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Cosmological baryon transfer in the SIMBA simulations

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The SIMBA Simulations

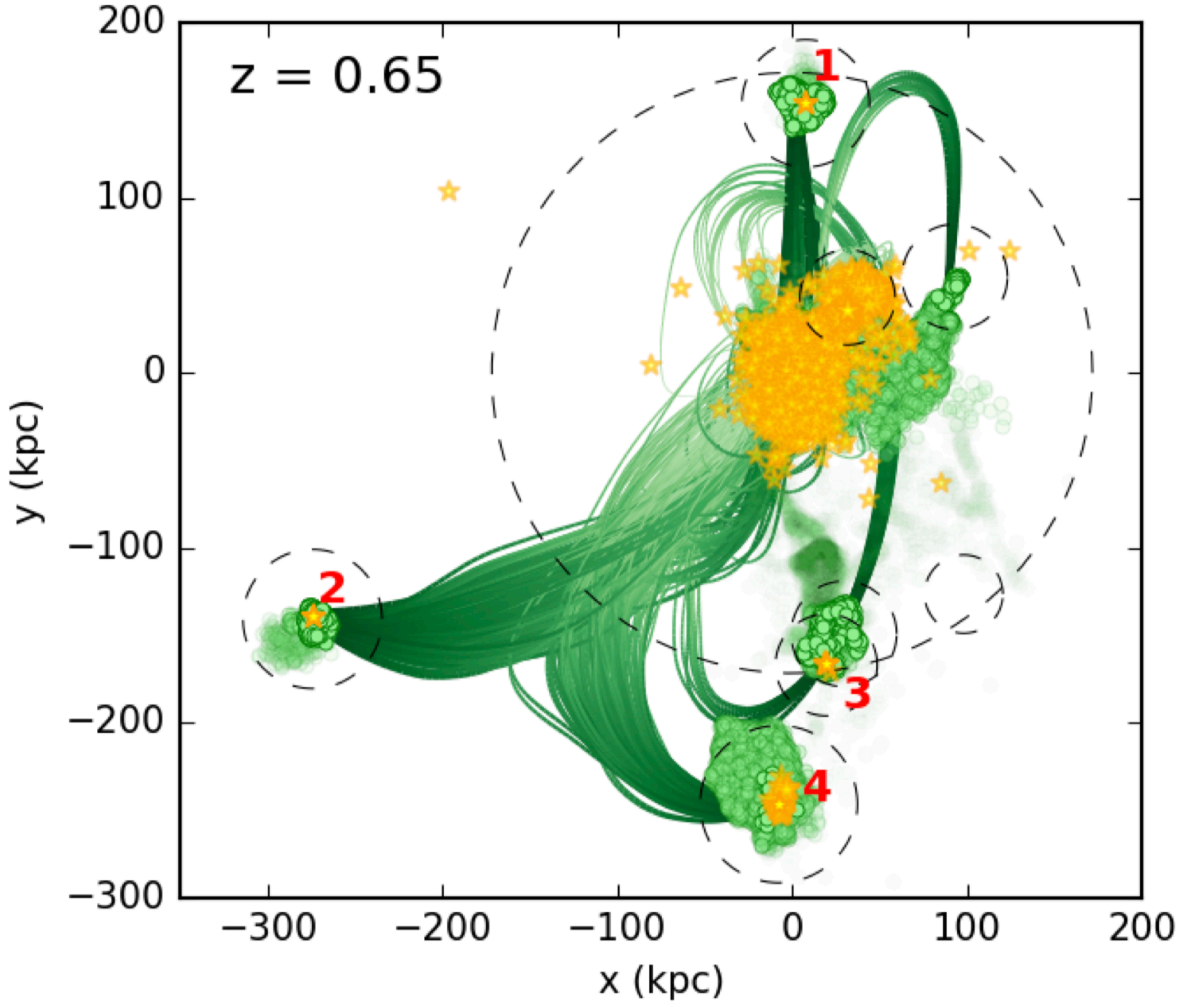
- Model 'calibrated' on FIRE galaxies
- Includes strong, kinetic AGN feedback with various jet modes
- This feedback can blow bubbles ~20 Mpc in size
- Baryonic mass resolution ~10x worse than EAGLE/Illustris
- More information in Dave+ 2019 or ask me afterwards

The SIMBA Simulations

- Also going to use two comparison models:
  - NoJet: Same as SIMBA but with AGN jets turned off (still includes thermal AGN feedback)
  - Non-Radiative: No galaxy formation model - just hydrodynamics and gravity

Previous Motivation

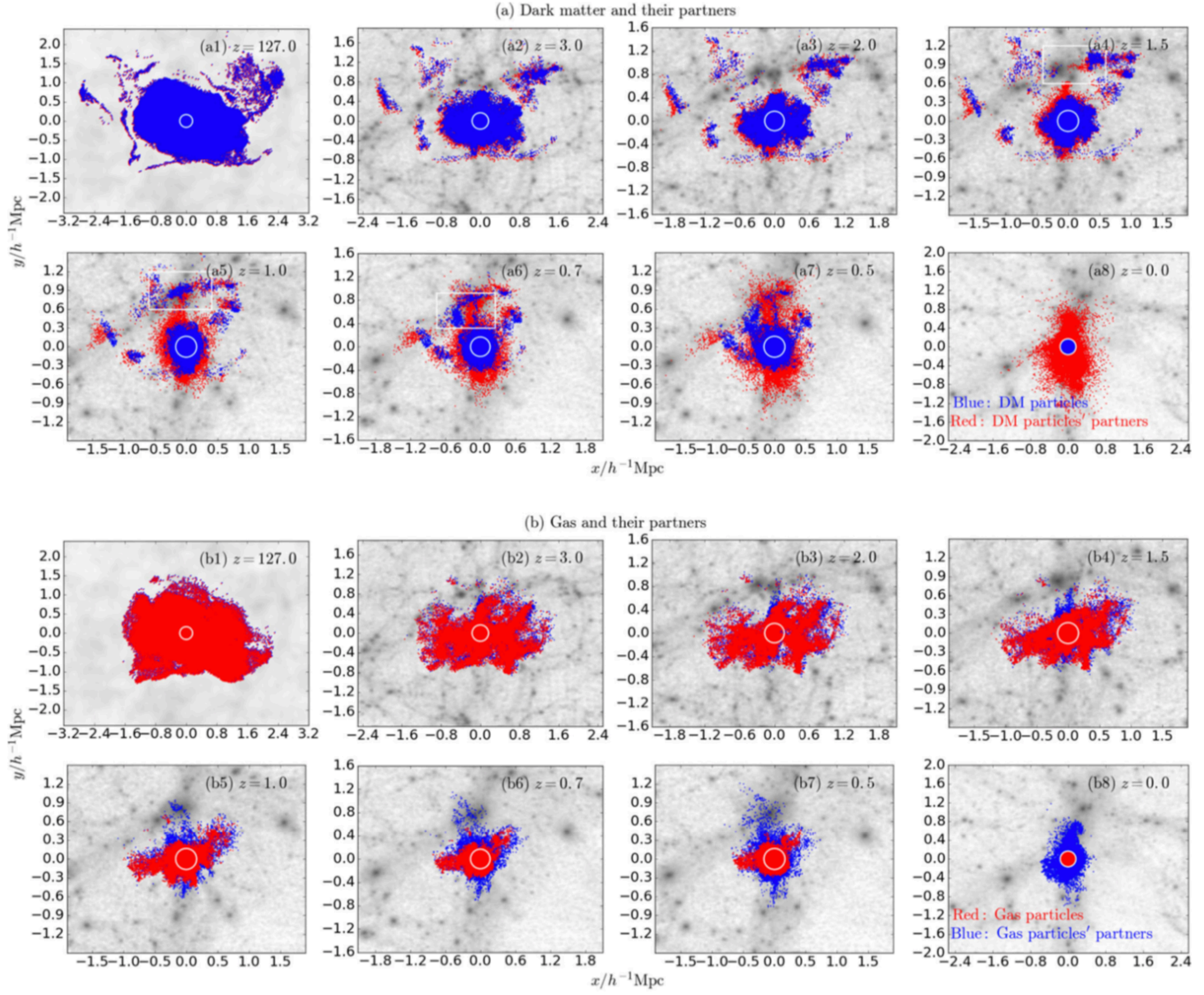
- Feedback causes gas to be blown out of galaxies
- This is especially true in simulations that include AGN feedback (and of course in the real Universe)
- Where does that gas go?



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

Previous Motivation

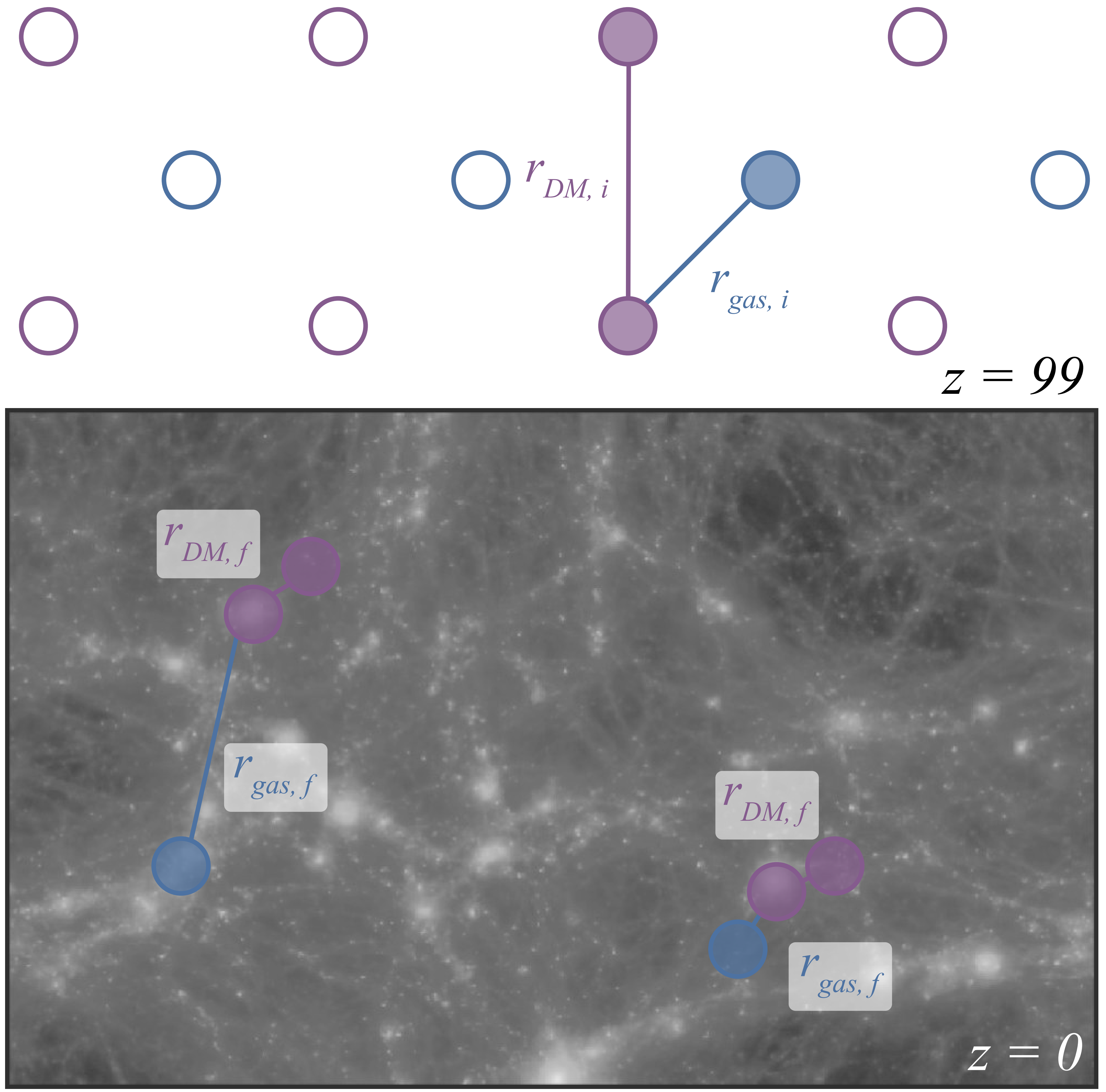
- Liao+ used non-radiative simulations to look at how baryons assemble into haloes v.s. dark matter.
- They saw that there can be huge levels of mixing between the two fluids.
- Key numerical result: 25% halo content is segregated from initially pairing dark matter or gas counterpart.



Liao+, The segregation of baryons and dark matter during halo assembly, 2017

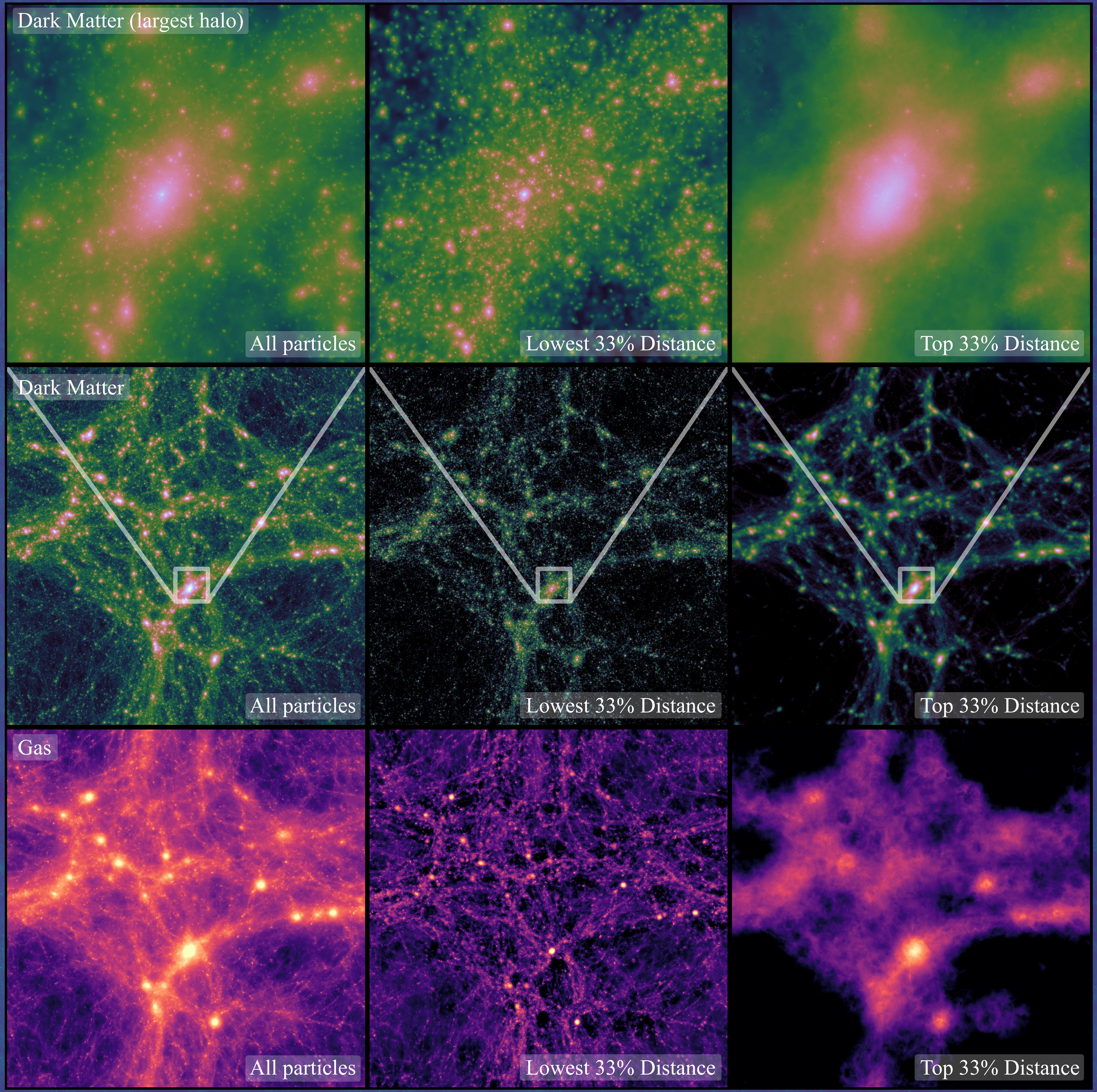
The Spread Metric

- Look at how dark matter and baryons move differently
- First pass: construct a metric that tells us how far particles have moved in the simulation, using only two snapshots.



Visualised

- Dark matter substructure picked out by low movement
- Gas in AGN bubbles picked up by high movement.



