# Density Profiles of Dynamical Dark Matter Halos

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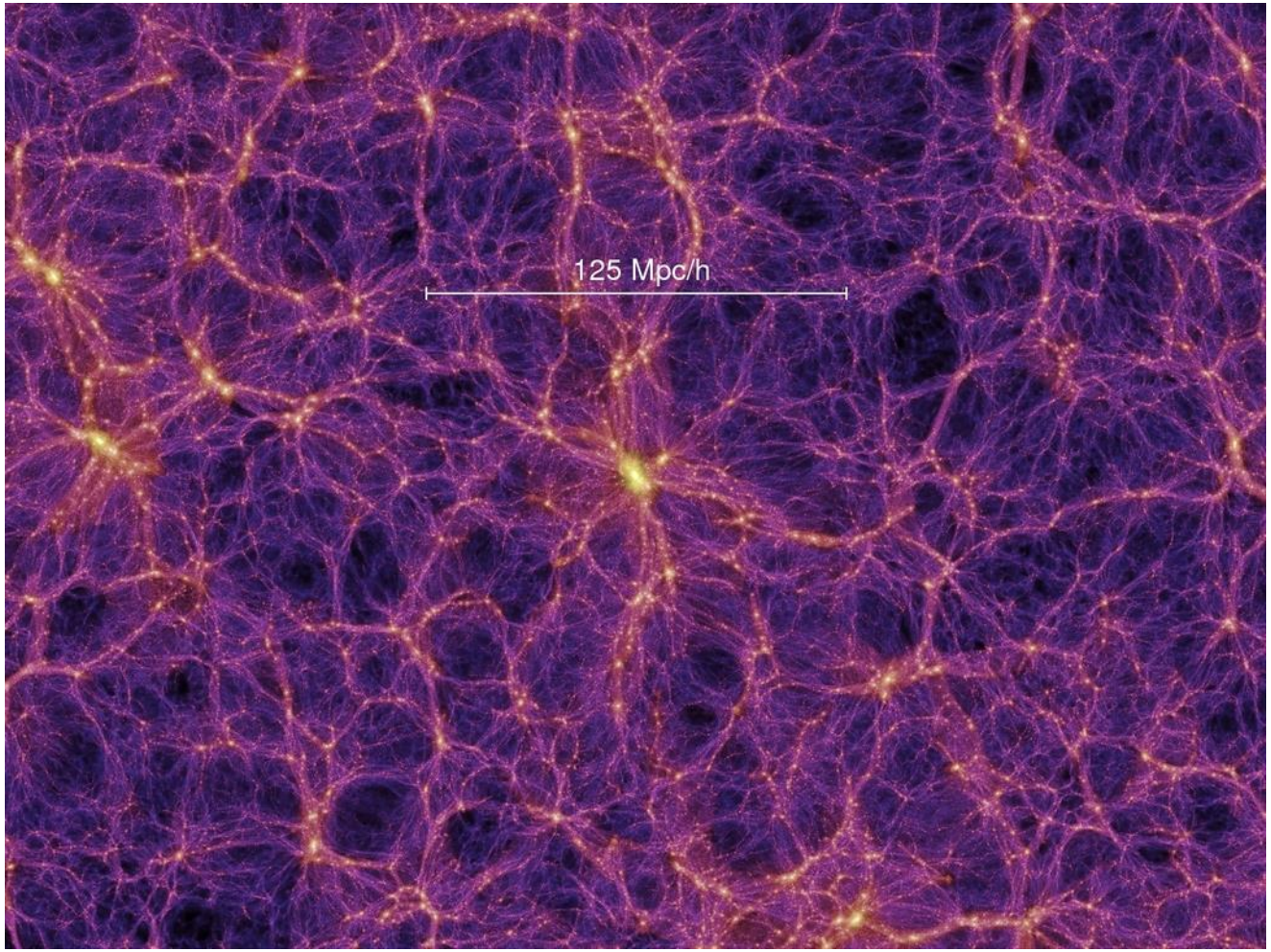
# Introduction

- In cosmology, we want to model matter distribution of the universe
- Dark matter collapses into structures called halos
- Distribution of matter in haloes are called density profiles



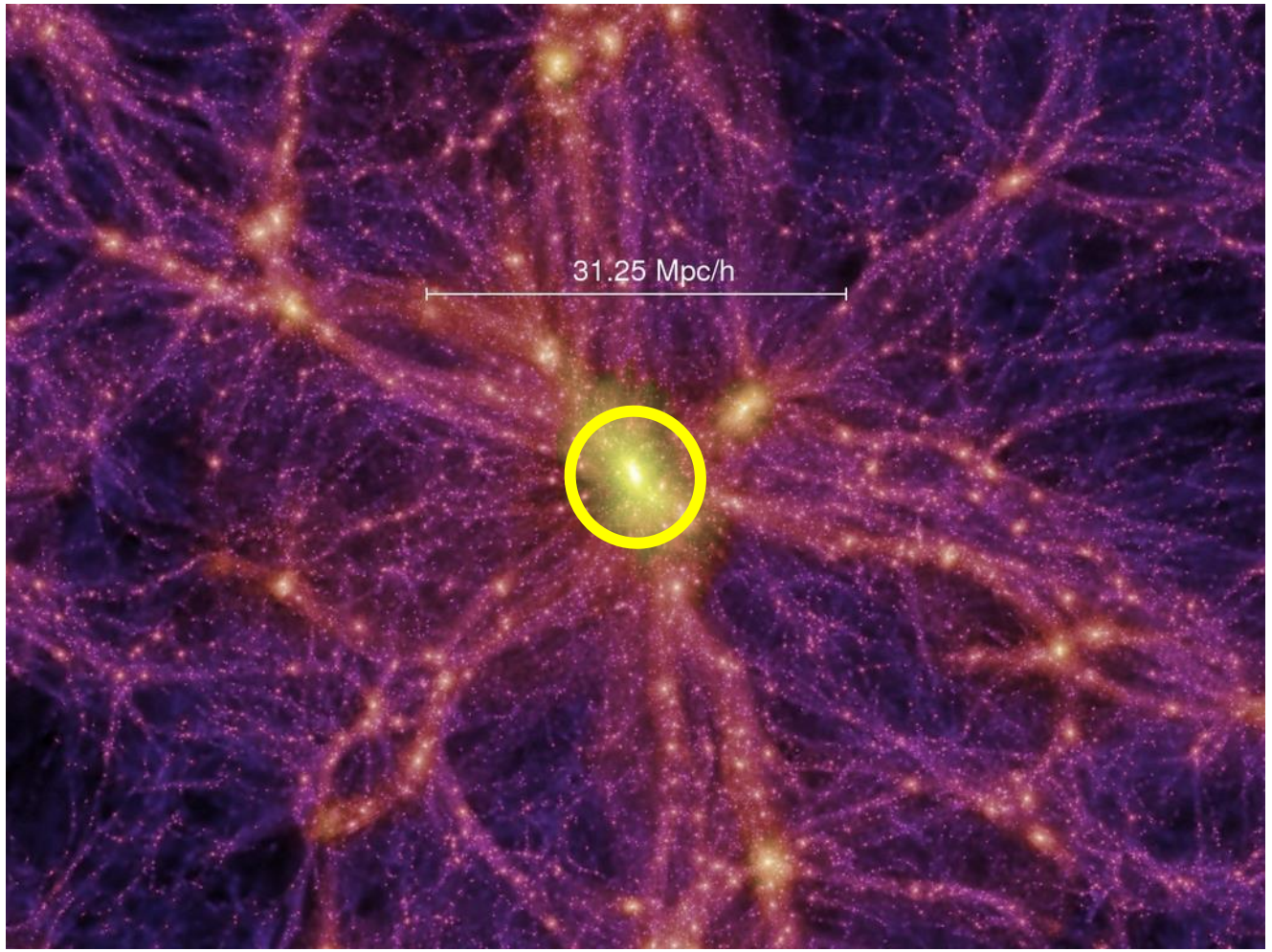

Credit: Millenium Simulation Project

# What is a Halo?

- Traditionally defined by fixed overdensities and NFW profiles:

$$\rho(r) = \frac{\rho_0}{\frac{r}{r_s}(1+\frac{r}{r_s})^2}$$

- This model is problematic
  - Semi-arbitrary/loosely motivated
  - NFW profile diverges
  - Ignores particle dynamics

