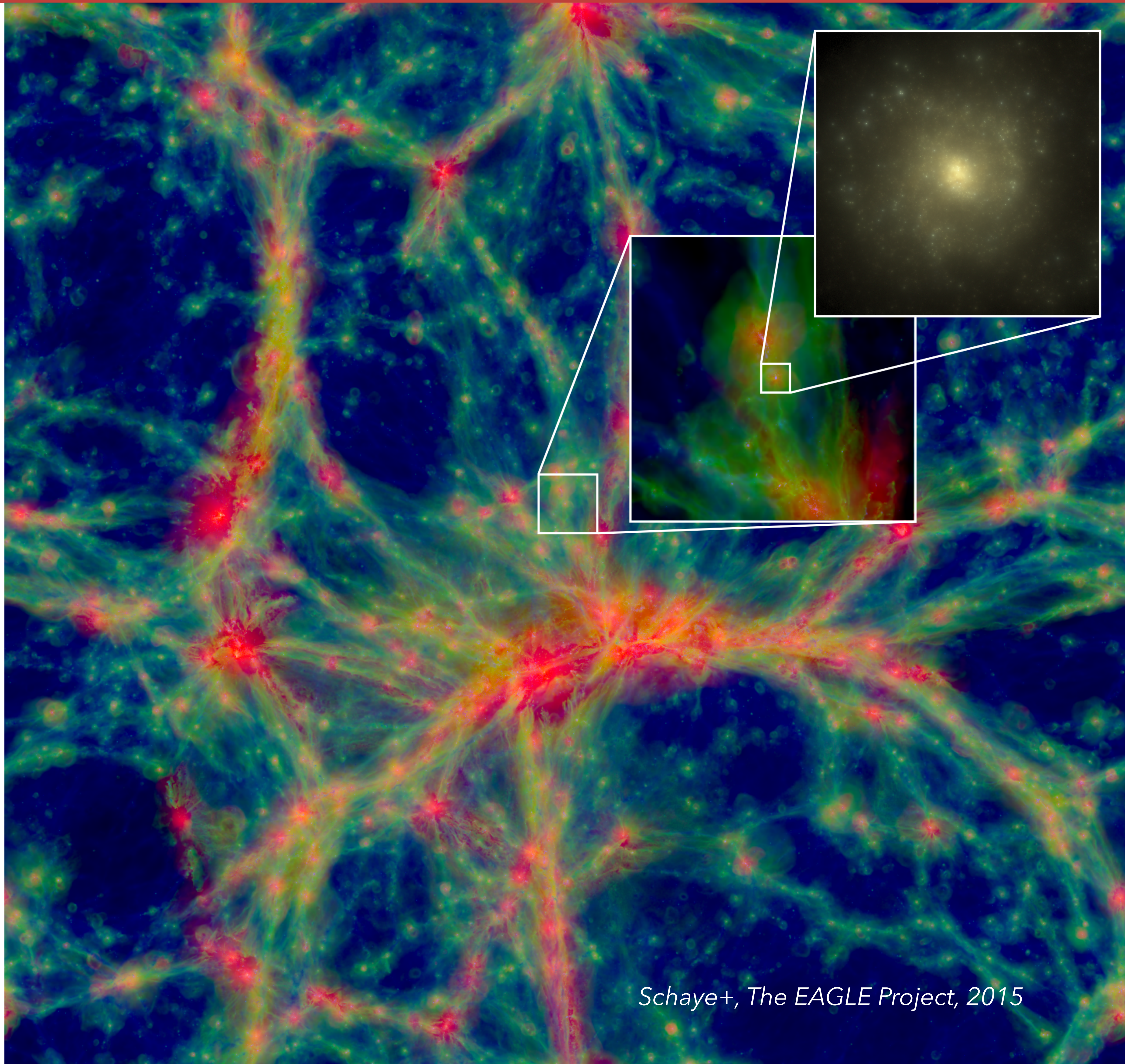
- Everything was easy!
- Forces are all attractive (i.e. only gravity)
- Dark matter follows a relatively simple path to it's final resting place at $z=0$.



Frenk, N-Body Simulations of Galaxy Formation,
Proceedings of the 130th Symposium of the International Astronomical Union, 1988

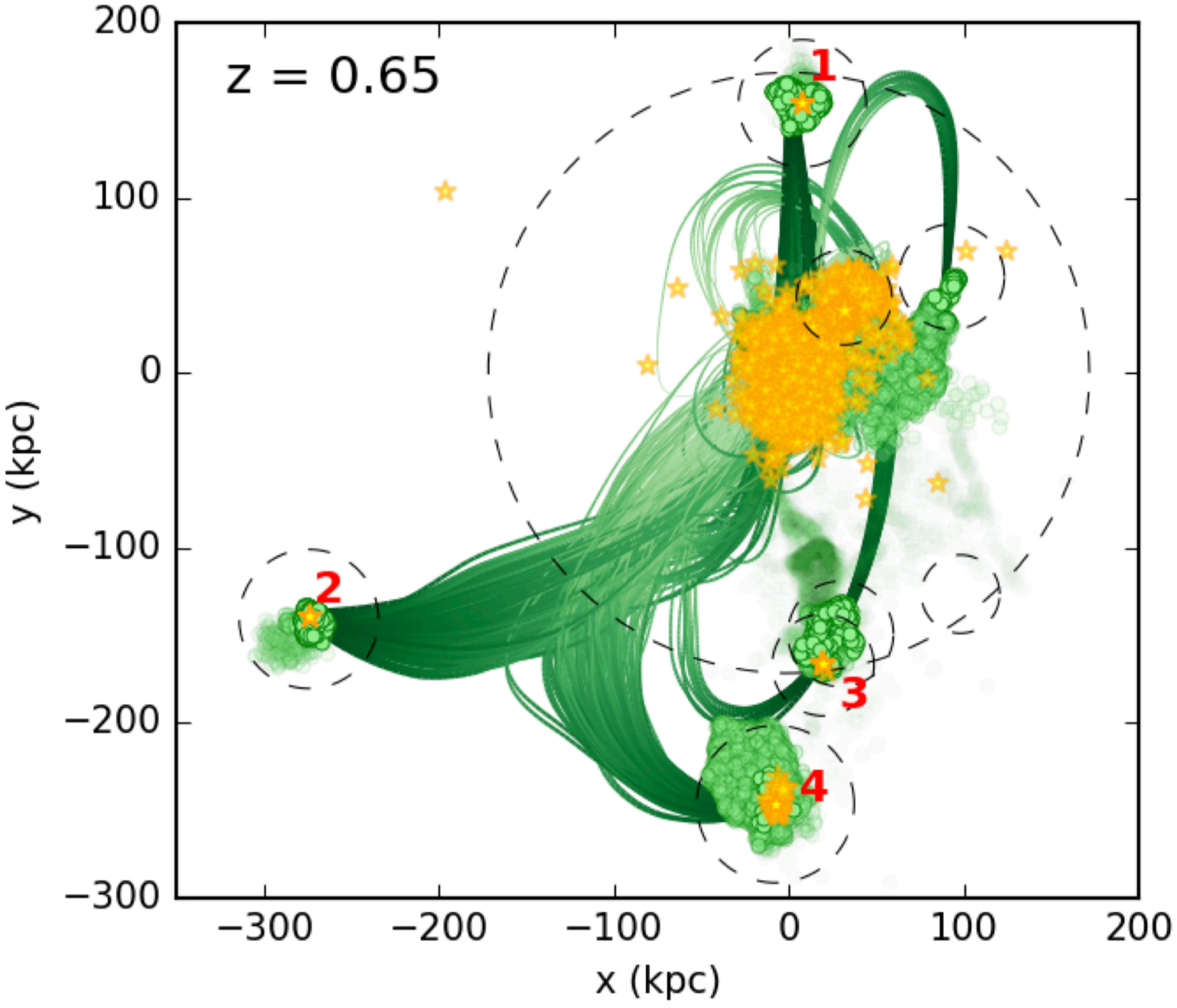
Present day state-of-the-art

- Gas dynamics, feedback models, star formation…
- Forces are now repulsive as well as attractive
- Clearly all matter no longer follows the same, simple, gravitational path as before