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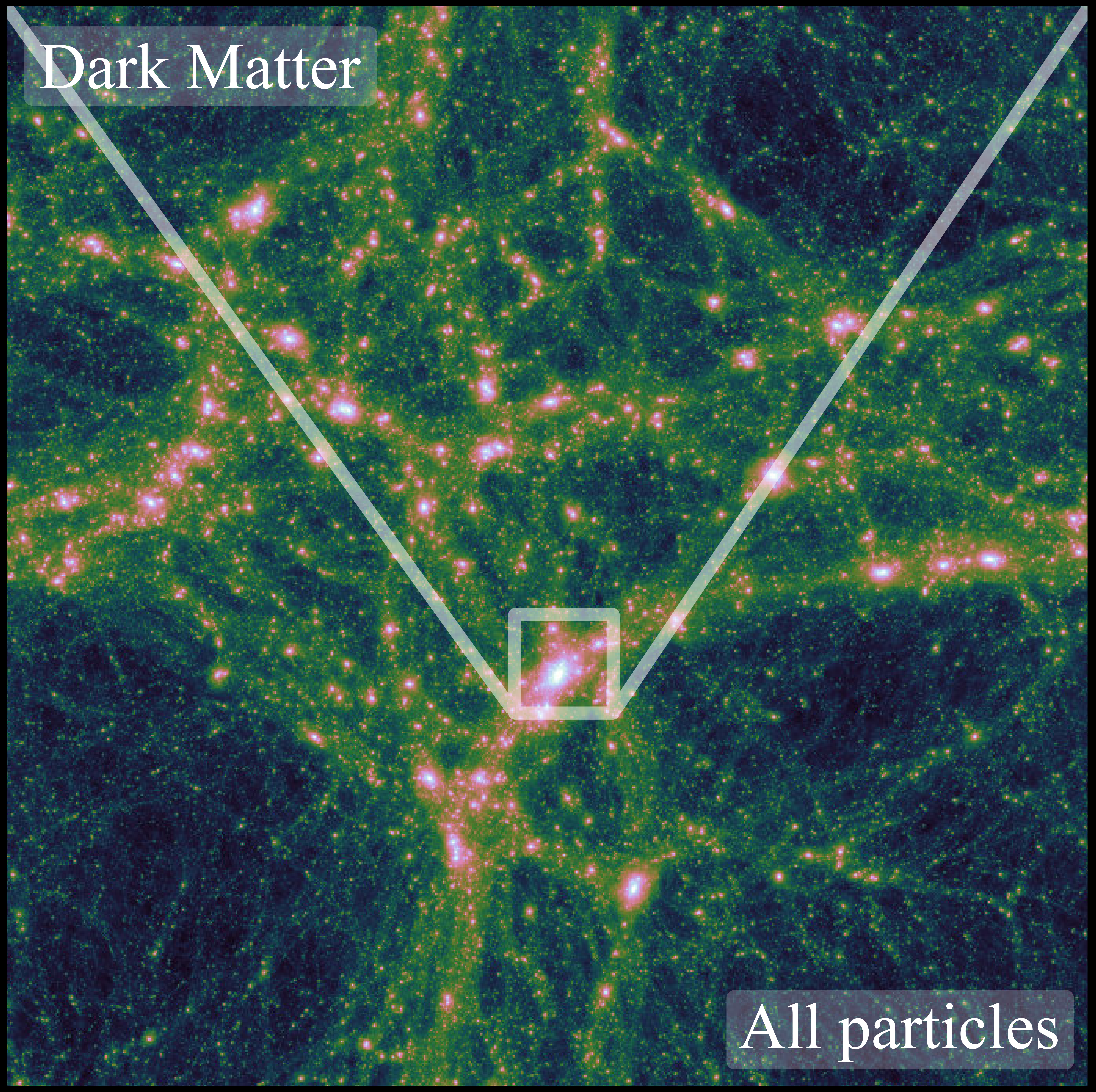


Matter
All particles
Lowest 33% Distance


Lowest 33% Distance
Top 33% Distance

Visualised

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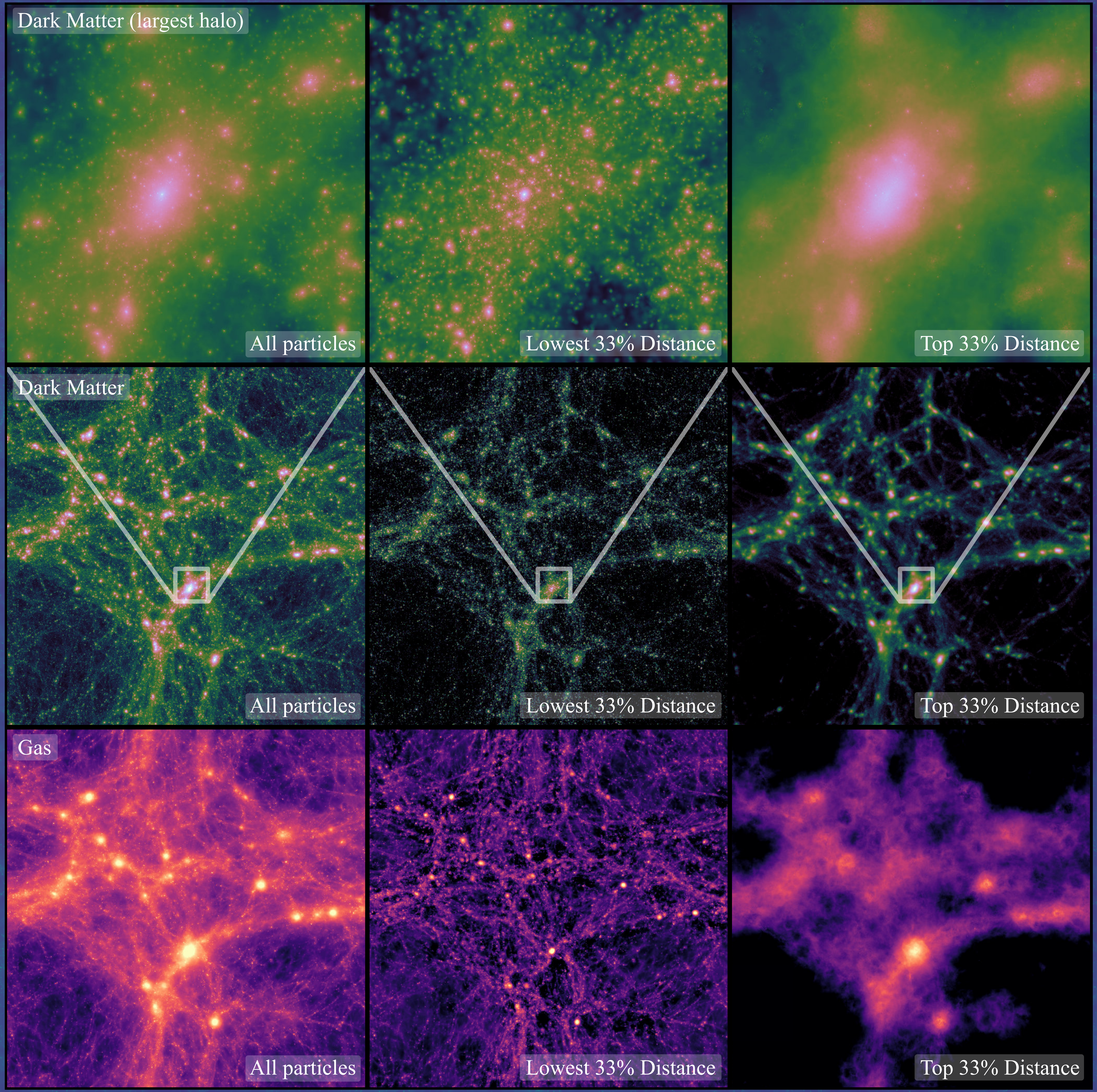

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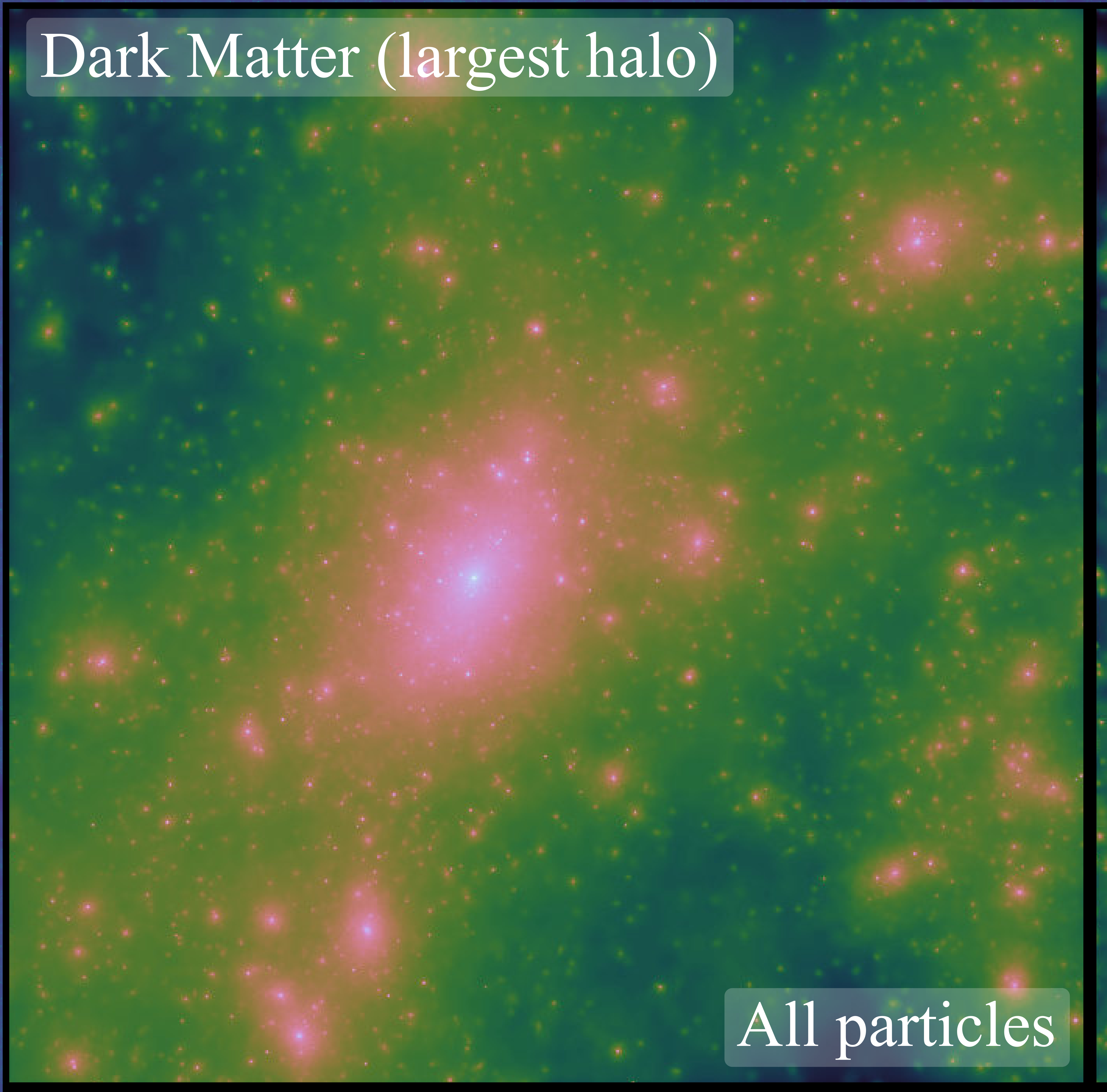


latter (largest halo)
All particles
Lowest 33% Distance


Lowest 33% Distance
Top 33% Distance

Visualised

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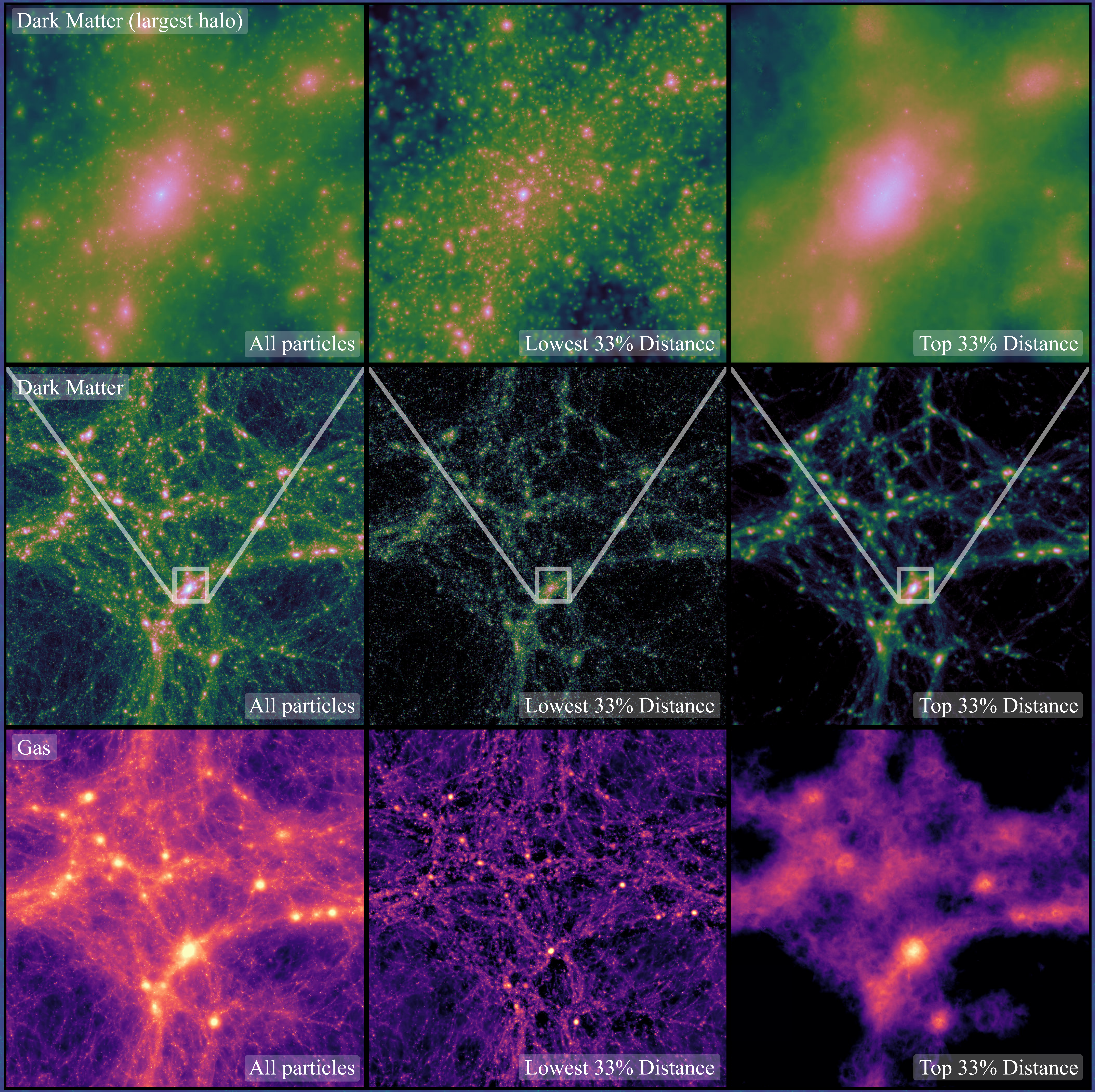

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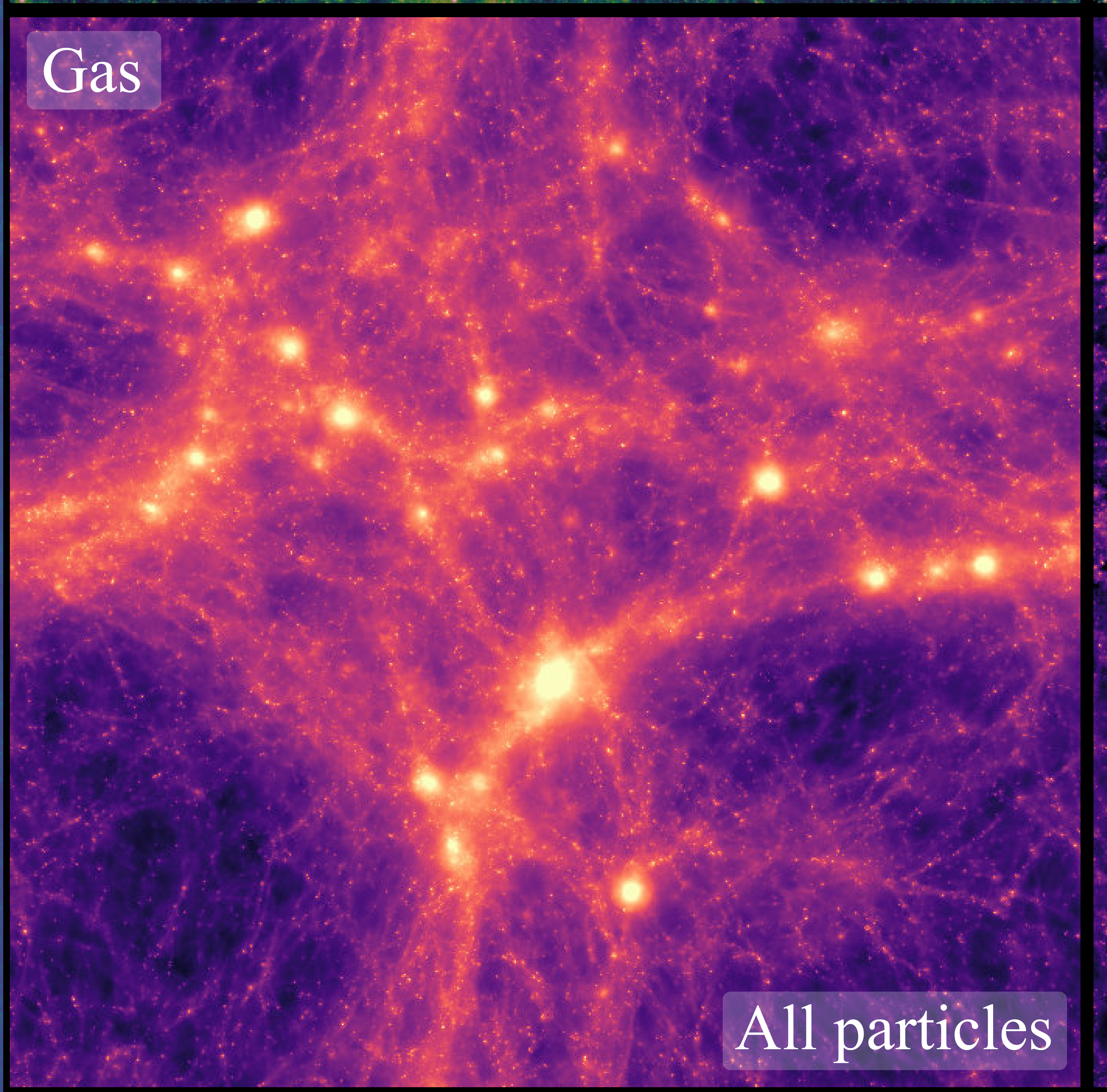