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# Dynamical Haloes

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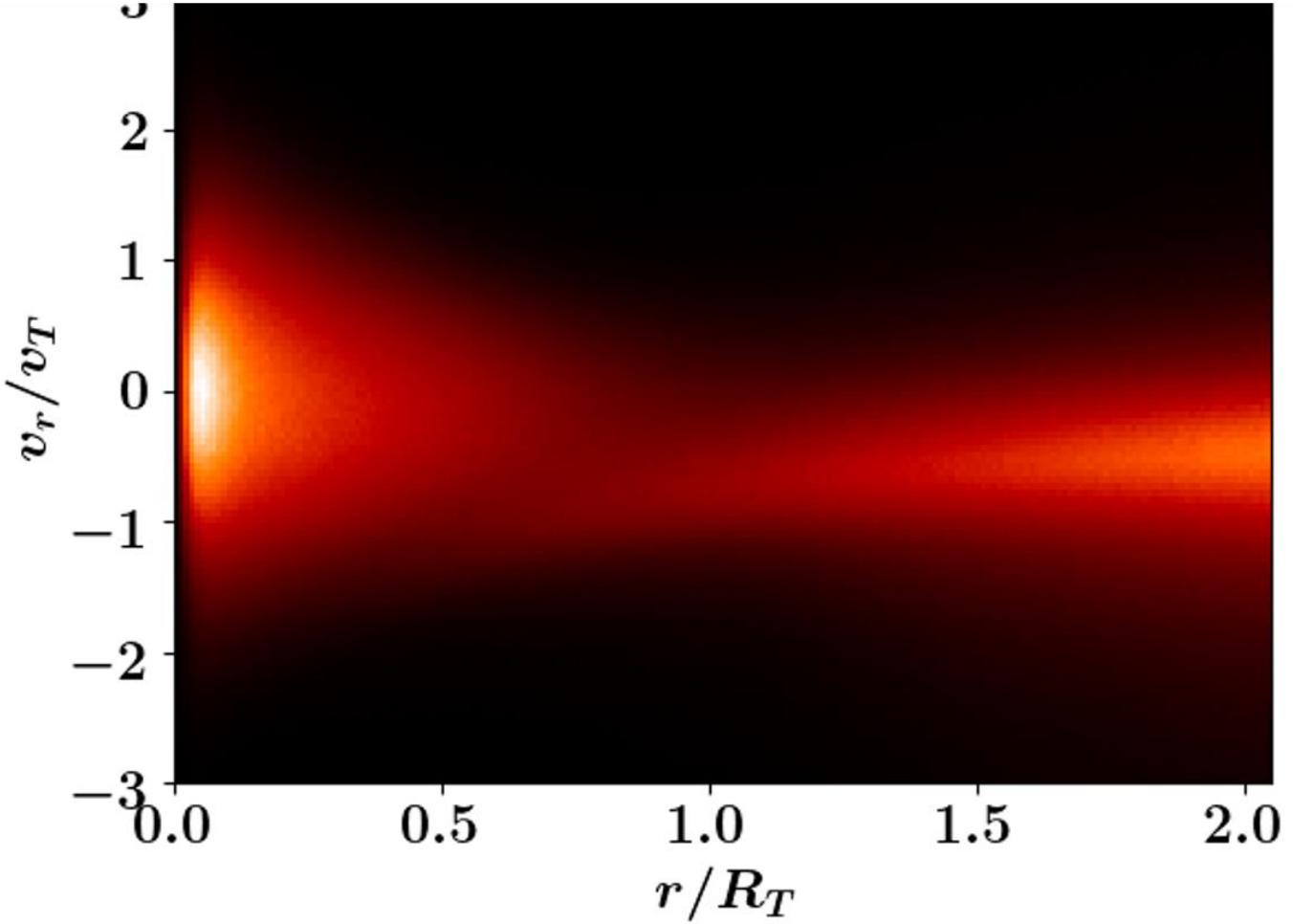

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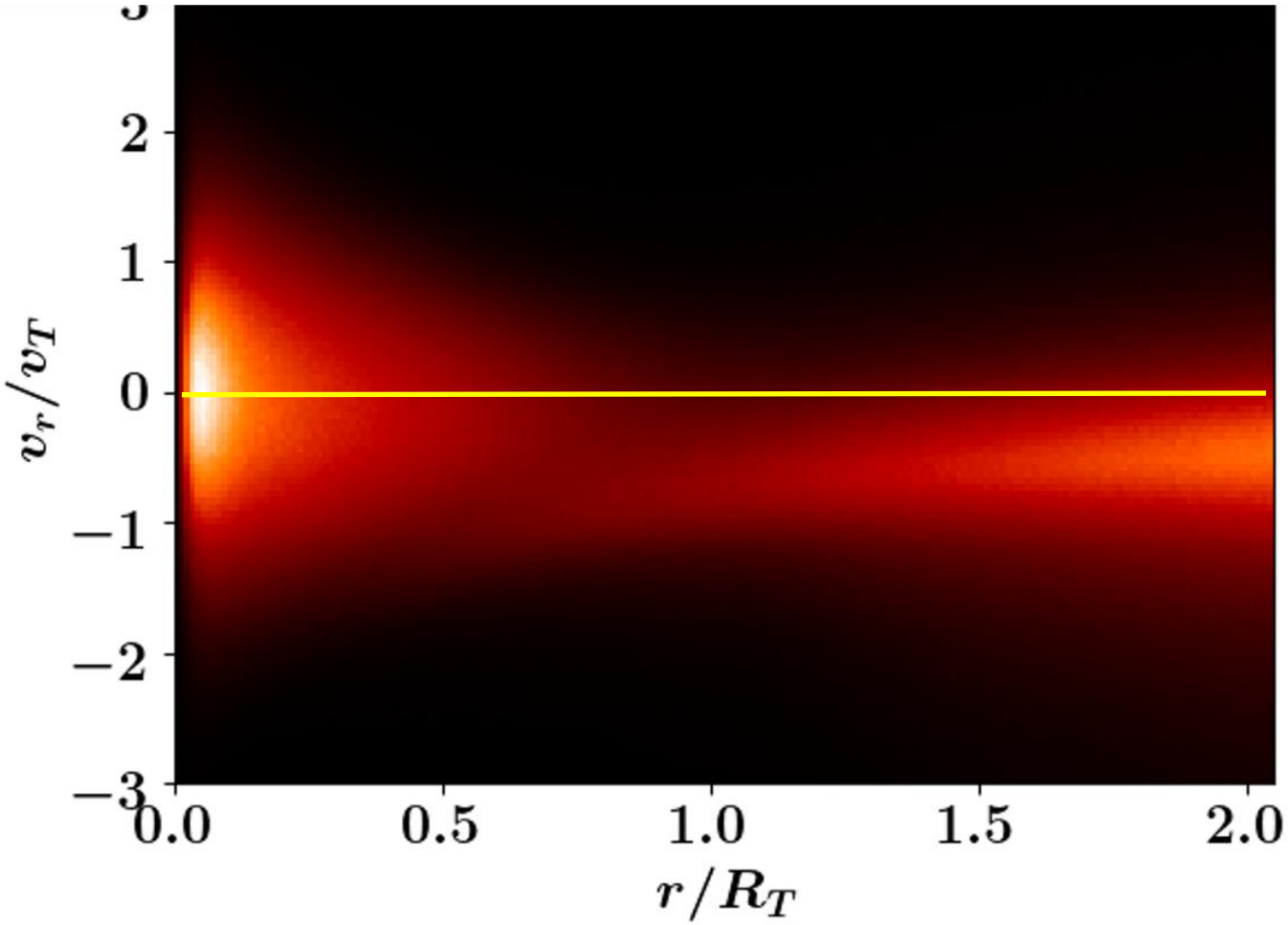
- We separate particles as "orbiting" and "infalling"