Physical Motivation

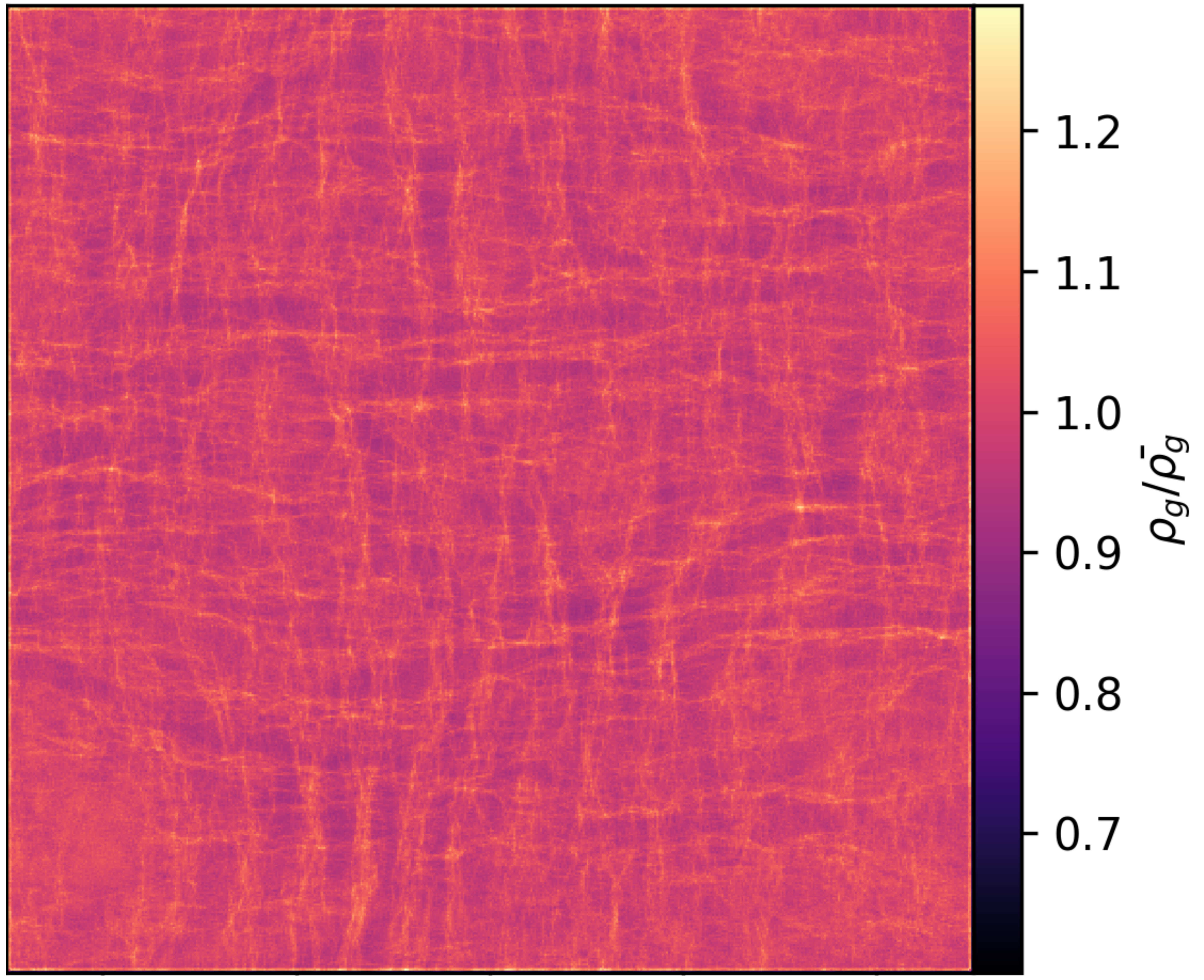
- Feedback causes *gas* to be blown out of galaxies
- This is especially true in simulations that include AGN feedback
- Where does that gas go?



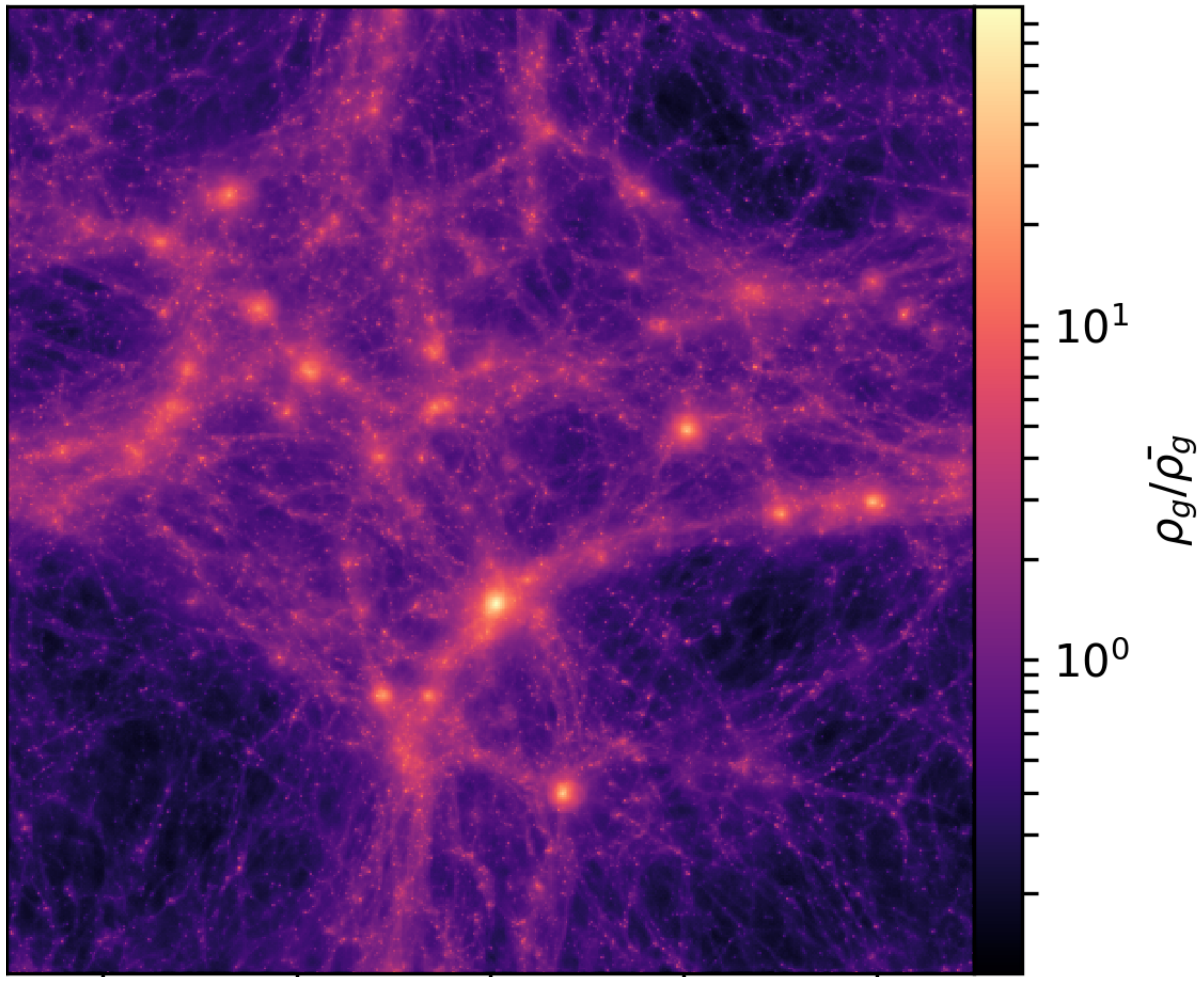
Angles-Alcazar+, Baryon Cycling and Galaxy Assembly on FIRE, 2017