All particles
Lowest 33% Distance


Lowest 33% Distance
Top 33% Distance

Visualised

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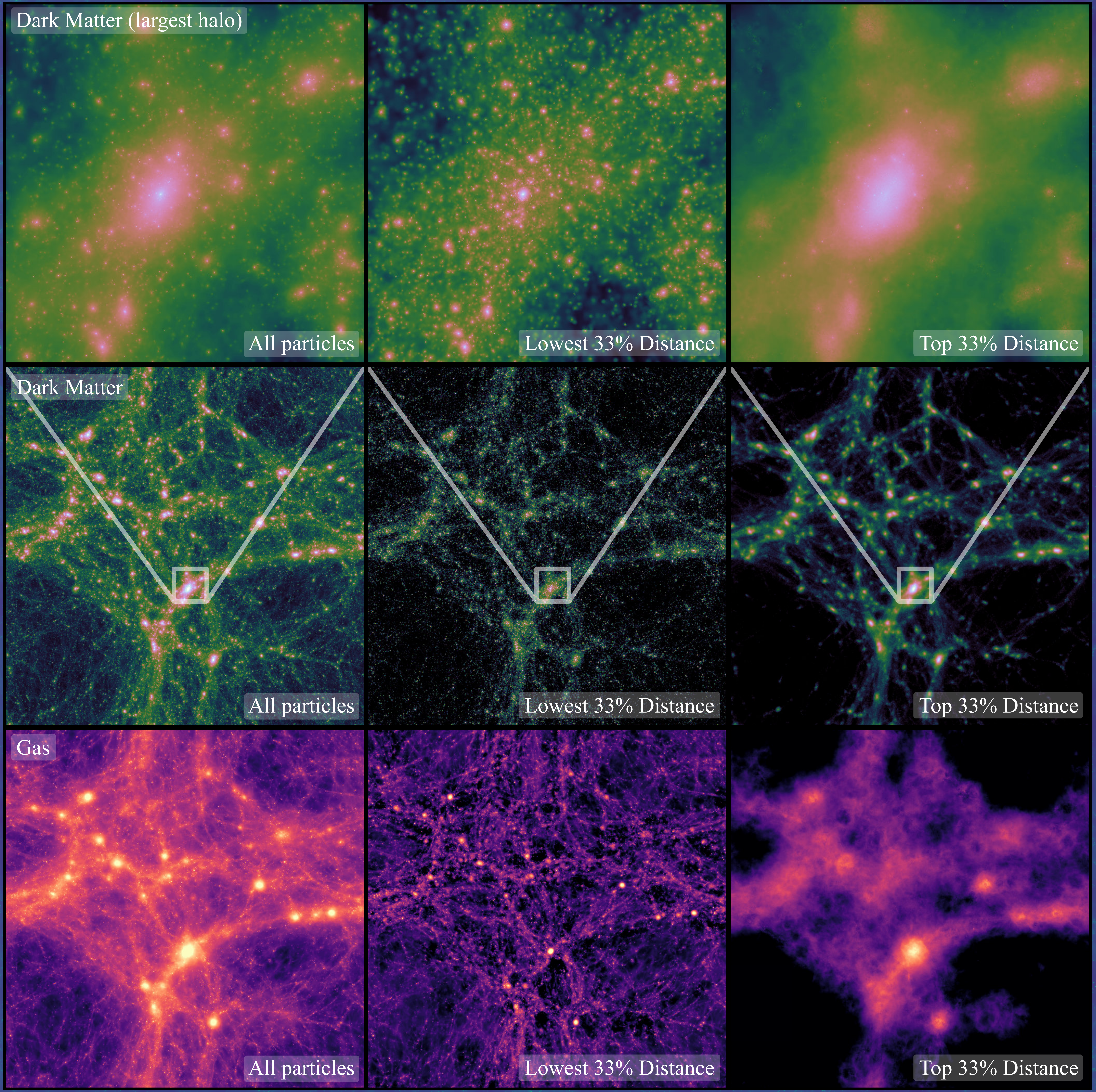
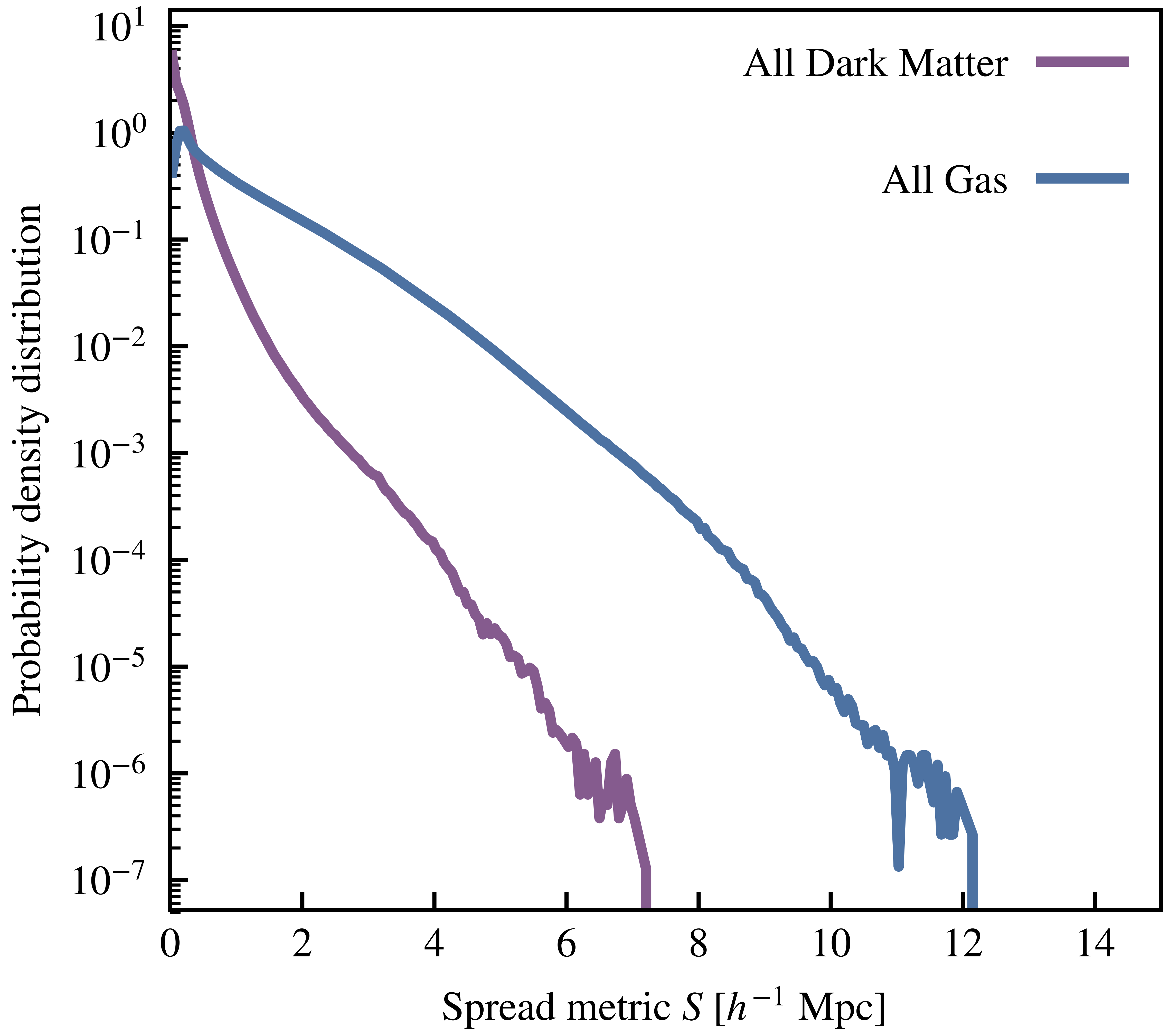


A closer look

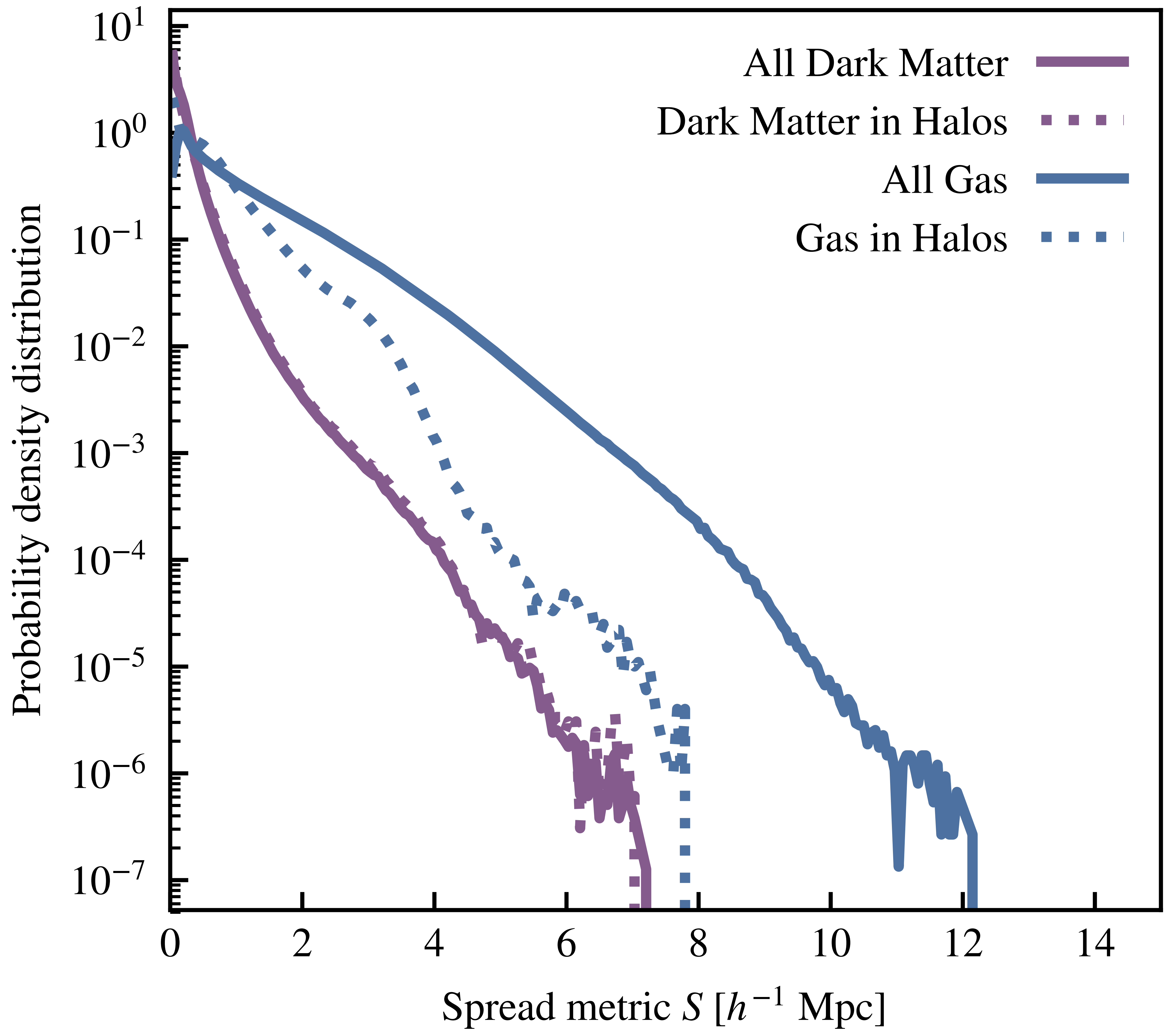
- Take a look at the distribution of distances for different types of particles

- Gas is much more spread out than dark matter, as expected from the above images



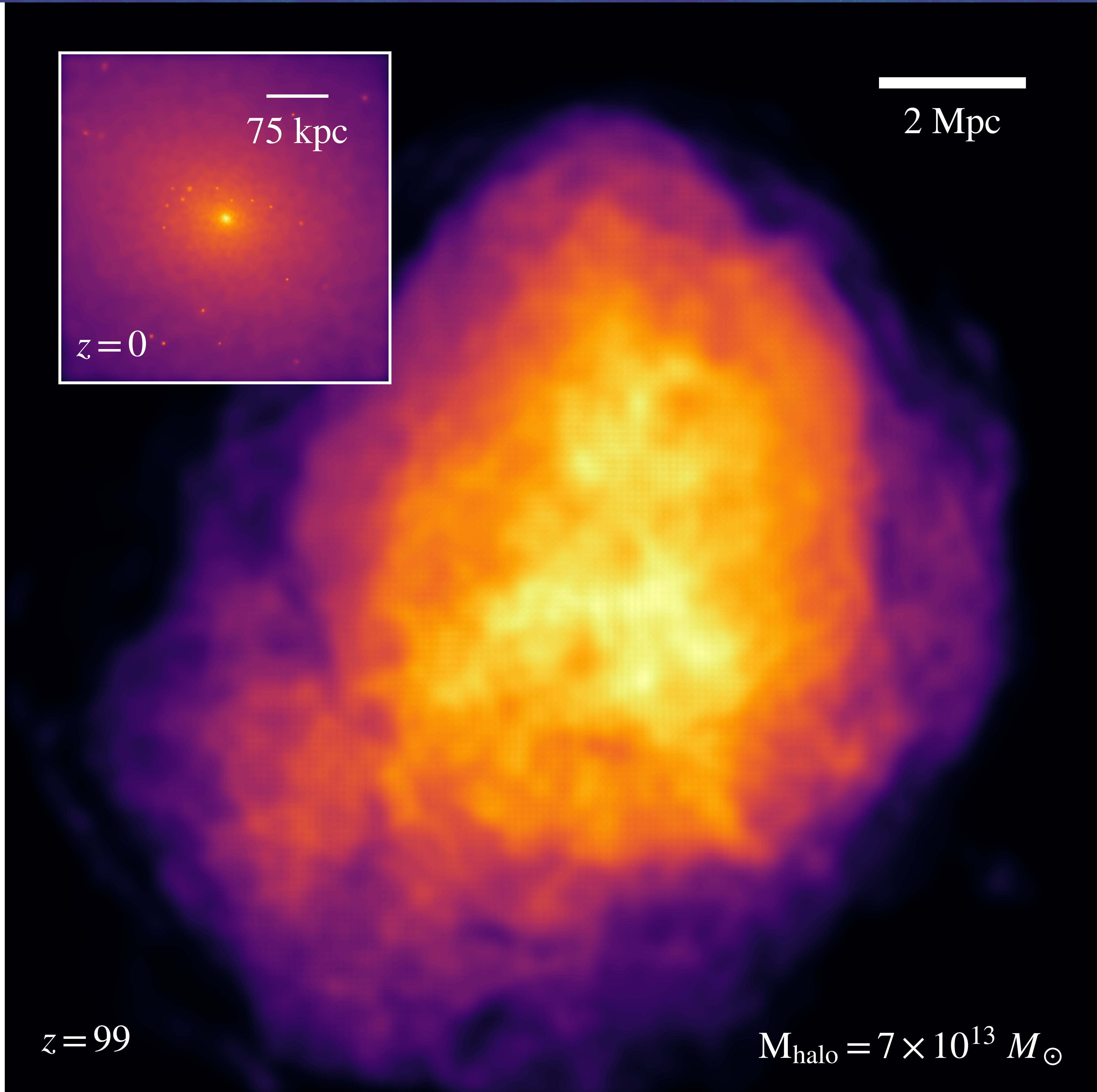
A closer look

- Splitting now by the particles only in halos, we see that gas in halos at *z=0* is much more closely bound to the dark matter than in general
- Dark matter in halos, though, behaves in the exact same way as dark matter out of halos (could be to do with the definitions we use)



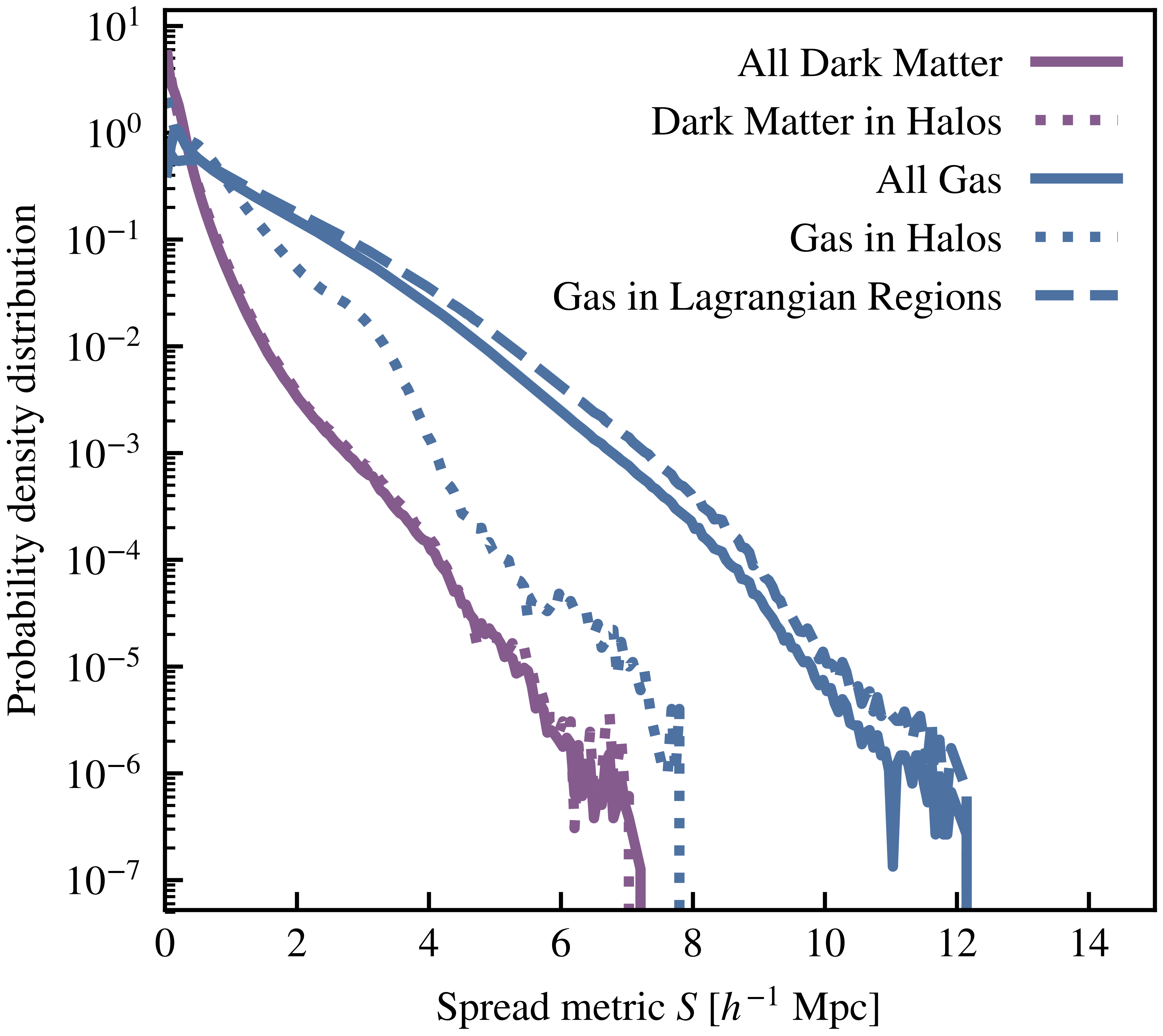
Lagrangian regions

- Lagrangian region definition:
  - Take all DM particles in halo at *z=0*
  - Find their position in initial conditions (*z=99*) - this is the Lagrangian region
  - Find nearest gas particles to all of these DM particles, those gas particles are now also in the same LR