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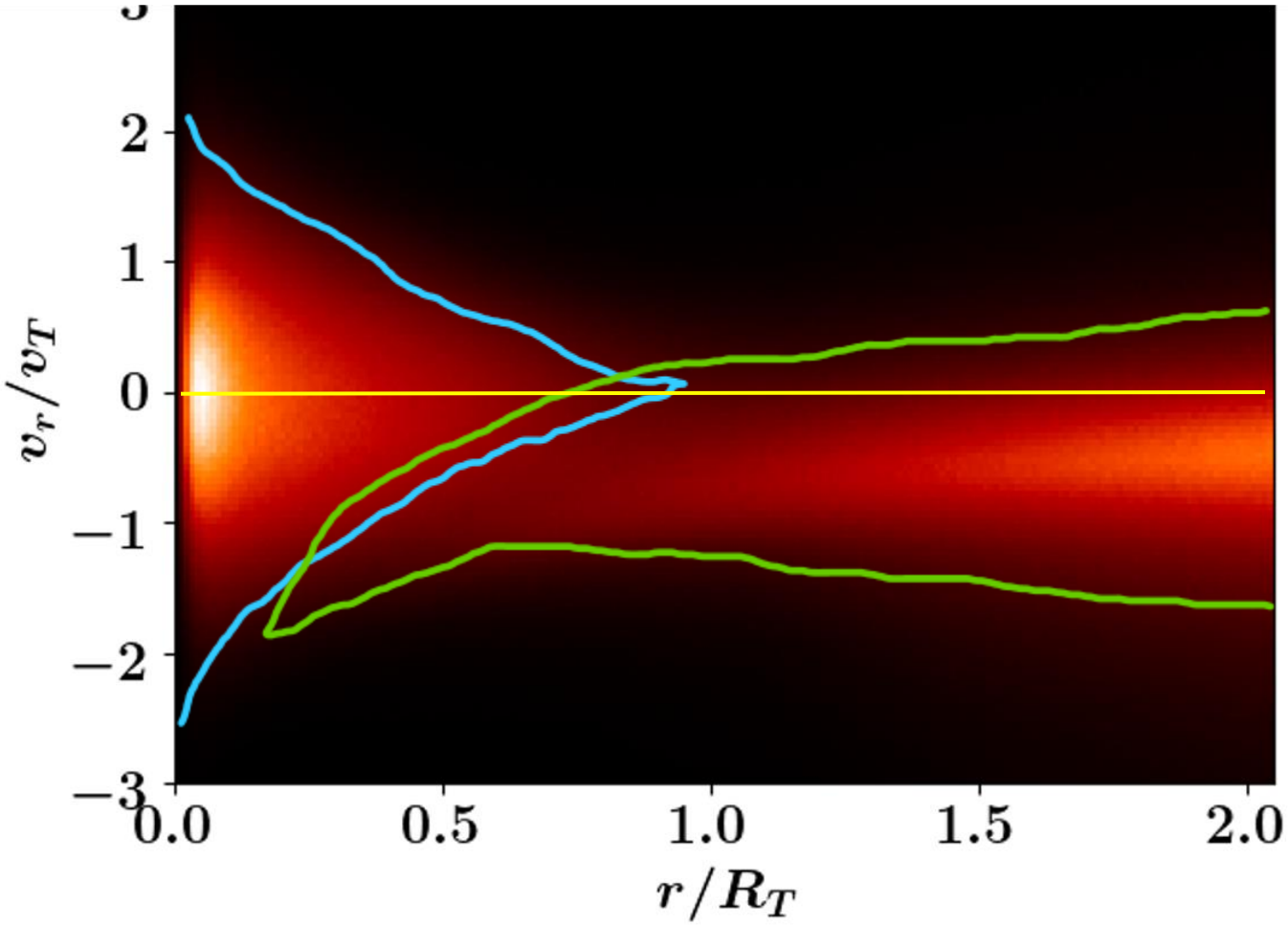

# Dynamical Haloes

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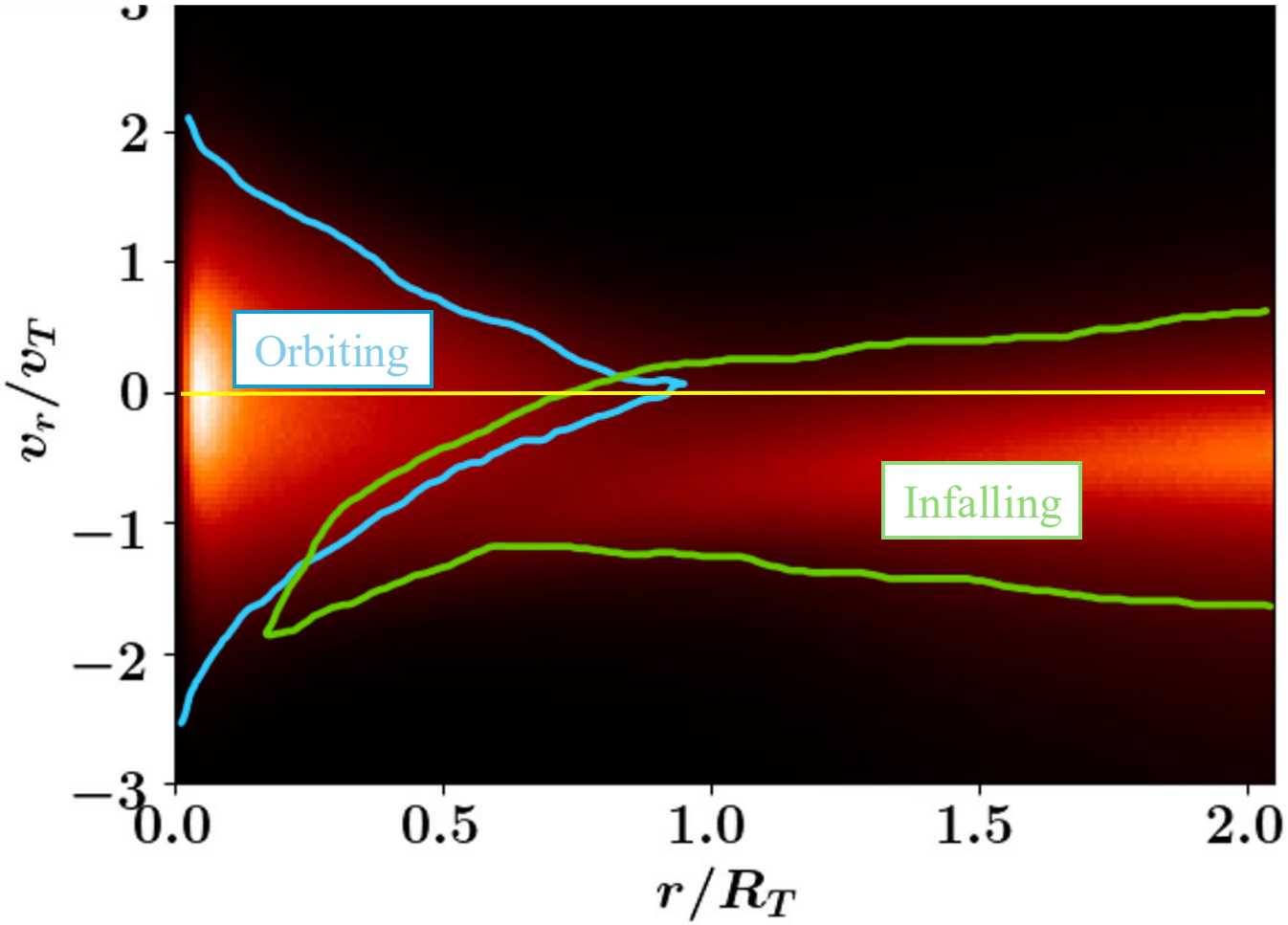
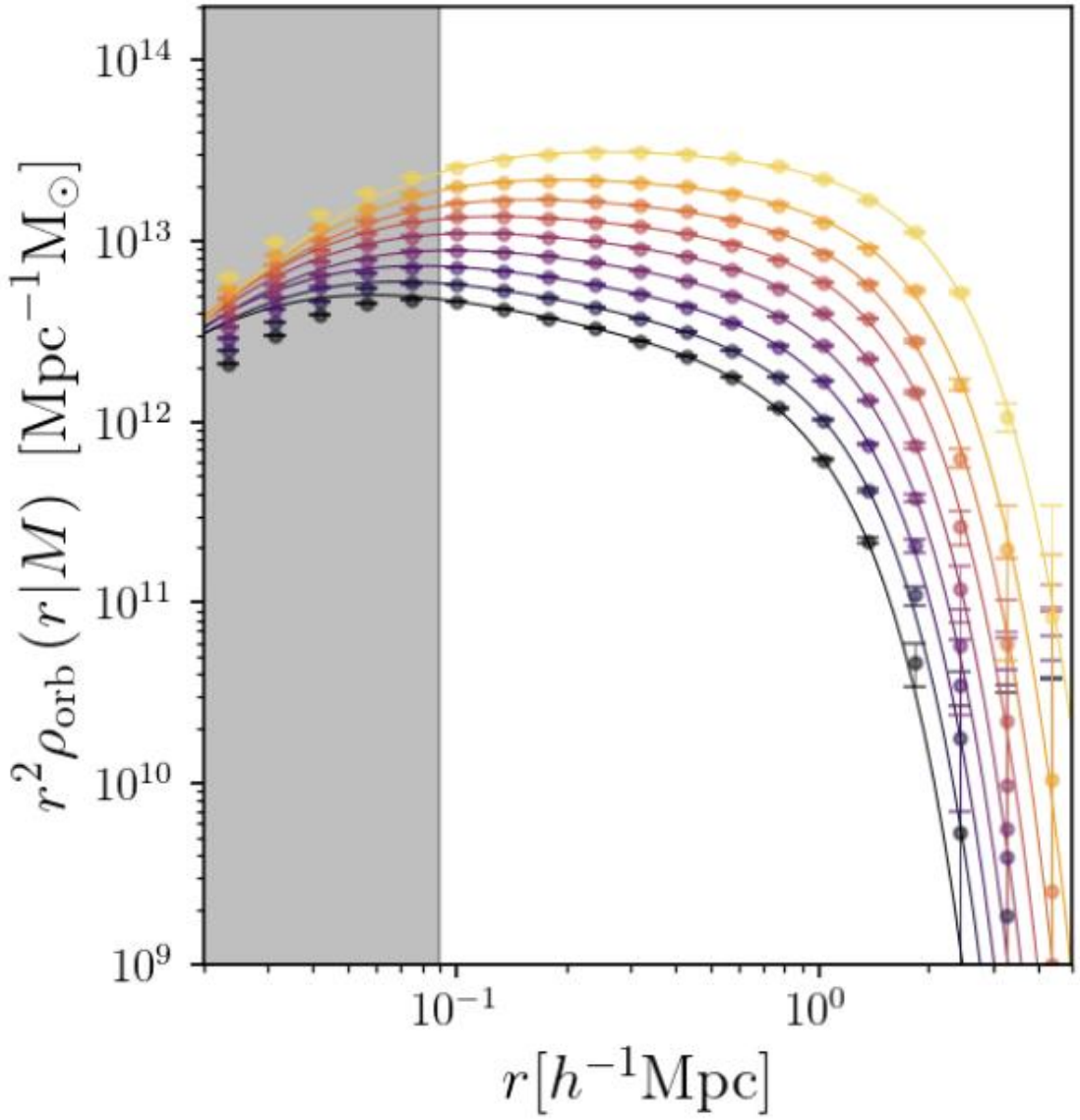
- We separate particles as "orbiting" and "infalling"
- *Dynamical halo:* the collection of its orbiting particles



