More precise dark matter density profiles with dynamical information

Claudia Muni
Andrew Pontzen, Jason L. Sanders, Martin P. Rey, Justin I. Read, Oscar Agertz

Cosmology 2023 in Miramare

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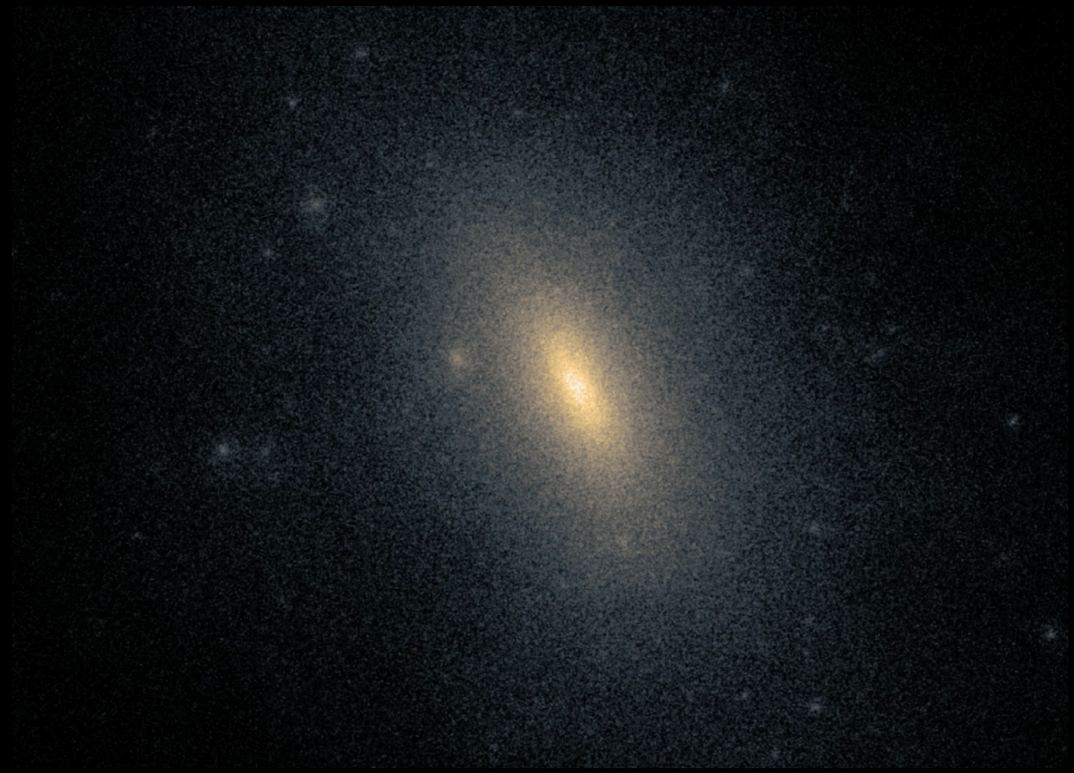
European Research Council

Background

Dark matter halos & cosmological simulations



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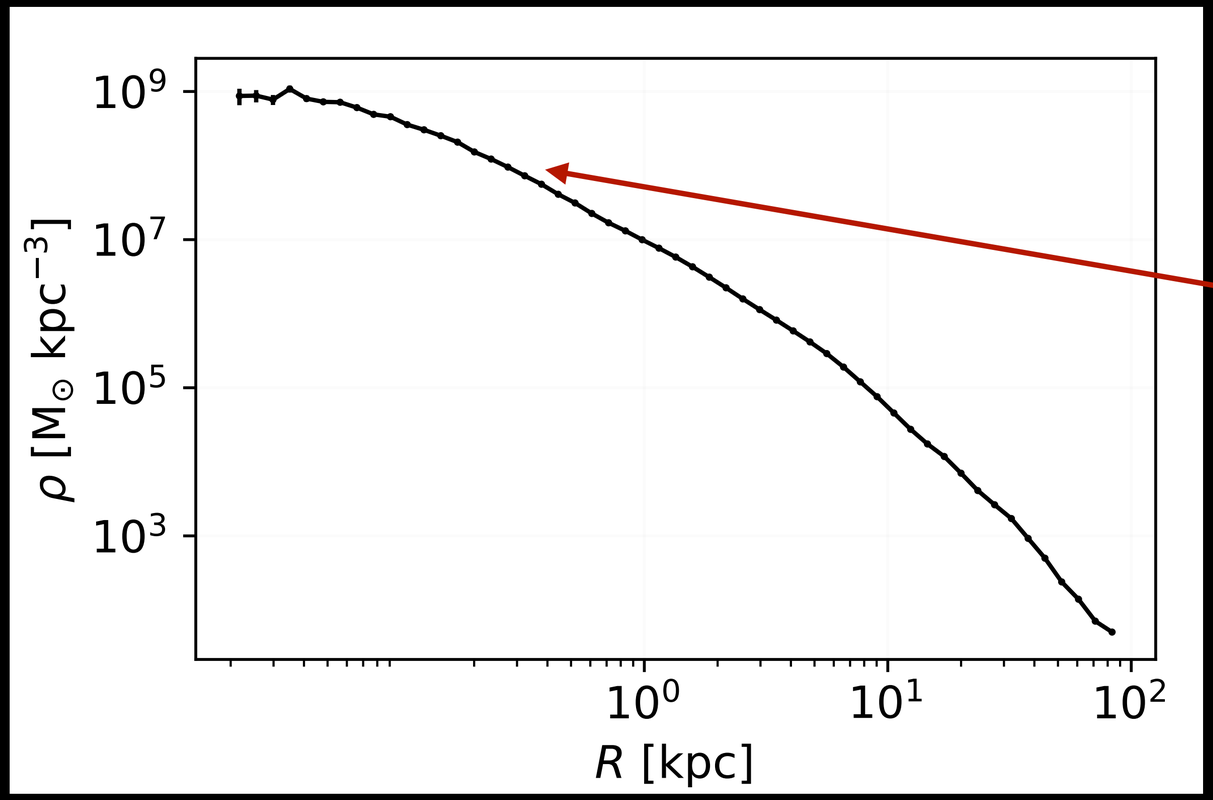

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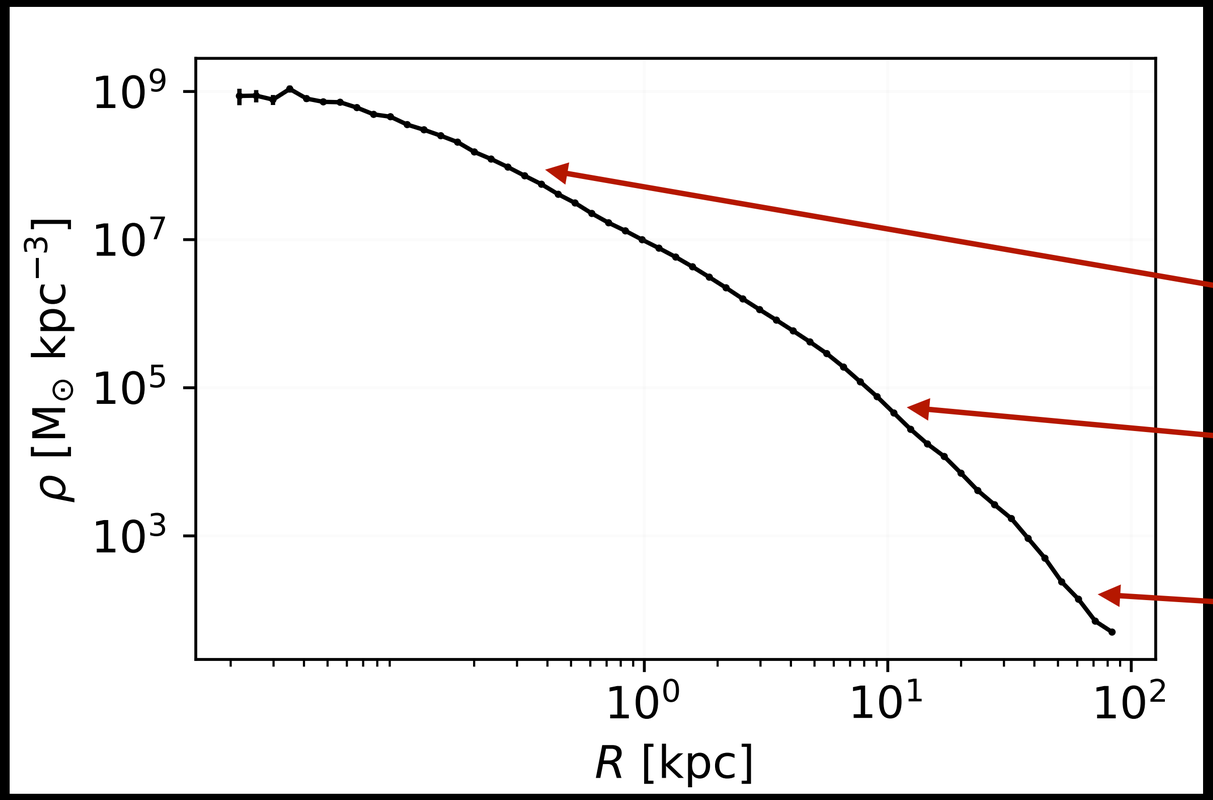

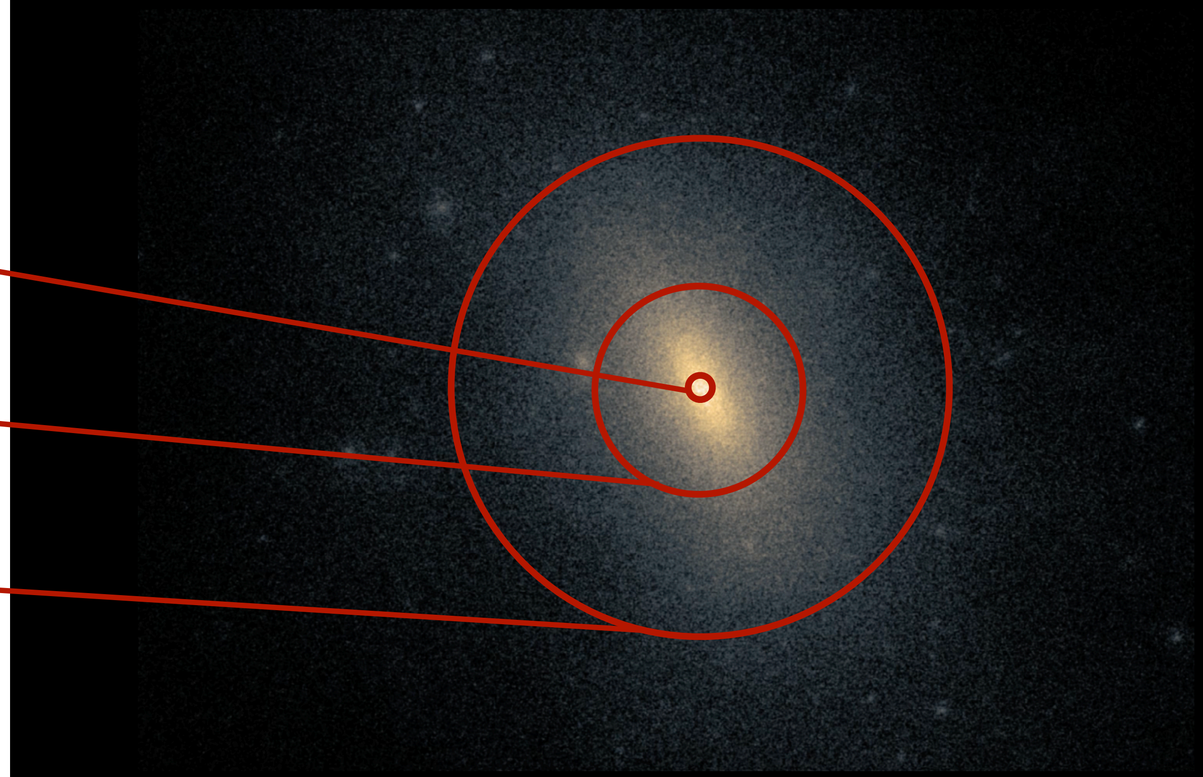

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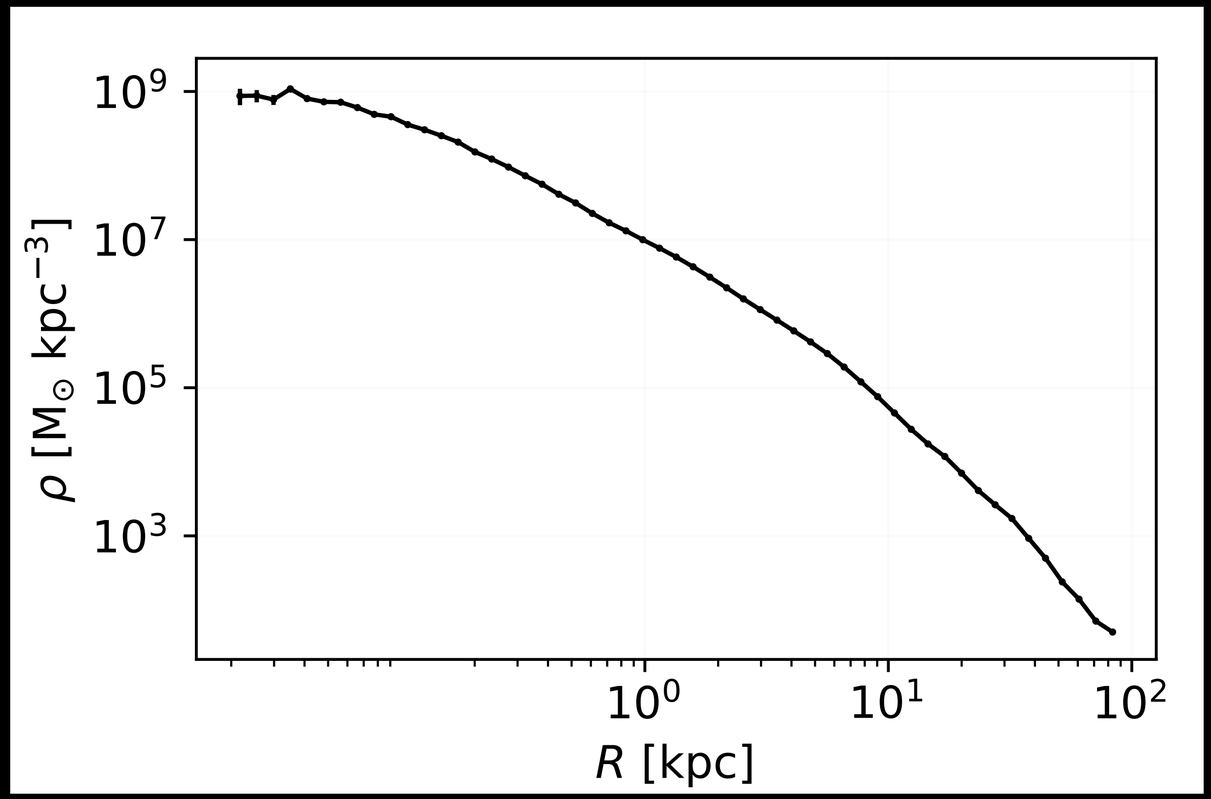
- Density profiles reveal information about the nature of dark matter



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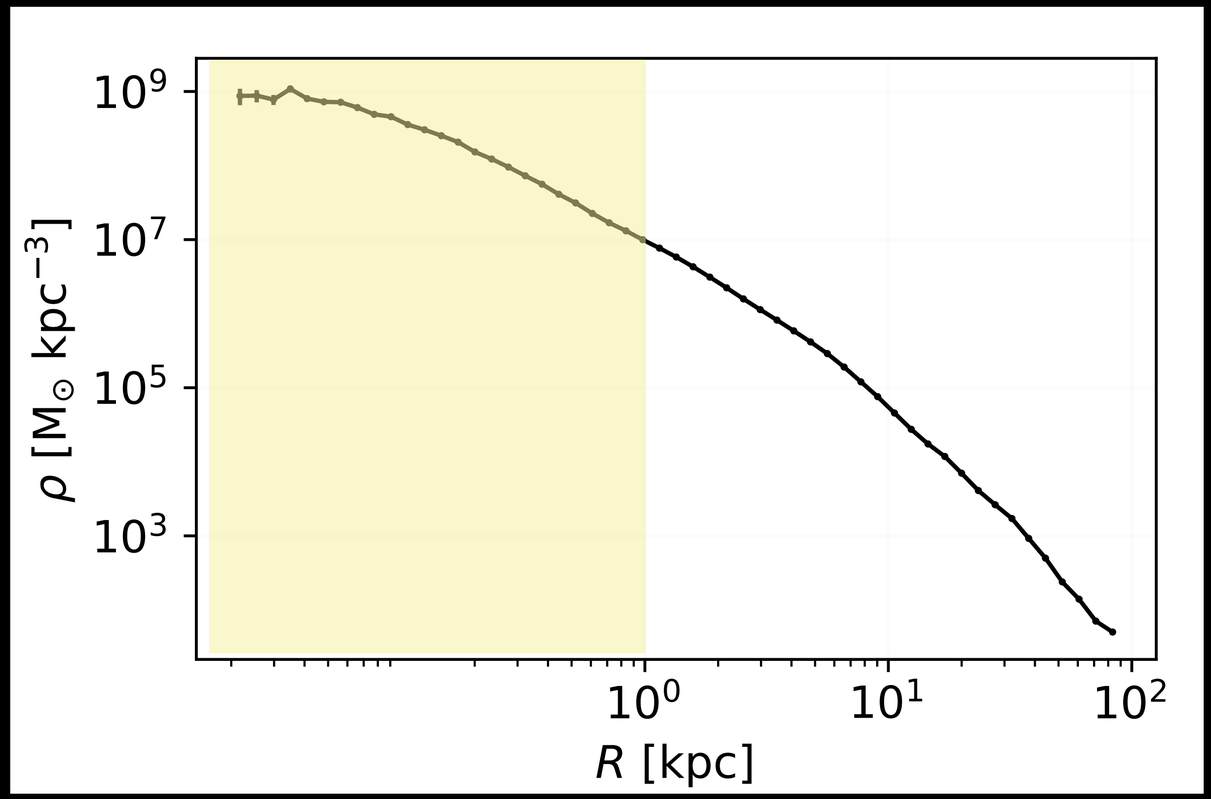