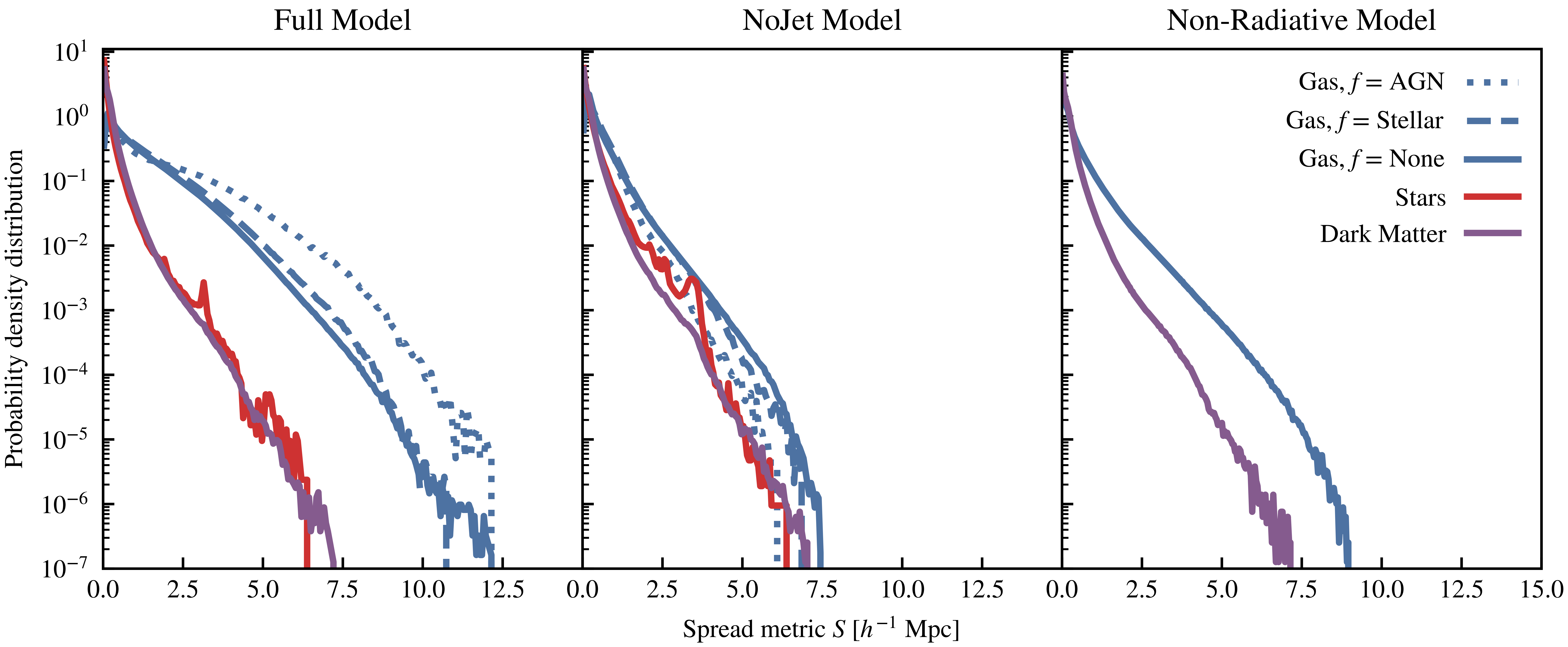


Effects on the distance

- Gas in Lagrangian regions, where the dark matter that ends up in halos at $z=0$ comes from, shows a bias to being powered out to larger distances

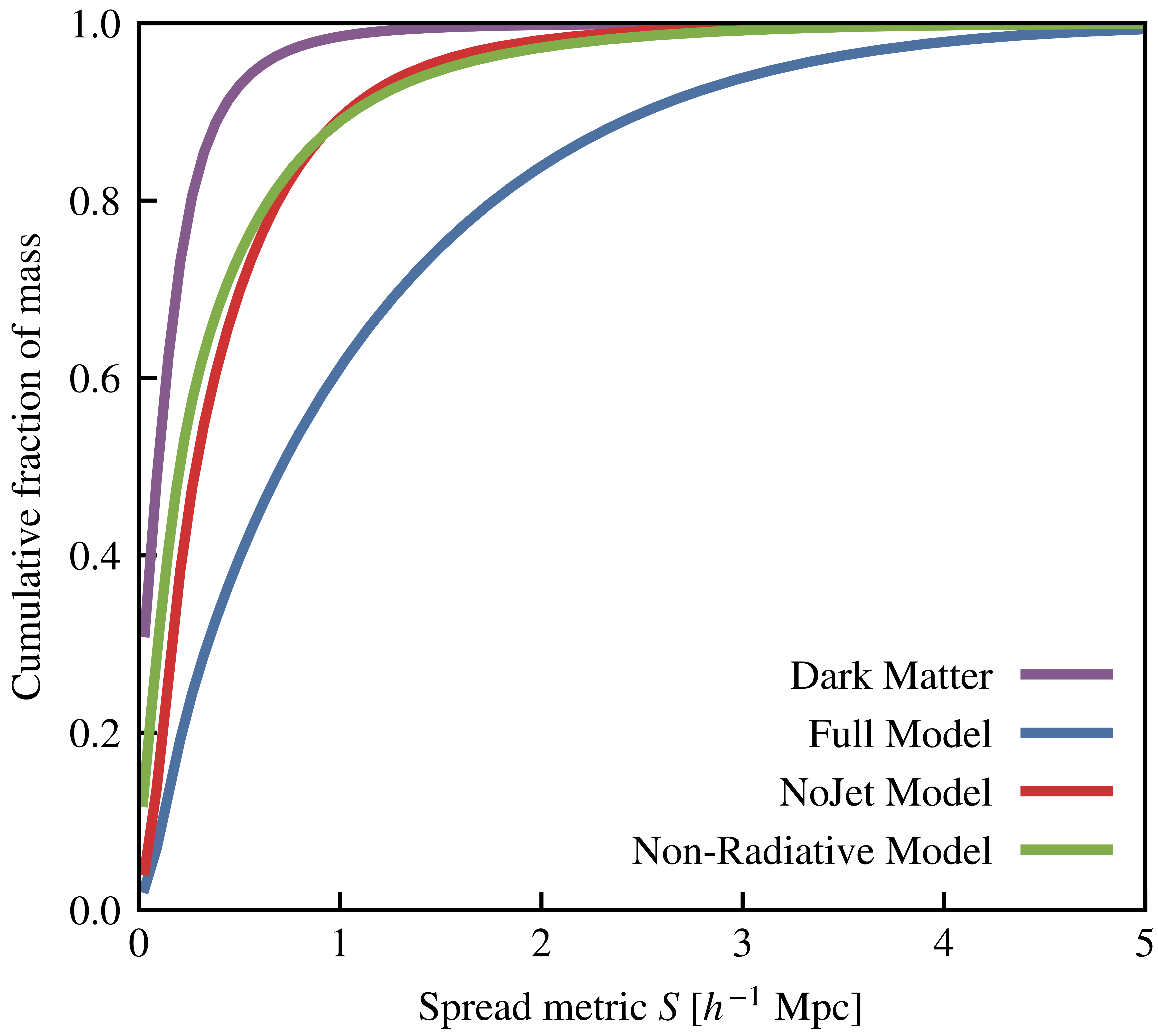


Model dependence

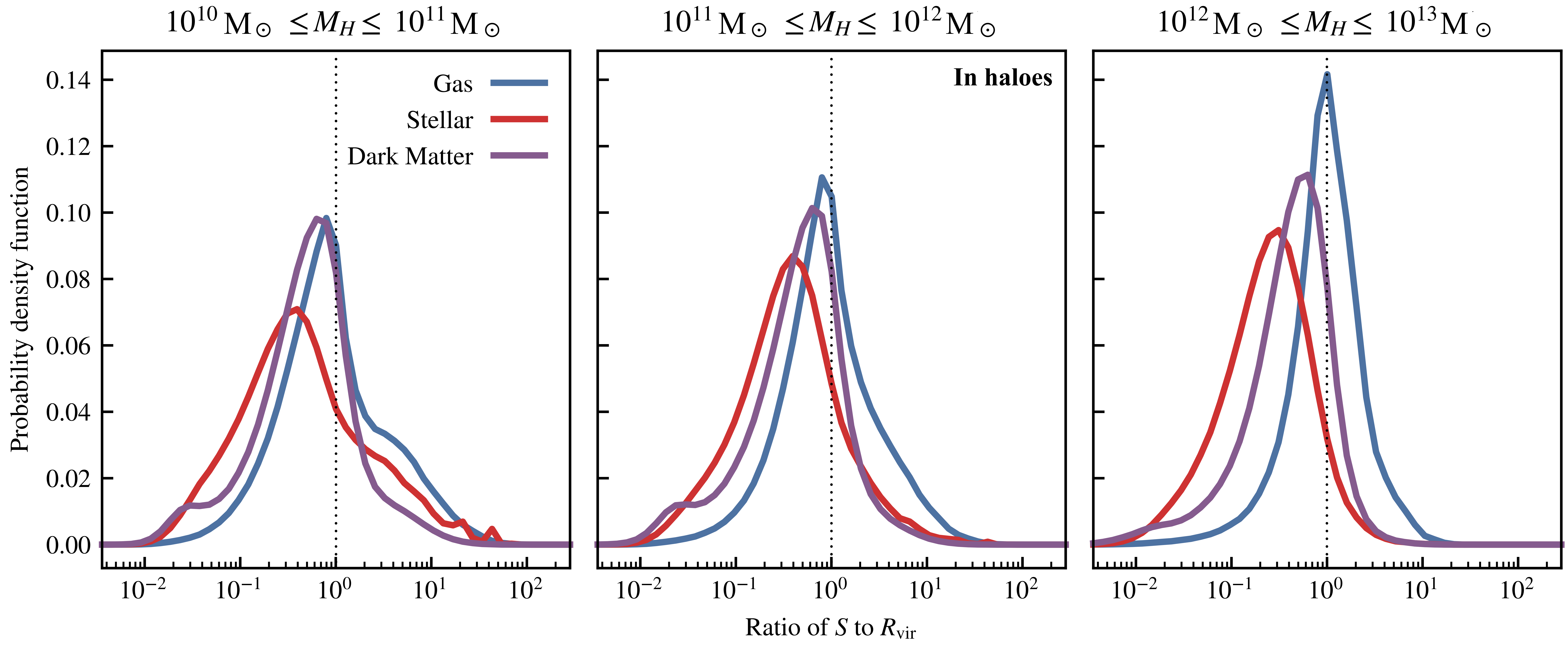


How much mass?

- "But that's a log-scaled axis!"
- How much mass is actually tied up in each distance?
- Pretty much all gas mass constrained to within 5 Mpc, despite outliers out to 12.



Relative to sizes of haloes



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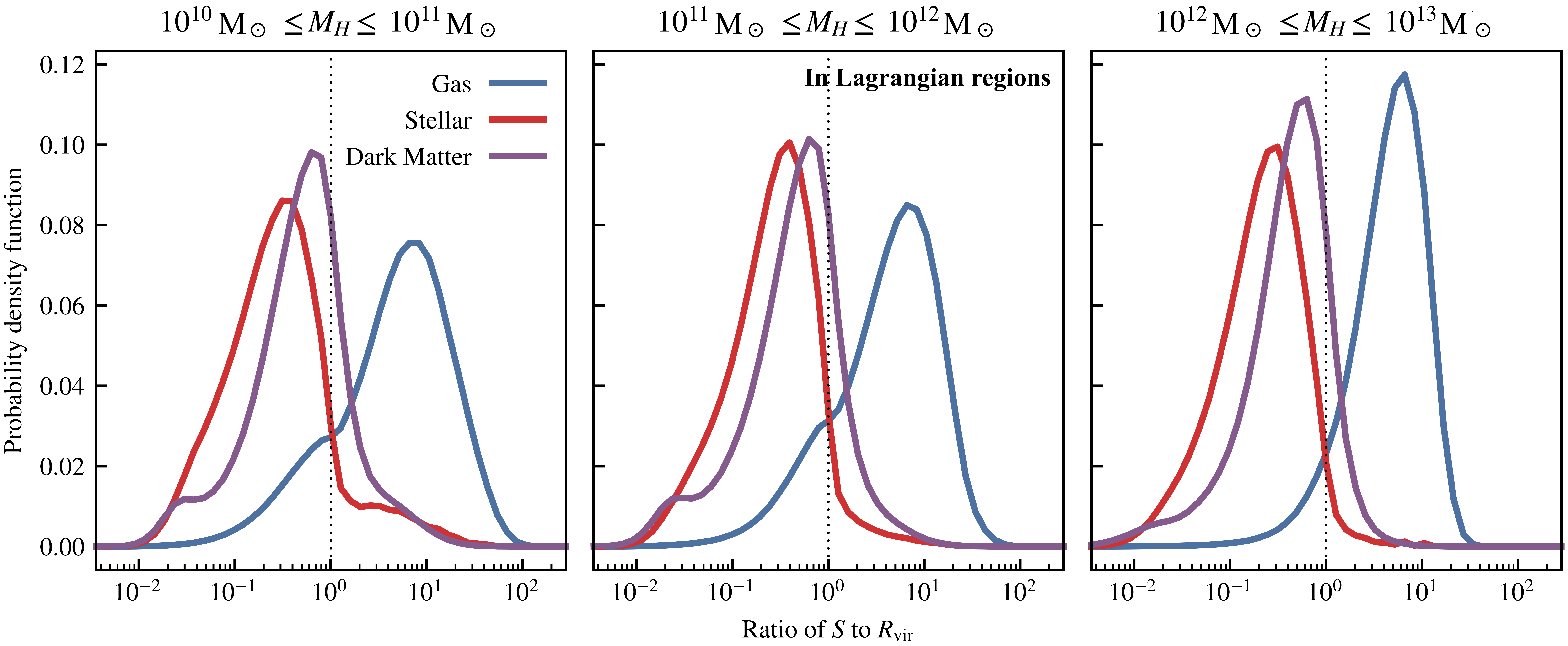
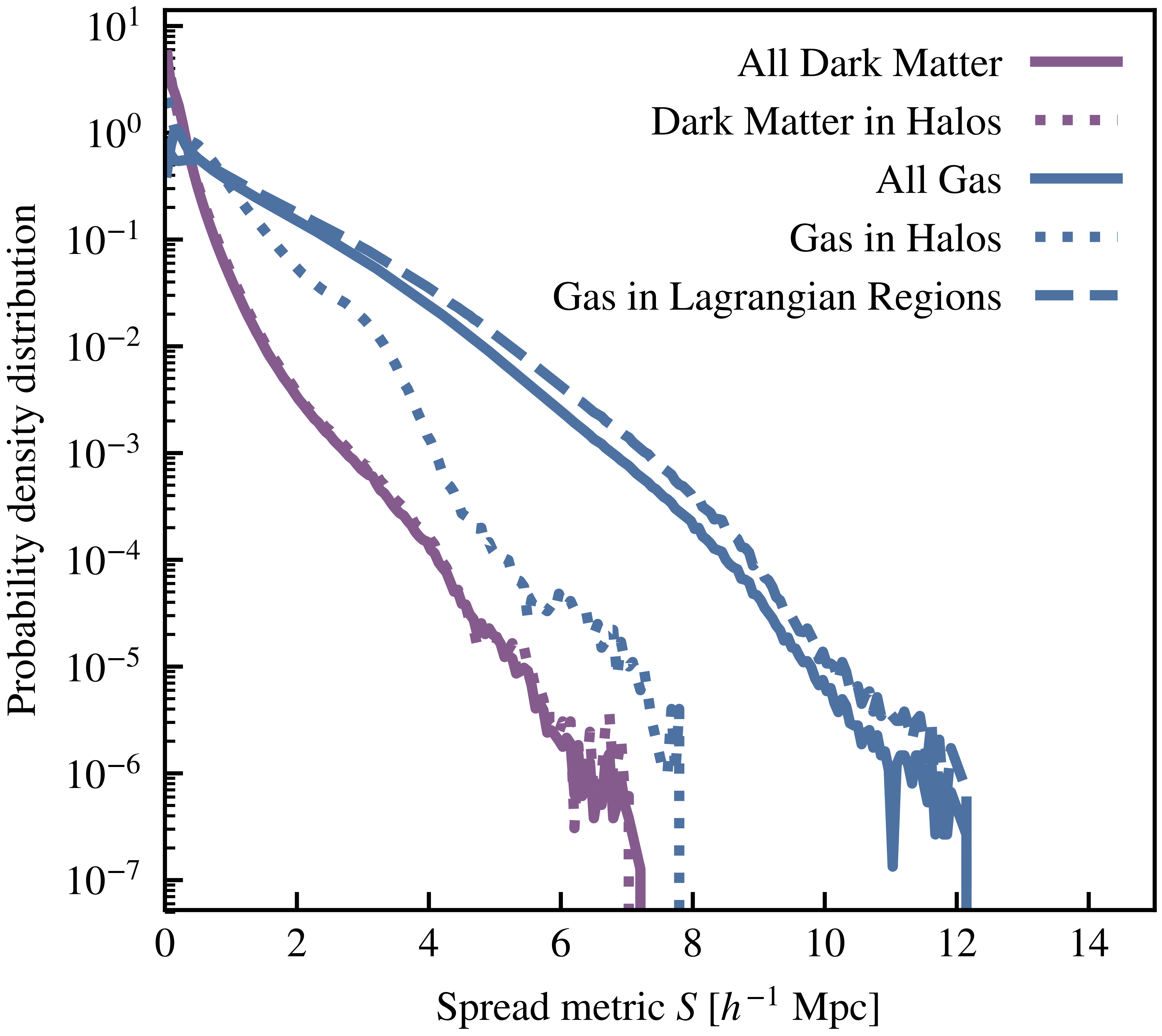