# Orbiting Density Model

- Previous work has developed a density profile for orbiting particles

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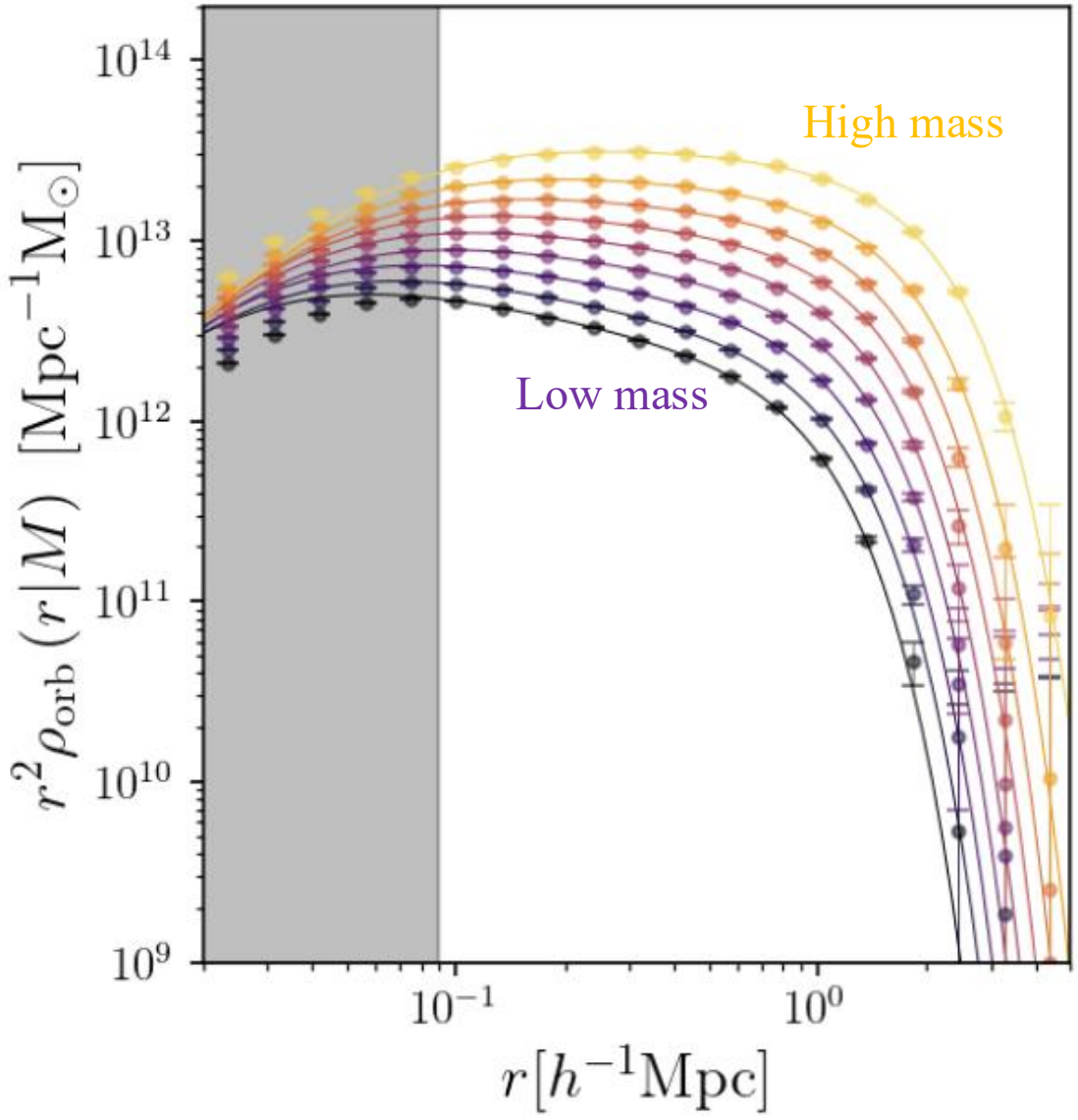


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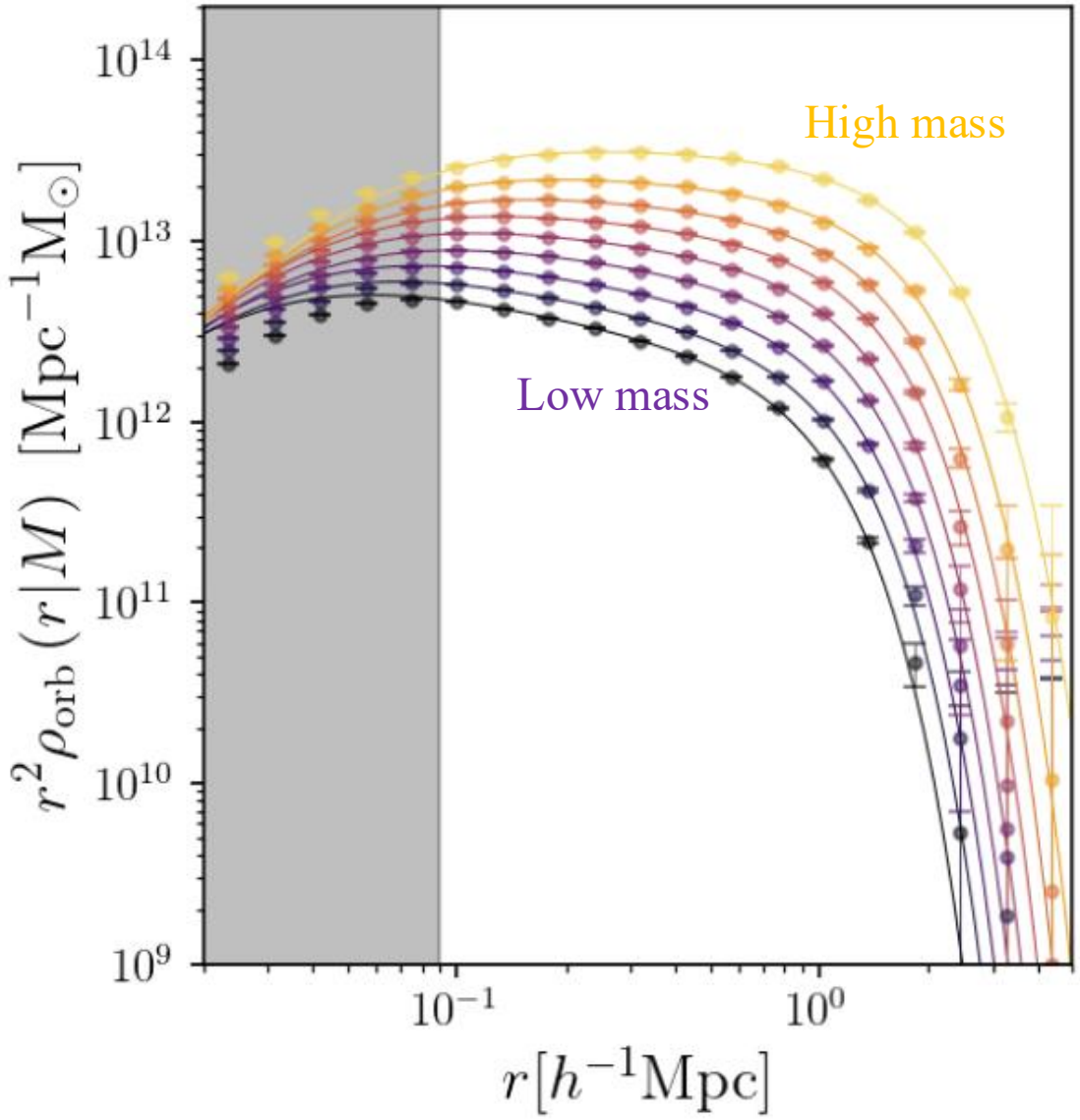