Studying mass transfer

z=99

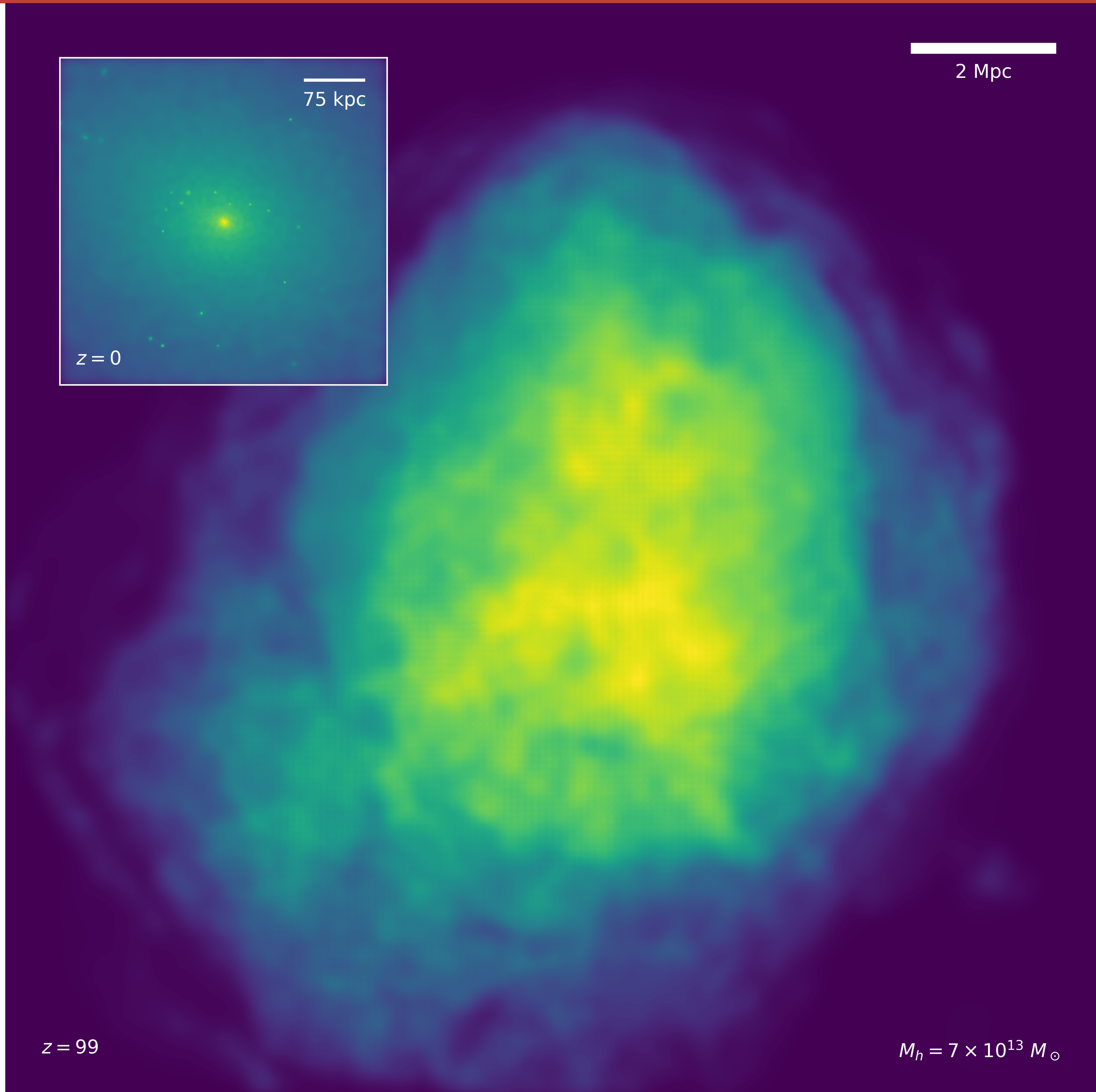


z=0



Identifying Lagrangian Regions

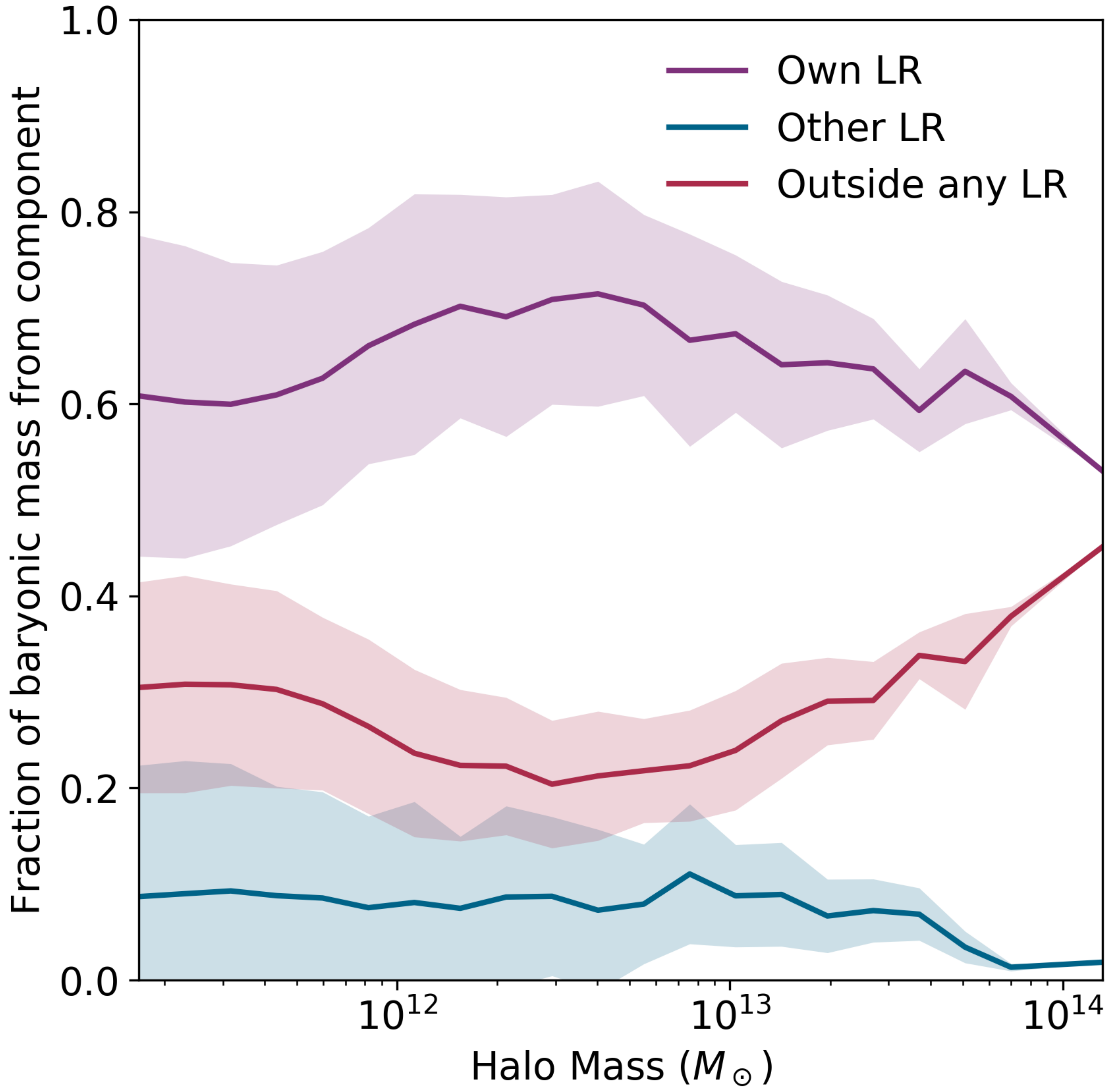
- Halos identified at *z=0* by AHF
- Dark matter defines LR
- For each gas particle, find closest DM neighbour to find appropriate LR.



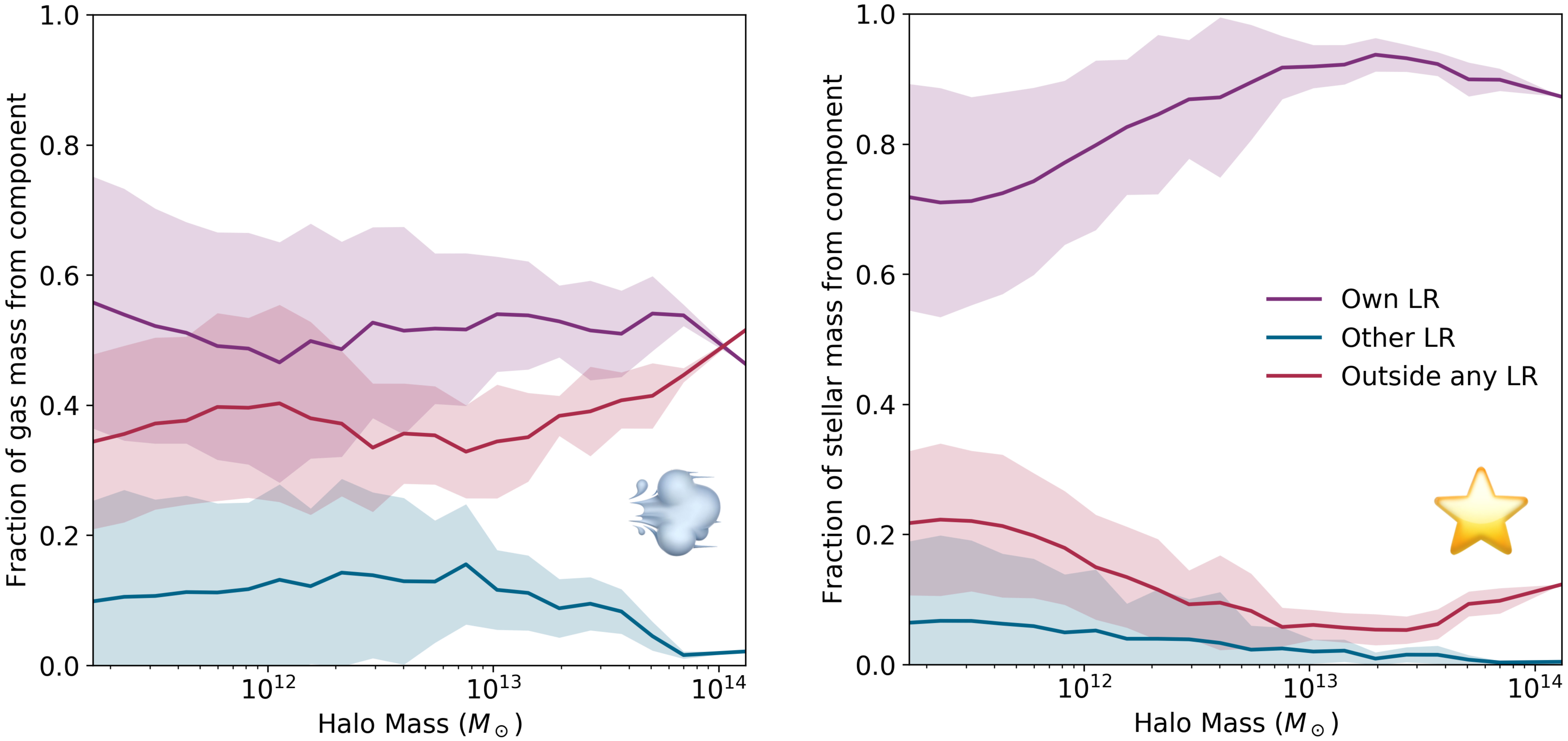
Lagrangian region for a high-mass halo in the Simba 50 Mpc box.
Zoom-in shows the corresponding halo at z=0.
Note the actual dark matter is uniform density.