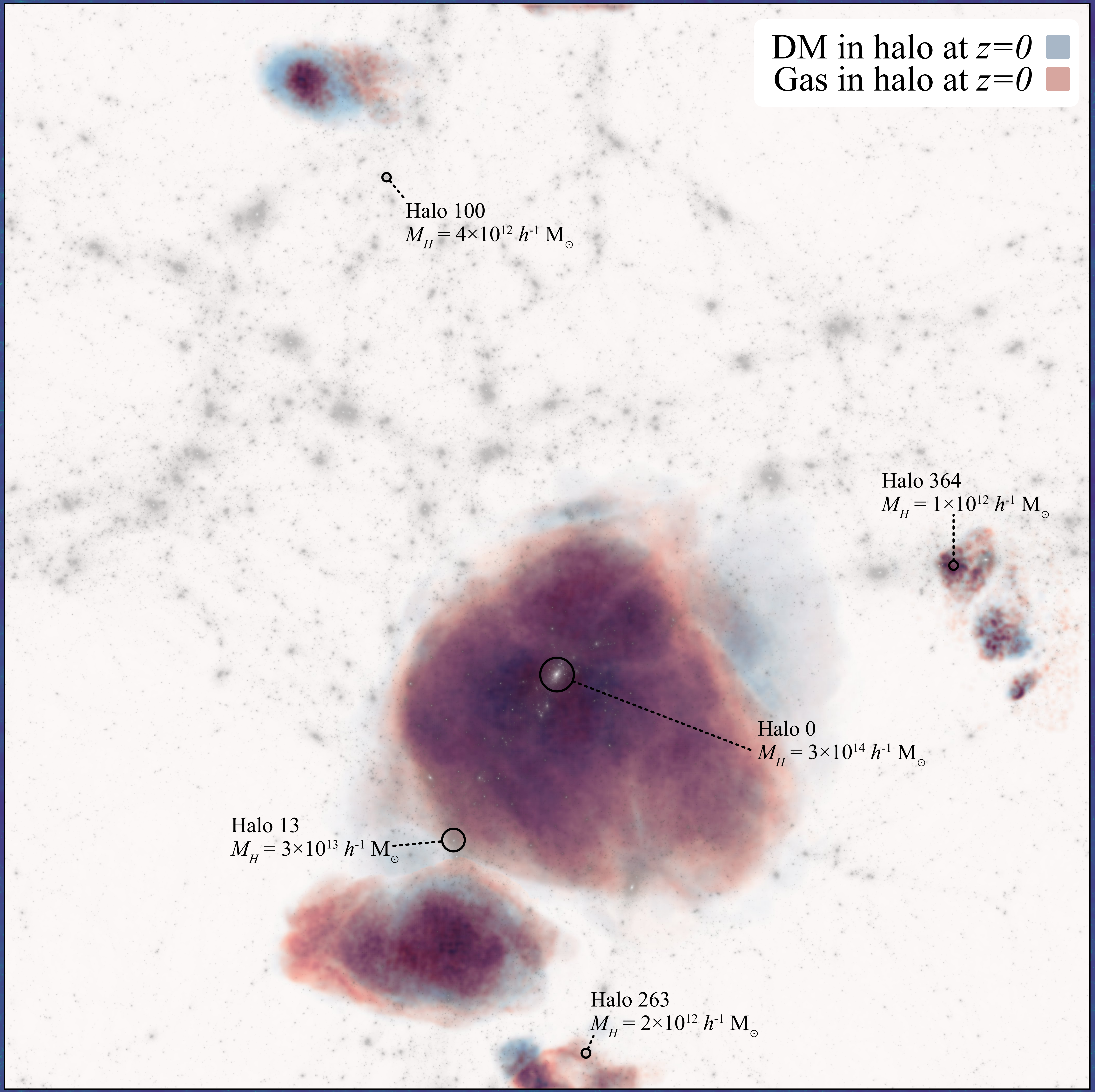
Quick summary

- Particles can be spread out to 7 Mpc (dark matter) and 12 Mpc (gas)
- Majority of gas constrained to within 5 Mpc (this is still > $3R_{\mathrm{vir}}$ of the largest halo in the box)
- Haloes and Lagrangian regions produce vastly different spread metric distributions



Halo View

- *z=0* distribution in the background
- *z=99* distribution in the foreground



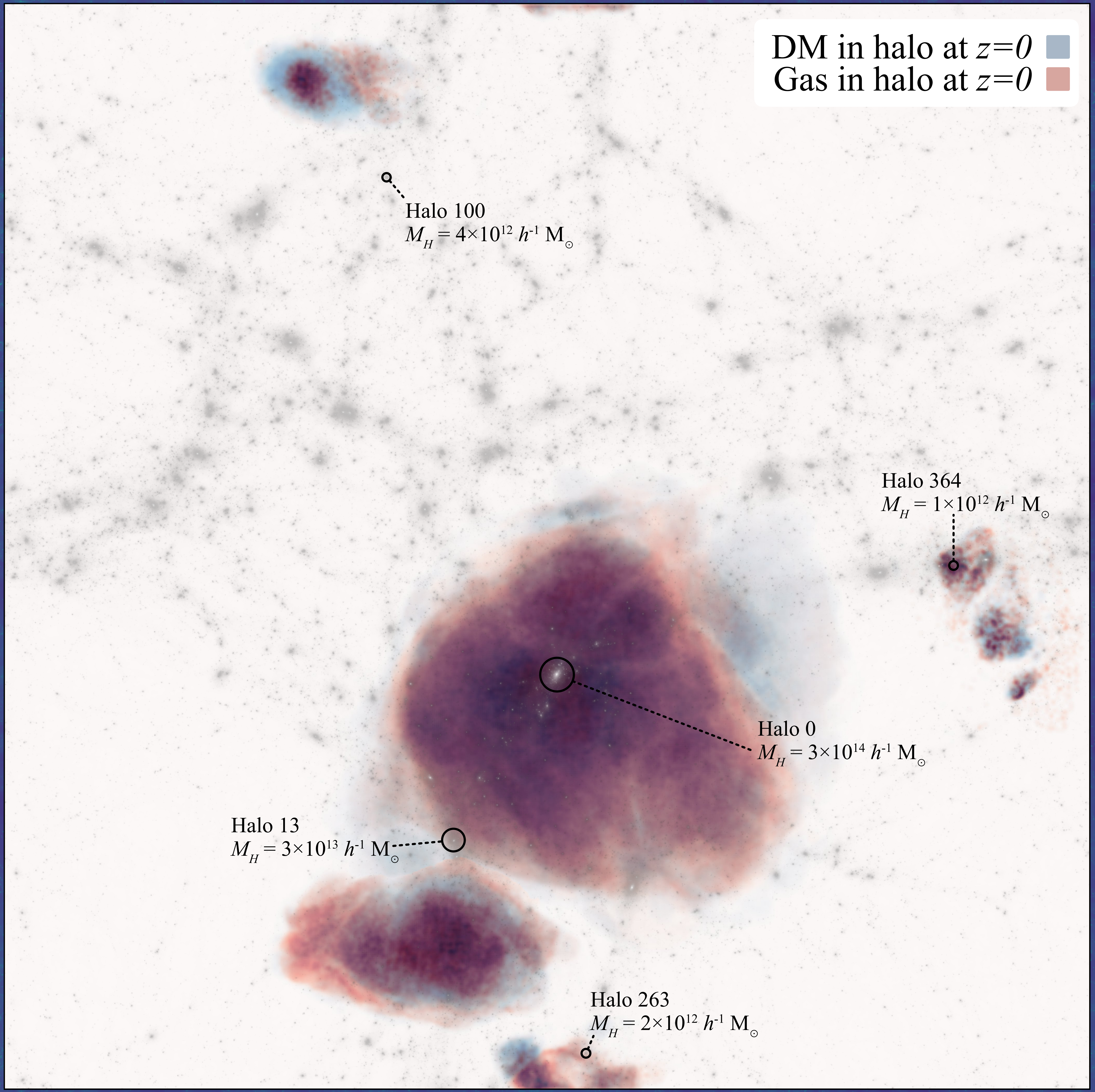
DM in halo at $z=0$
Gas in halo at $z=0$
Halo 0
$M_H = 3\times10^{14}\ h^{-1}\ \mathrm{M}_\odot$
$h^{-1}\ \mathrm{M}_\odot$

DM in halo at z=0
Gas in halo at z=0
Halo 13
$M_H = 3\times10^{13}\ h^{-1}\ \mathrm{M}_\odot$
Halo 263
$M_H = 2\times10^{12}\ h^{-1}\ \mathrm{M}_\odot$


DM in halo at $z=0$
Gas in halo at $z=0$
Halo 100
$M_H = 4\times10^{12}\ h^{-1}\ \mathrm{M}_\odot$

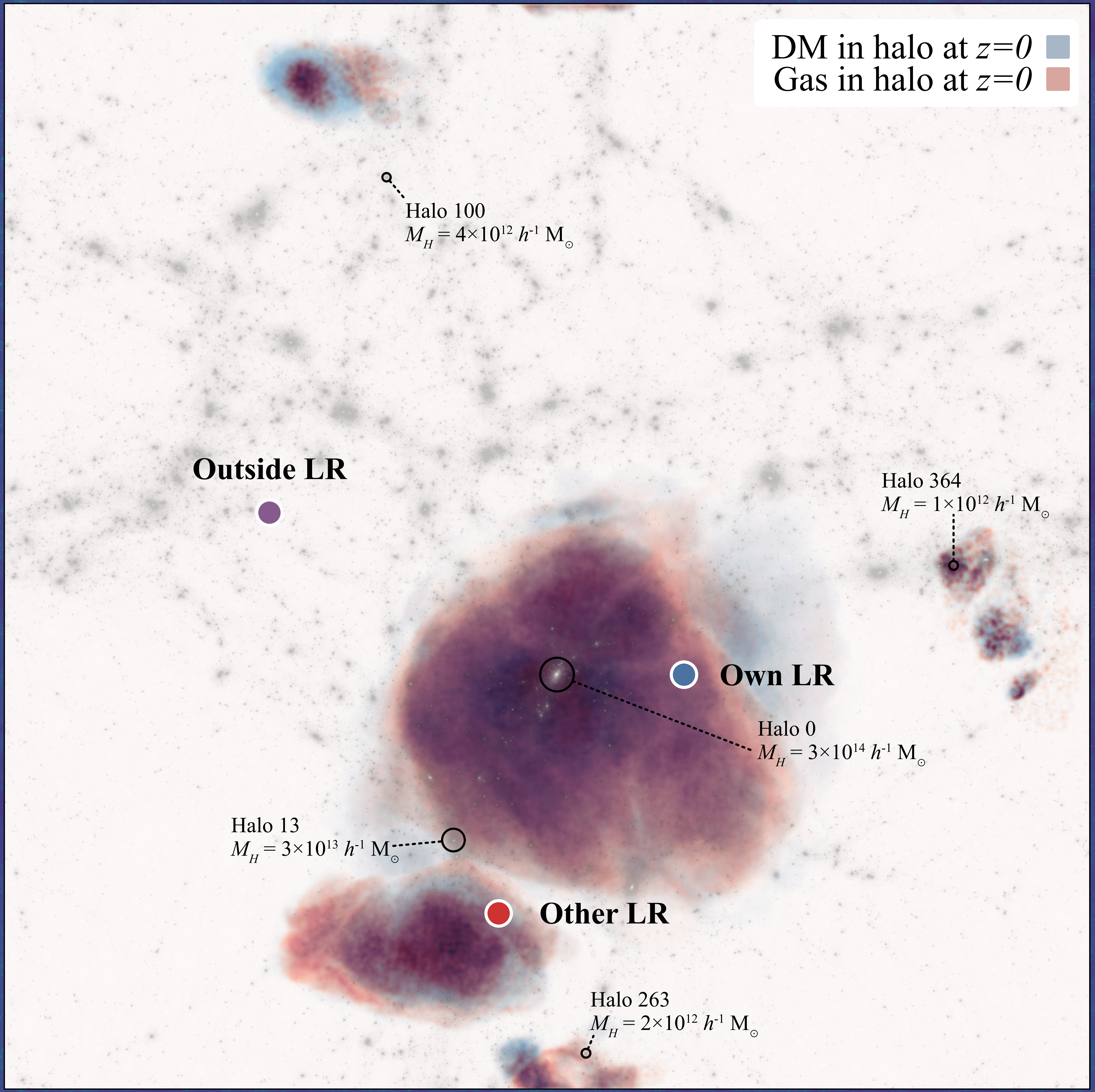
Halo View

- *z=0* distribution in the background
- *z=99* distribution in the foreground



Binning

- Three bins:
  - Same halo as LR
  - In halo from outside LR
  - In halo from other LR



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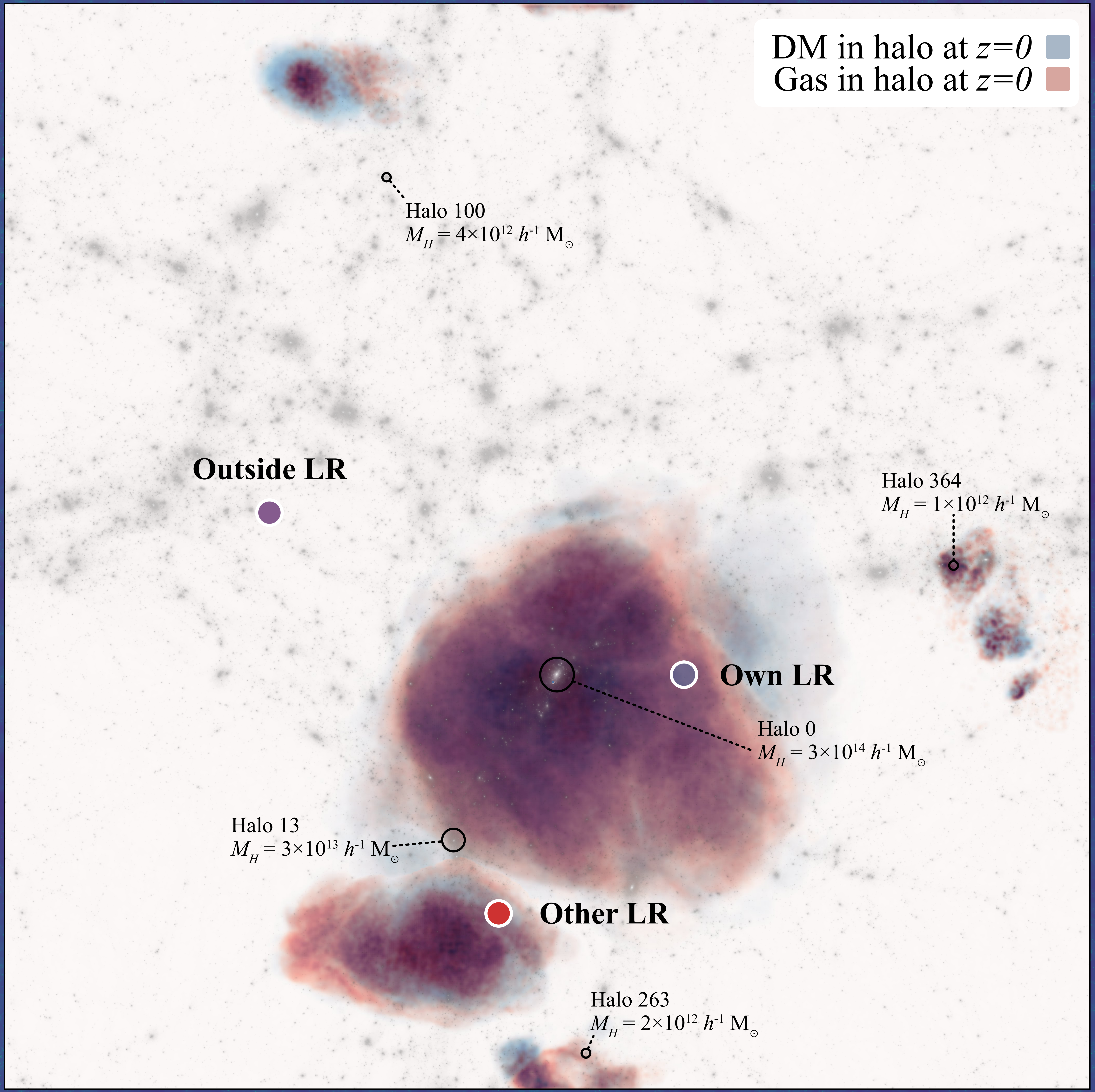