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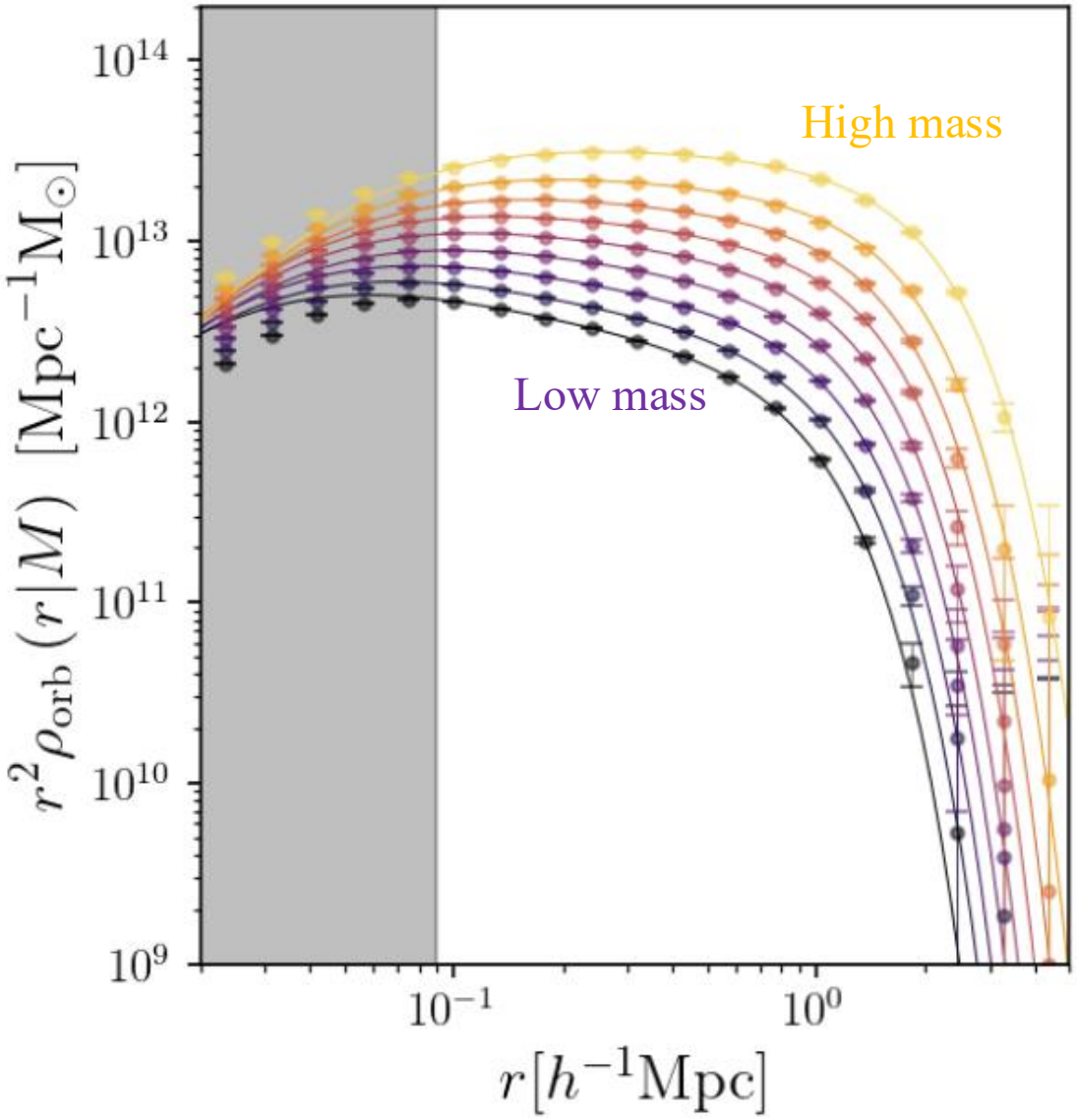
$$\rho_{\rm orb}(x|M_{\rm orb}) = A\left(\frac{x}{\epsilon}\right)^{-\alpha(x)} \exp\left(-\frac{x^2}{2}\right)$$

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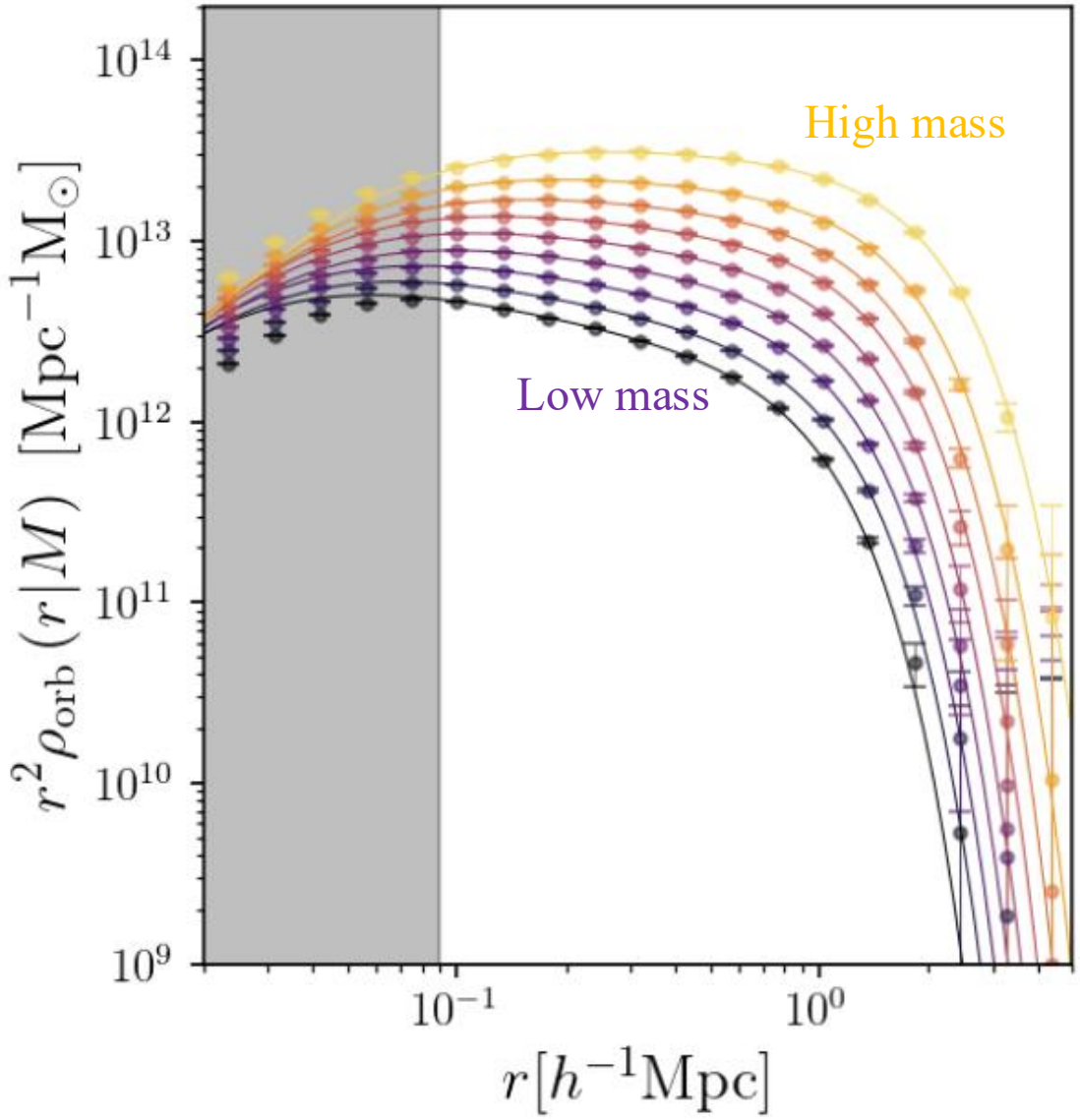