Computing transfer

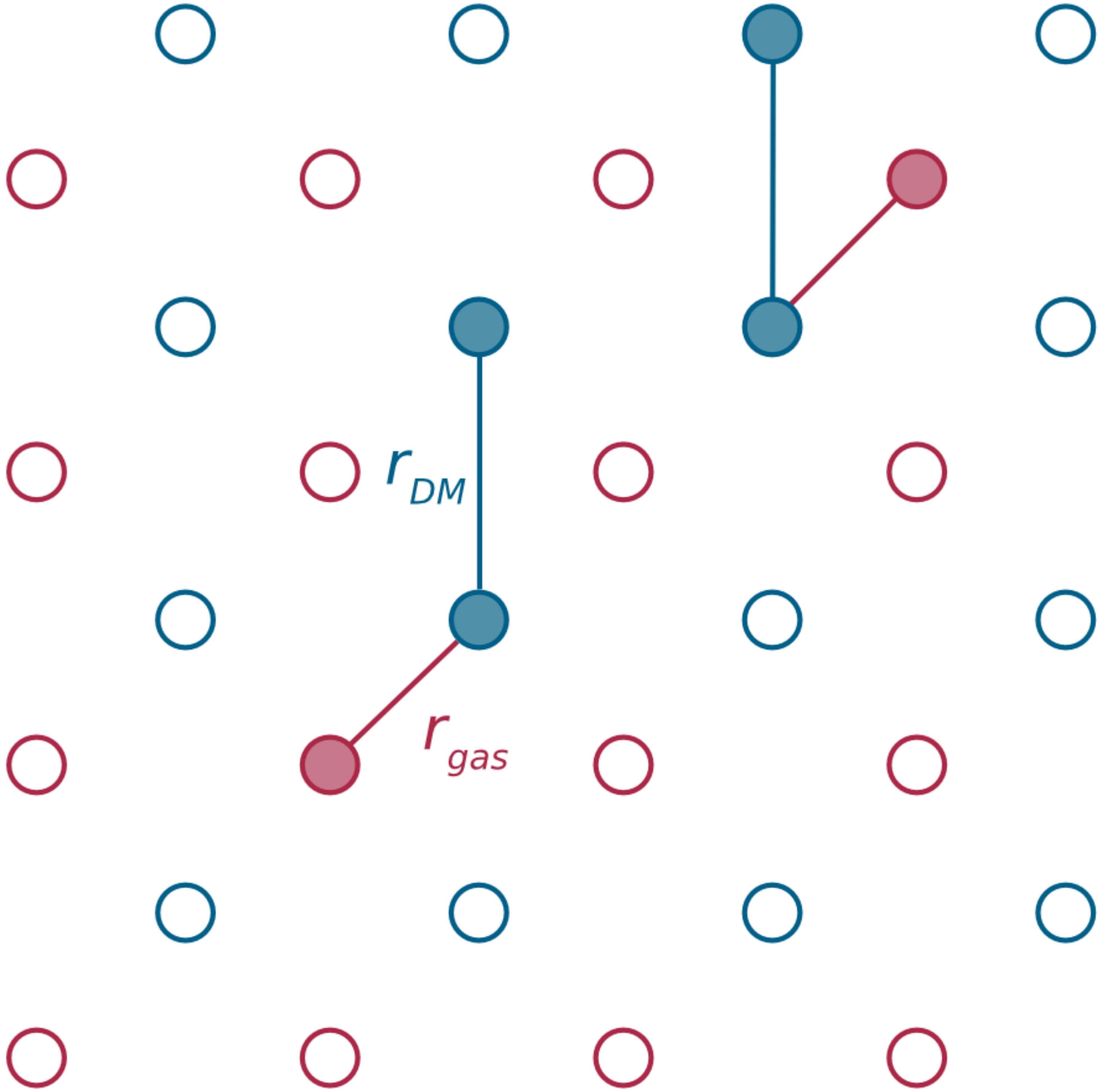
- For every gas and star particle at *z=0* we perform ID matching with the relevant *z=99* progenitor.
- We then know the LR it belonged to, and the halo at *z=0* that it resides in.