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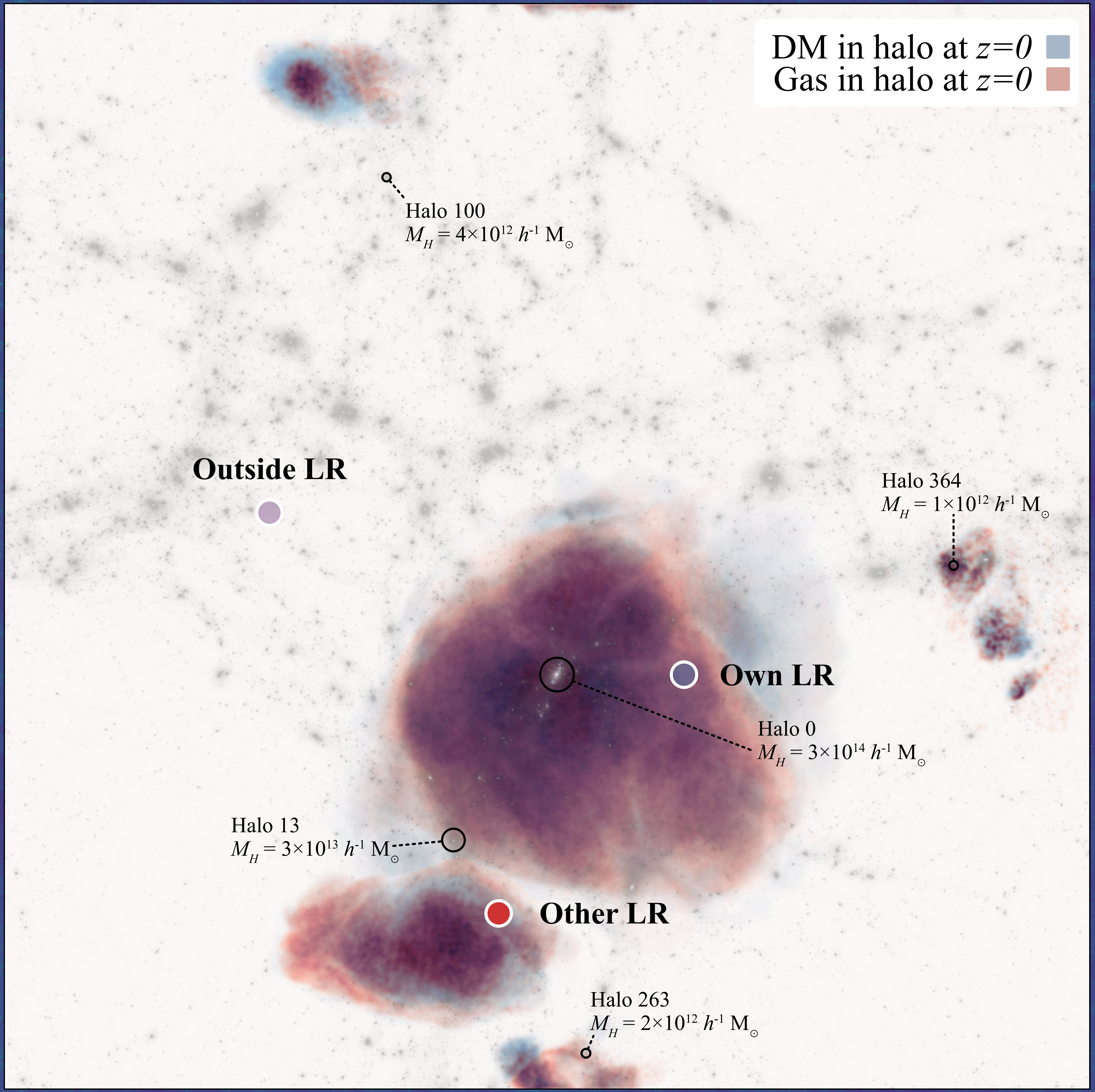

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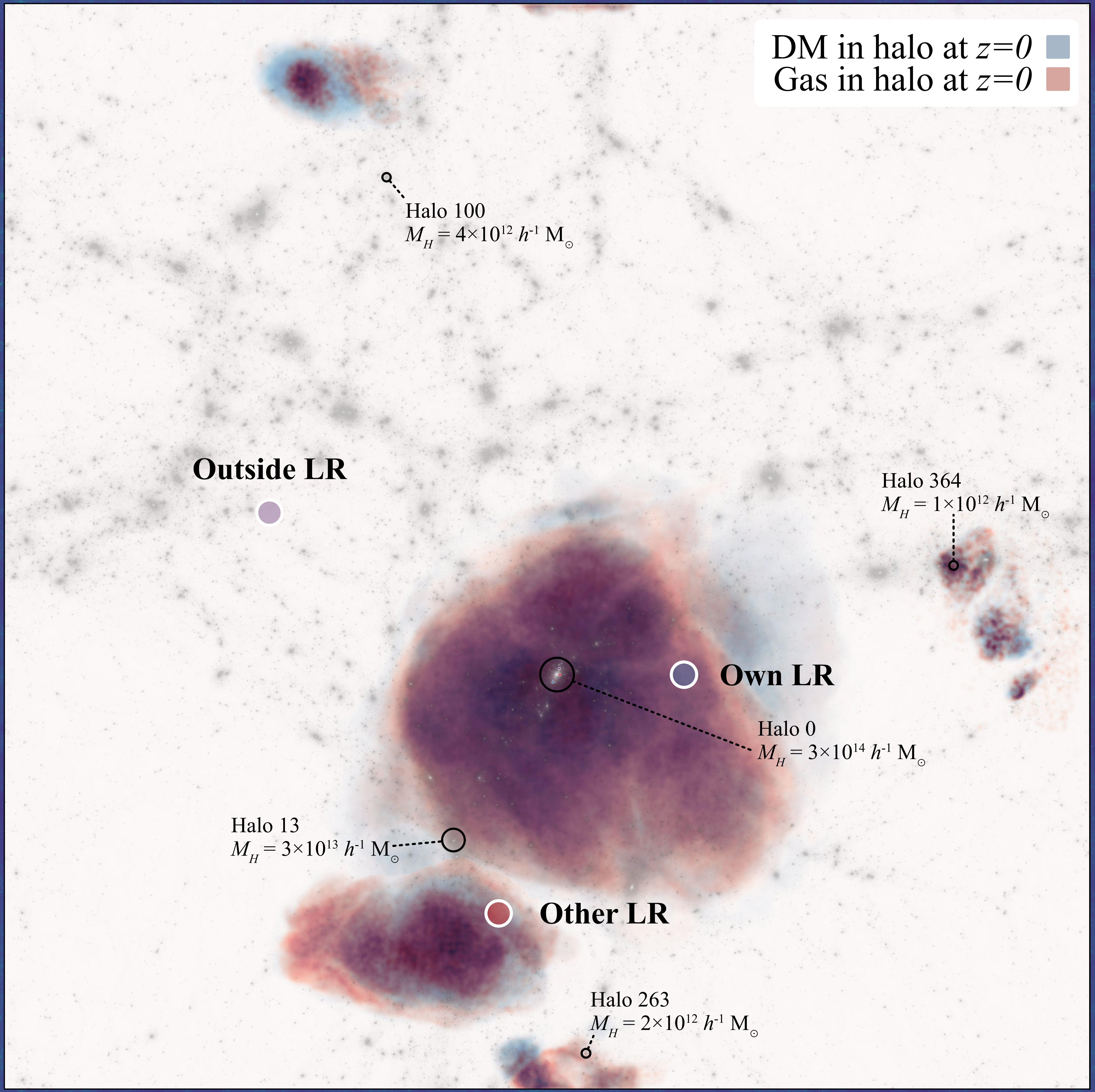
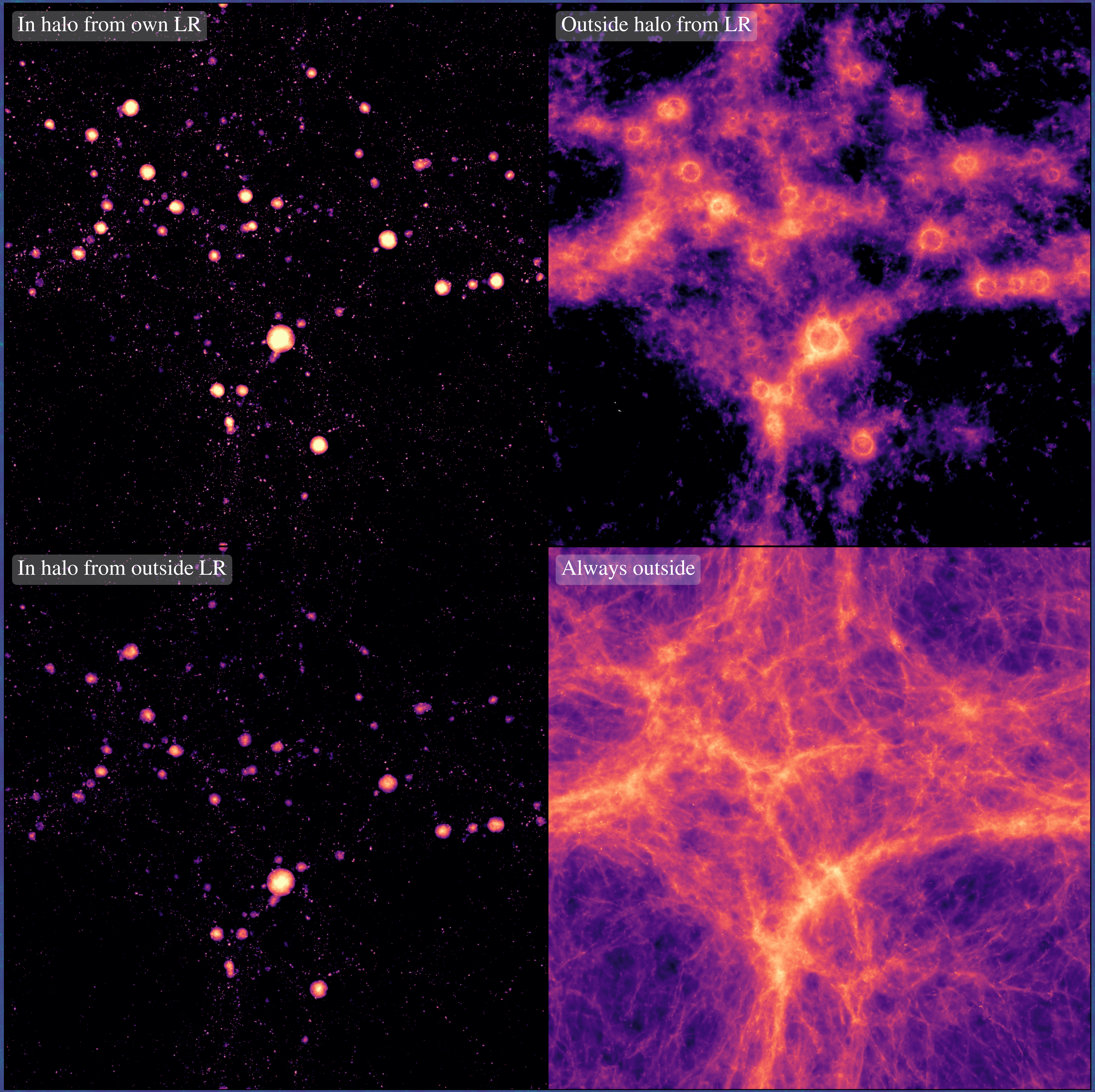


Baryon Distributions

- What do those distributions look like when projected for the whole box?



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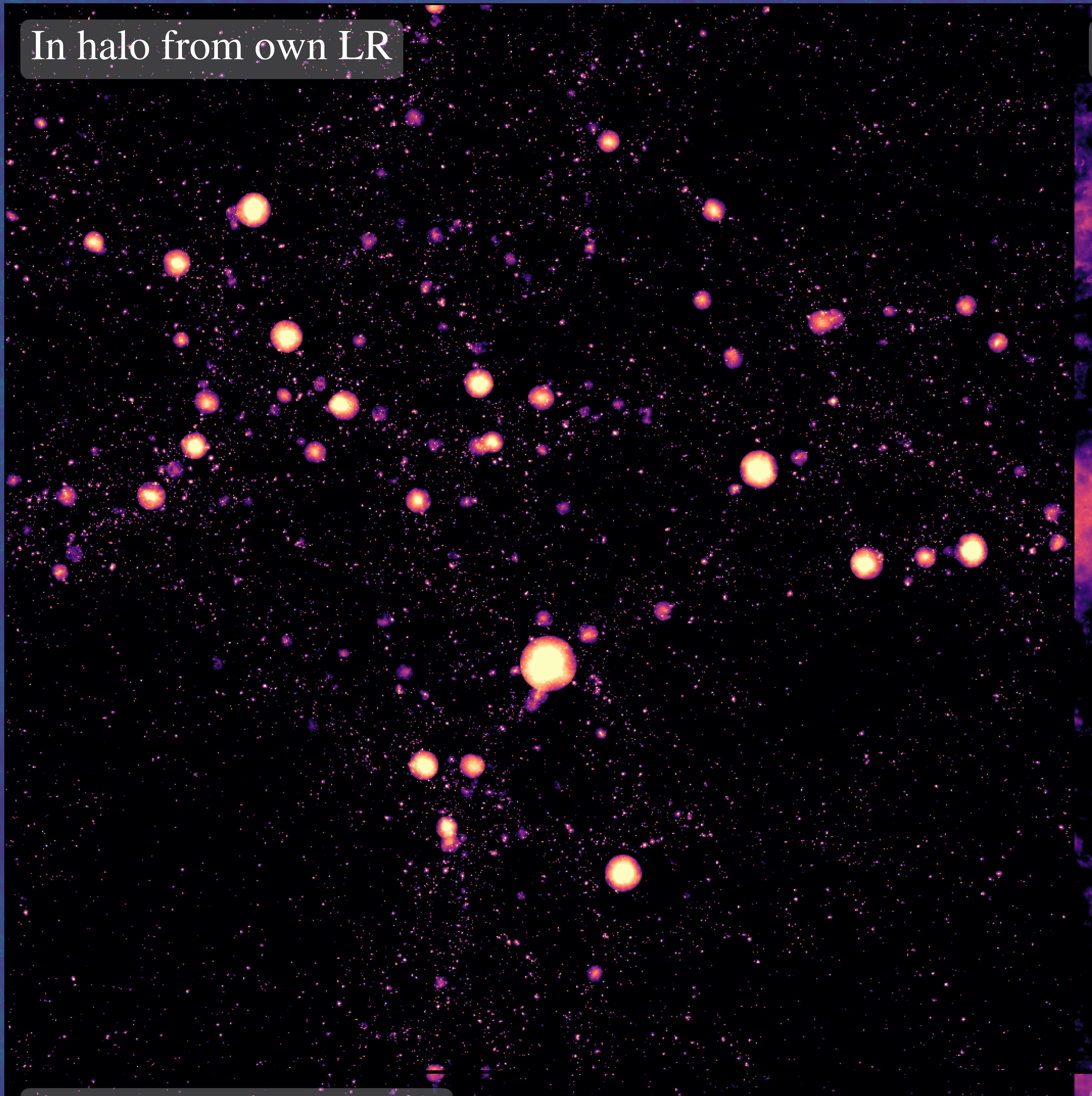


om outside LR
Always outside

Baryon Distributions

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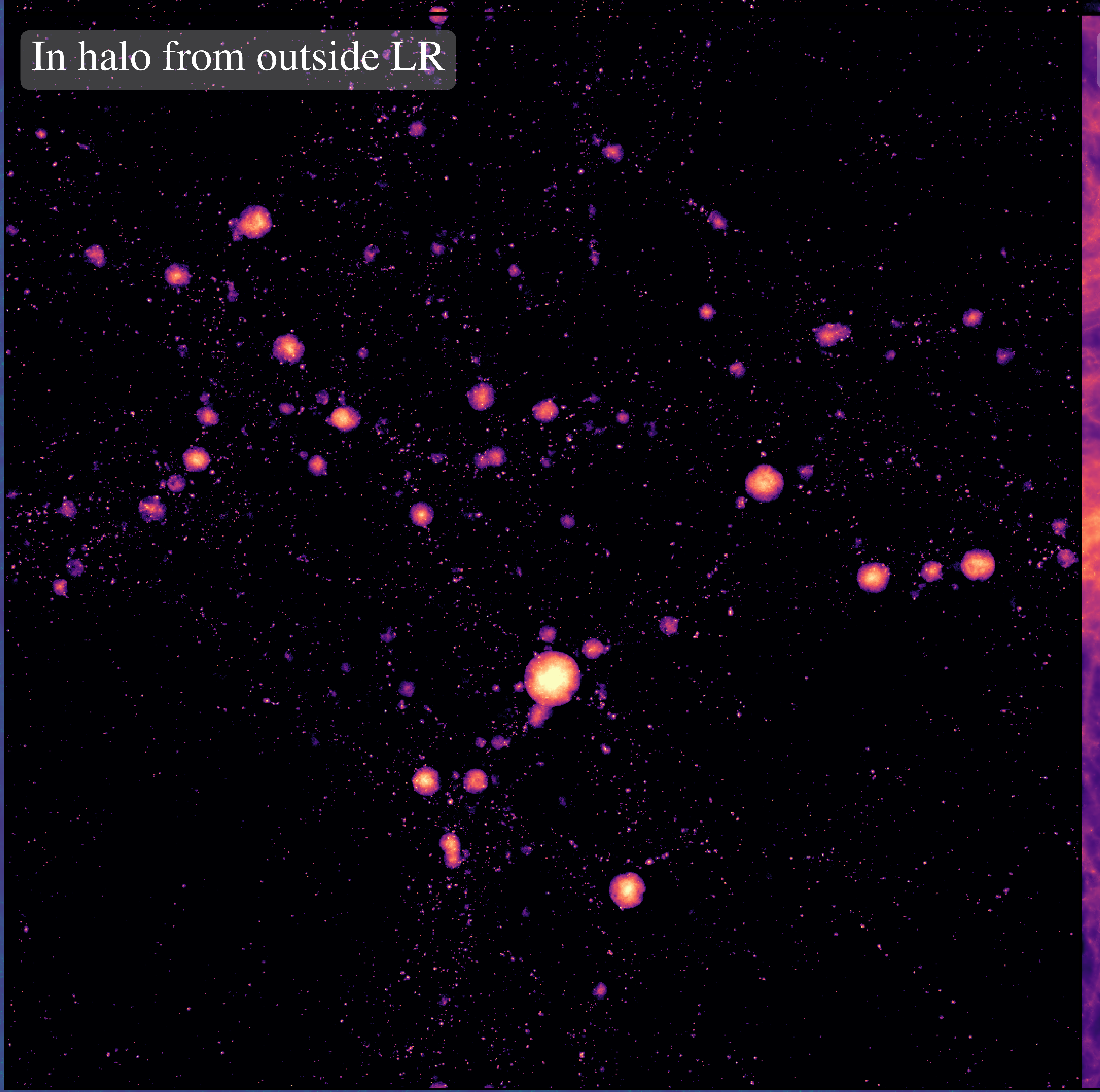