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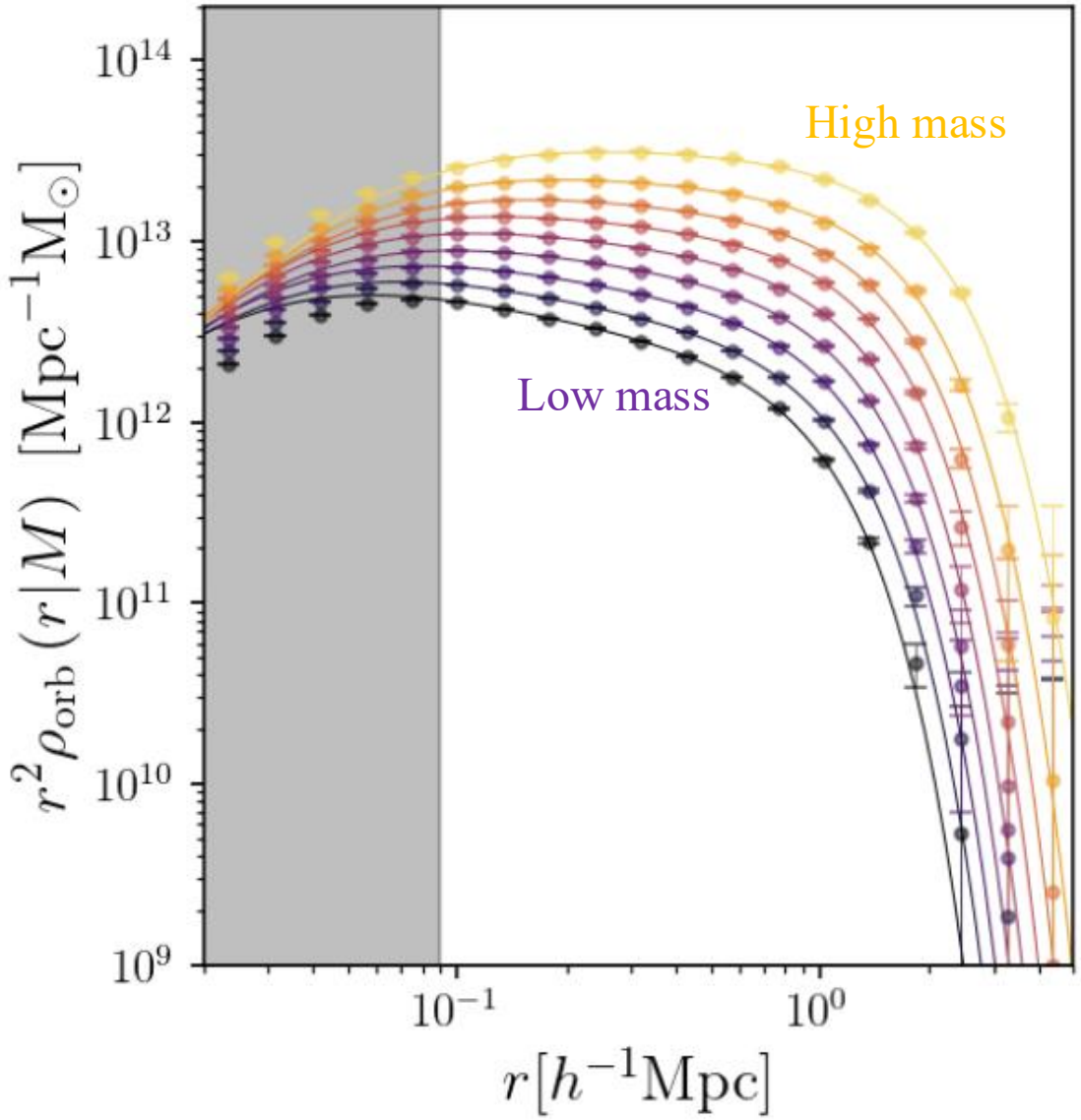
Halo radius

$$\rho_{\rm orb}(x|M_{\rm orb}) = A\left(\frac{x}{\epsilon}\right)^{-\alpha(x)} \exp\left(-\frac{x^2}{2}\right)$$

Asymptotic slope

$$\alpha(x) = \alpha_\infty \frac{x}{x+\epsilon}$$

- Two shape parameters: halo radius and (asymptotic) slope

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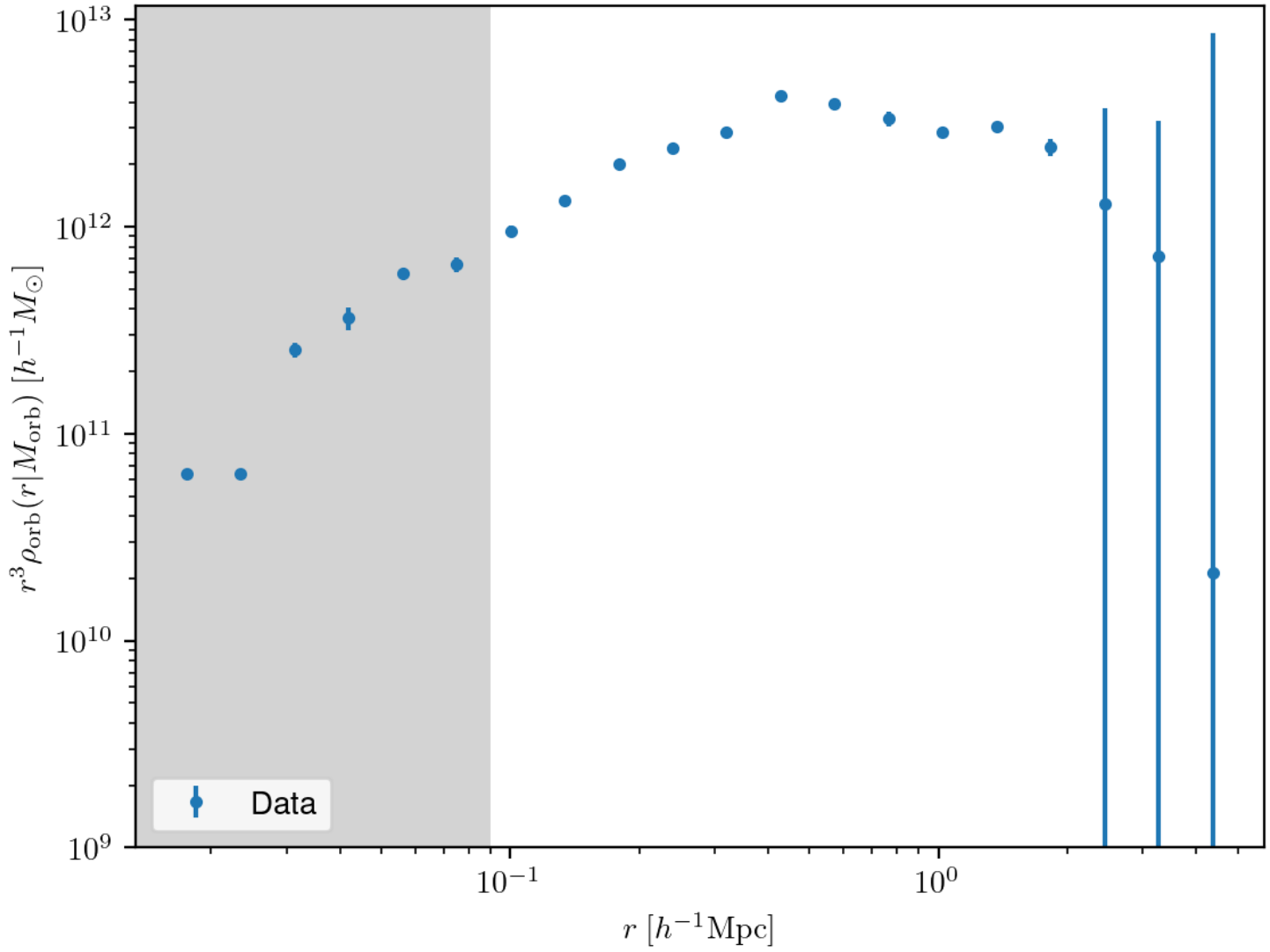
# What About Individual Halo Profiles?

- We can fit this model to individual profiles
- Minimize cost function to get best-fit parameters