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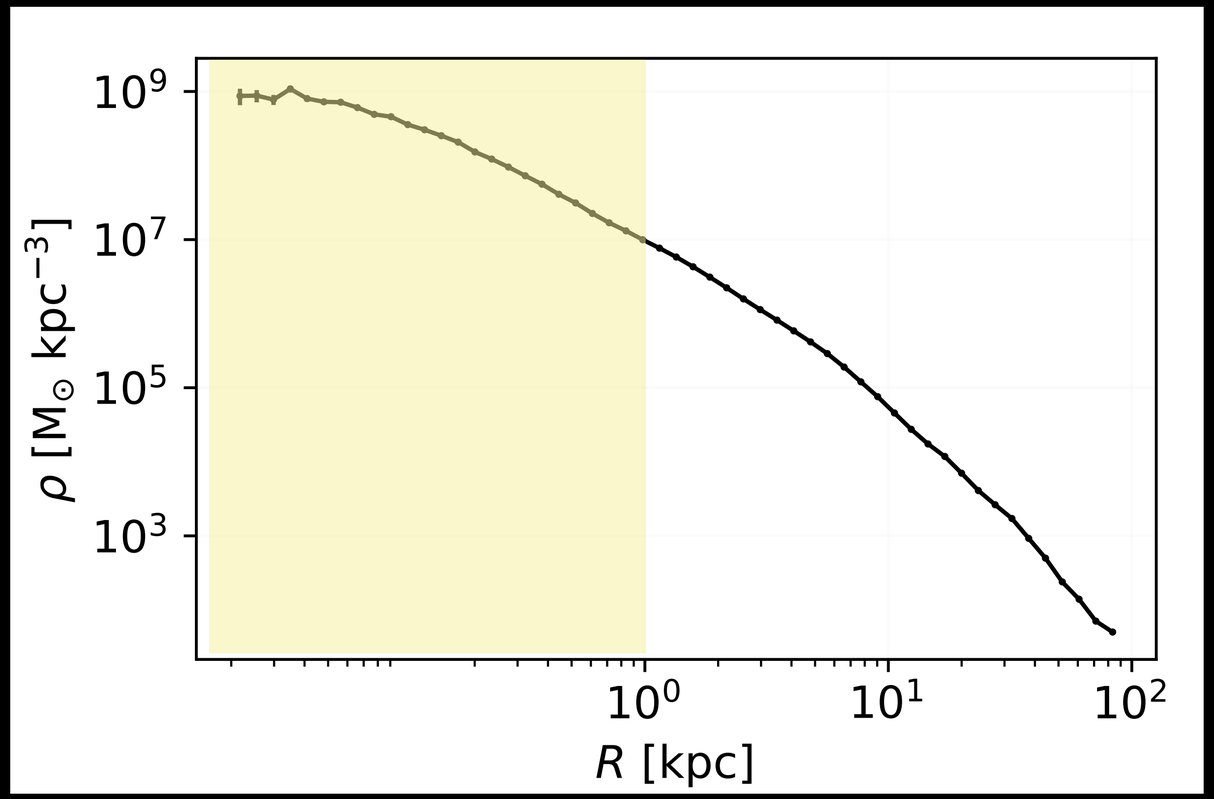
- Making profiles more precise is extremely important (indirect detection, strong lensing)



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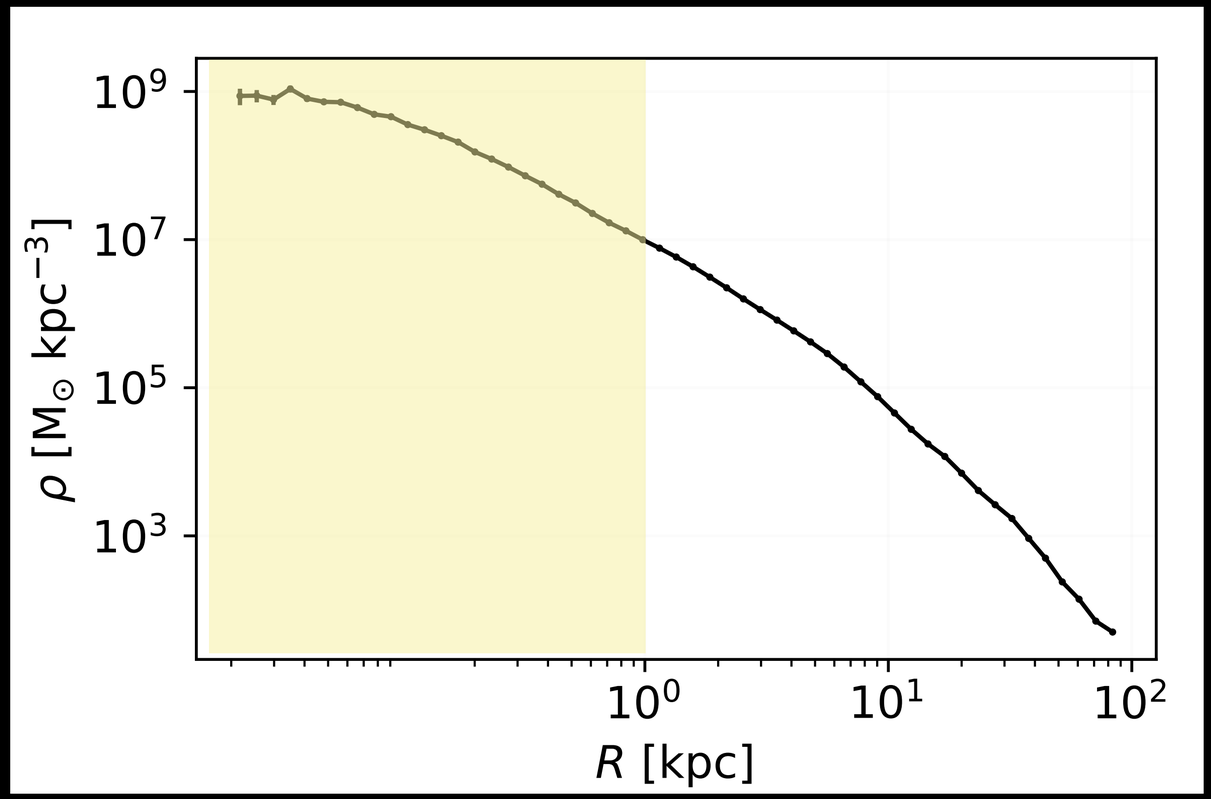
- Observations need to be compared to theoretical predictions (based on simulations)



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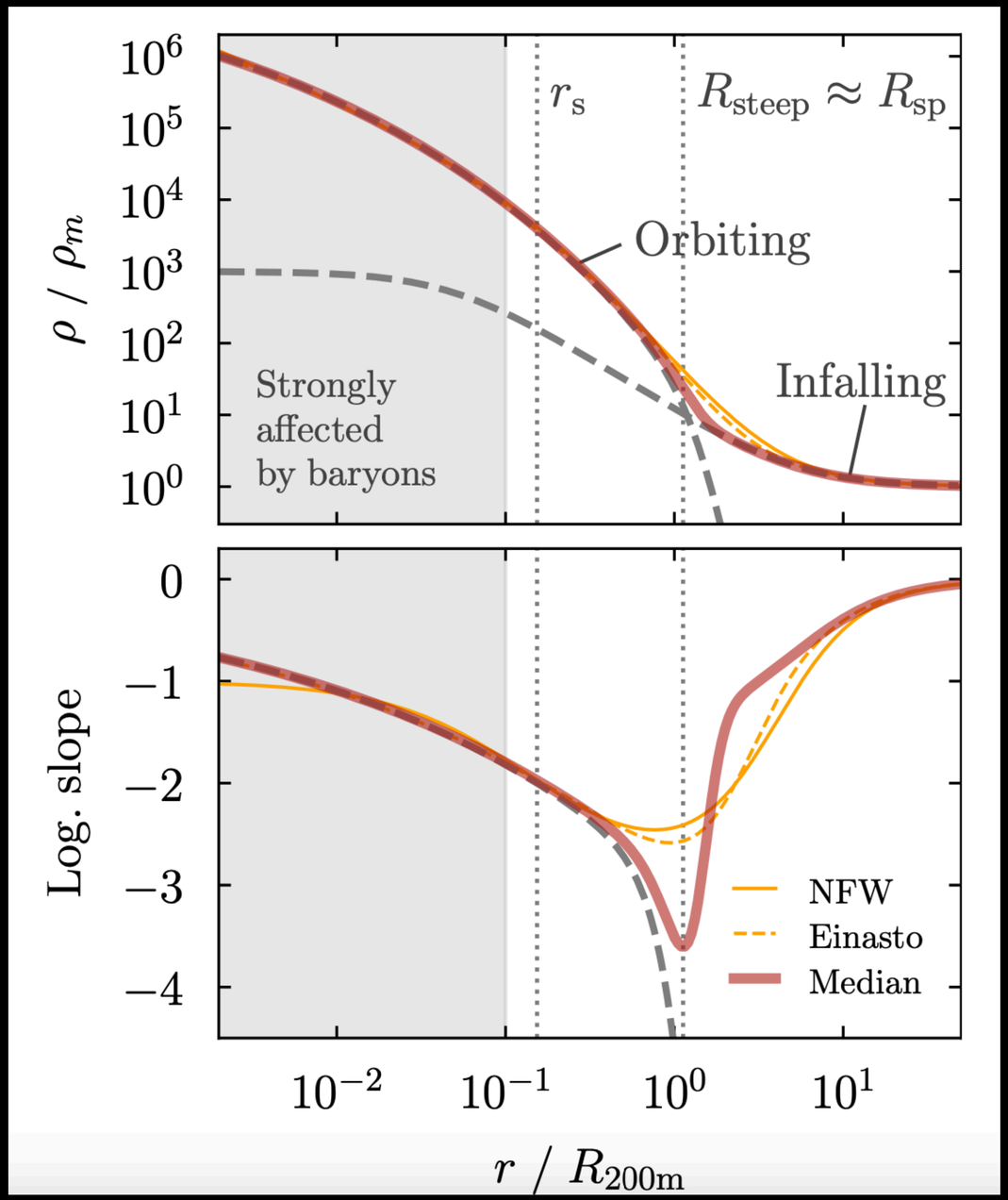

[Diemer 2022a]

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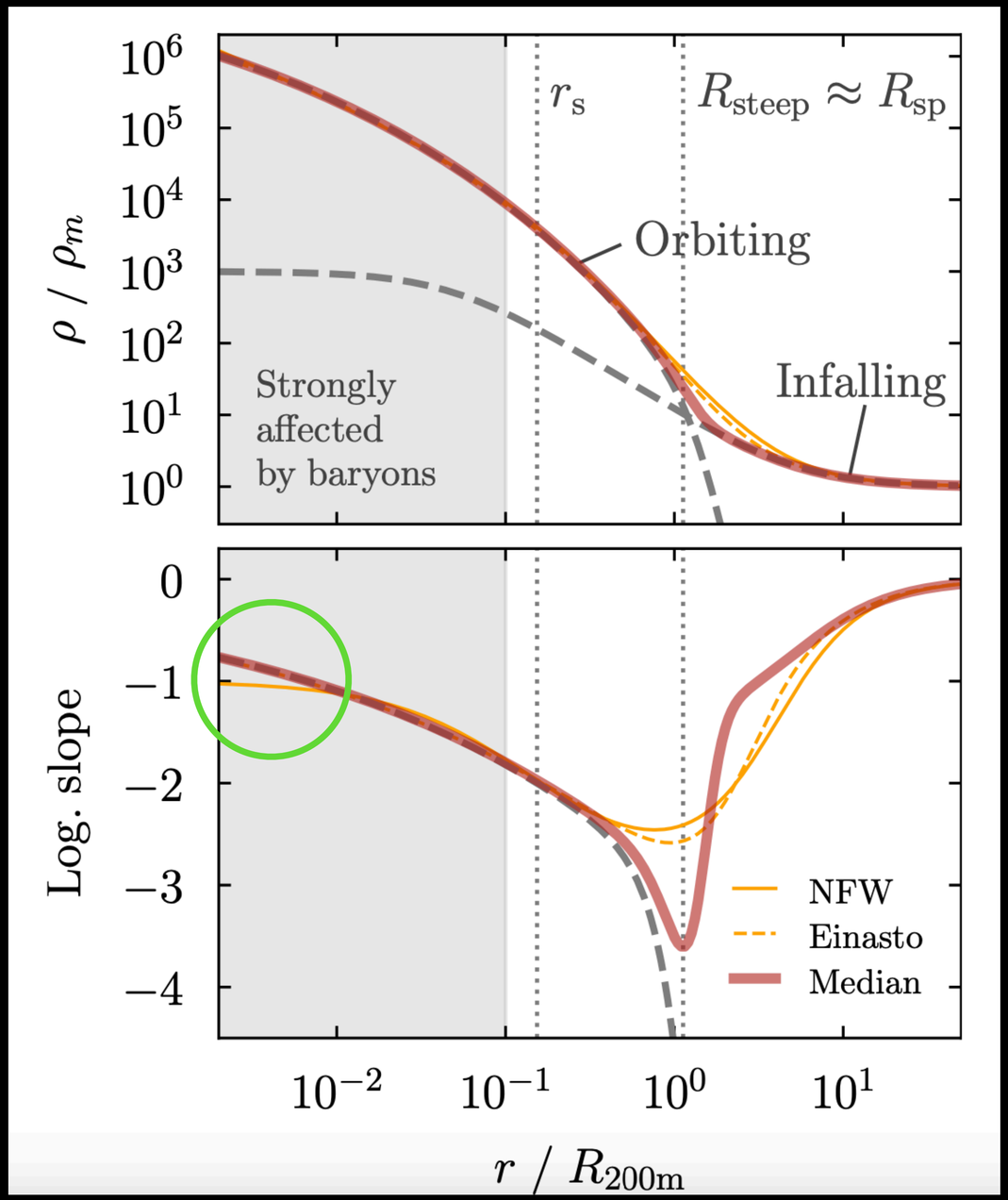

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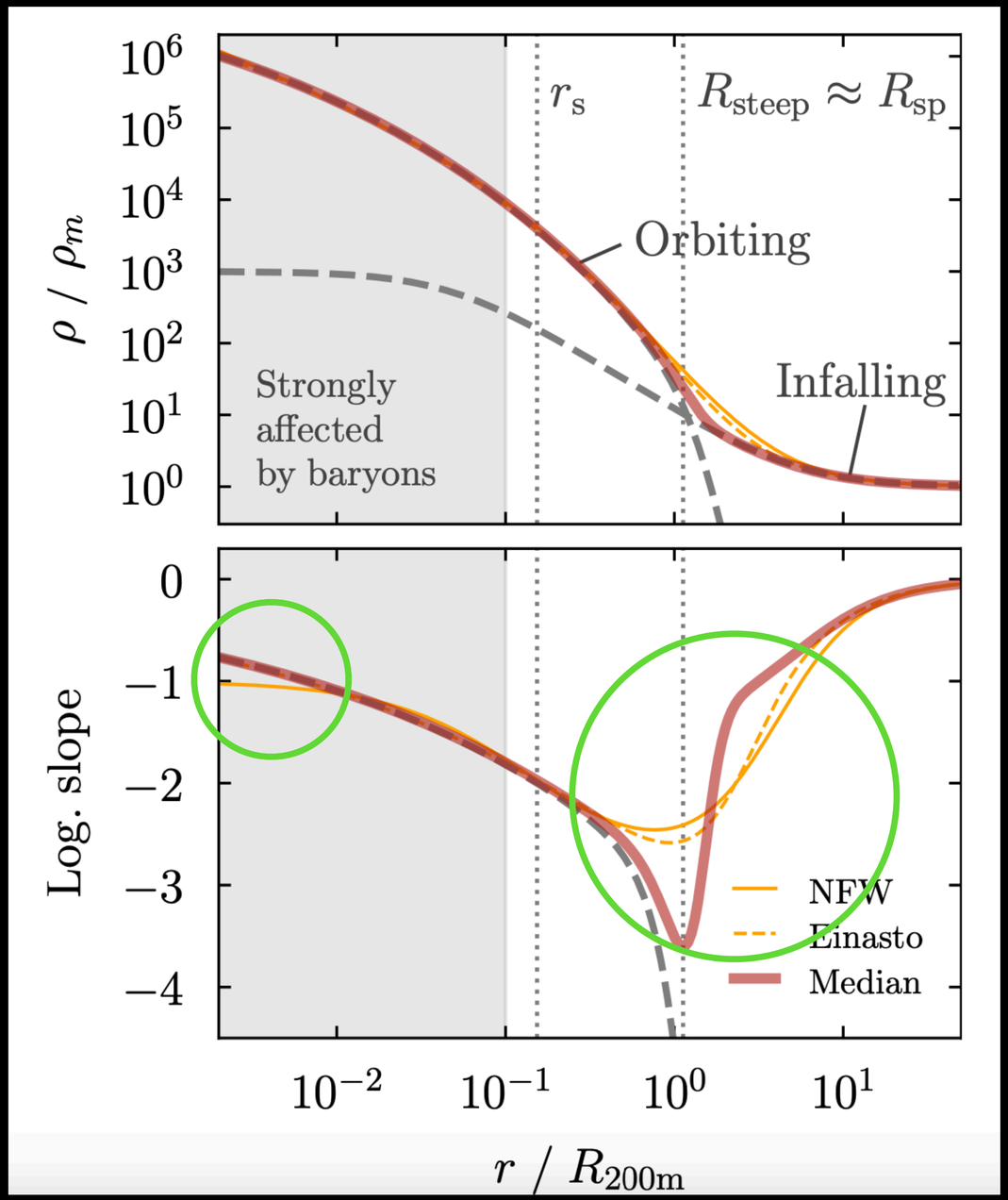