om own LR
Outside halo from LR

Baryon Distributions

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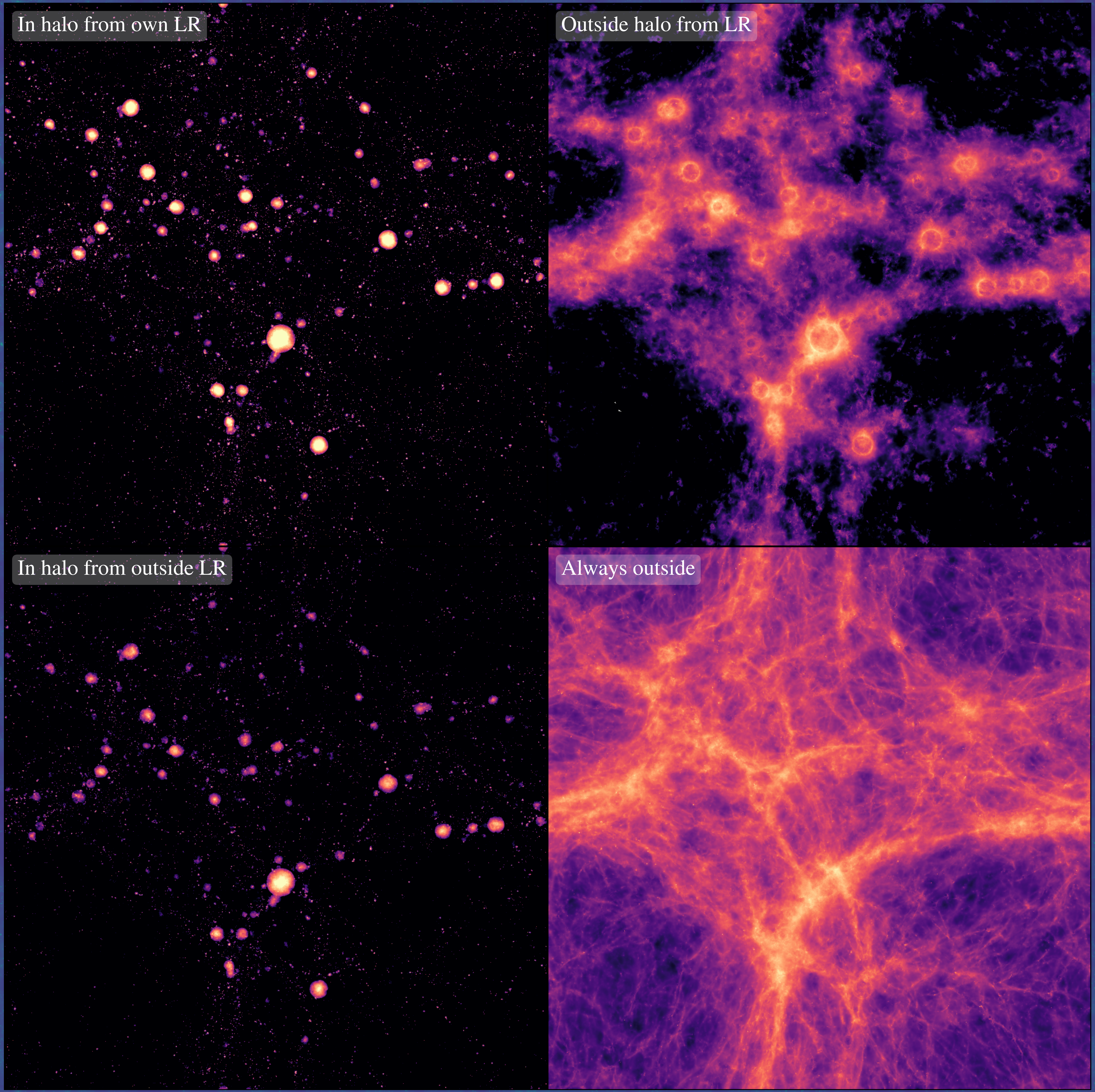
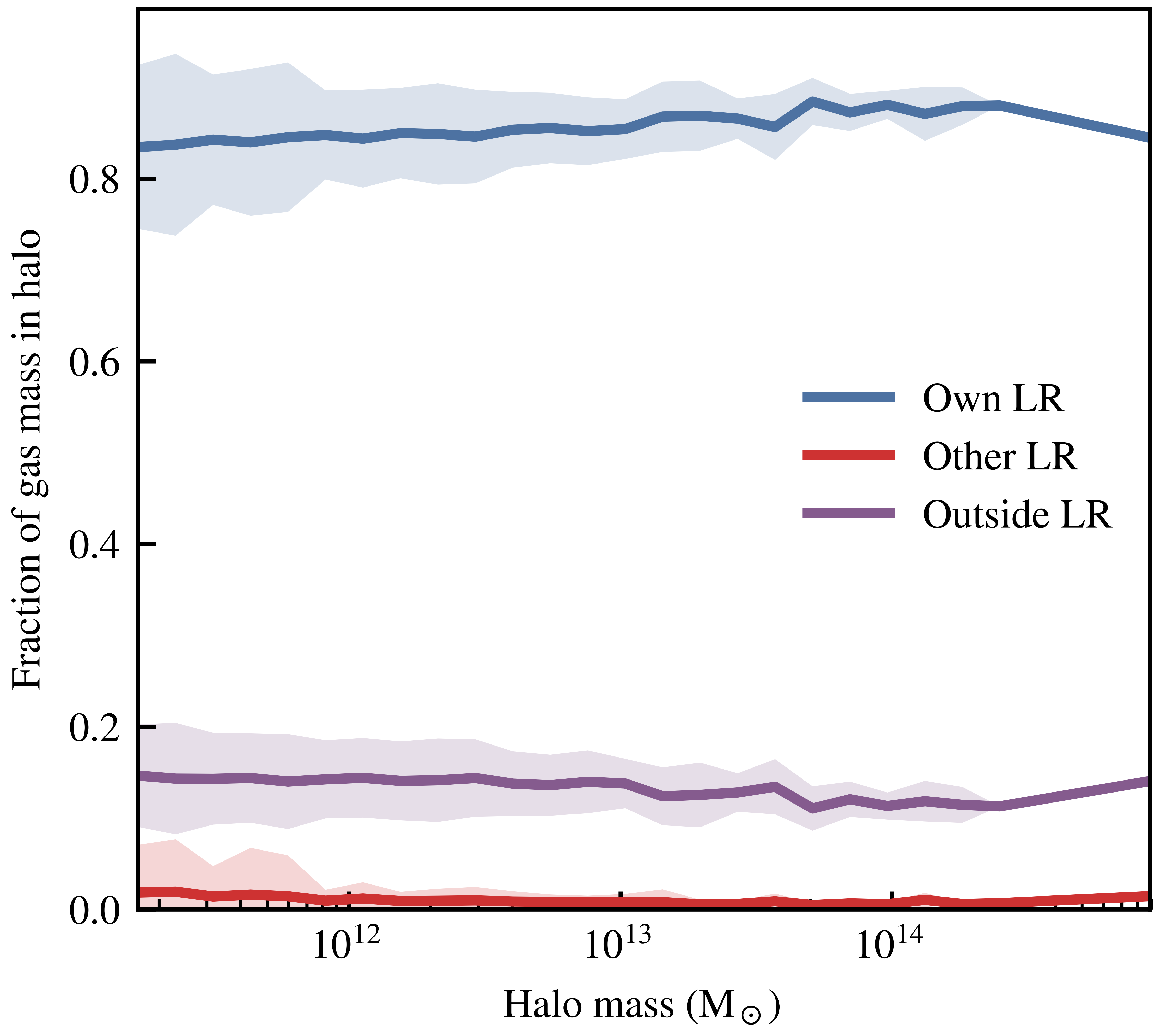
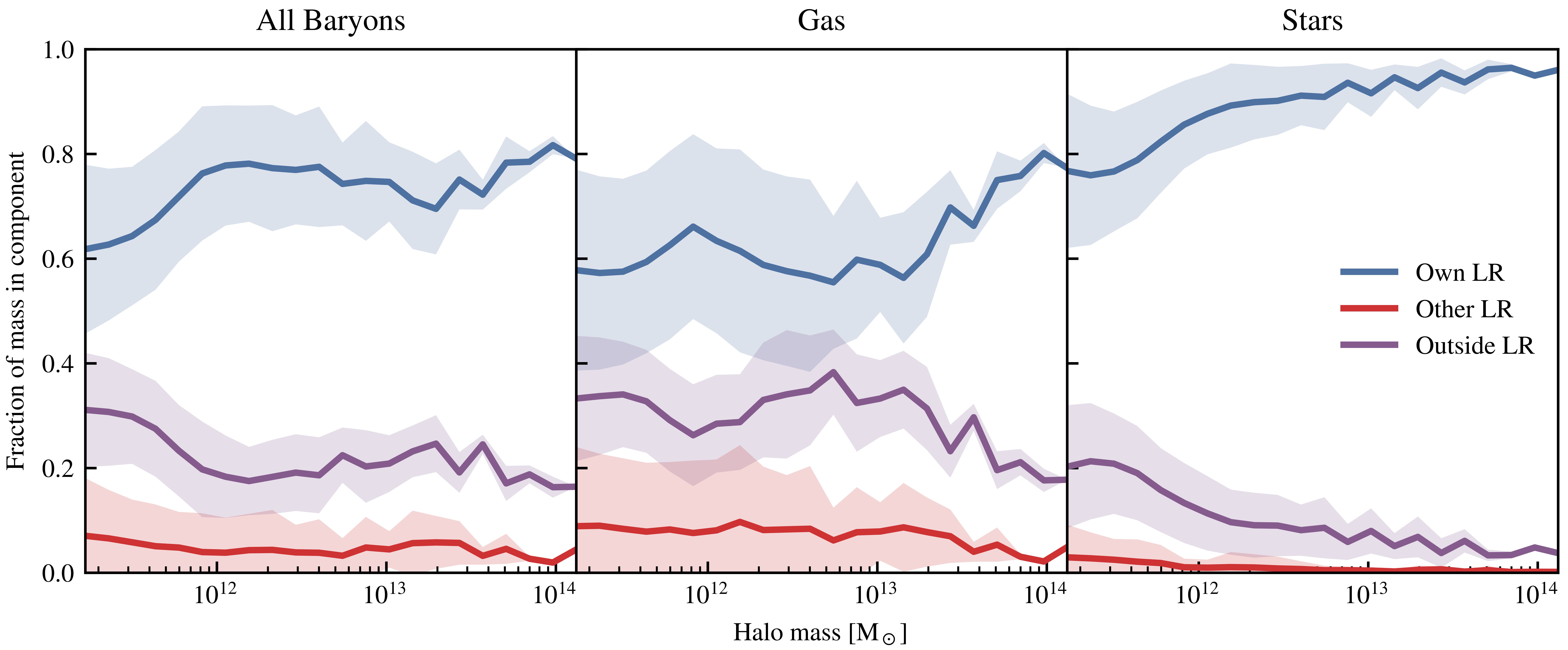


Numerical Results: Simple Case

- Start with the simplest case!
- Non-radiative case, i.e. without a galaxy formation sub-grid model
- Mixing between gas and dark matter leads to 15% 'contamination' of baryons from outside Lagrangian regions!



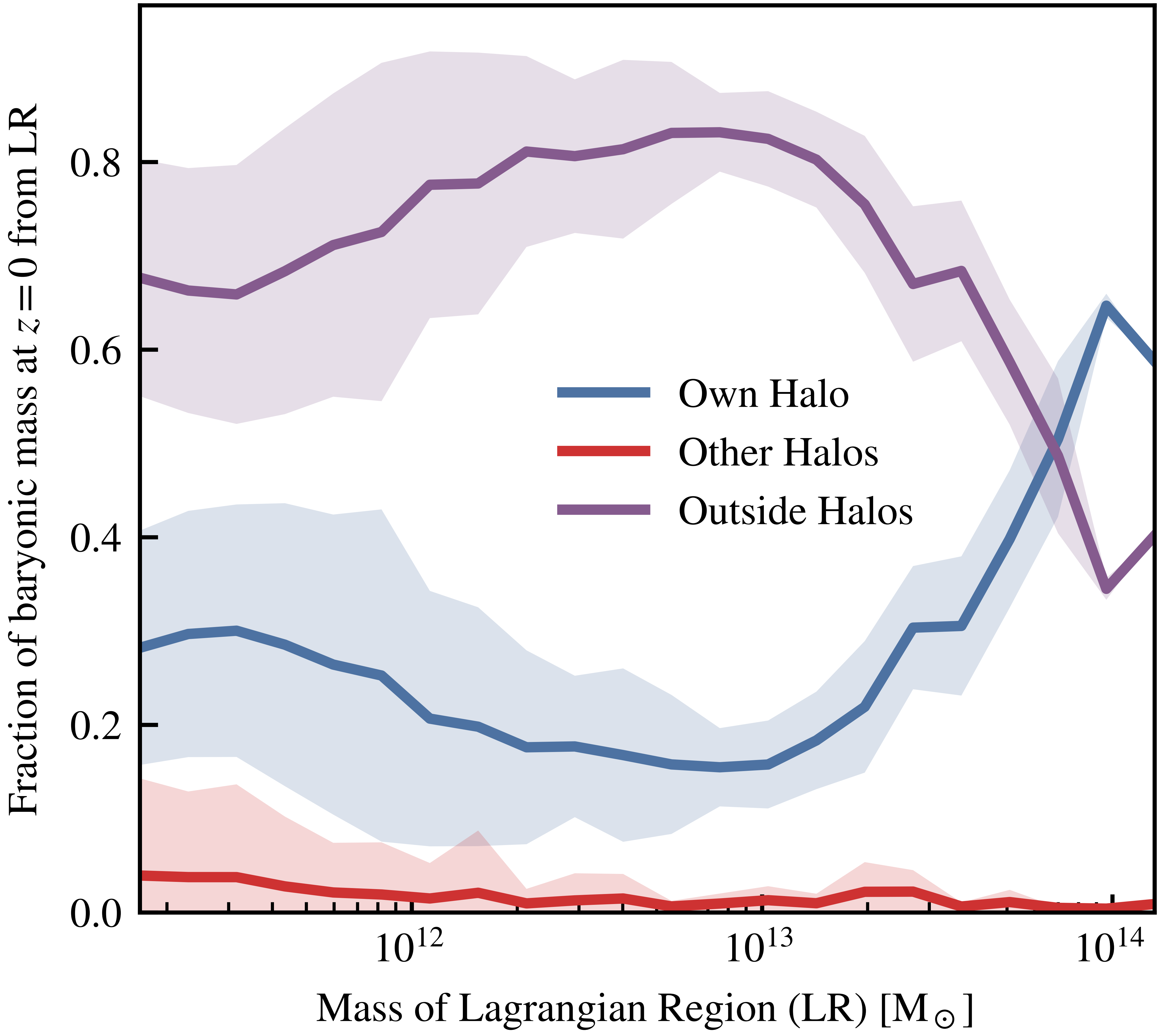
Full model!