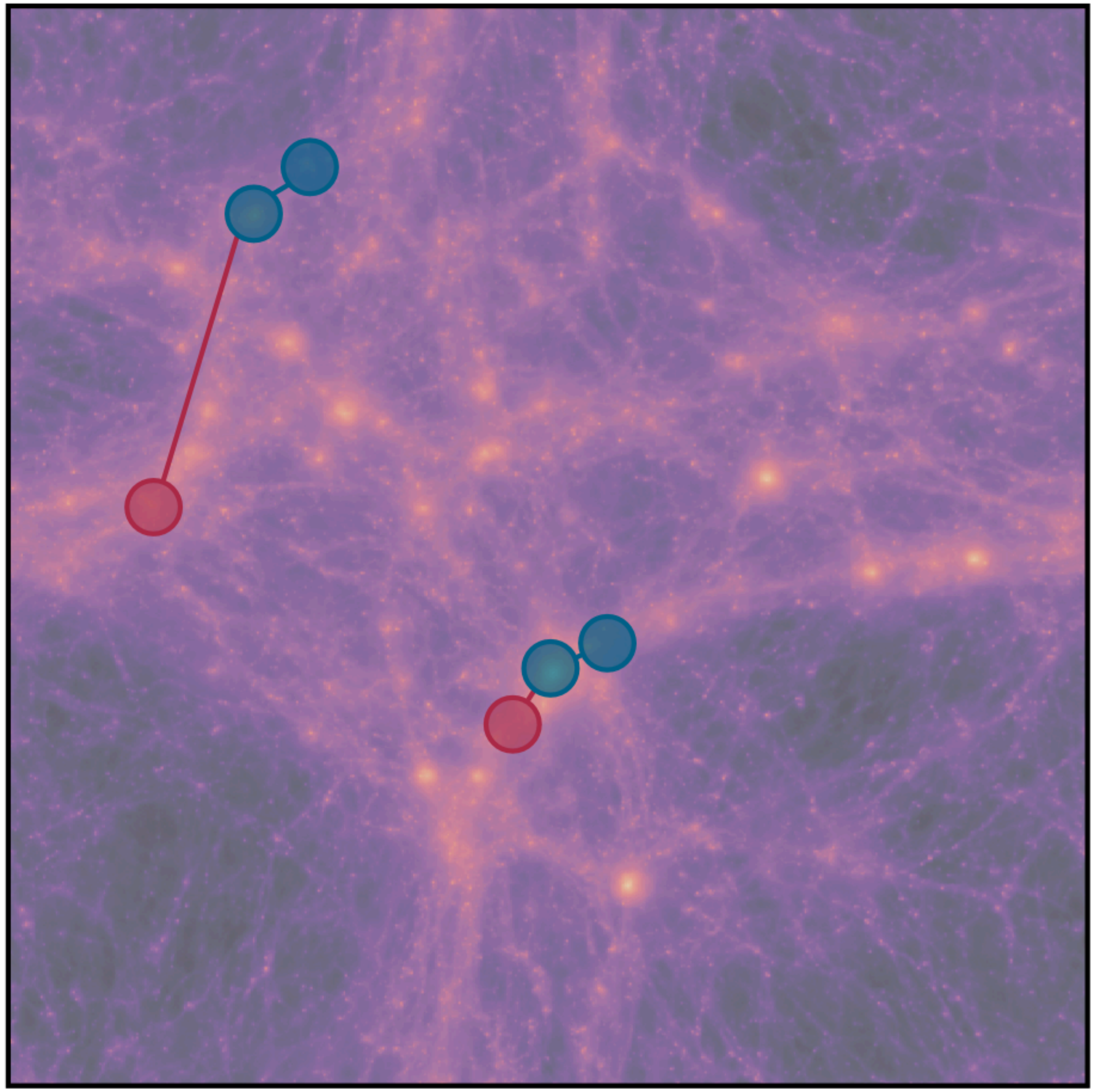


A closer look



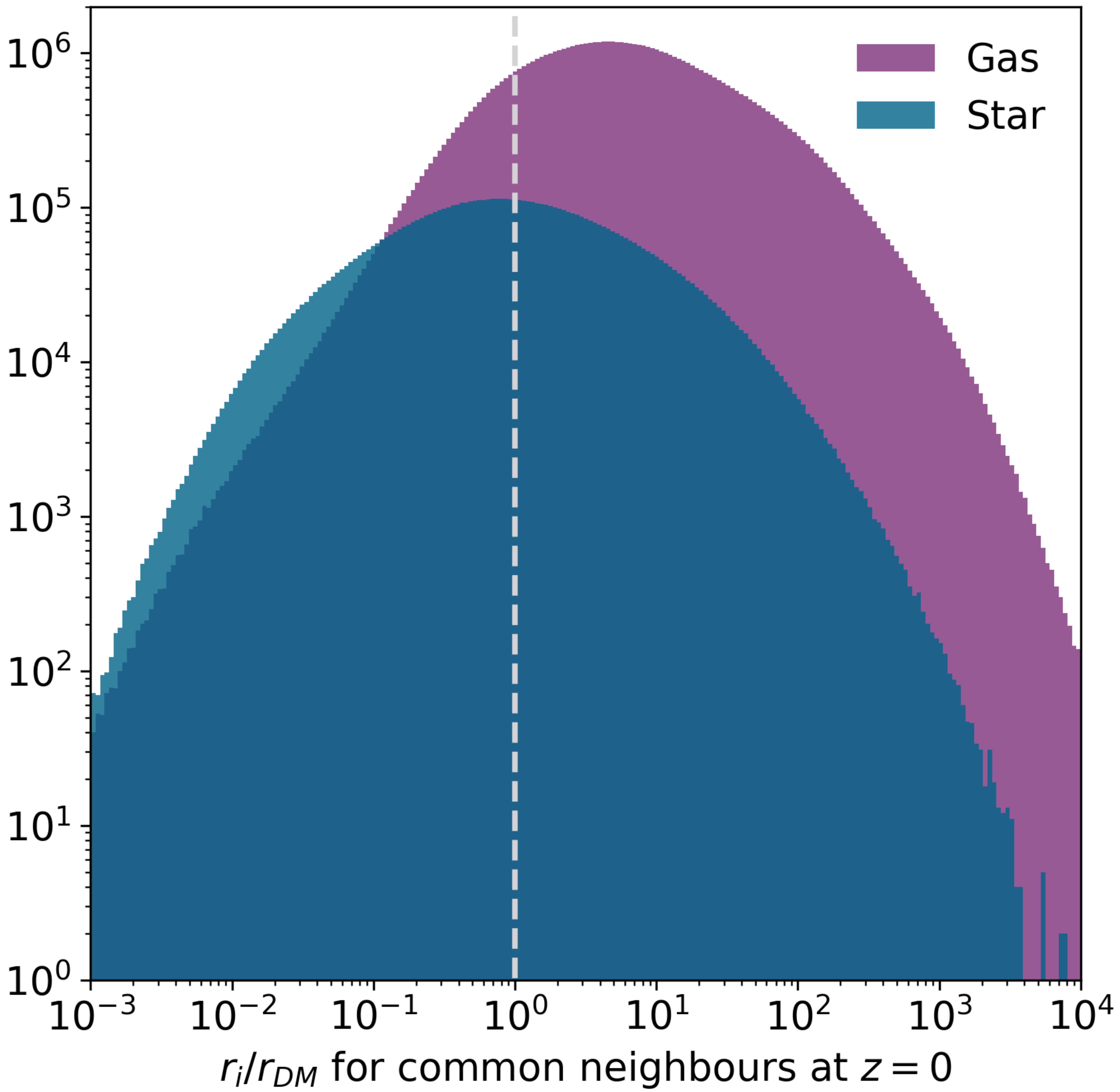
A halo-catalogue independent measure





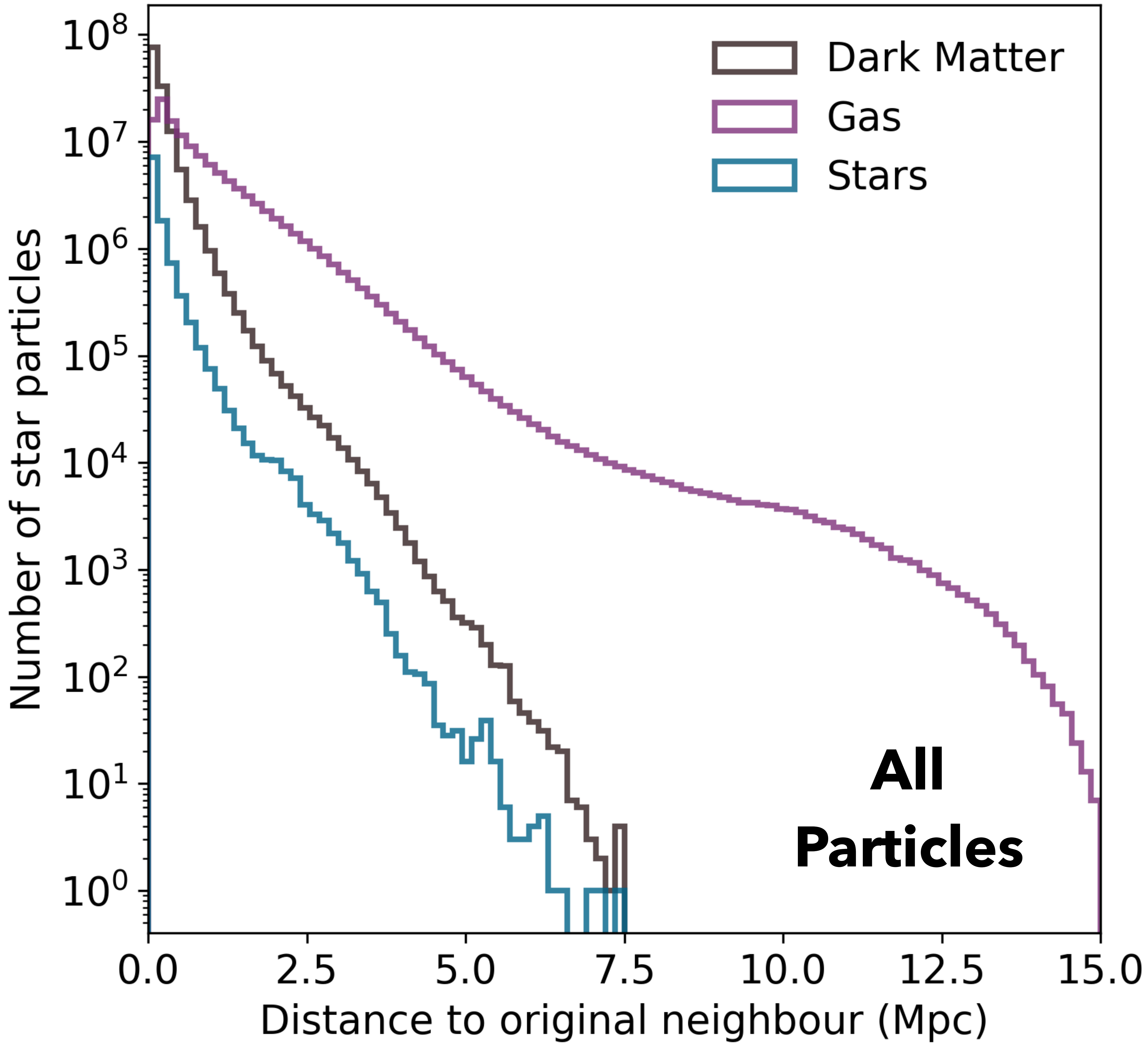
Who ends up further away?

- Gas (and stars) end up significantly displaced from their original neighbour
- Gas dynamics either prevent infall (unlikely this is the major effect at z=0) or feedback blows gas out of galaxies!