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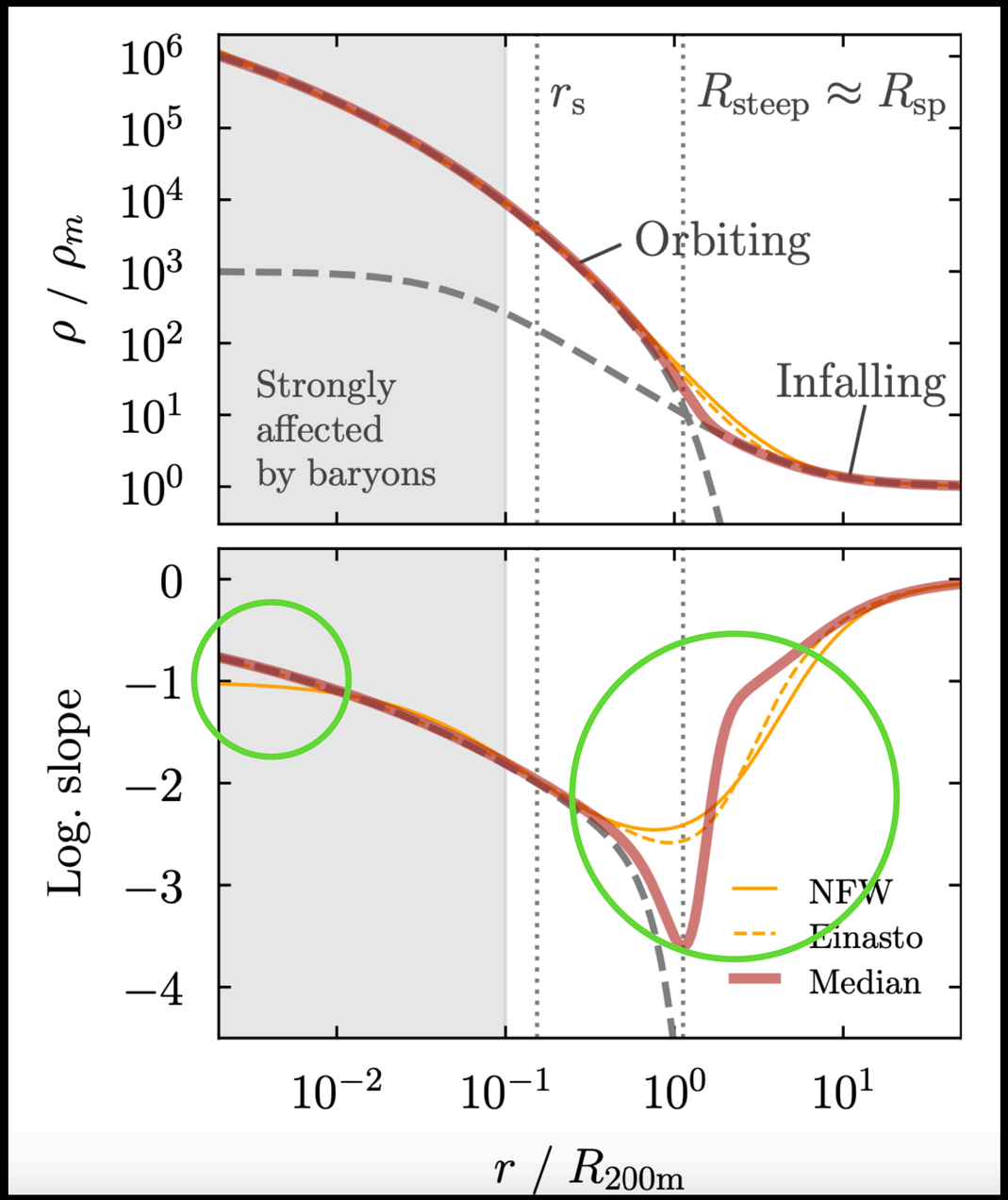
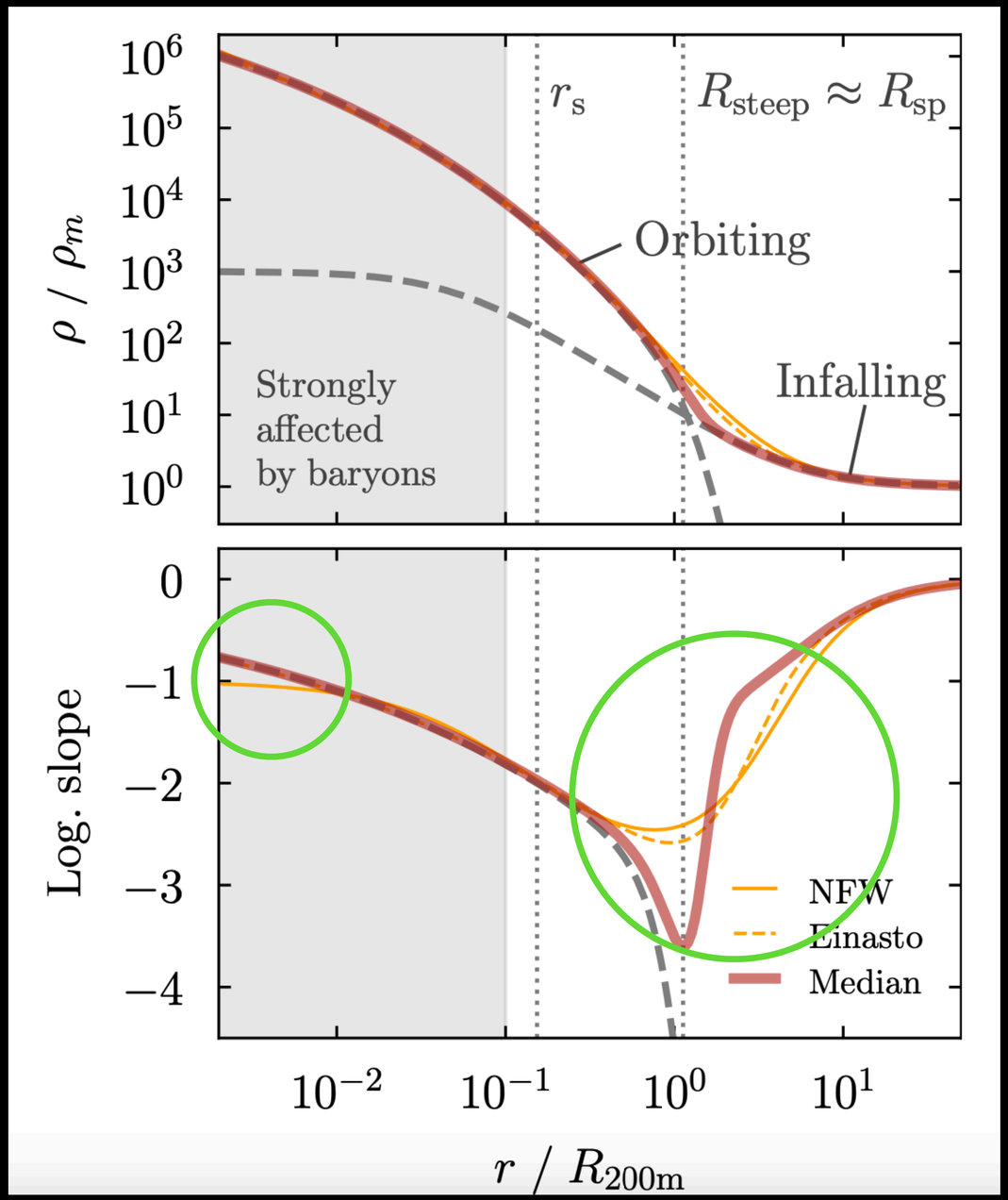


[Diemer 2022a]

Background

Dark matter density profiles

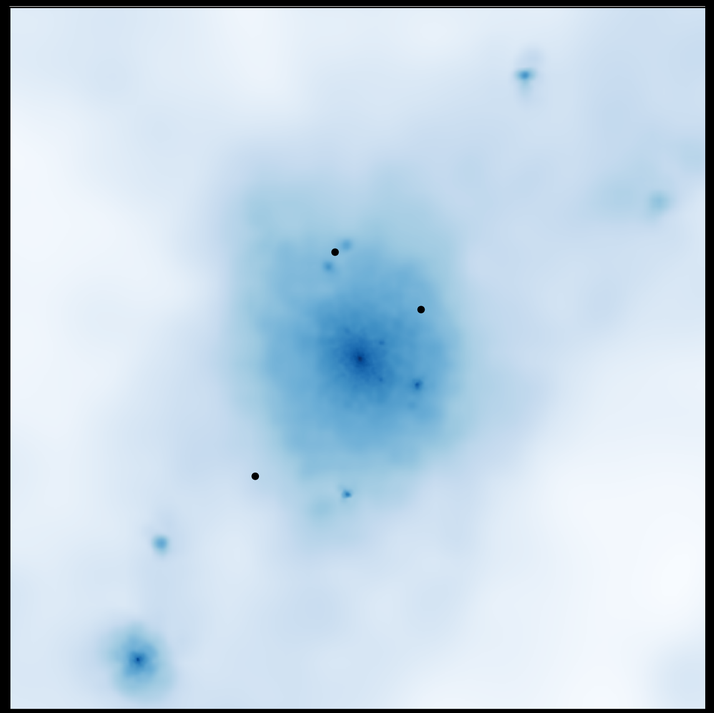
- Profiles often described by a power law (NFW, Einasto, …) but:
  - at small radii: statistical fluctuations and finite resolution is a problem
  - at larger radii: contributions from the particles in the outskirts of the halo alter the density profile



[Diemer 2022a]

‘Dynamical’ density profiles

- A *dynamics-based* method



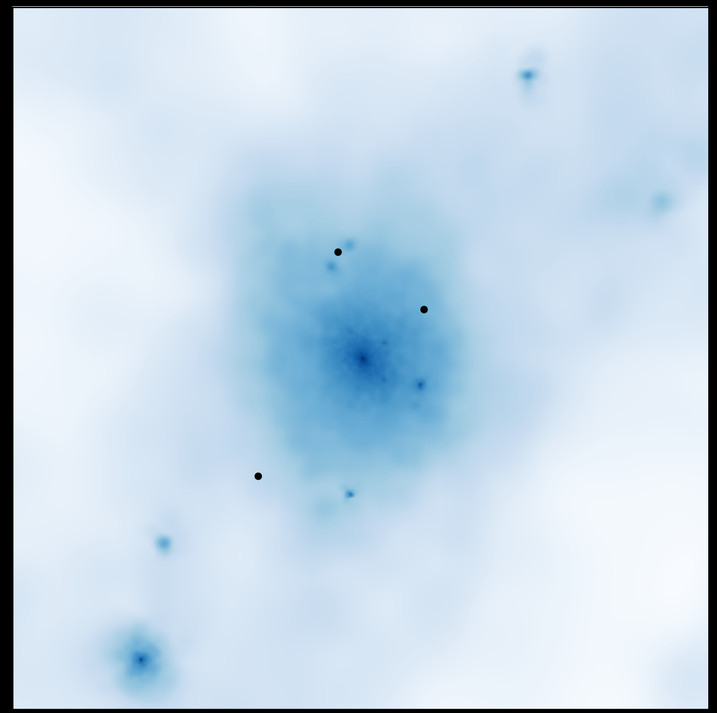
Particle orbits

Dark matter distribution

‘Dynamical’ density profiles

- A *dynamics-based* method

The particles from points become orbits



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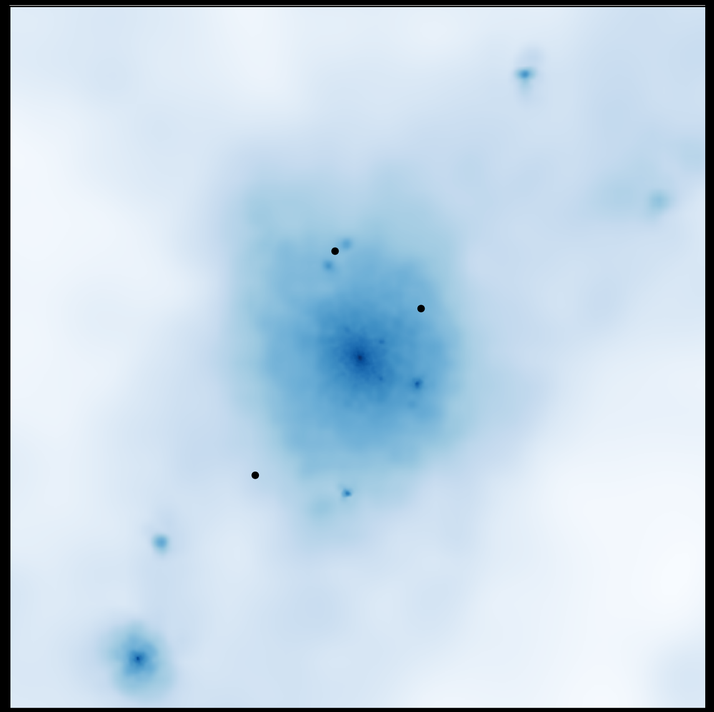

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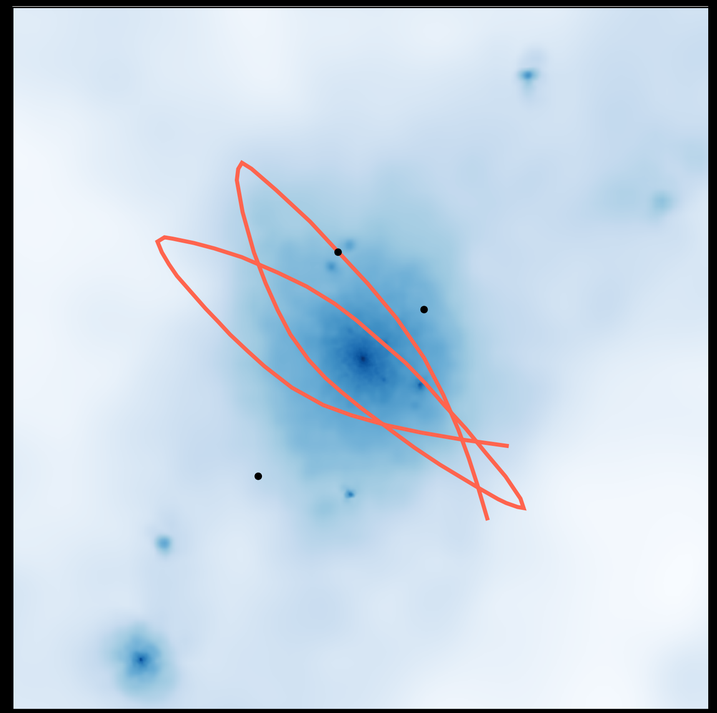

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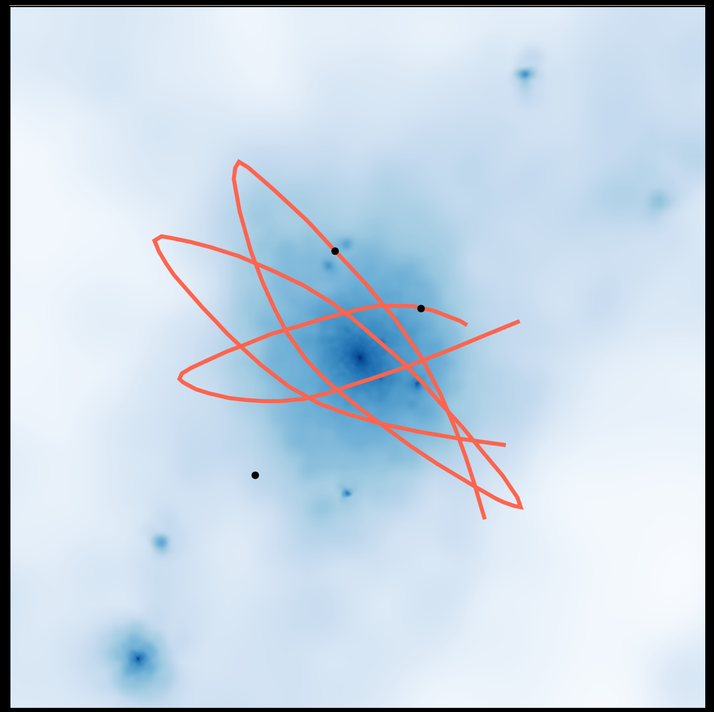

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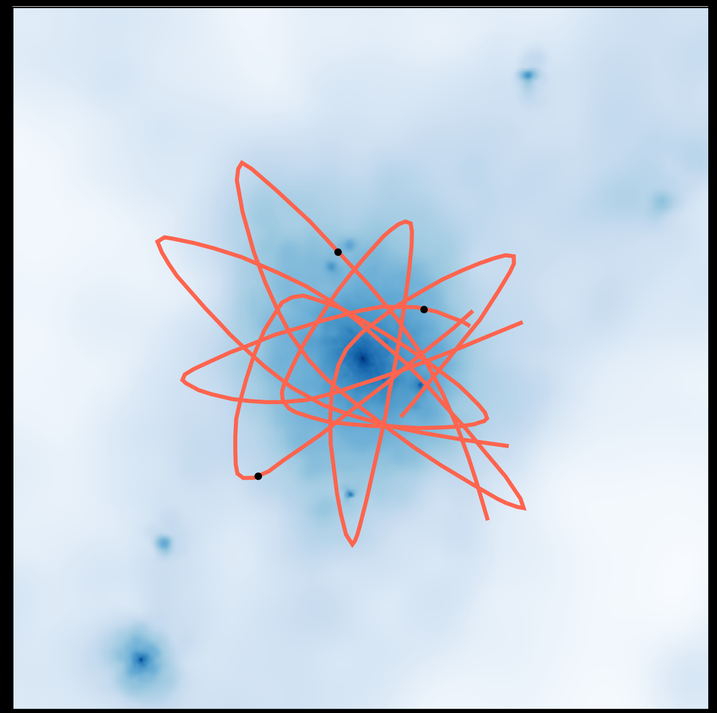

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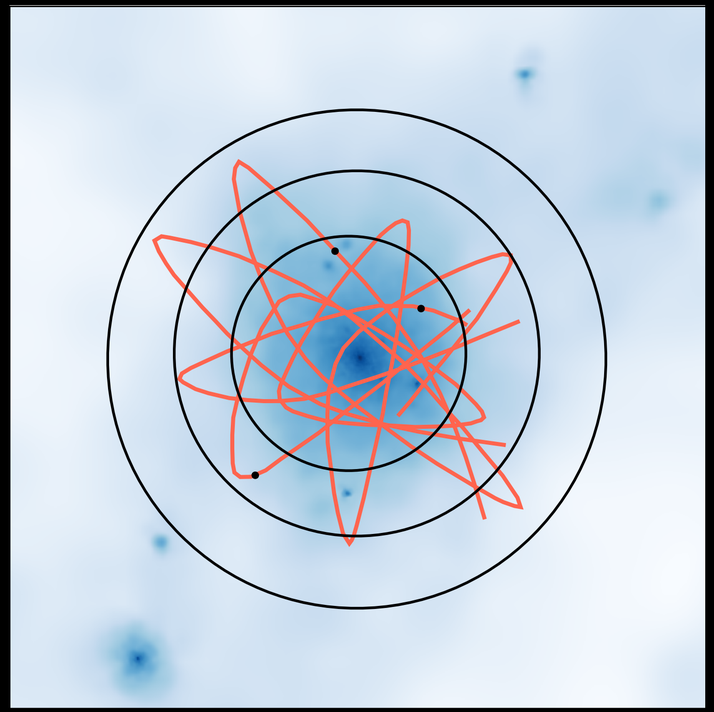

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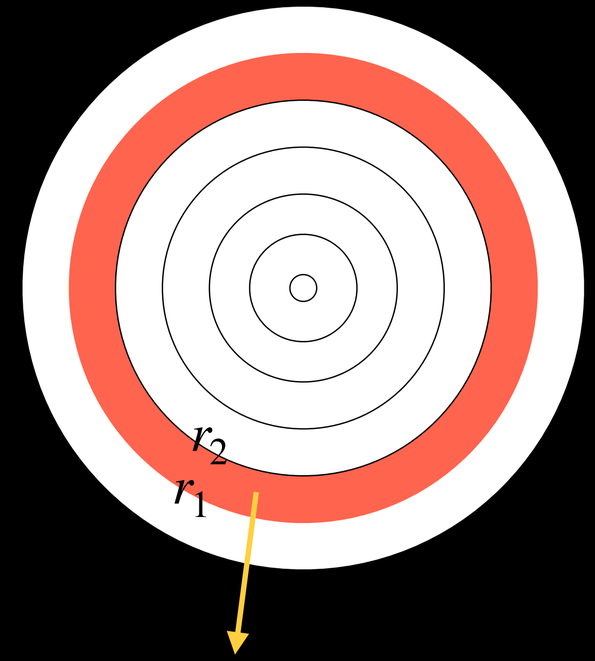
Why is this method different?