All Baryons
Gas
Stars
Fraction of mass in component
0.0
0.2
0.4
0.6
0.8
1.0
10^{12}
10^{13}
10^{14}
Halo mass [$M_\odot$]
Own LR
Other LR
Outside LR

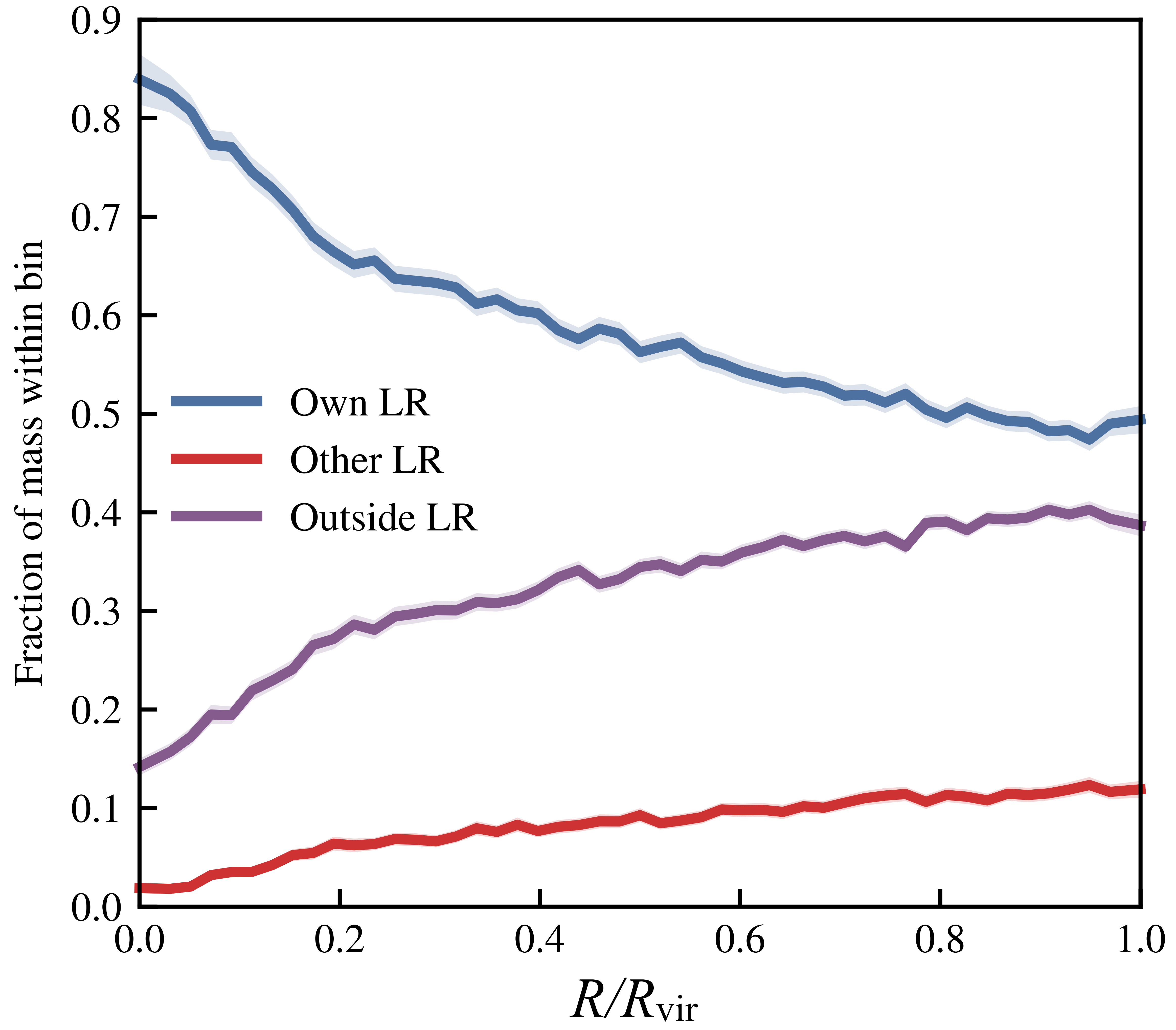
Where do the baryons go?

- Now look at all baryons in the Lagrangian region
- What is their eventual fate?
- Can see the hole blown in 'own halo' from AGN feedback around MW mass and above.

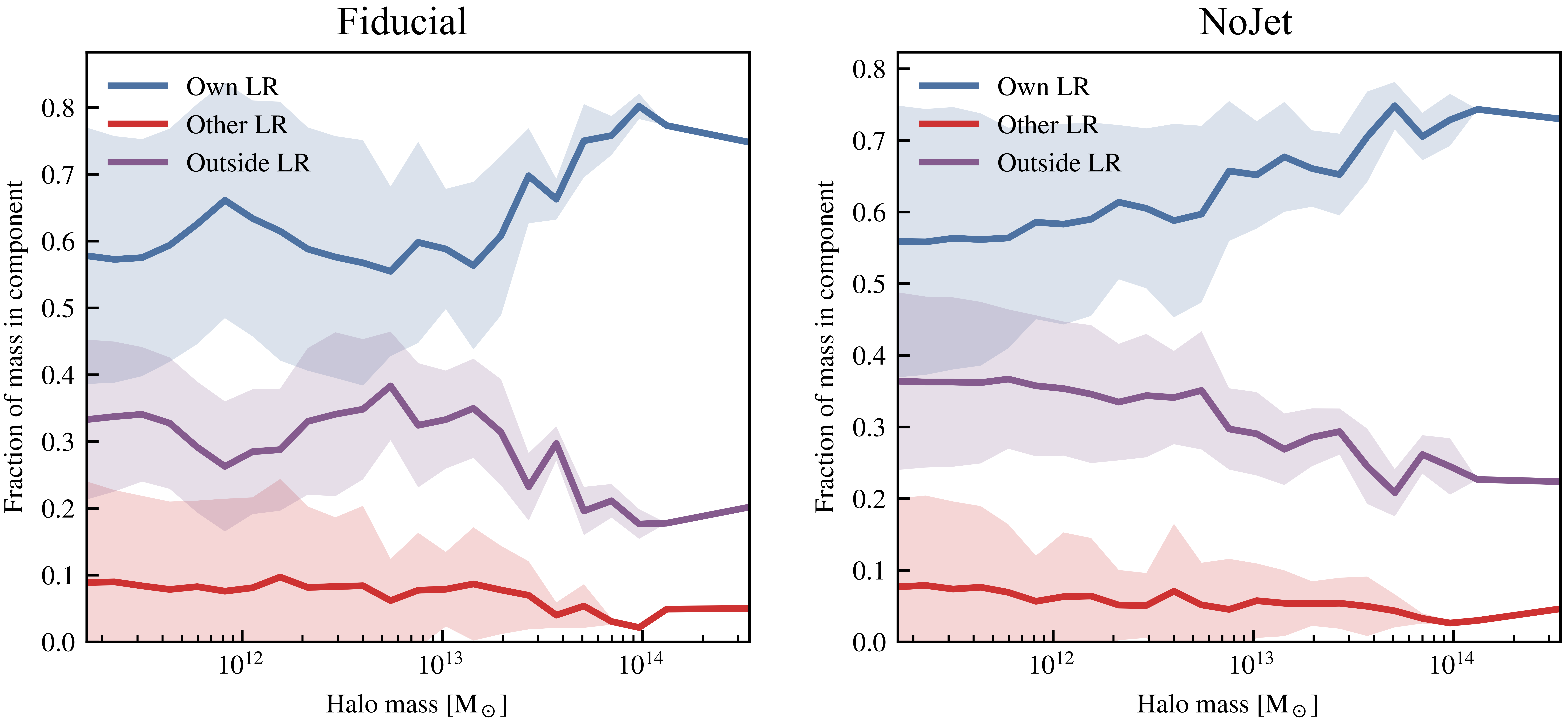


Resolved properties

- Consider all 10^{12} - 10^{13} $M_\odot$ haloes, and bin their gas profiles radially.
- Unfortunately, we can't do lower mass than this due to SIMBA's resolution.
- Further into the CGM we see more contamination from extra-Lagrangian gas.



Taking away the jets



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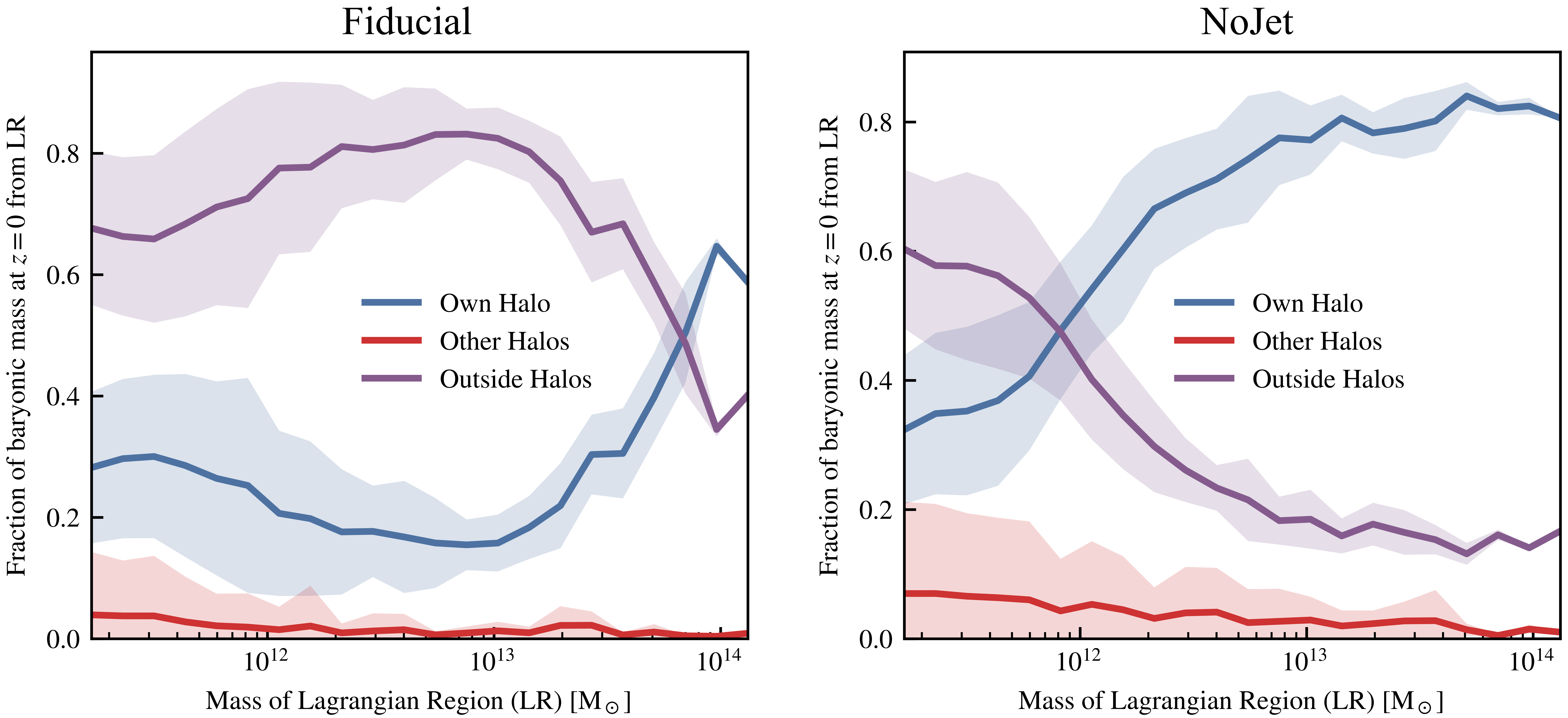

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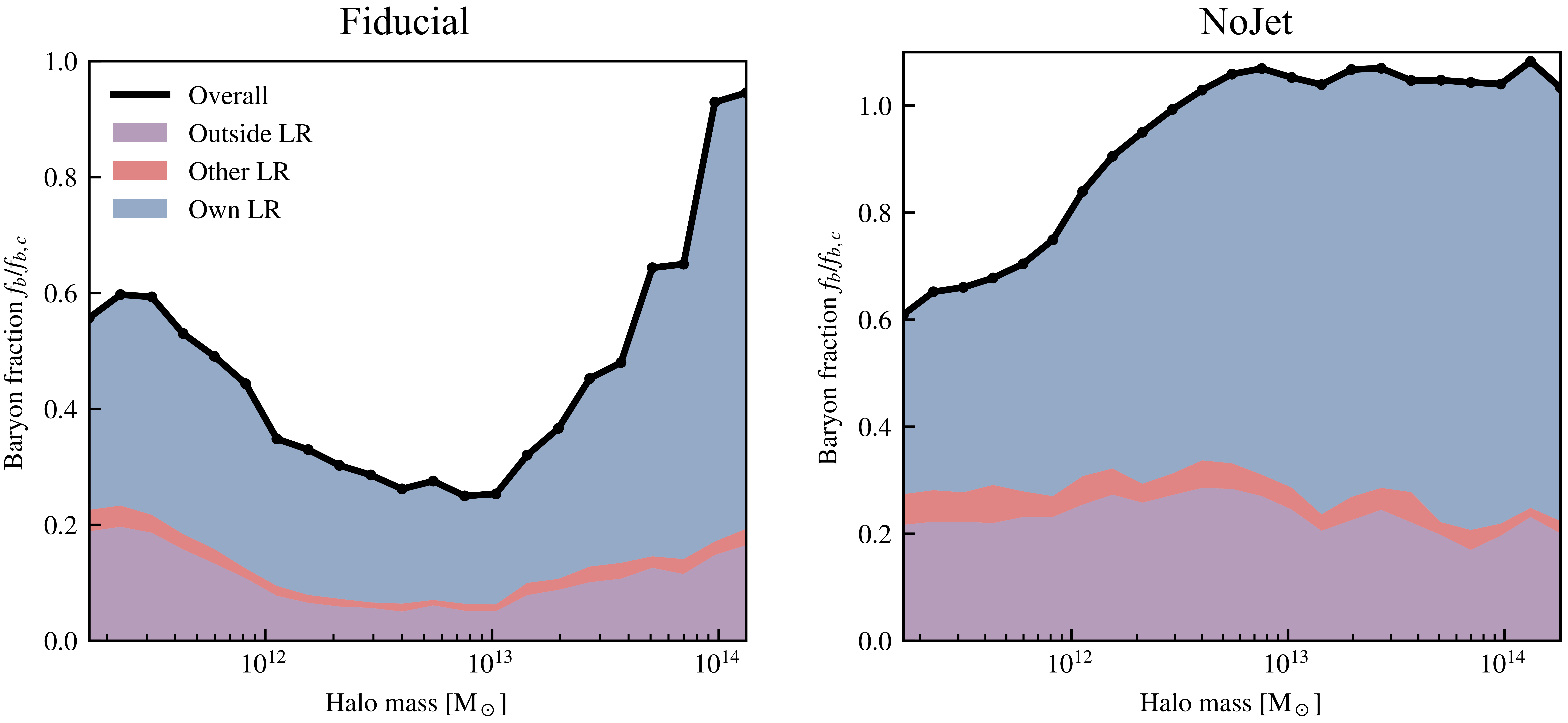
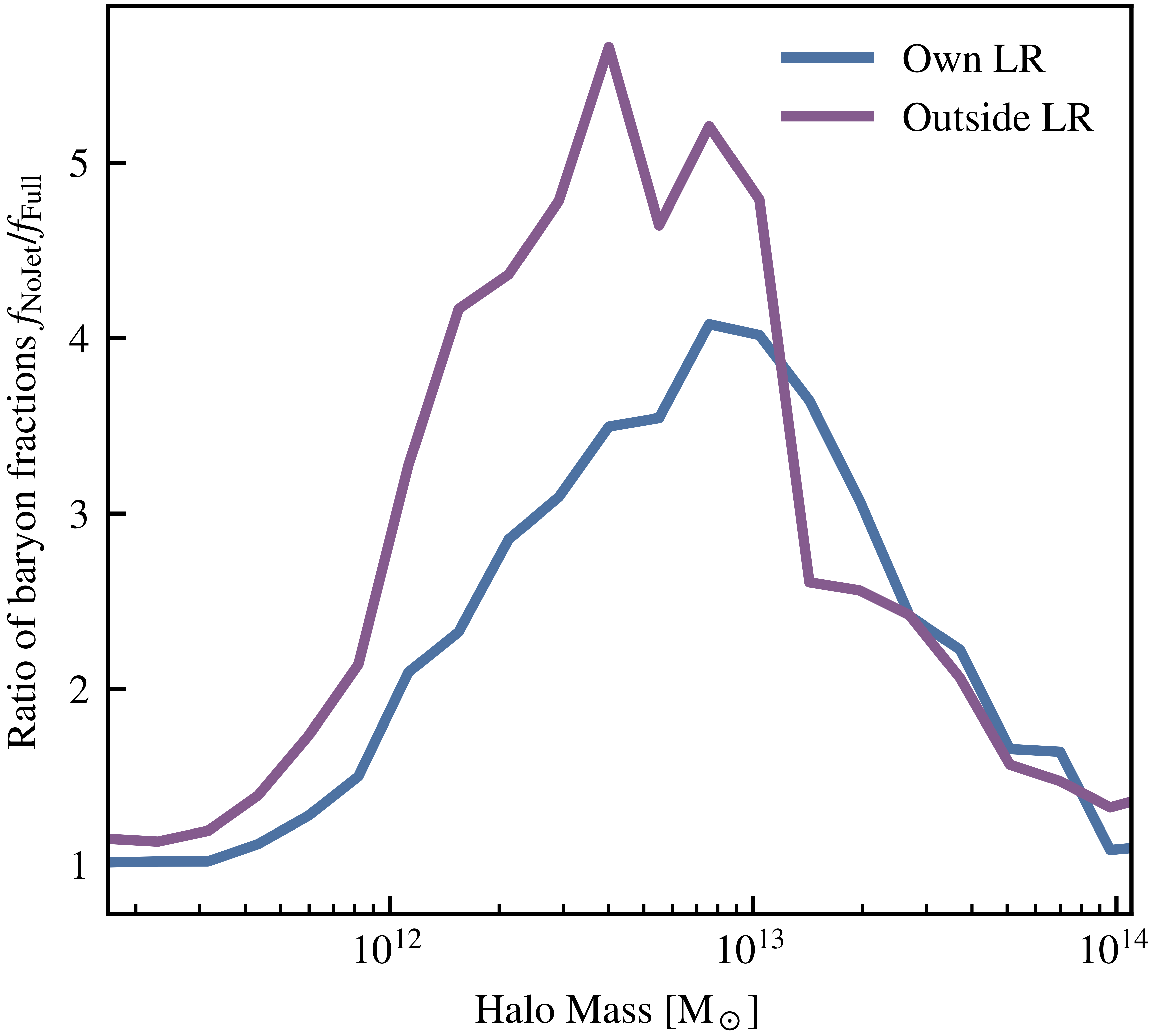


Taking away the jets

- Clear that there is a more complex interaction between jets and halo gas than simply 'jet blows gas out'

- Jets only directly interact with 0.4% of particles!

- Seems that gas from outside the LR is affected more significantly by these jets than gas from inside - points to preventative feedback?



Conclusions

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- SIMBA exists!
- Constraint on the maximal spread of baryons
- Able to **extract gas that has been affected by strong feedback** (including entrained gas)
- **10% of the gas mass** in a MW-mass halo **originated** from the LR of **another halo**!
- Plan to **extend this analysis to EAGLE, IllustrisTNG, and EAGLE-XL** (eventually)