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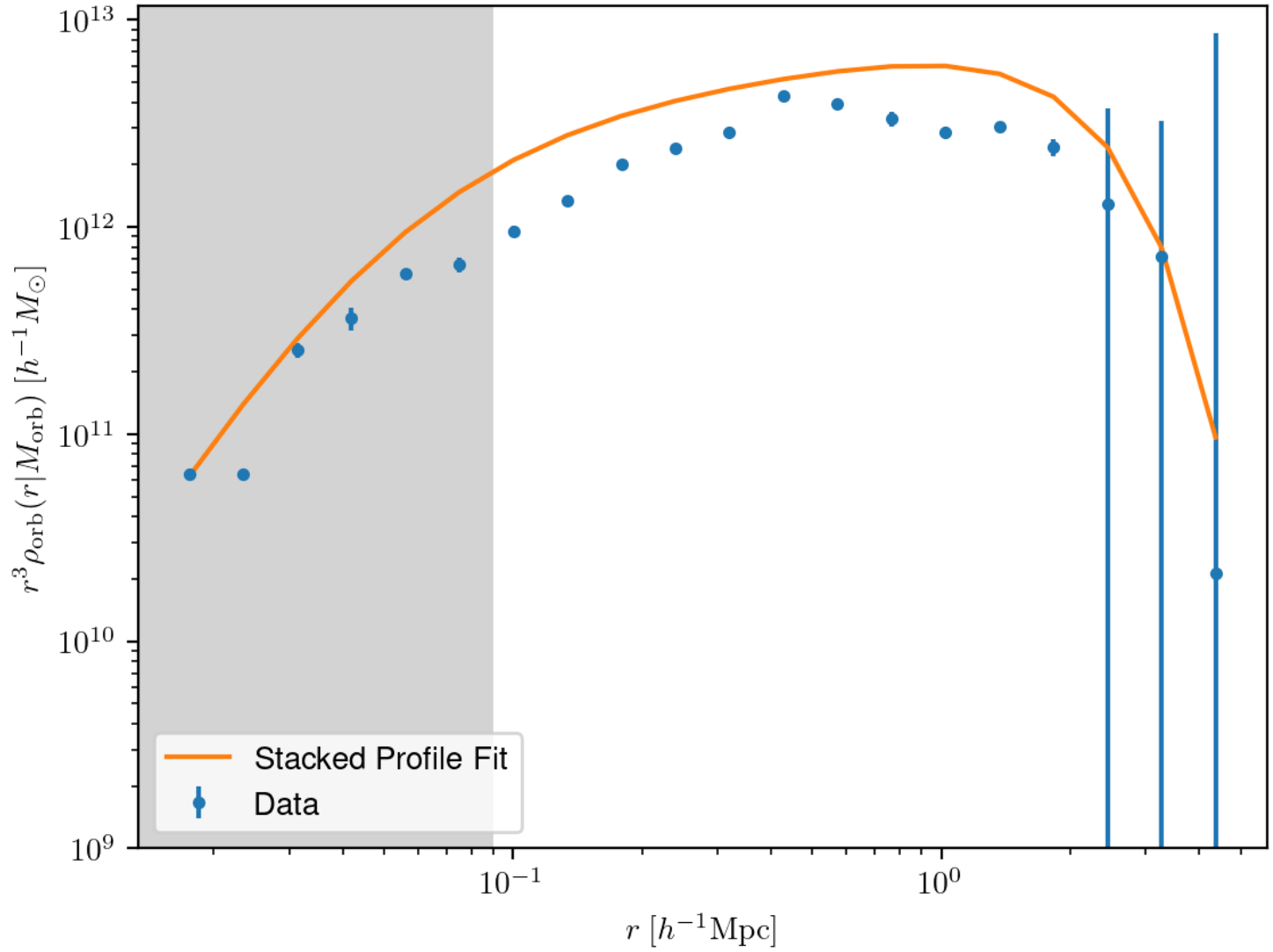

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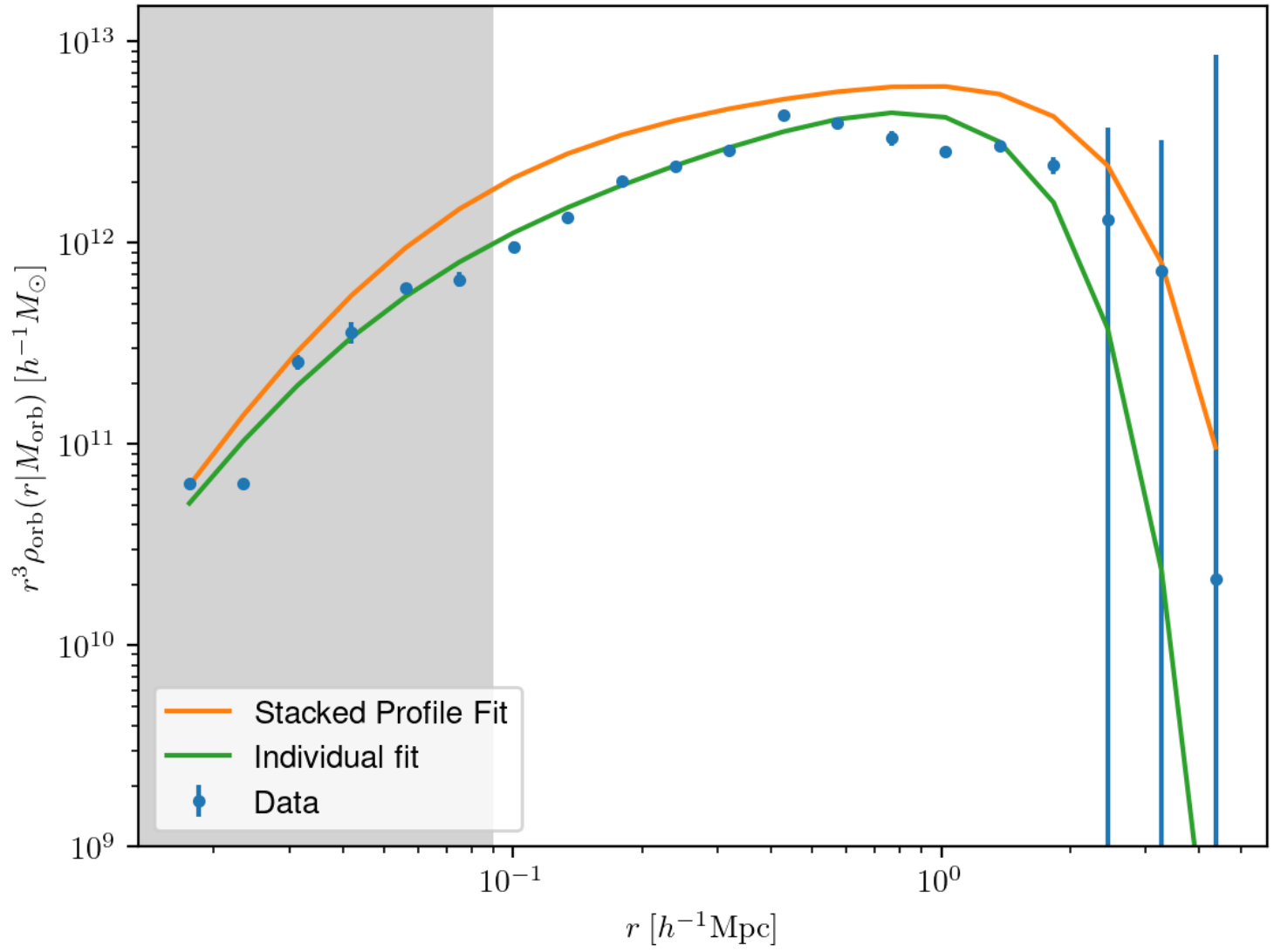


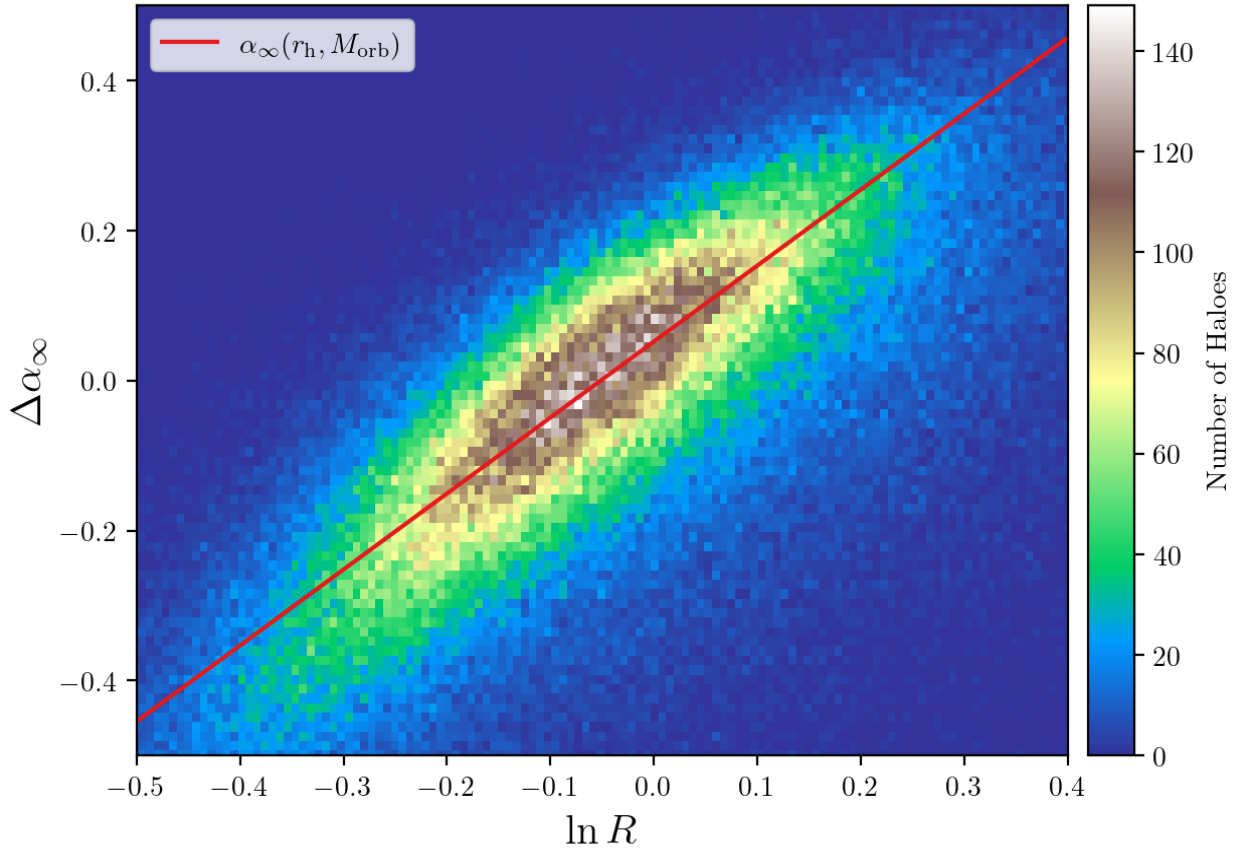
# Are the Free Parameters Related?