- Traditional ‘binned’ way of calculating profiles: only the position of the particles are used
- Traditional method is throwing away important information from the particles phase-space



$$\frac{M(r_1 < r < r_2)}{\frac{3}{4}\pi(r_2^3 - r_1^3)}$$

Calculating the dynamical profiles

1. Calculate (spherical) gravitational potential $\Phi(r)$ [Pontzen+ 2015]
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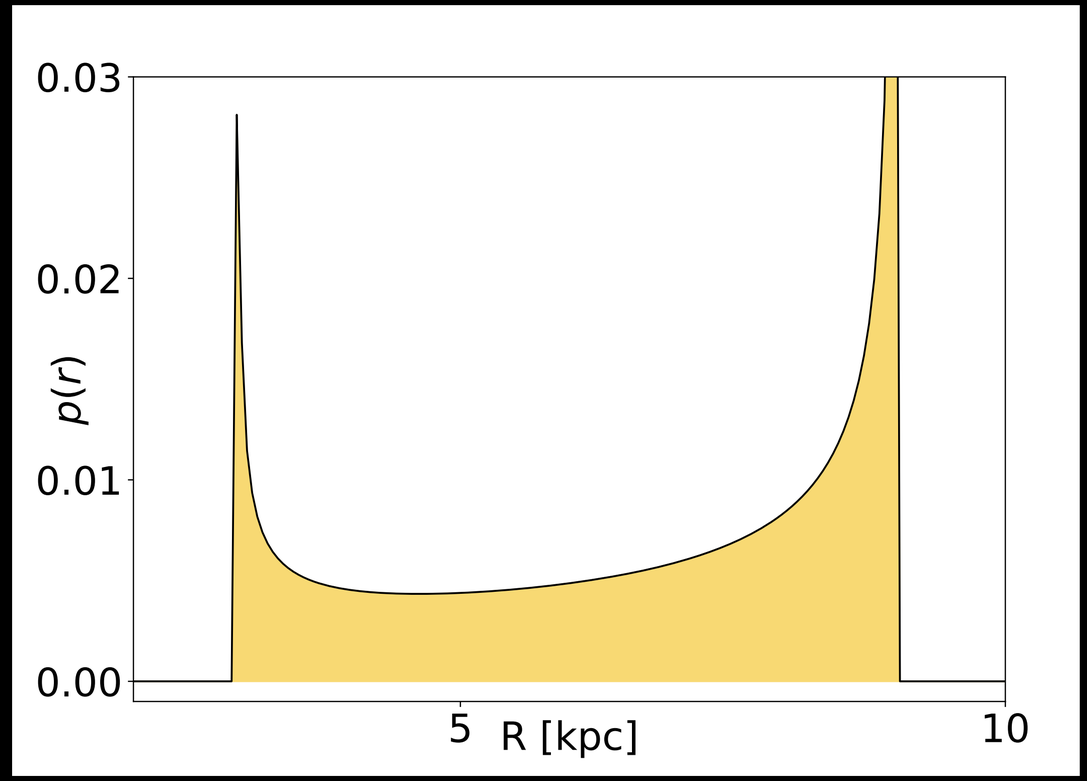

Calculating the dynamical profiles

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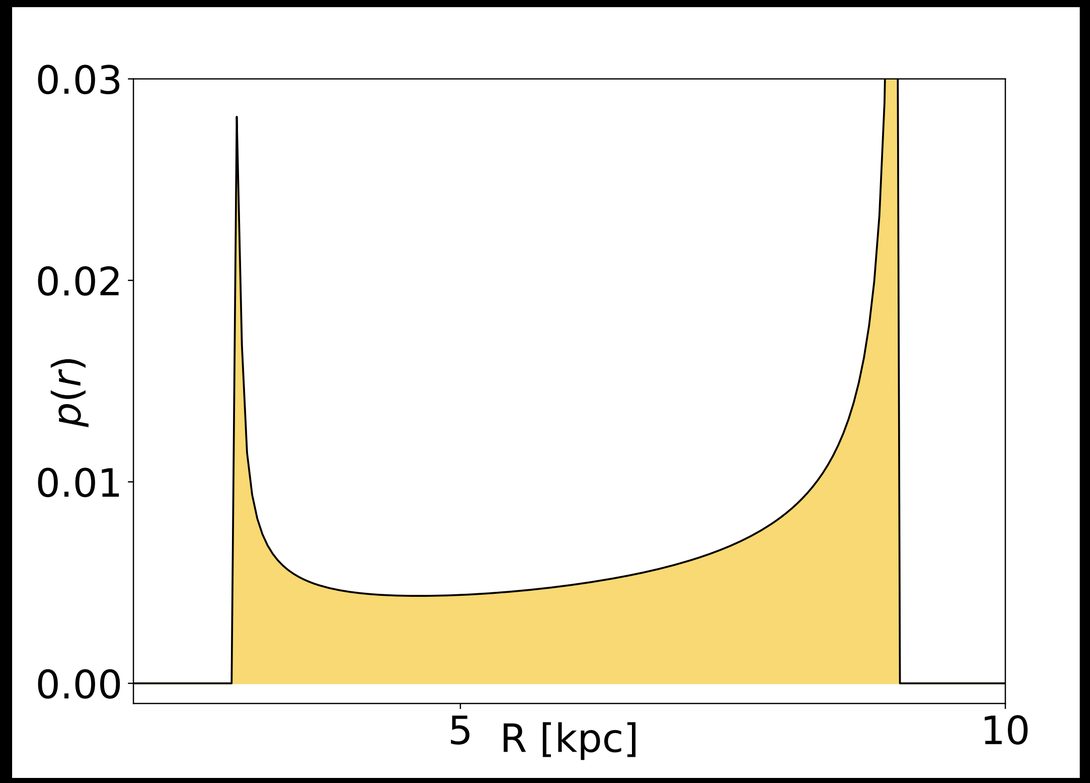
2. ‘Integrate’ the orbits of the particles in the potential
   - Integration is slow! We calculate the probability density $p_i(r)$ of finding particle i at radius r
3. The dynamical profile is then calculated as

$$\rho(r_k) = \frac{\sum_{i=1}^{N} m_i p_{i,k}}{\text{volume of the bin}}$$



Calculating the dynamical profiles

Iteration of the gravitational potential

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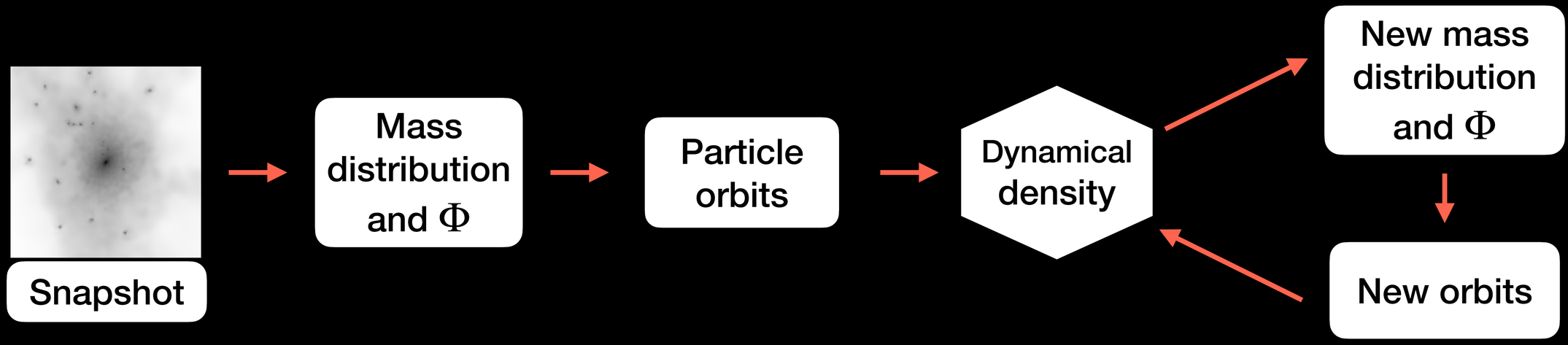
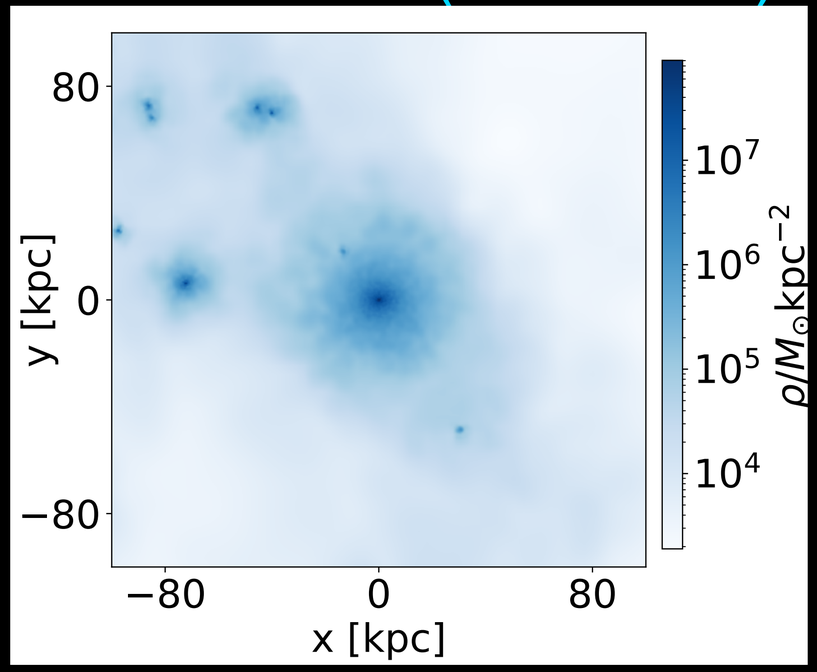


The simulation snapshots

- A selection of 7 snapshots at z=0 with a wide range of masses

EDGE sims ($M \sim 10^9$)



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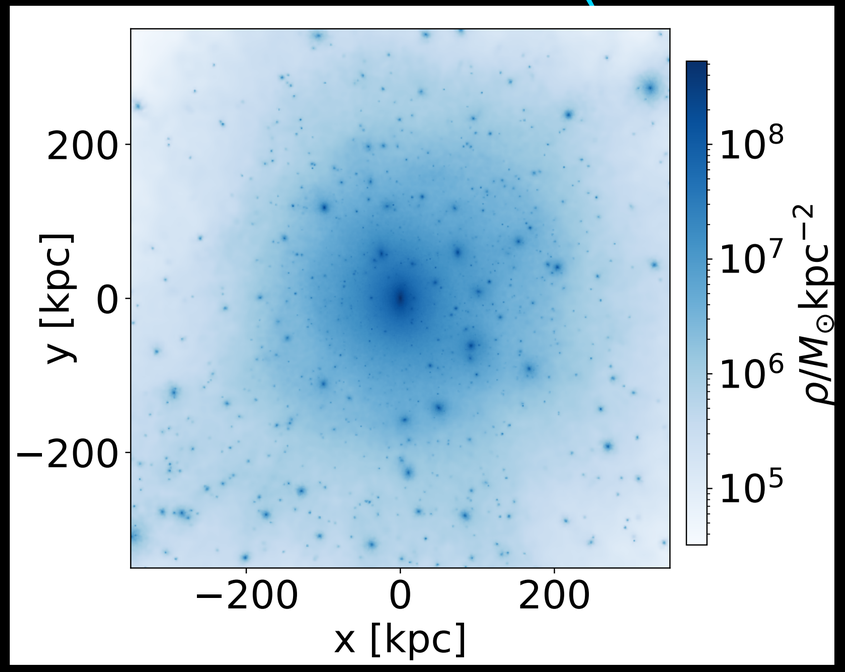

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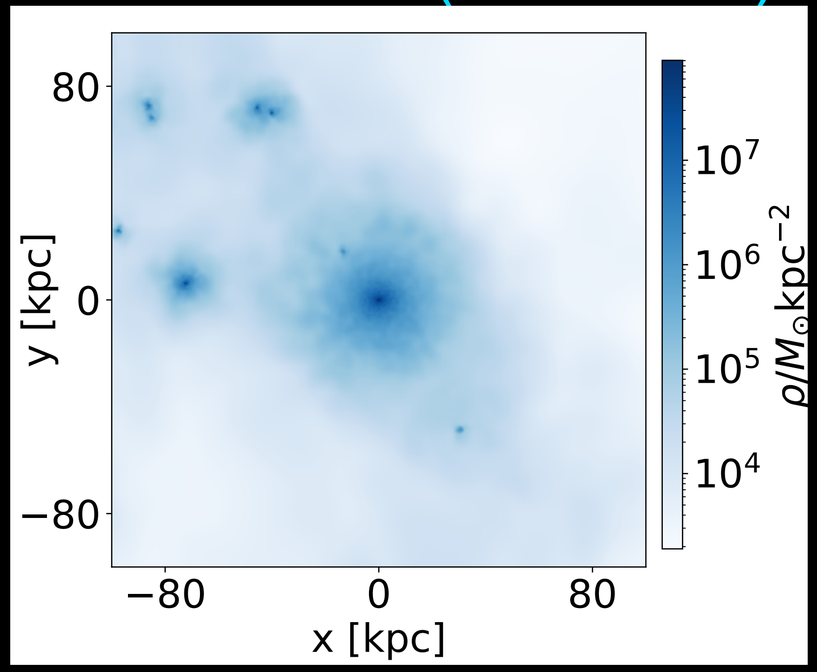

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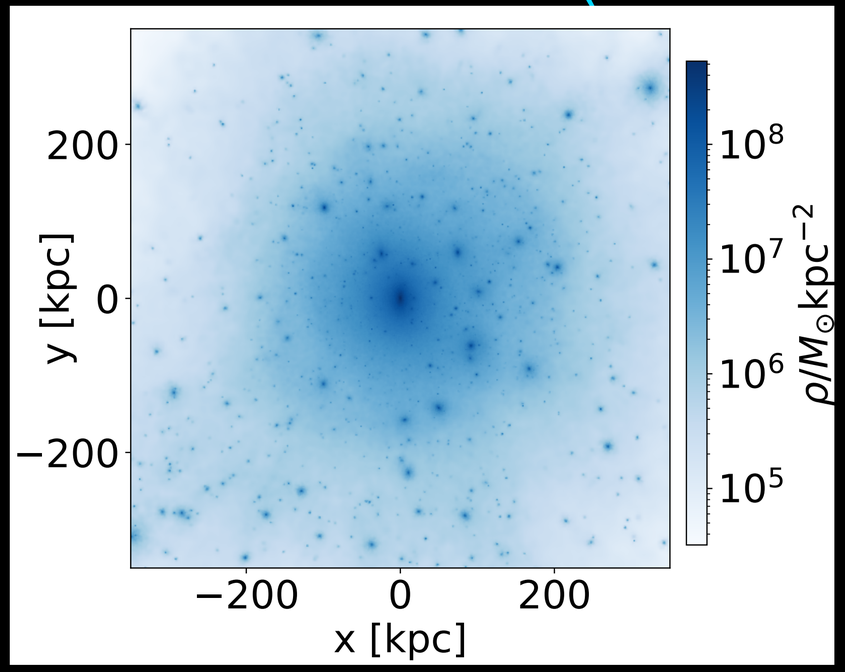
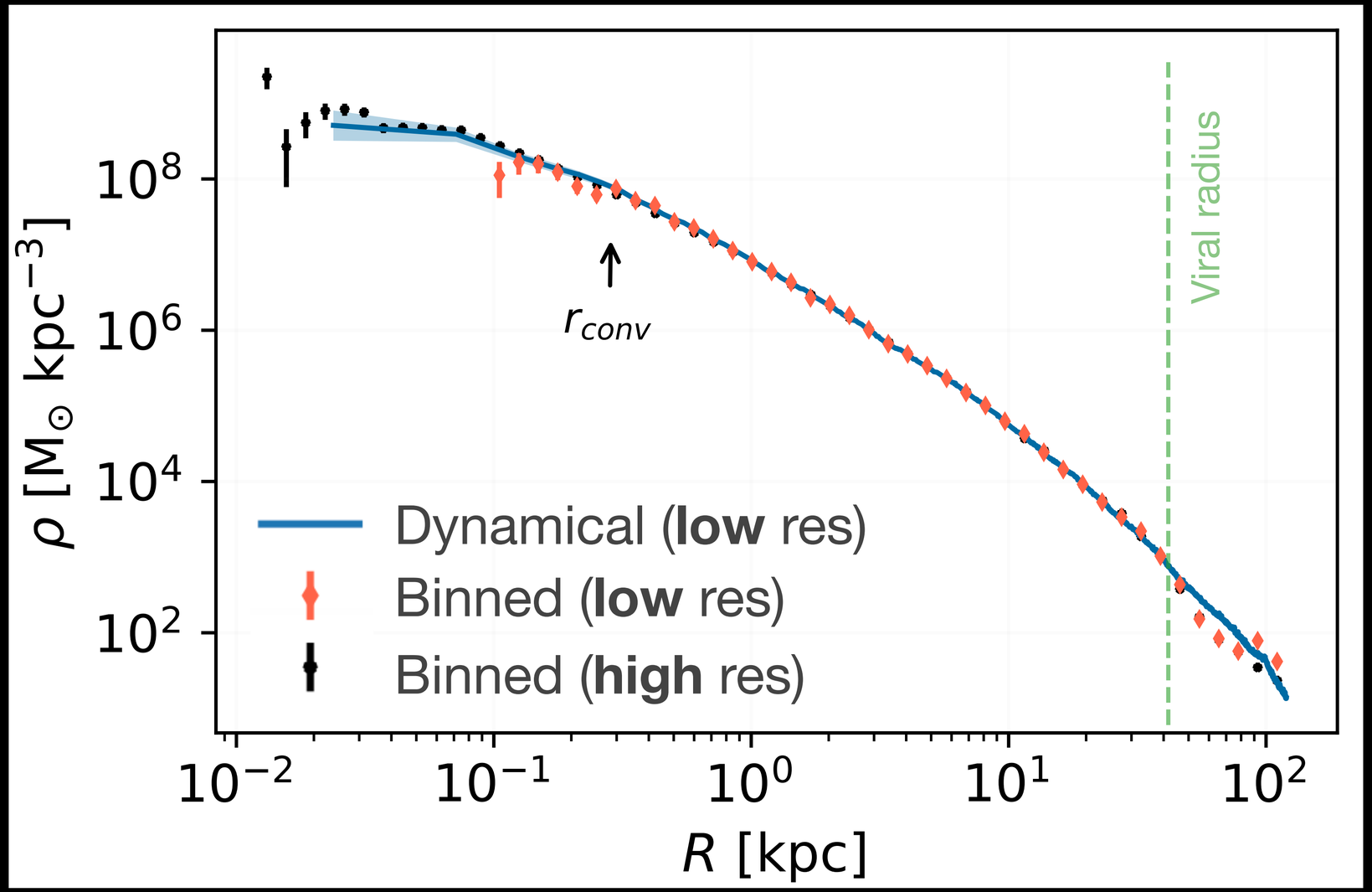


- Halos re-simulated at 2 different resolutions: LOW and HIGH

Results

Dynamical density profiles



[Muni+ in prep]

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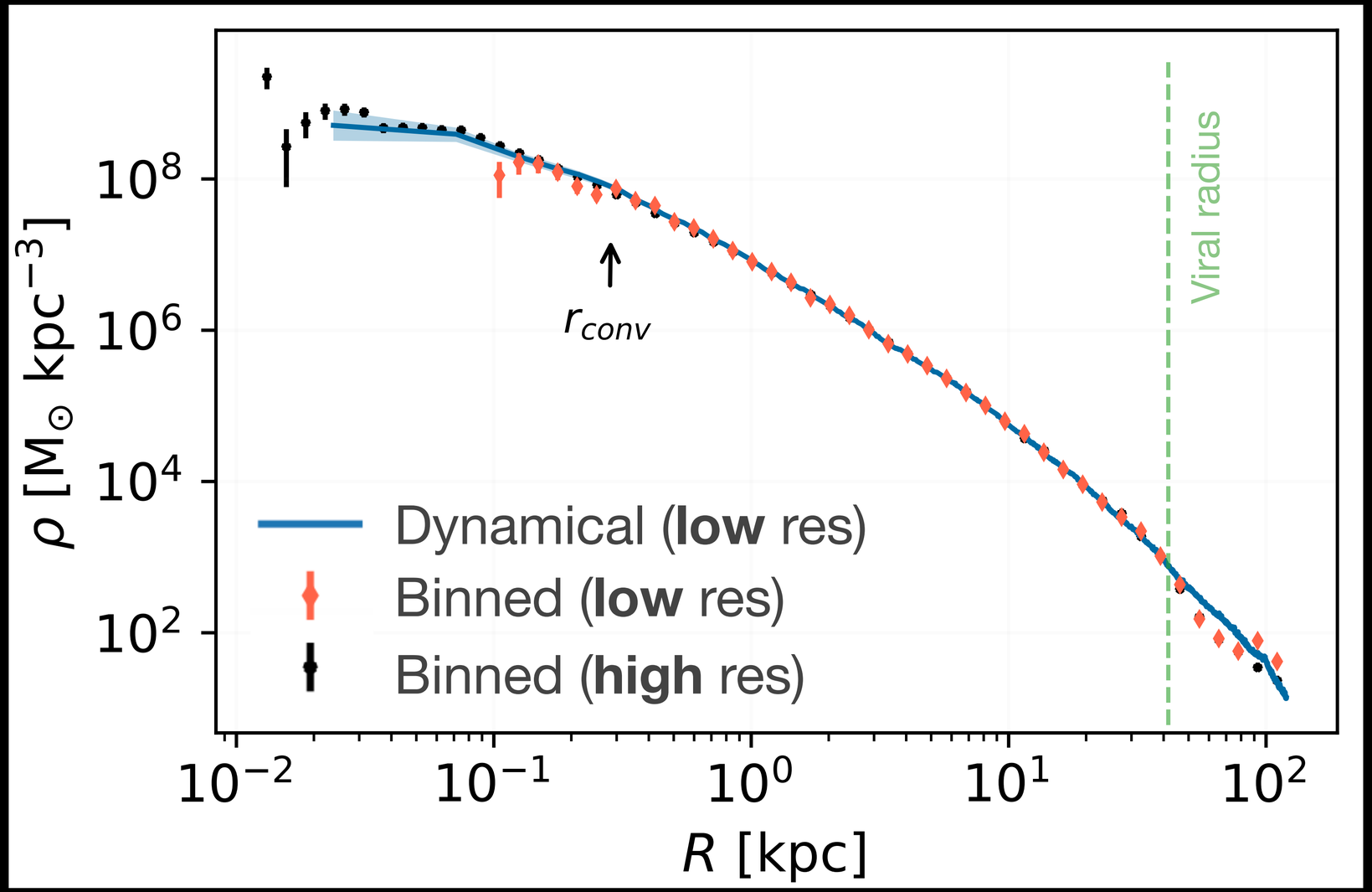