Distribution of distances

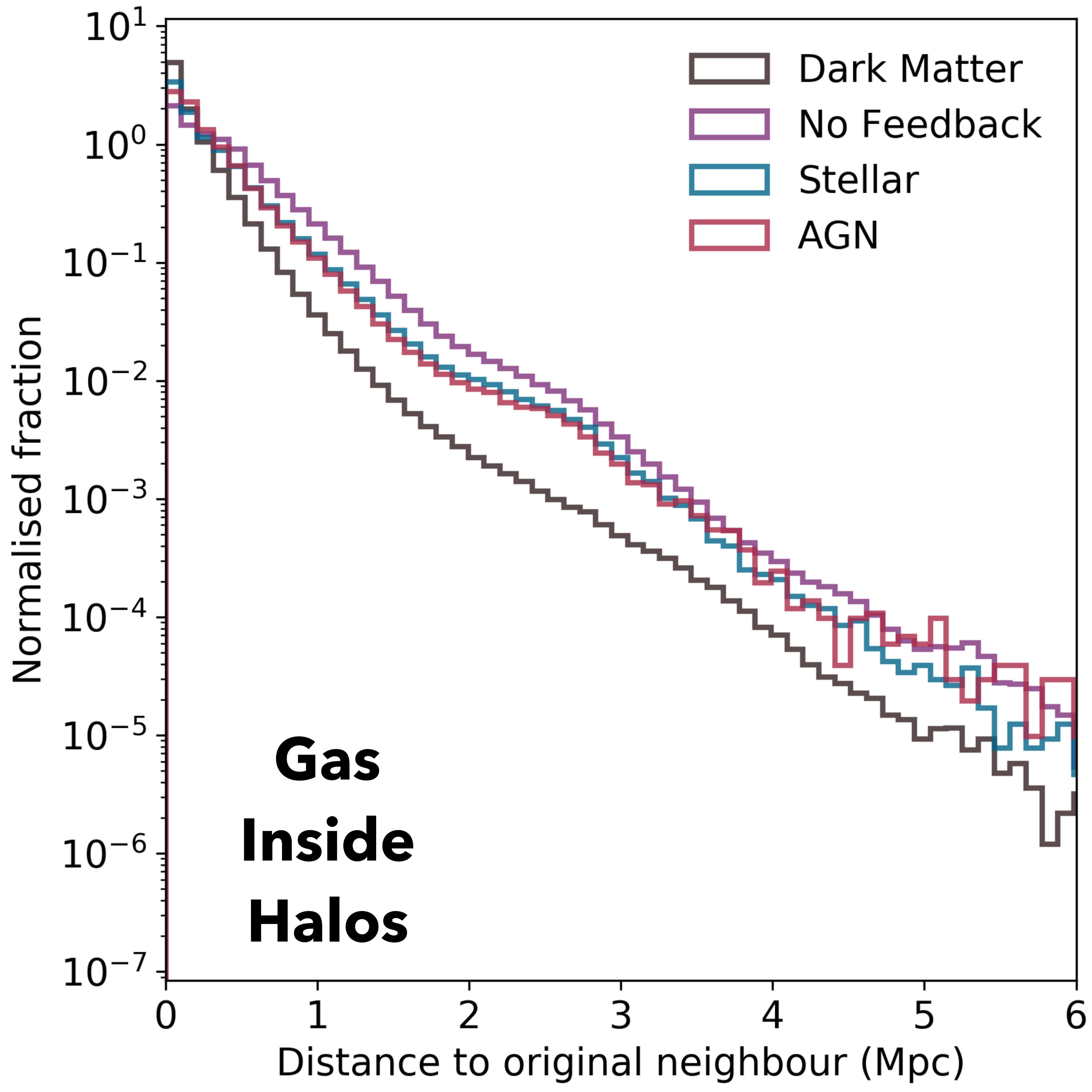
- Gas ends up with a much more extended distribution than the stars or dark matter
- Dark matter and stars end up with very similar distributions



Distribution of distances

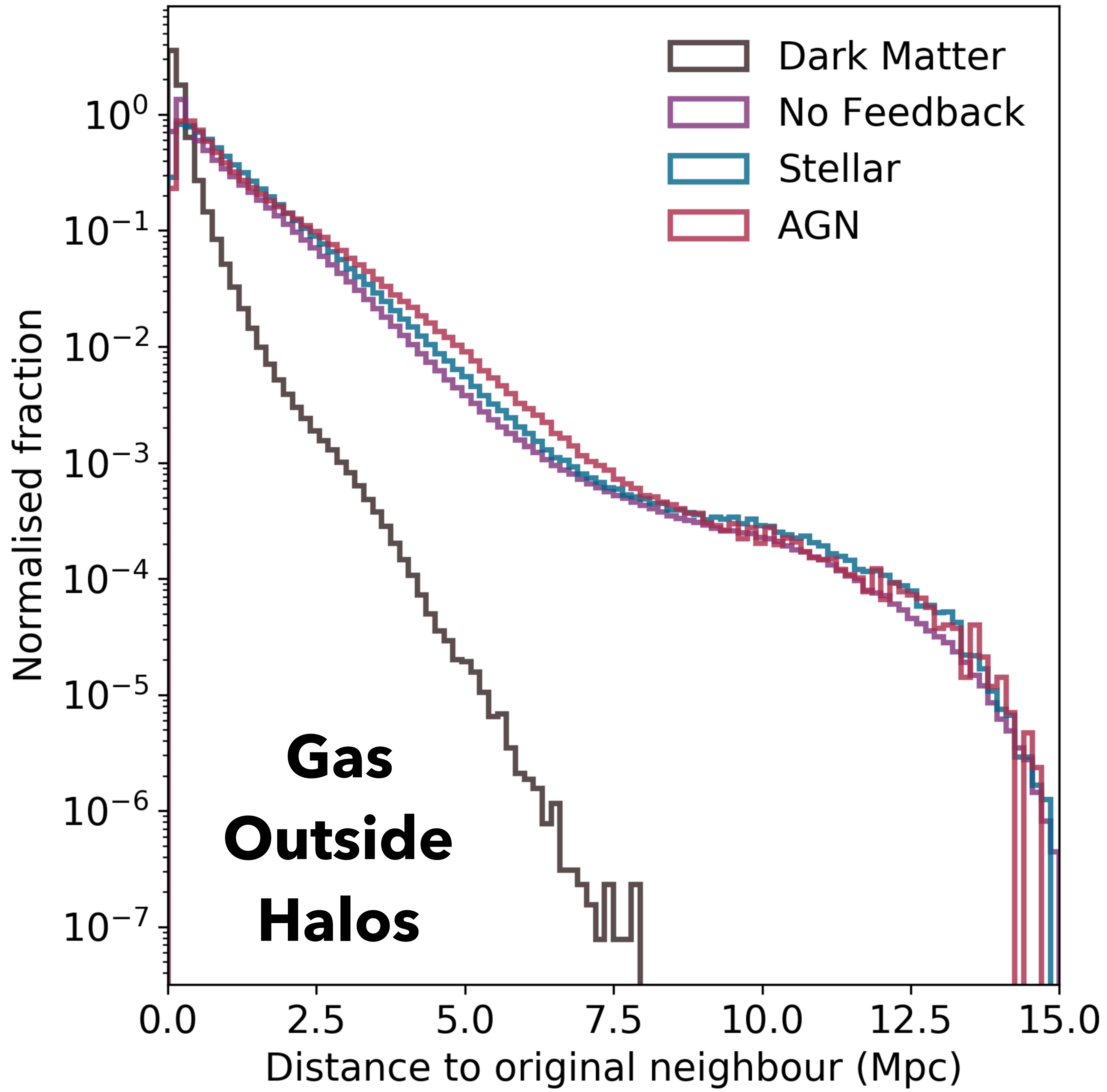
- Inside galaxies, it doesn't matter if a particle has interacted with a feedback process

- The gas and dark matter follow very similar distributions



Distribution of distances

- Outside halos, we find particles blown out to many times the viral radius!
- This very long tail shows more gas that has been "touched" directly by AGN and SNe
- Note that other particles could have been dragged out and not be marked