- For each halo, we can plot one best-fit parameter against the other

$$\Delta\alpha_\infty = \alpha_\infty - \alpha_{\infty,\mathrm{st}}(M_\mathrm{orb})$$

$$R = \frac{r_\mathrm{h}}{r_{\mathrm{h,st}}(M_\mathrm{orb})}$$

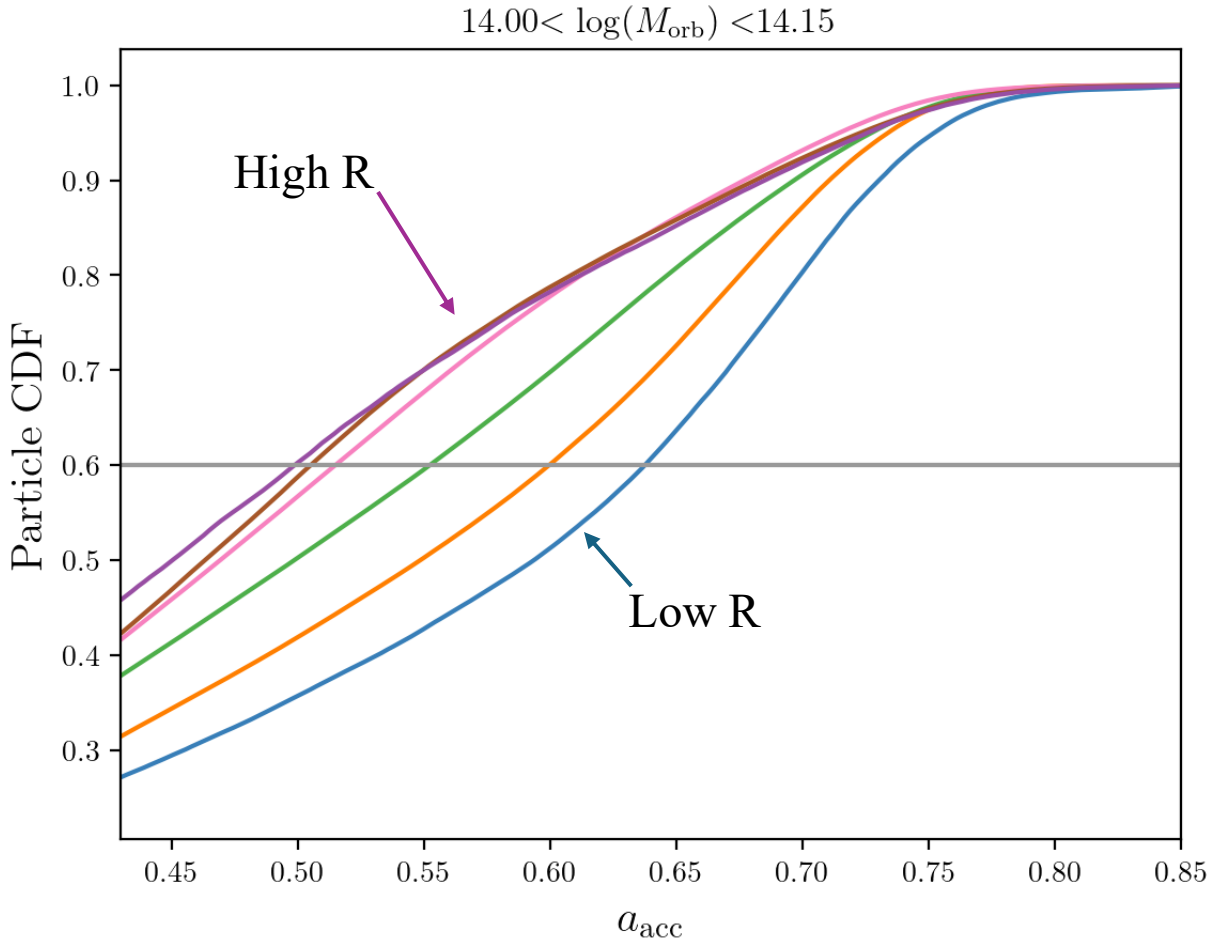
- Halo radius and profile slope are tightly correlated at fixed mass
- We only need the halo radius to fit individual halo profiles



# Dependence on Formation Time

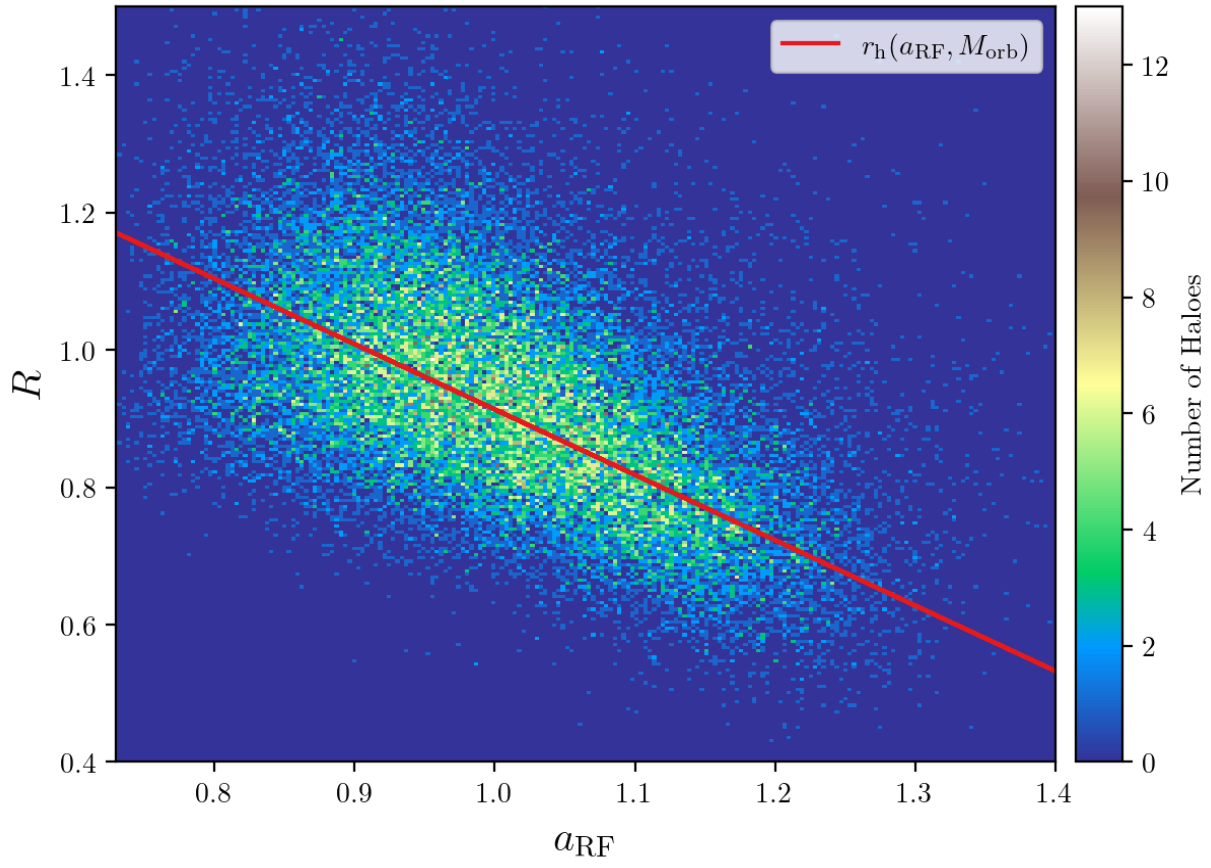
- Does the halo radius depend on a halo's relative age?
- To characterize halo accretion history, we bin by mass and R
- We see at a CDF value of 0.6, the R bins are most different

$$a_{\mathrm{RF}} = \frac{a_{60}}{\mathrm{median}(a_{\mathrm{acc}})}$$



# Dependence on Formation Time

- Halo radius has some dependence on relative formation time
- We can predict the halo radius from mass and relative age
- Likewise, we can predict relative age from mass and halo radius



# Conclusions

- Orbiting density profiles have an exponential truncation and a varying slope; we call the truncation scale the halo radius

- We can characterize a dynamical halo's density profile by just fitting for this halo radius

- This halo radius also has some dependence on when the halo formed in the simulation