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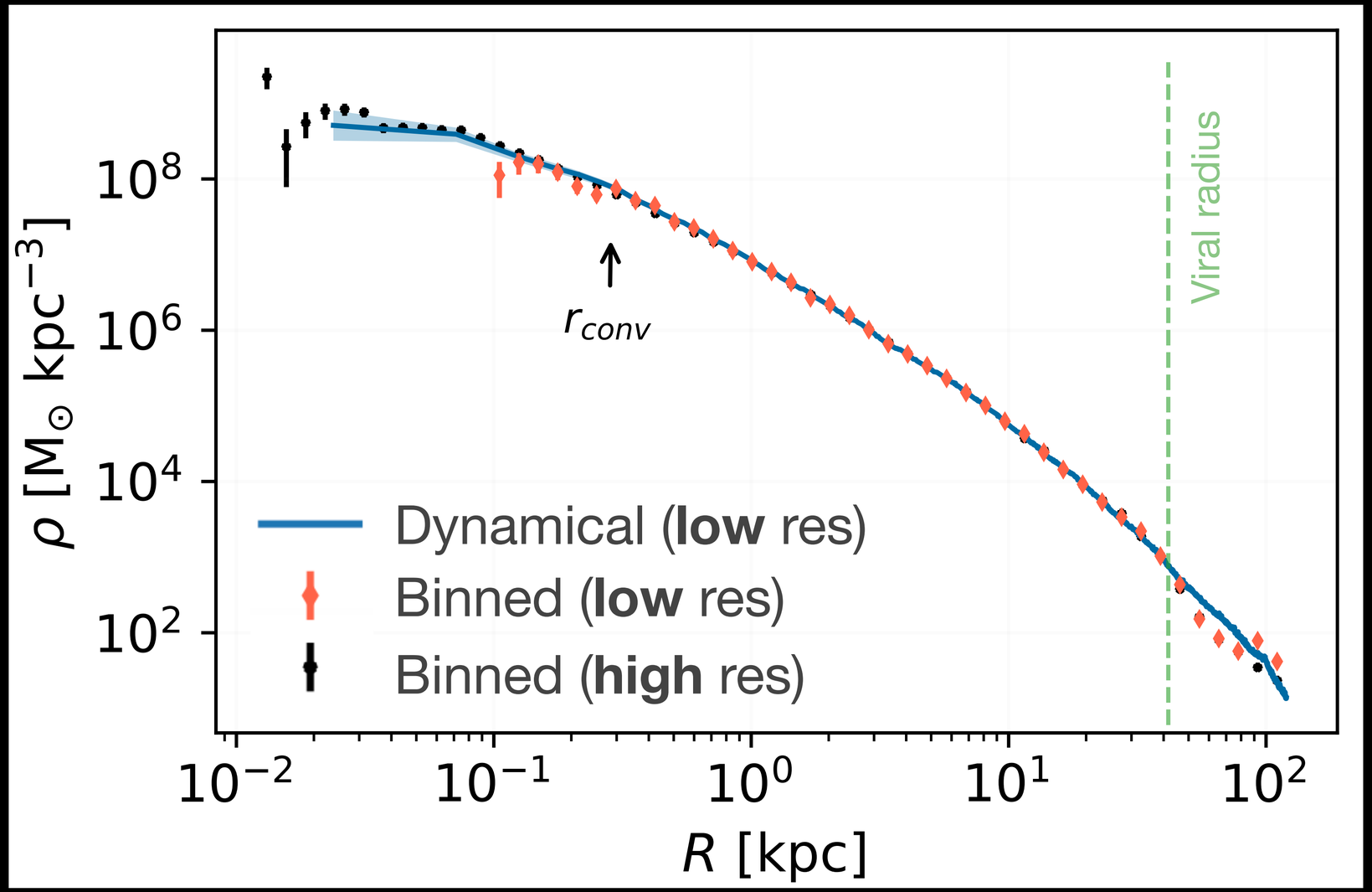

- Dynamical profile agrees well with both binned distributions for most of the radial extent
- Poisson noise is considerably reduced

[Muni+ in prep]

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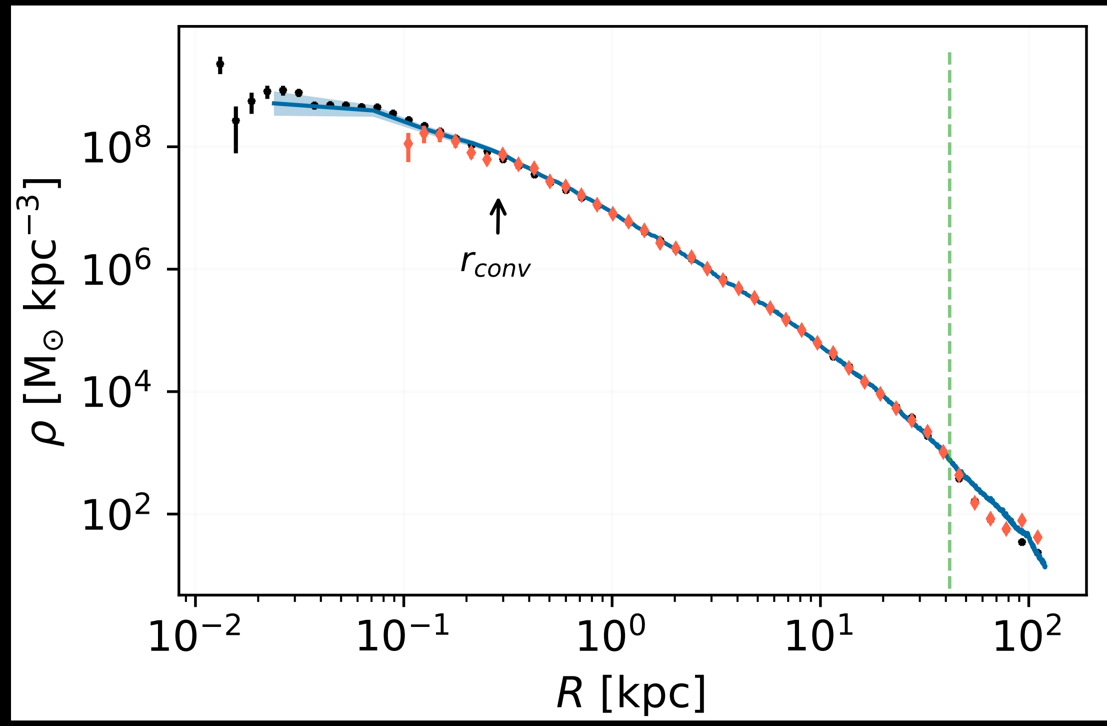
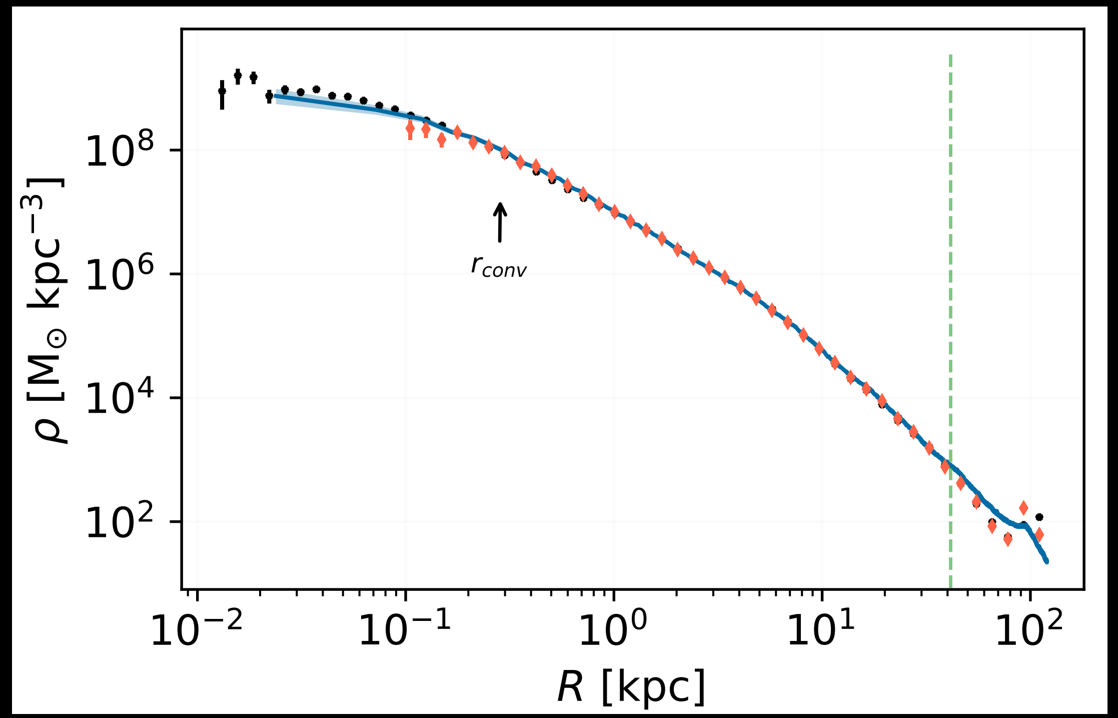
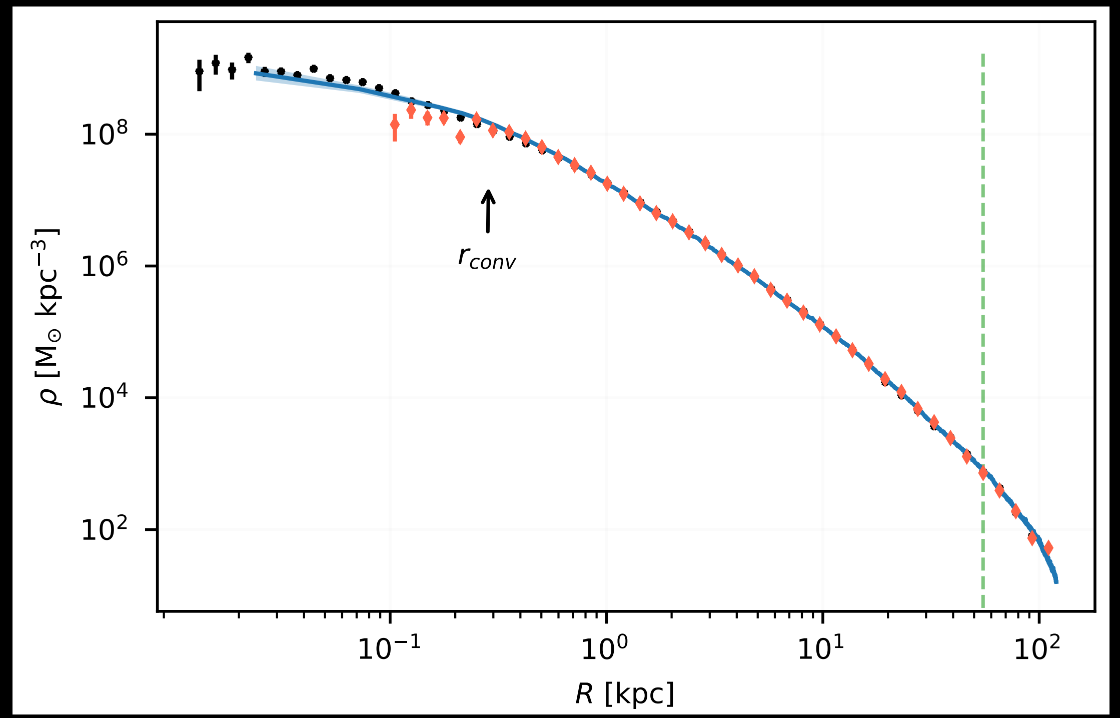
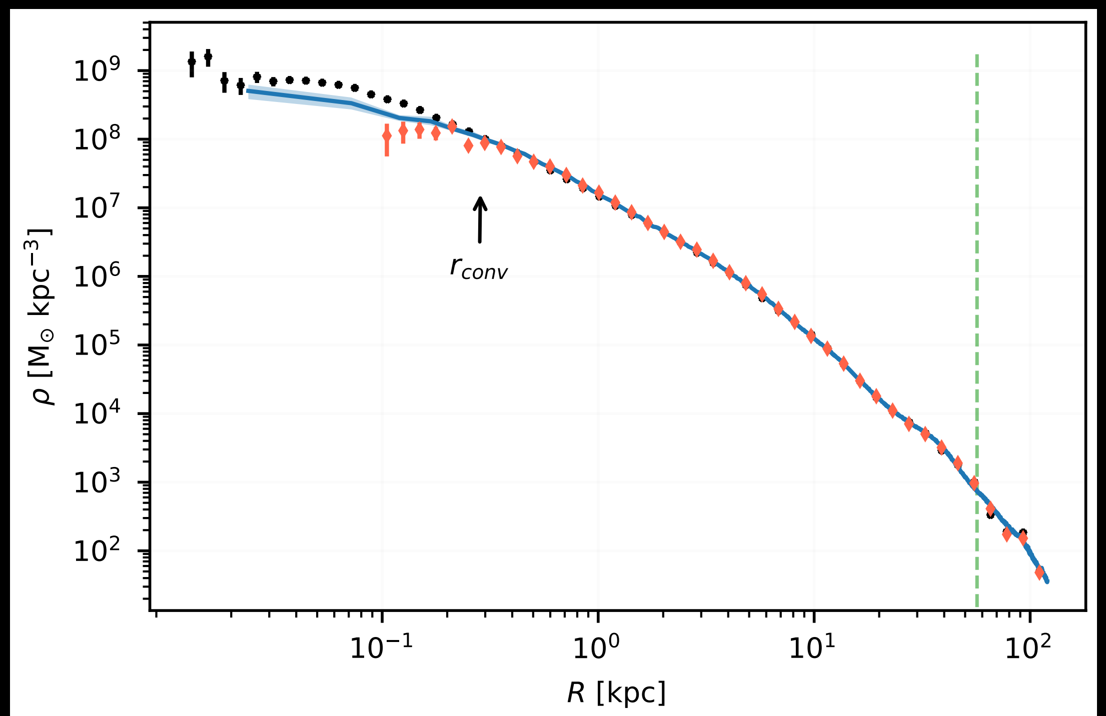
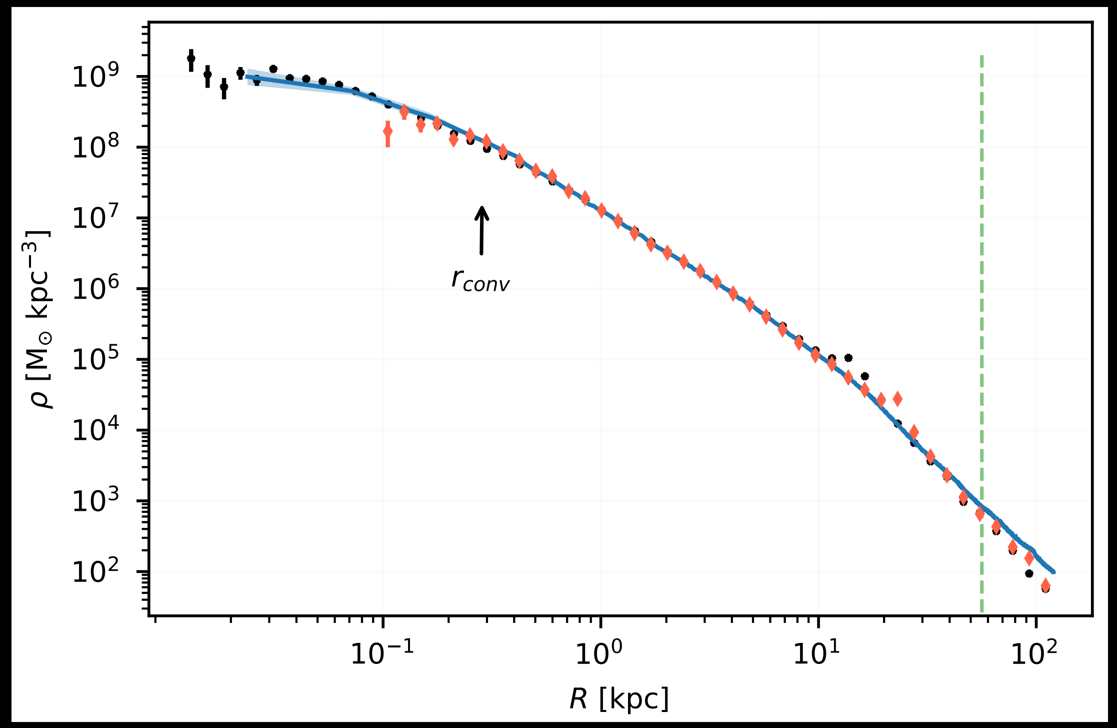