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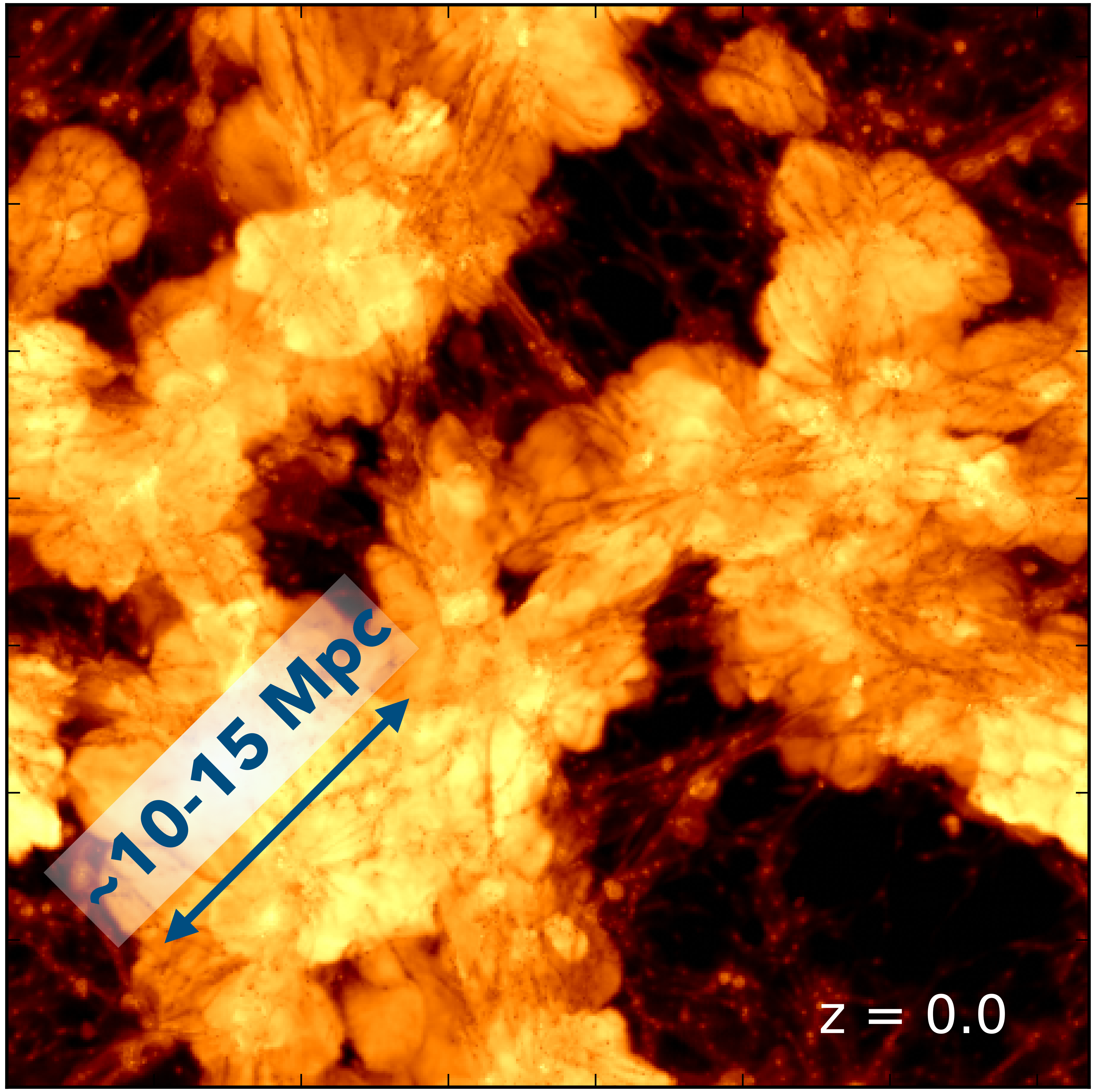
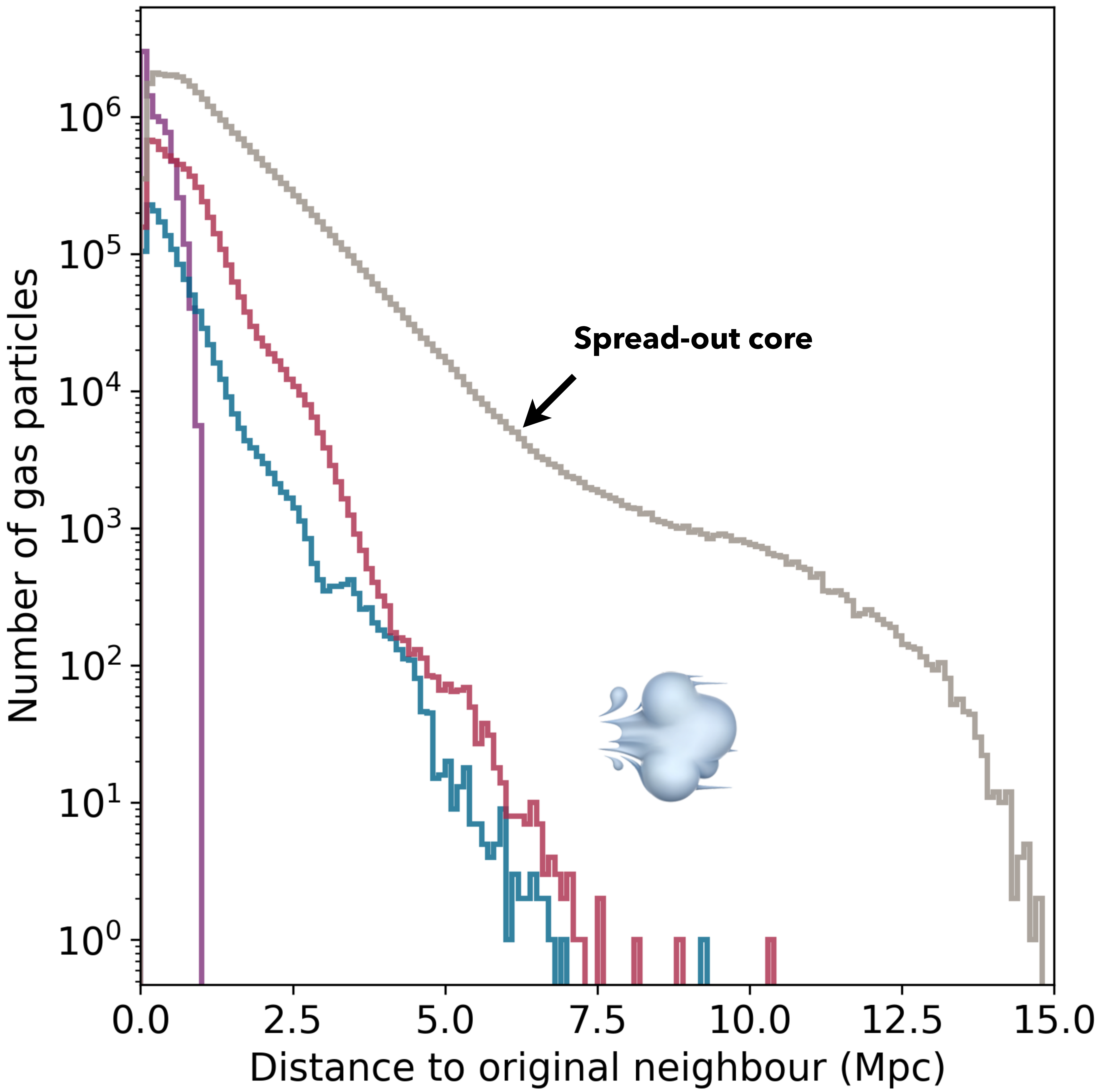
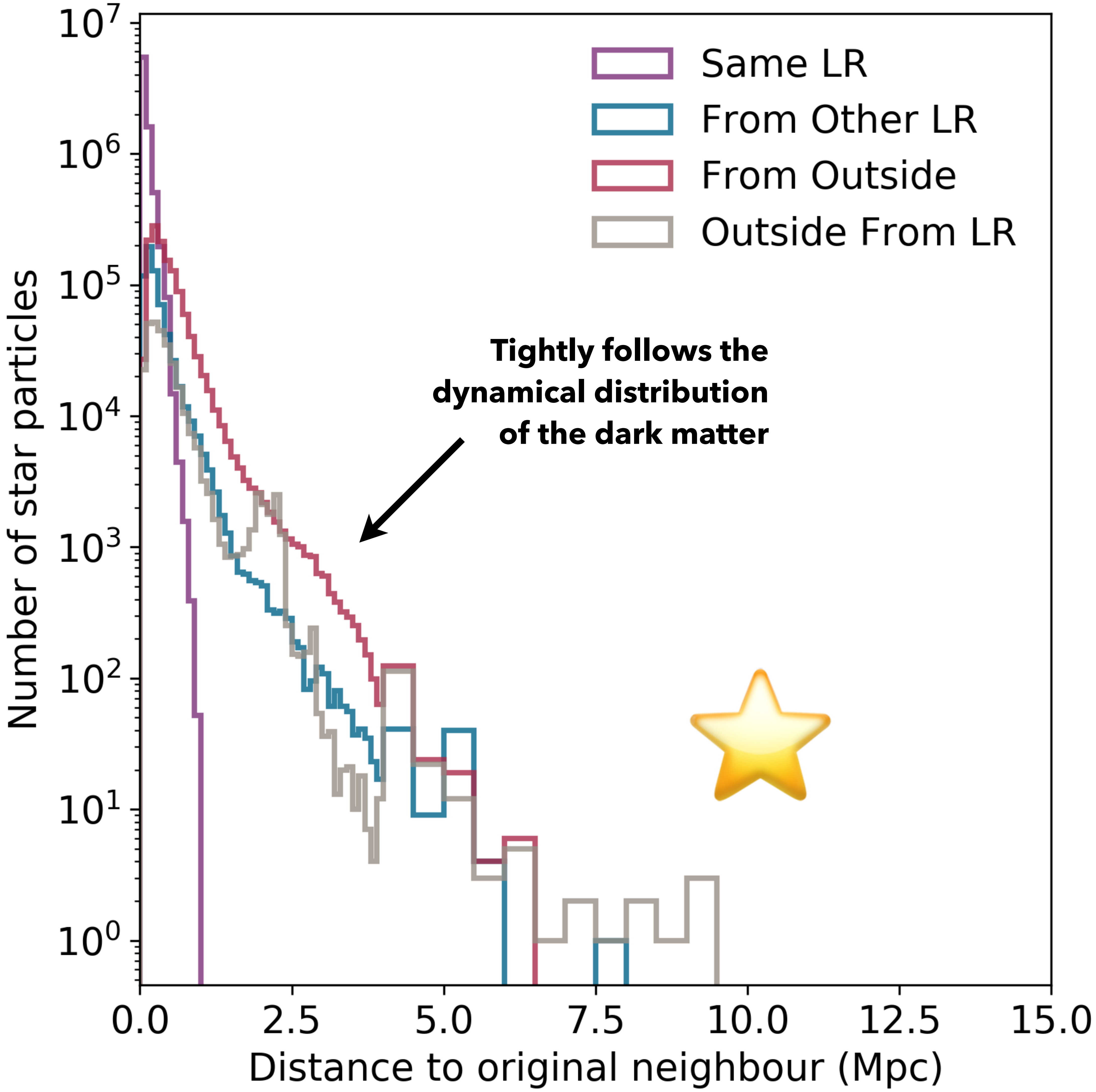