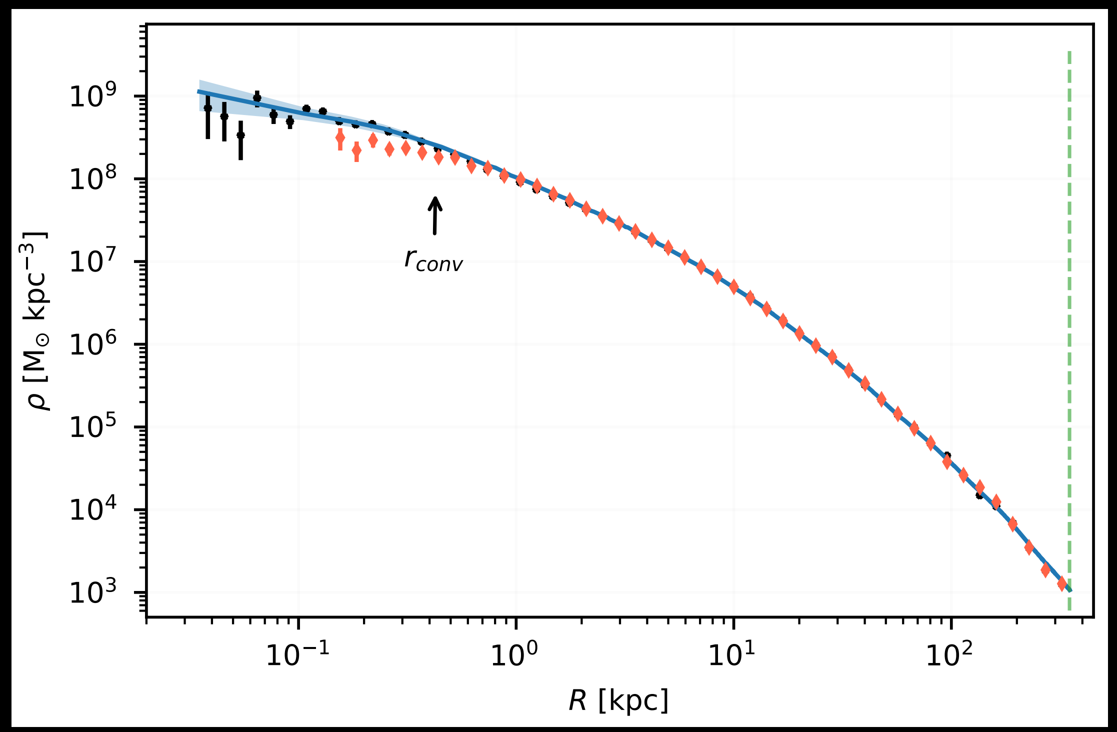


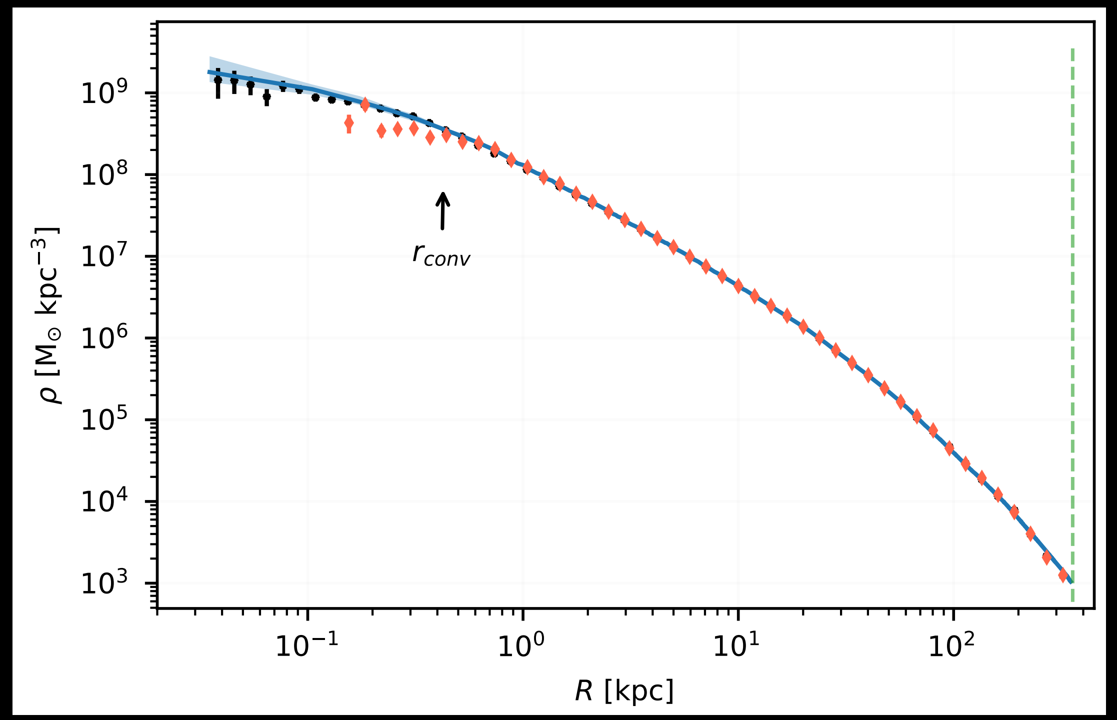


Similar results for all our halos









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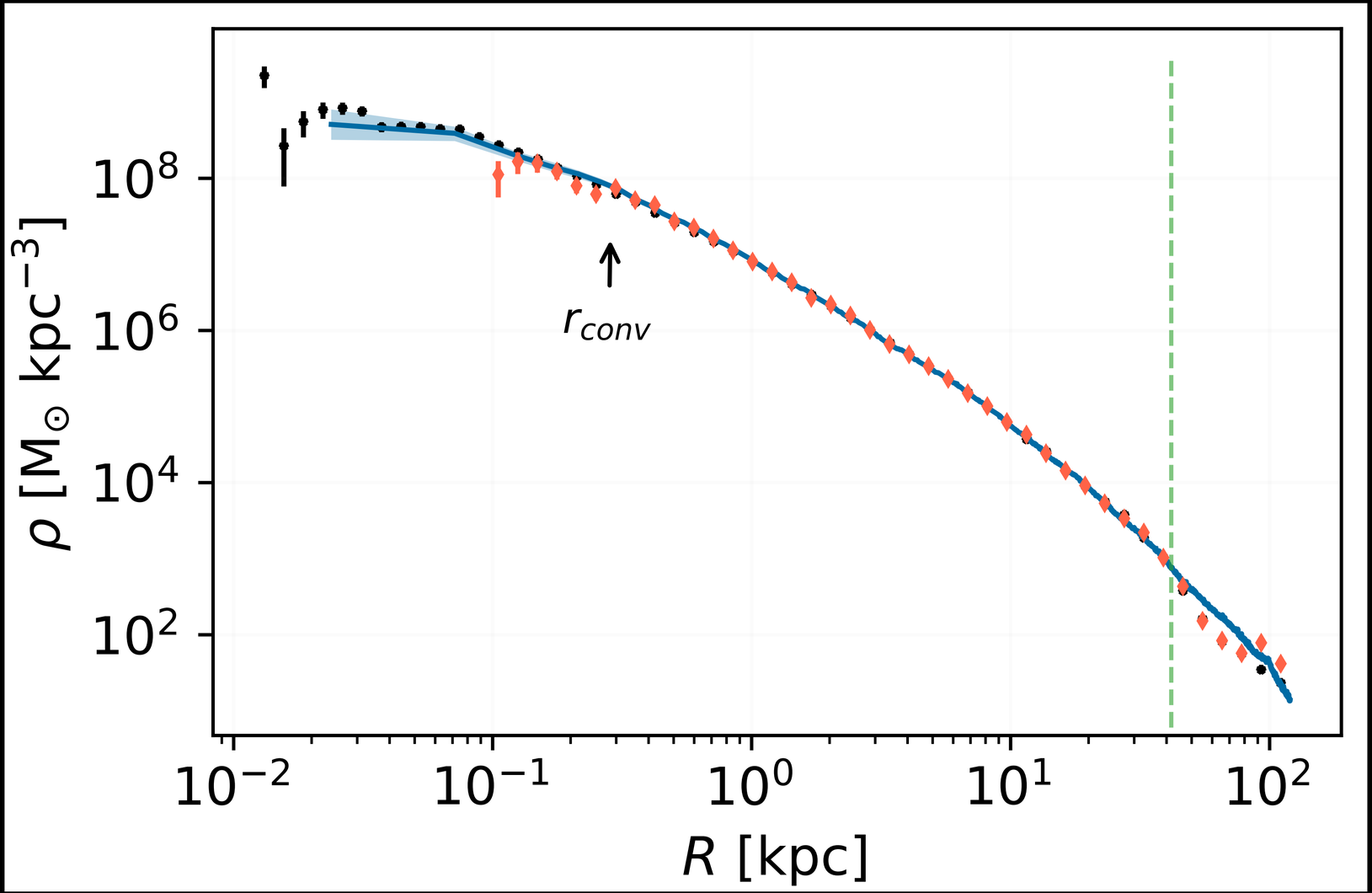
VINTERGATAN ($M \sim 10^{12}$)

Dynamical density profile

Inner regions



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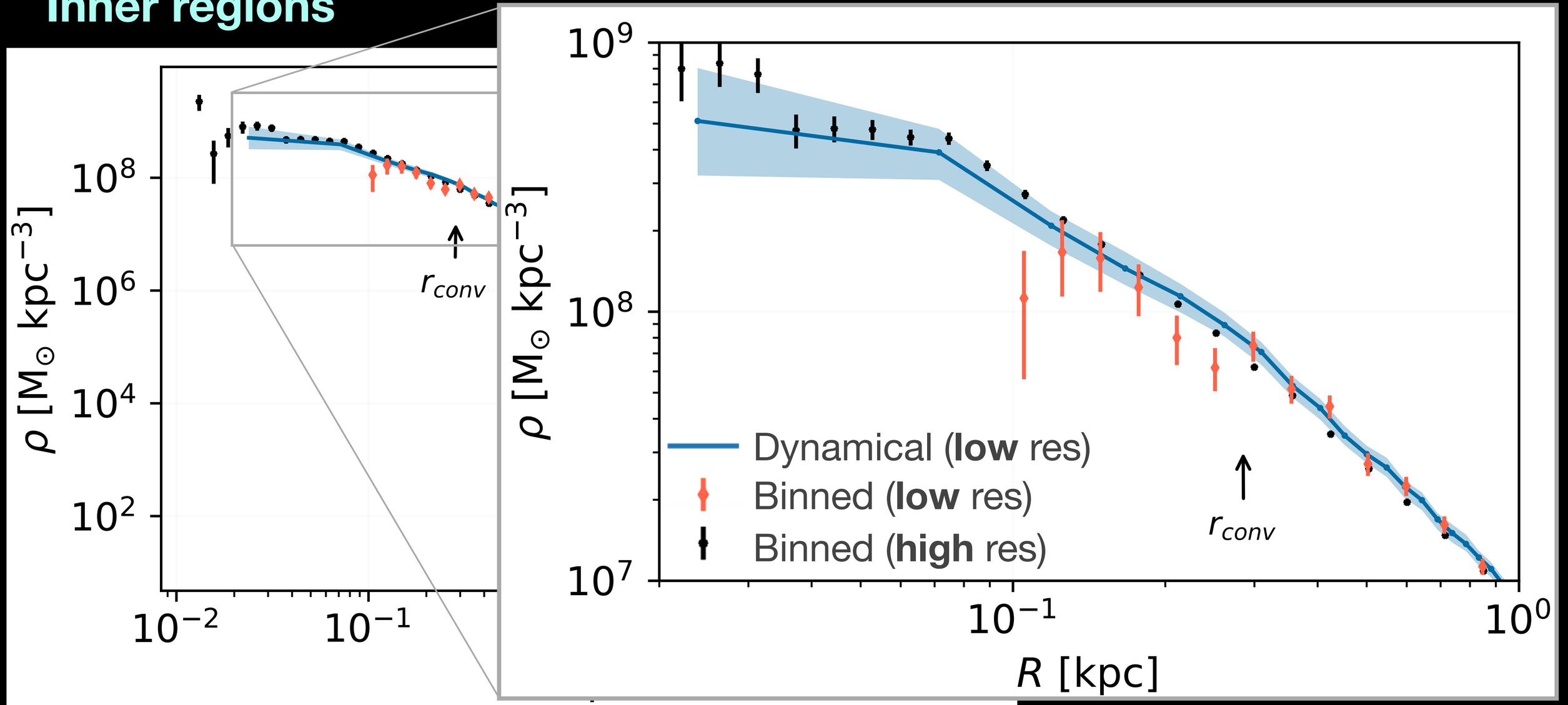
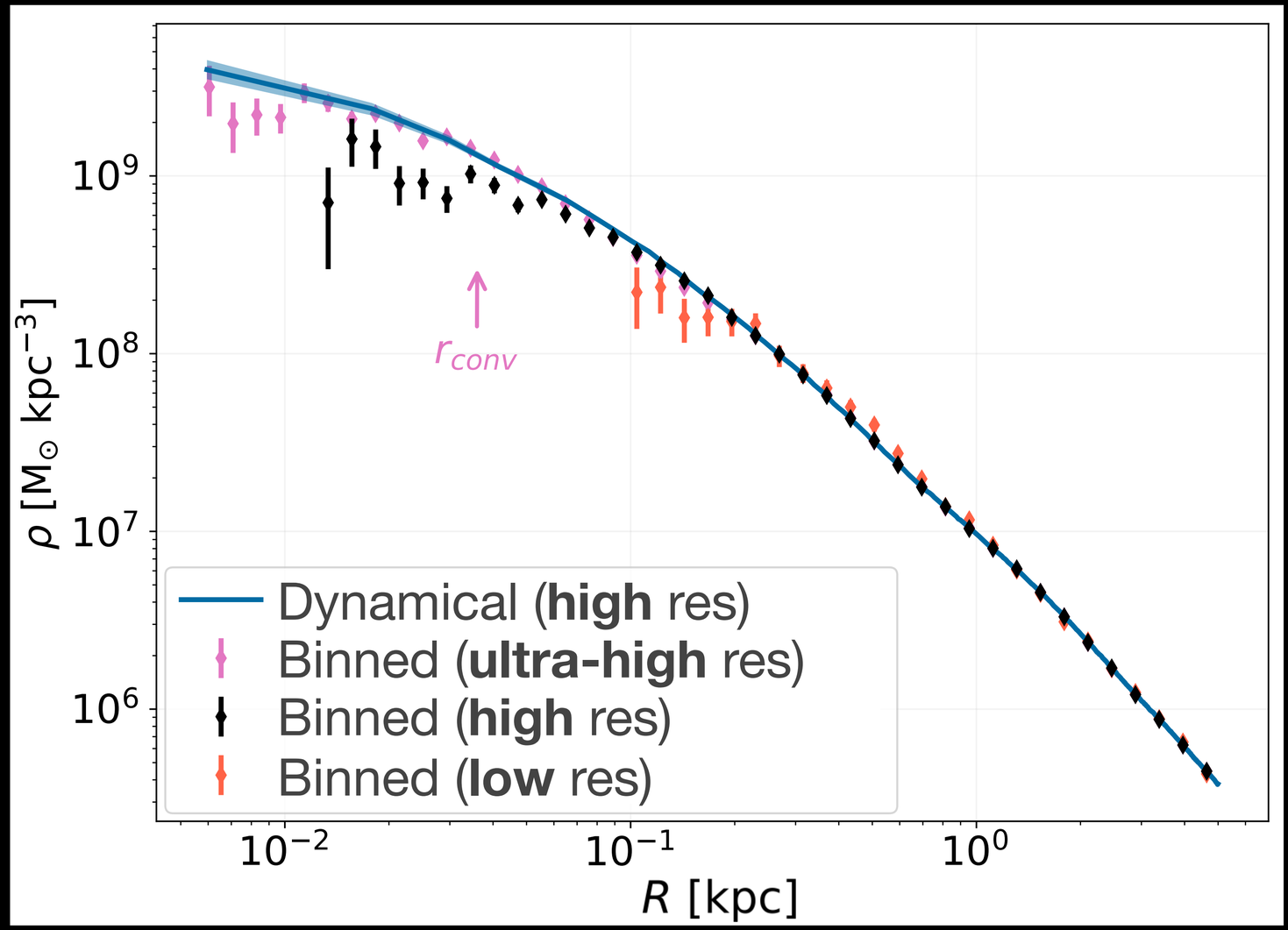


Resolution independence

Ultra-high resolution



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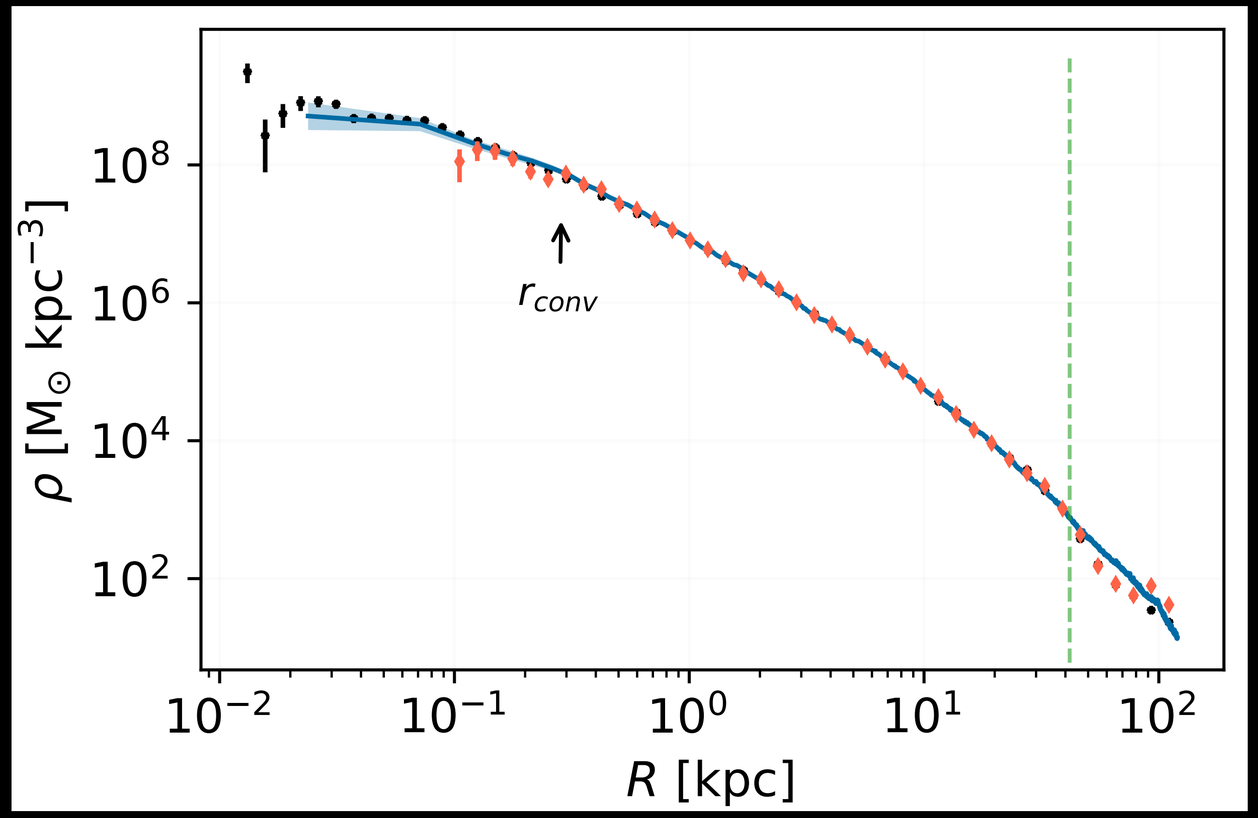
Dynamical density profile

Outer regions



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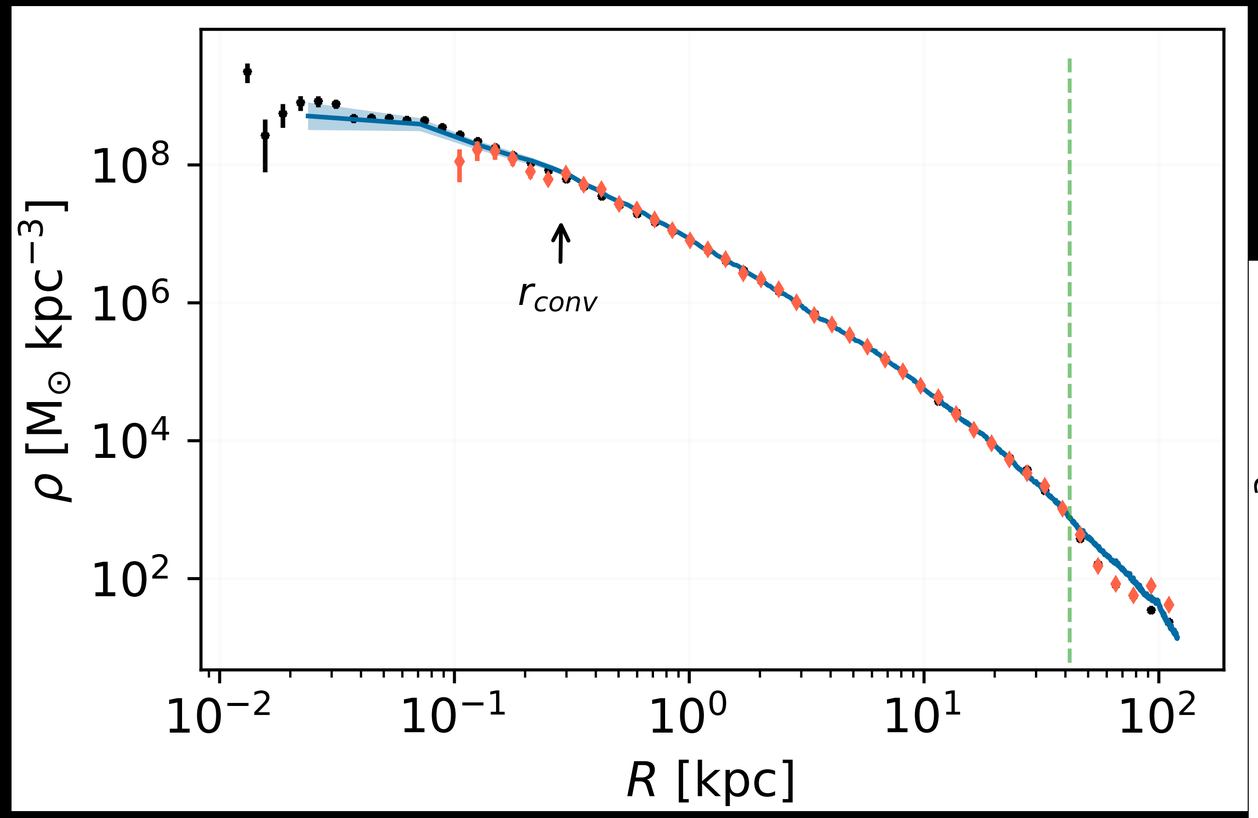

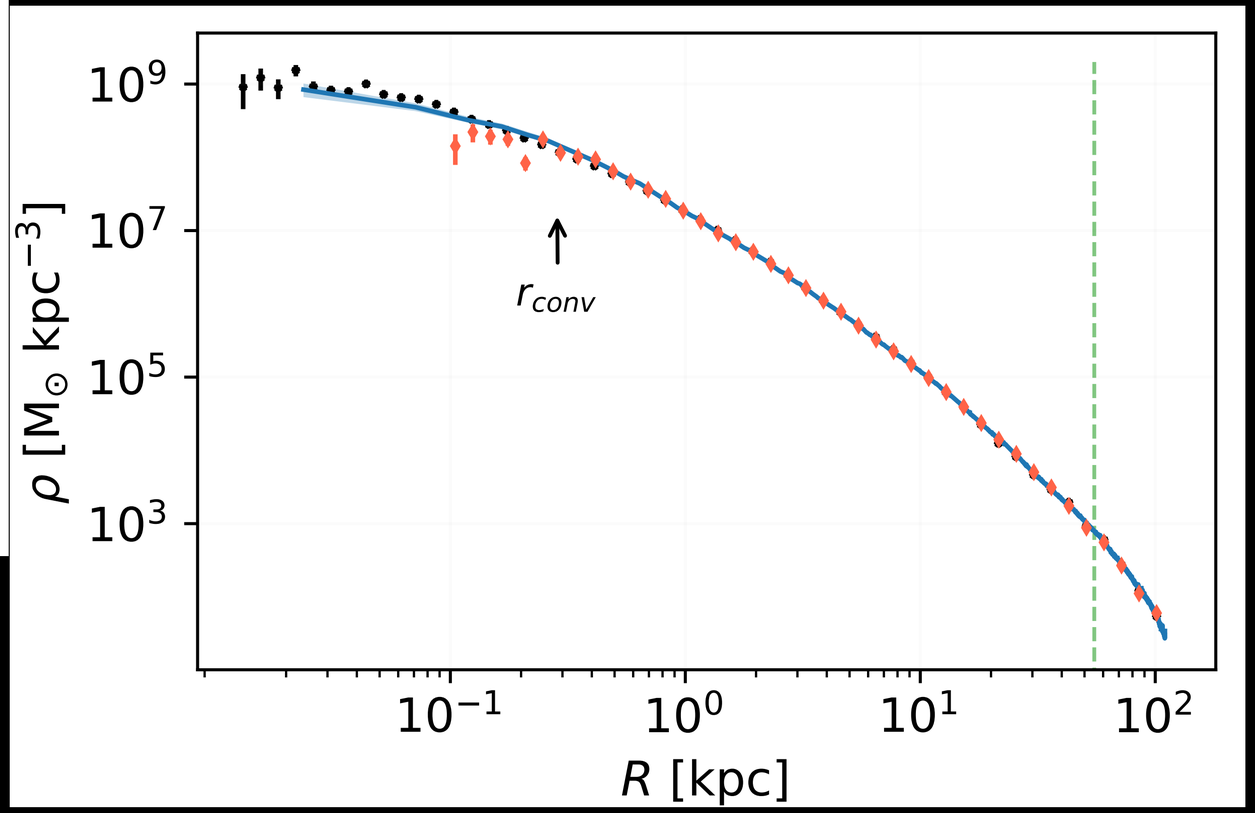

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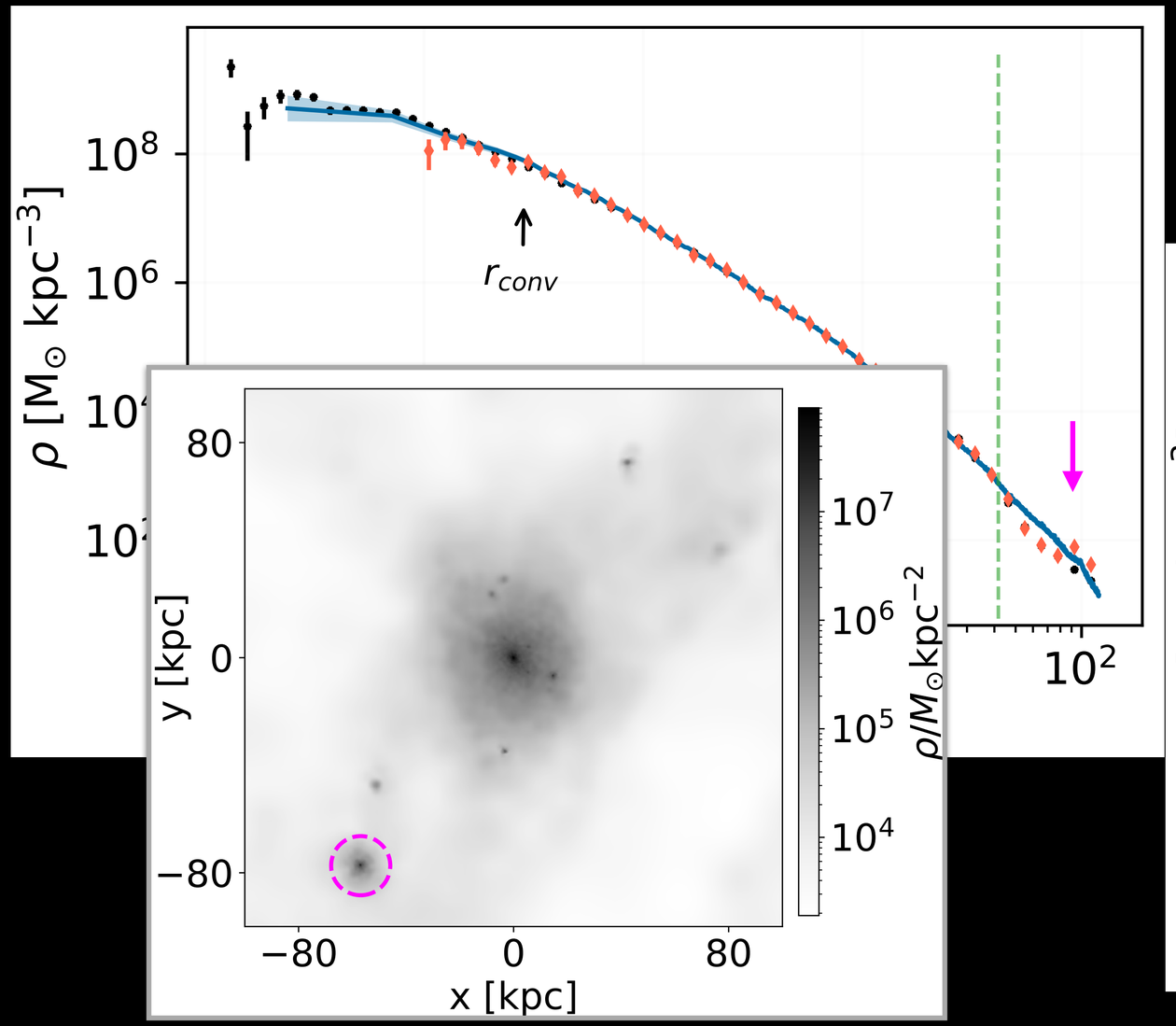

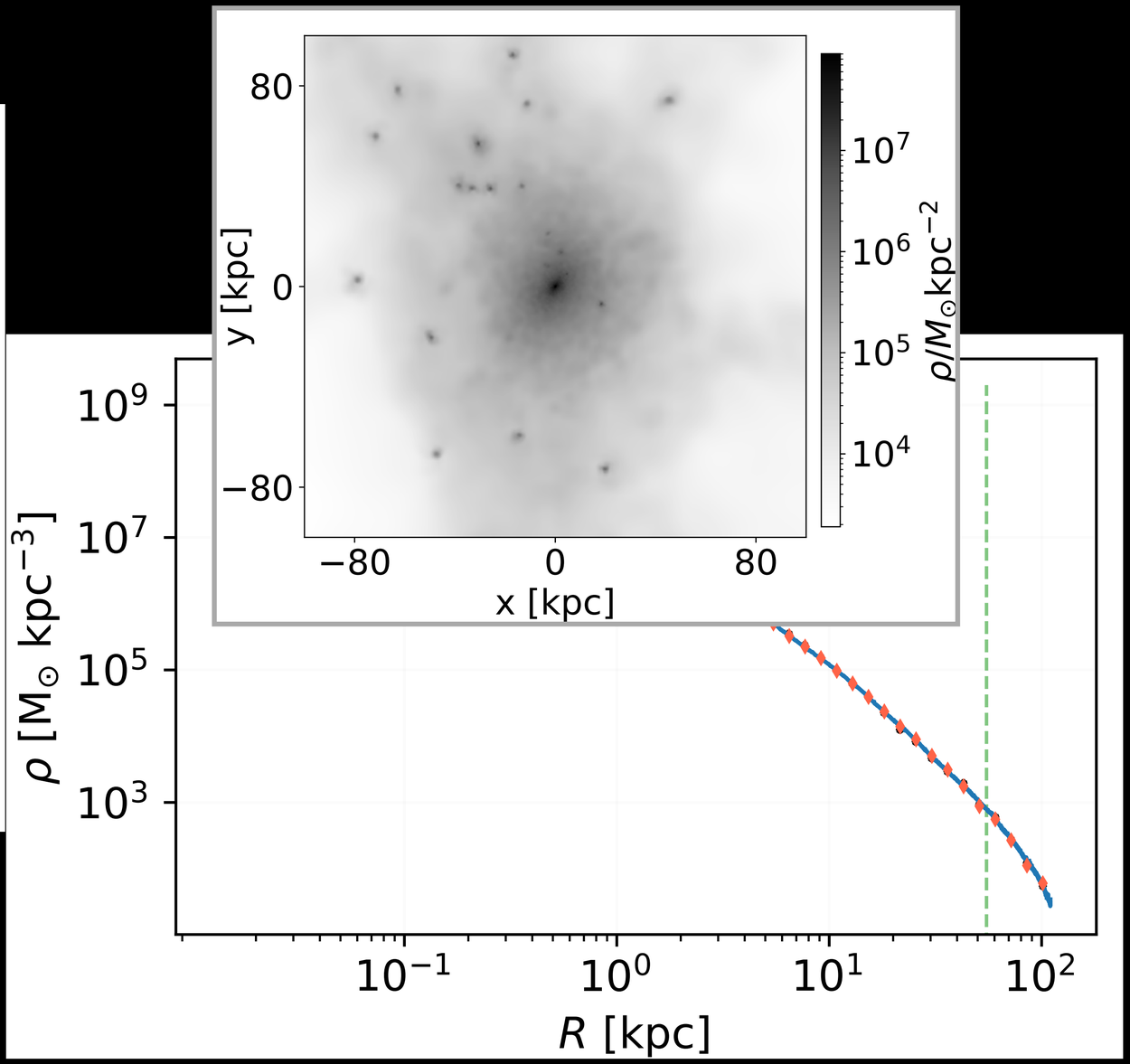

Summary

- Including dynamical information gives an improved representation of the density profiles
- Poisson noise is significantly reduced
- Method allows to extrapolate the behaviour below convergence radius (where binned estimates are unreliable)
- Central gradients are consistently steeper (at the same resolution) in qualitative agreement with the higher res
- Method continues to agree at large radii (if there aren’t any large substructures)
- Results are resolution independent

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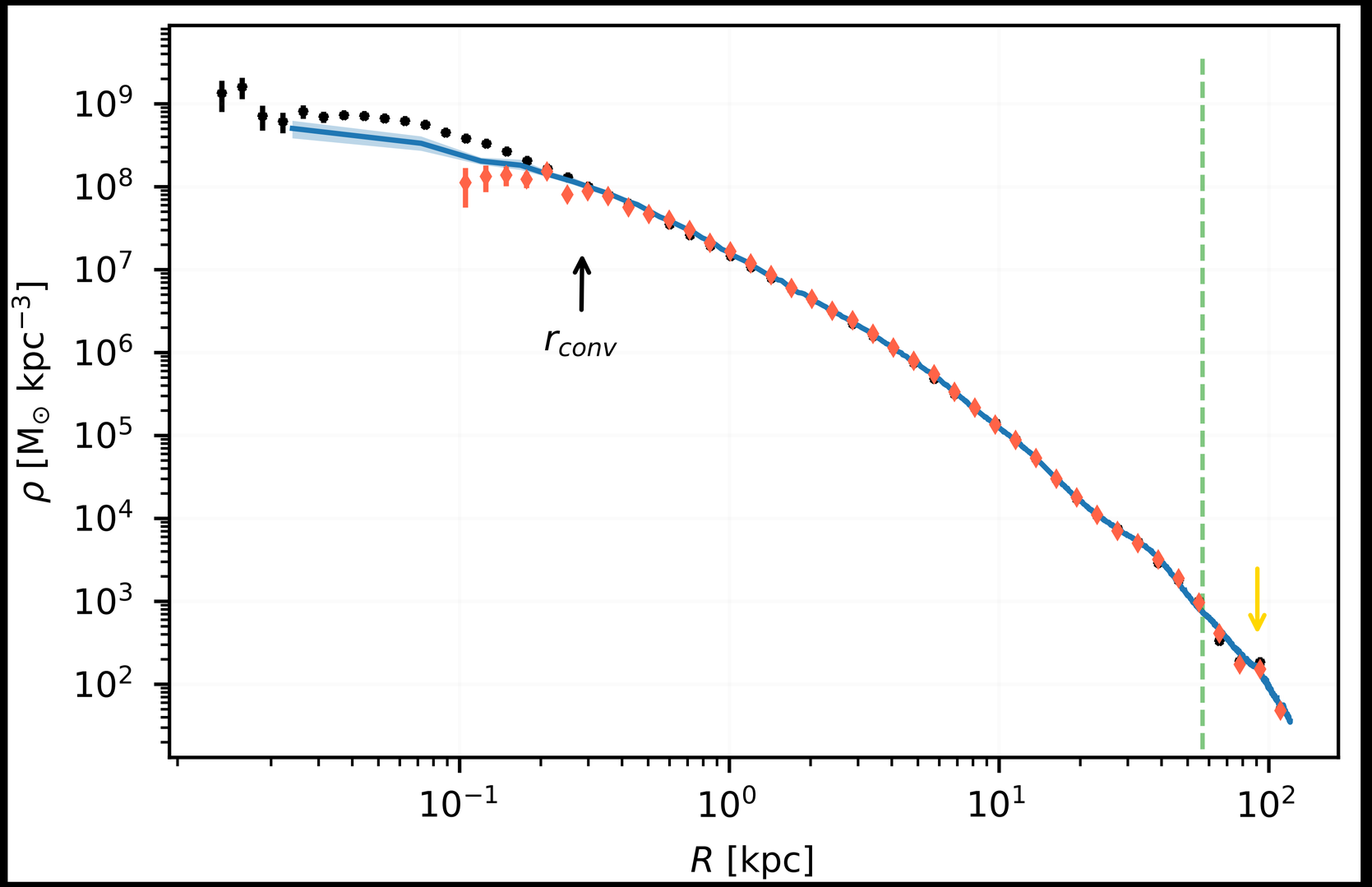
Post-merger halo



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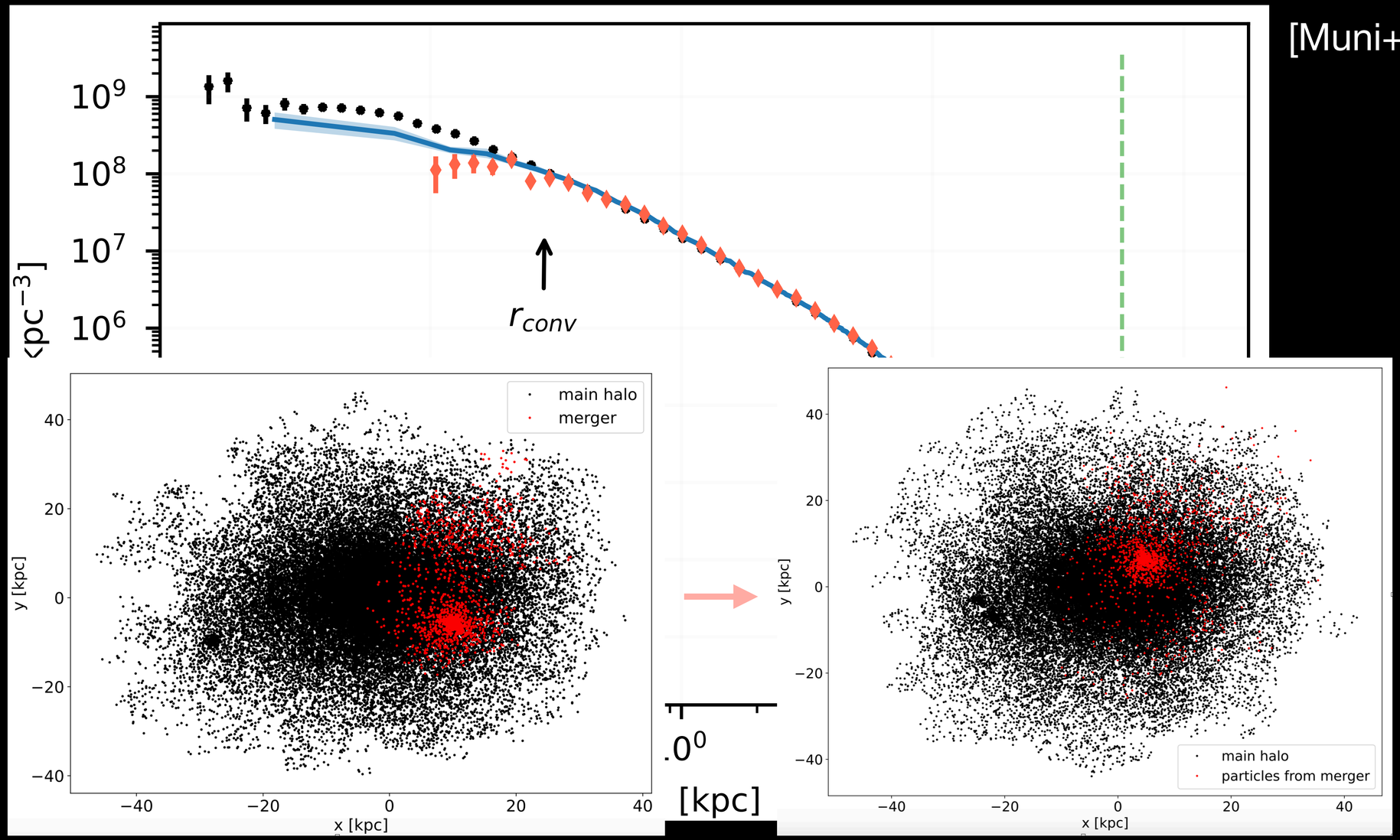