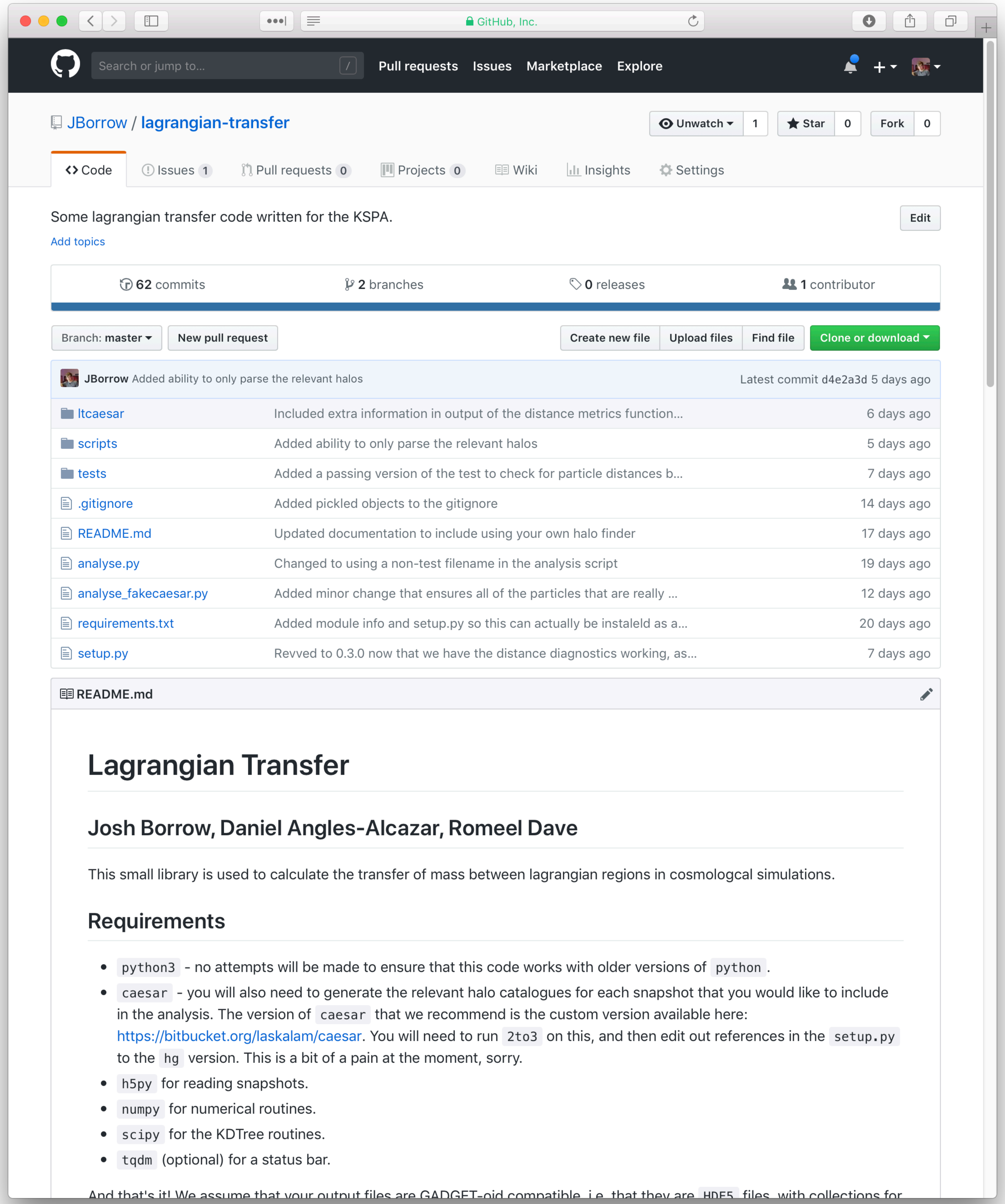
Do stars and gas behave differently?





LTCaesar: Buy now!

- This analysis is completely general to particle-based codes
- Currently works with any gadget-oid
- Download the code and run your own analysis!
- https://github.com/jborrow/lagrangian-transfer
- Analysis is fast (less than 1 hour for 512^3)



Ongoing questions

- What happens in a simulation ran without feedback?
- Is there a maximal scale for this transfer? (Need bigger boxes)
- What happens with different feedback models? Mufasa, EAGLE, …
- Should this have an observational signature?

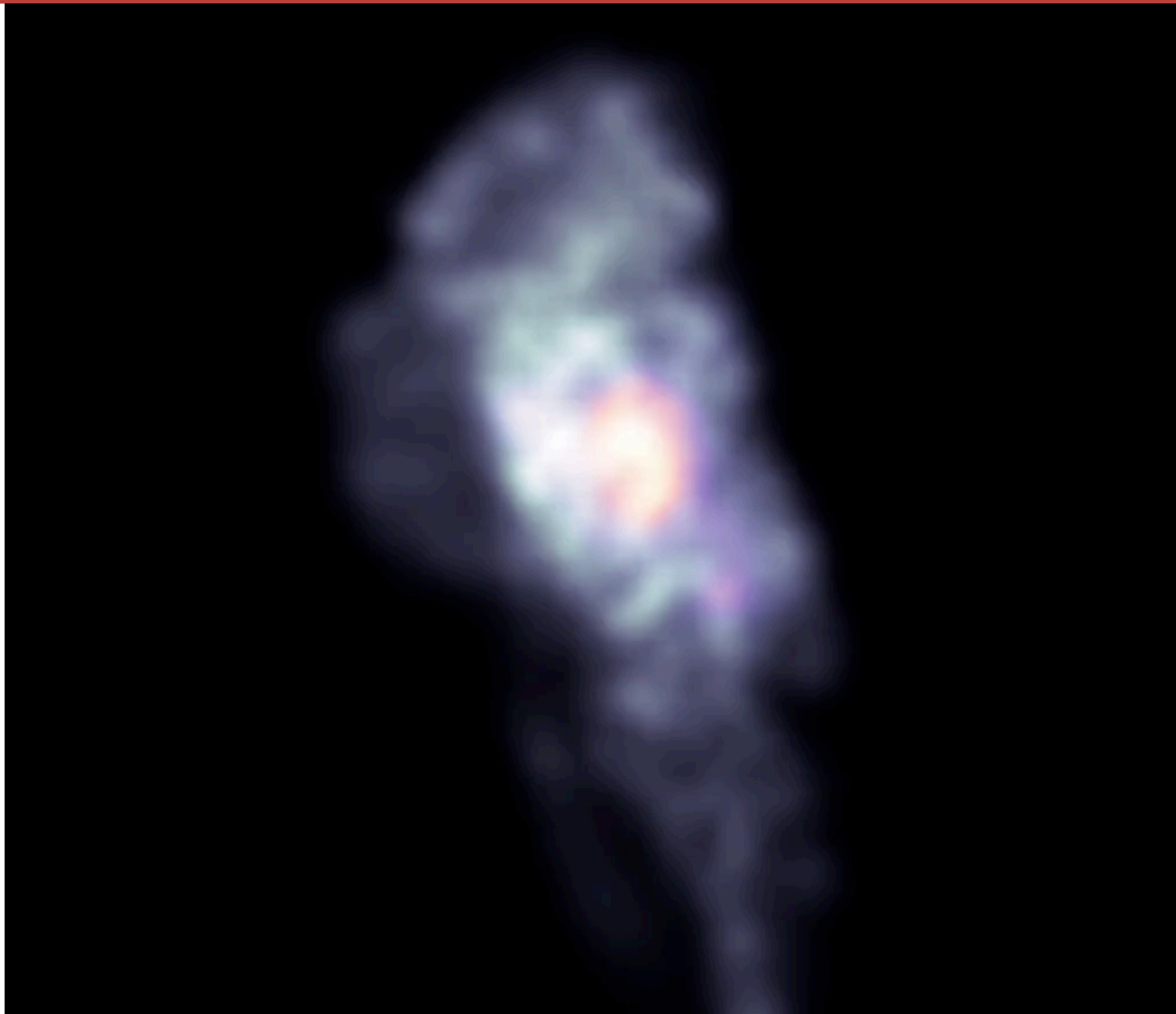
Conclusions

- There is significant transfer between halos in cosmological simulations
- Gas and dark matter end up significantly displaced from each other
- The particles that transfer can form stars; up to 10% of a given halo's stellar mass can come from other LRs
- Code available for download and use by the community.

On not using the convex hull

- The purple here is the LR of a single galaxy, with the white region being made up of the LR of another halo

- The holes/substructure in these LR's is not a problem, but a feature.



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Caesar v.s. AHF