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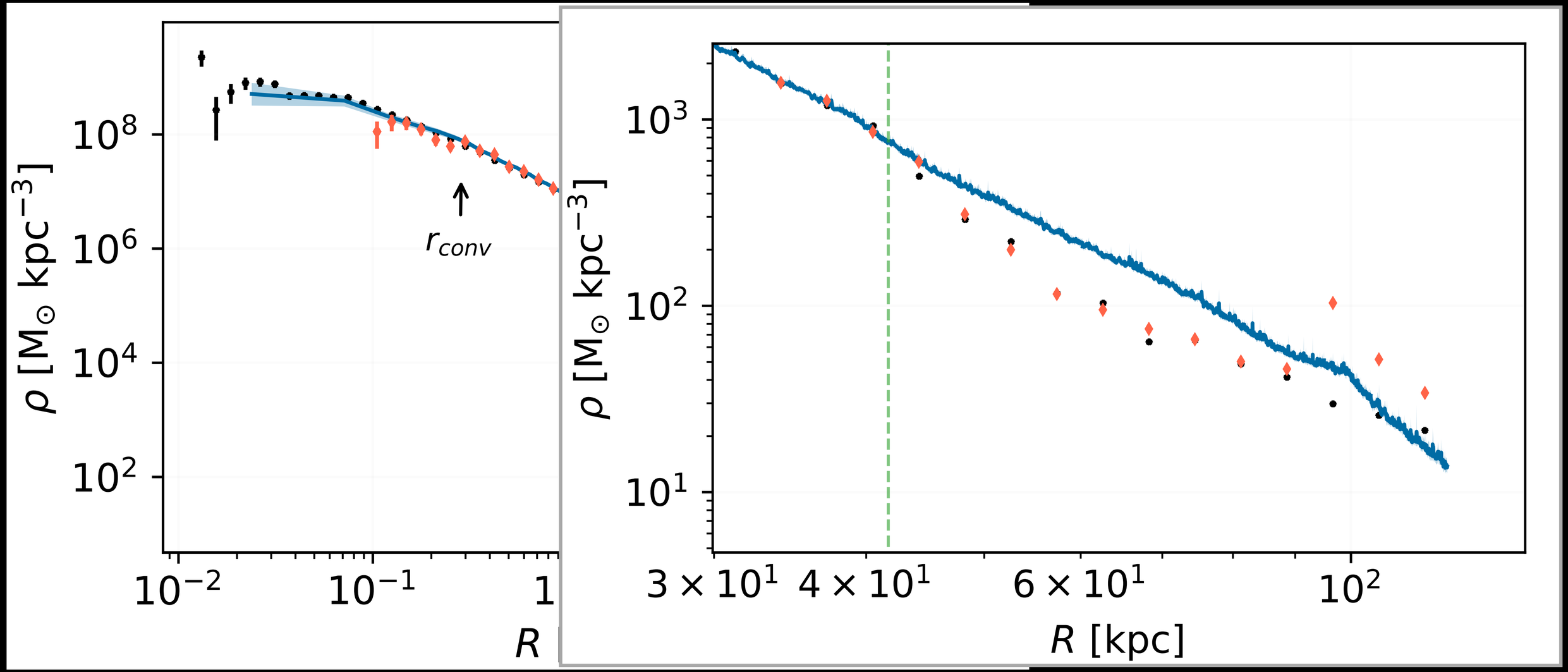
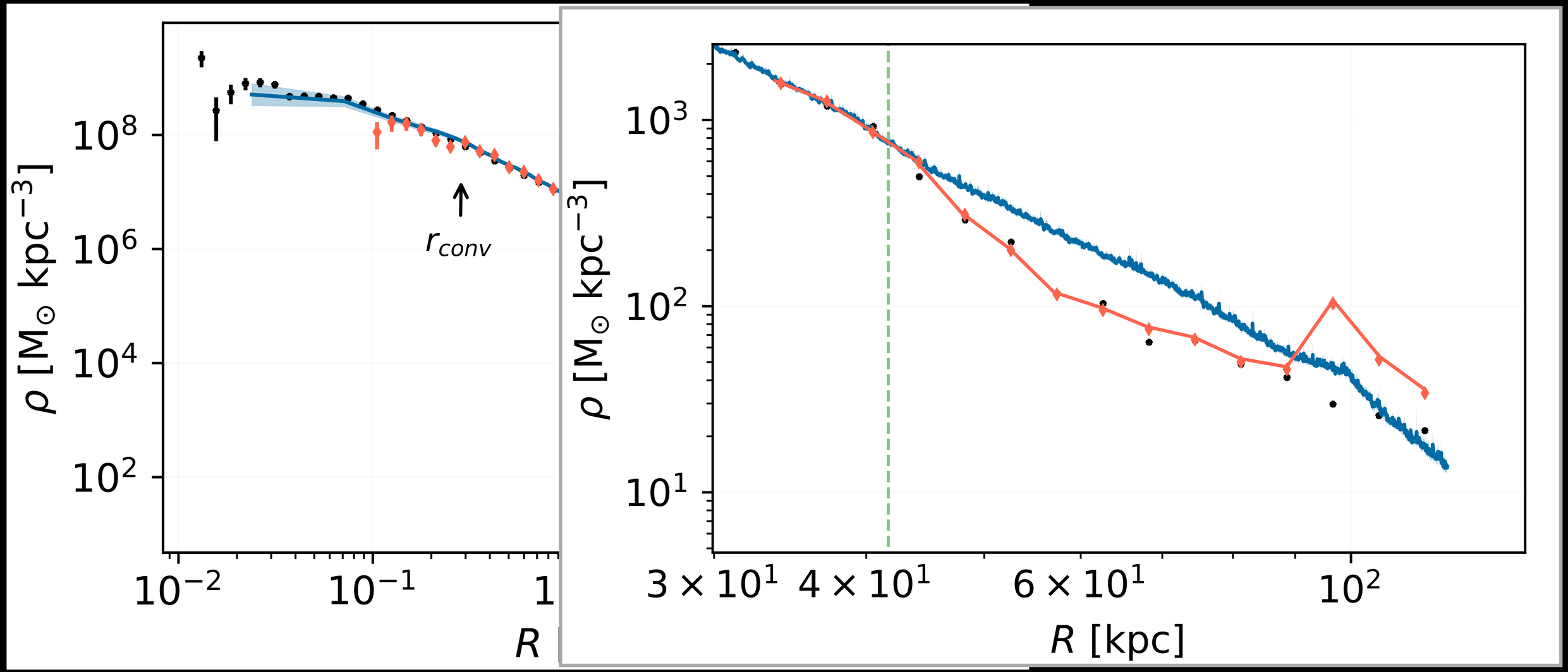


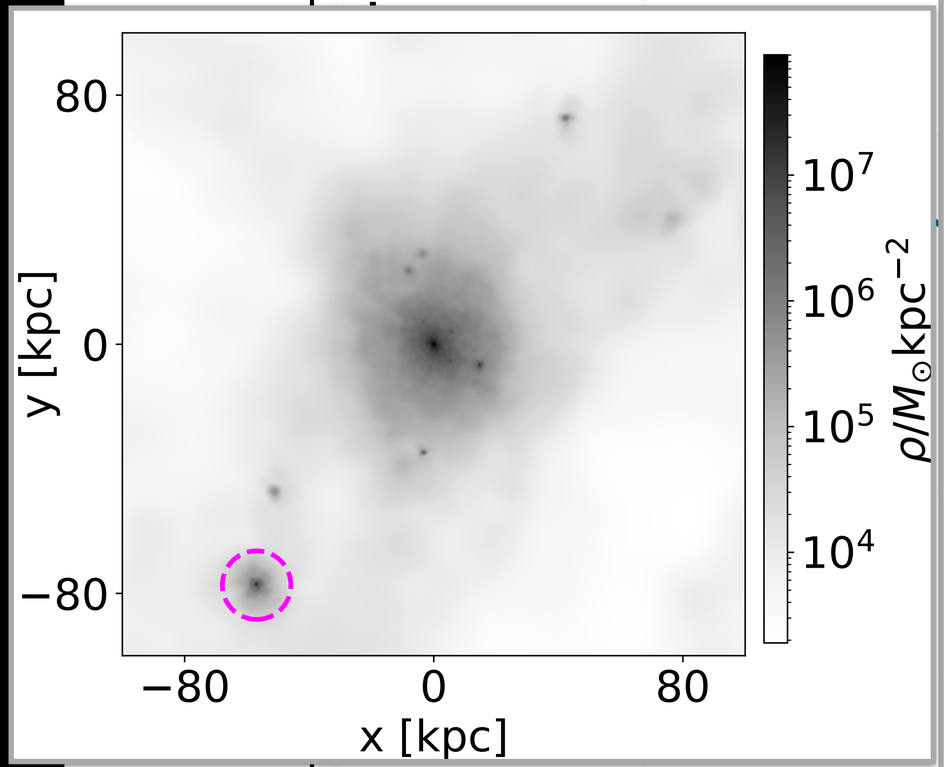
Dynamical density profile

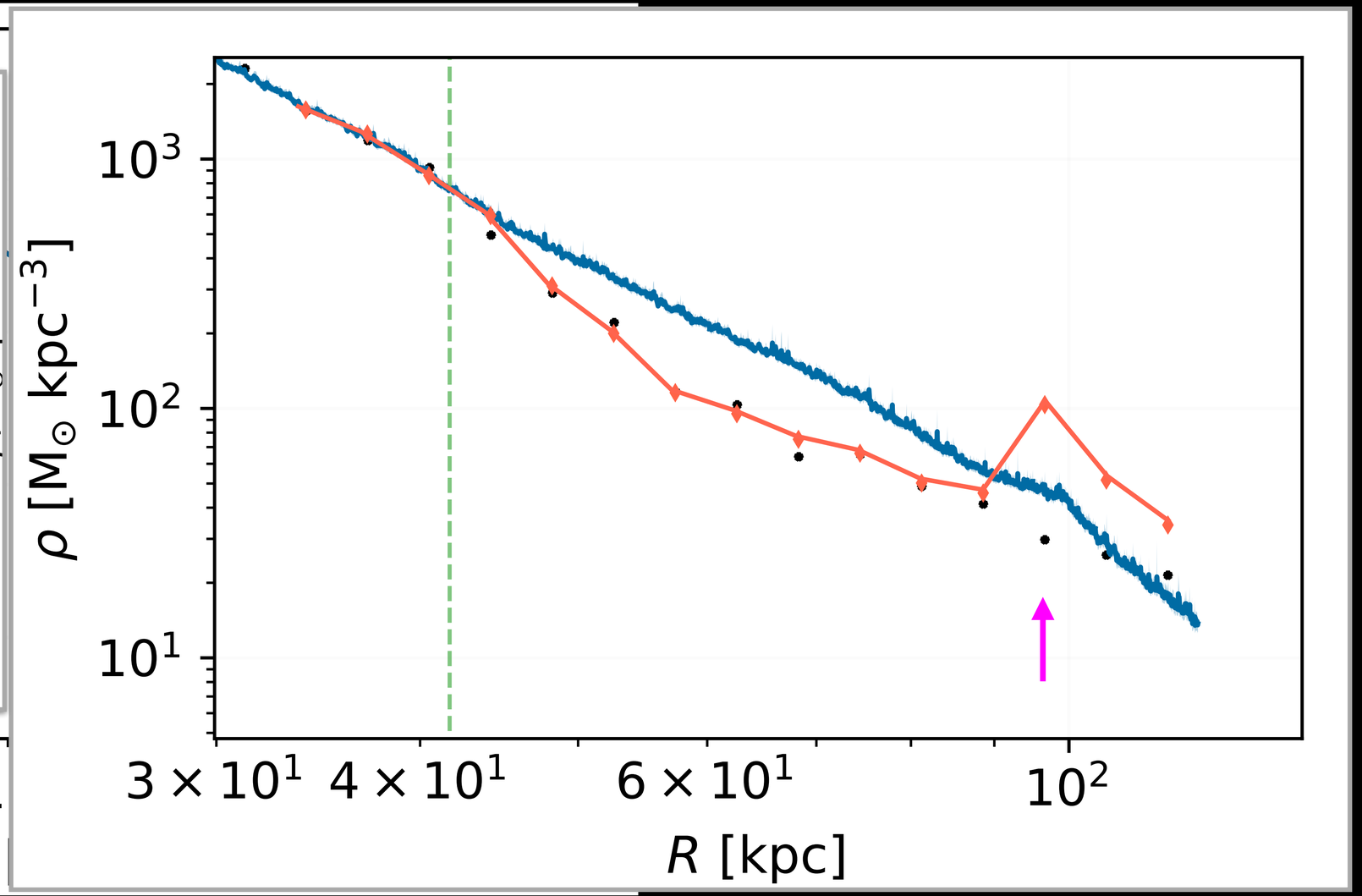
Outer regions



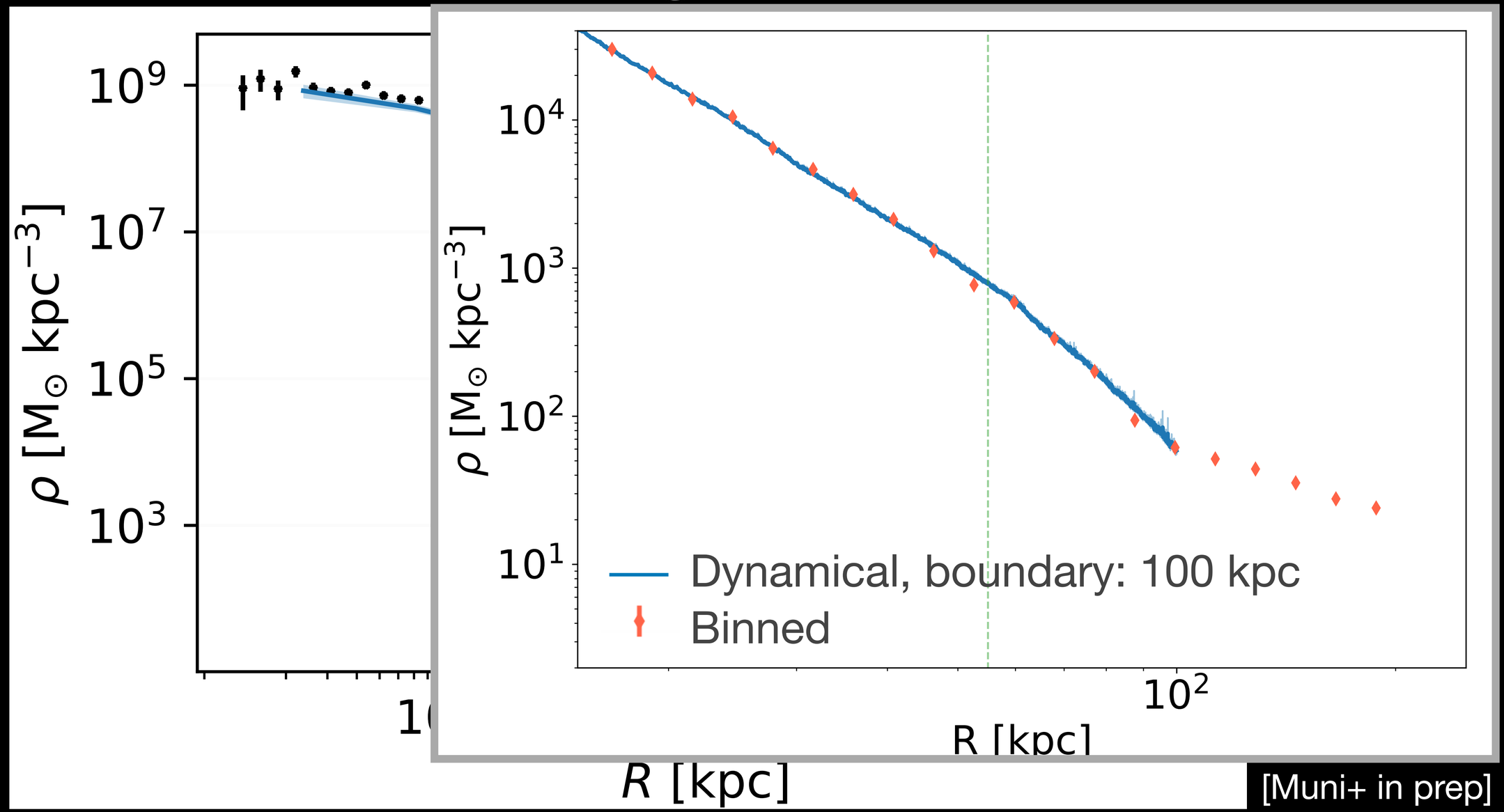
Dynamical density profile

Outer regions



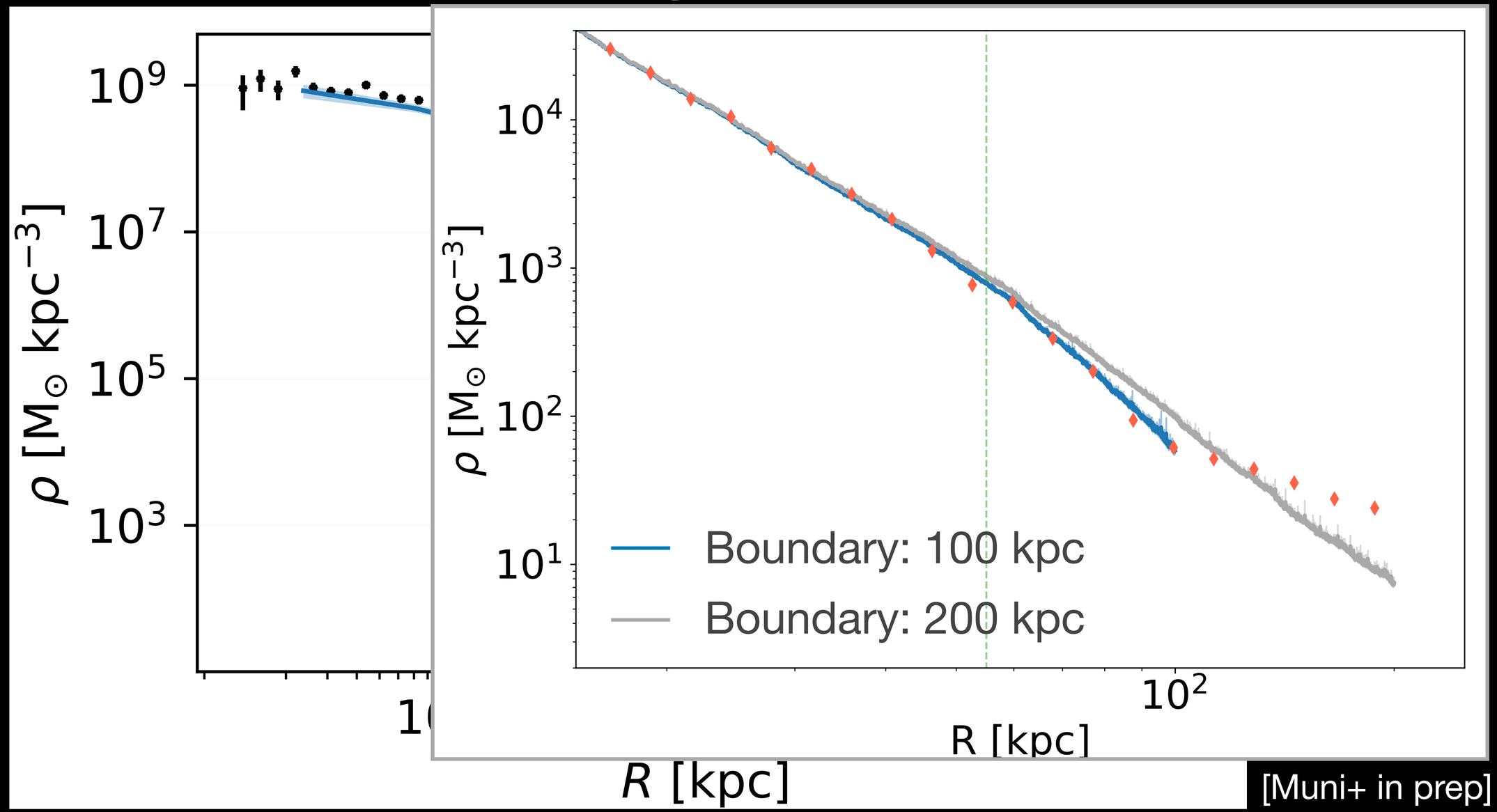


Effect on the outer regions



[Muni+ in prep]

Effect on the outer regions



[Muni+ in prep]