

DORCHA simulations suite

Nature, nurture, and the phase space distribution of the
Milky Way's high redshift progenitors today

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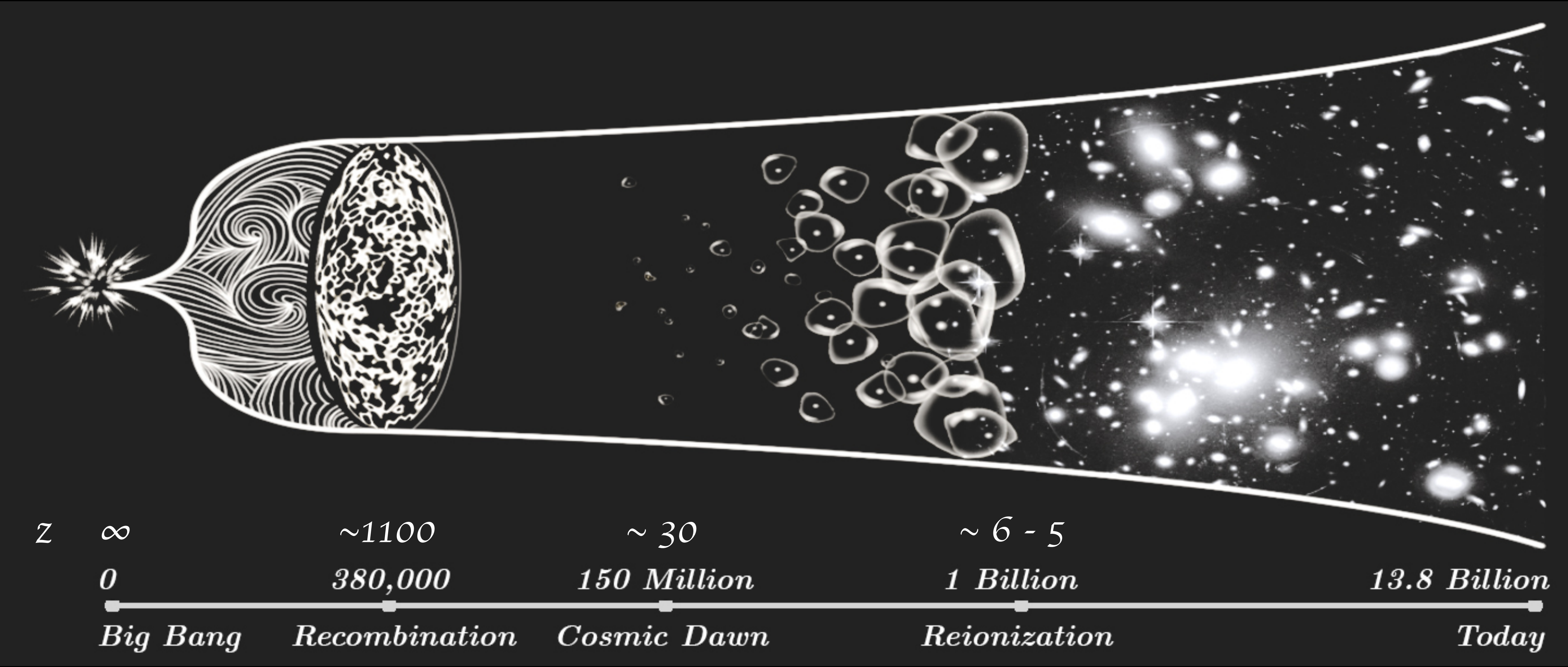
With thanks to: Chris Power & Kris Walker (UWA), Stuart Wyithe (ANU)

Project PID2022-138855NB-C32 financed by



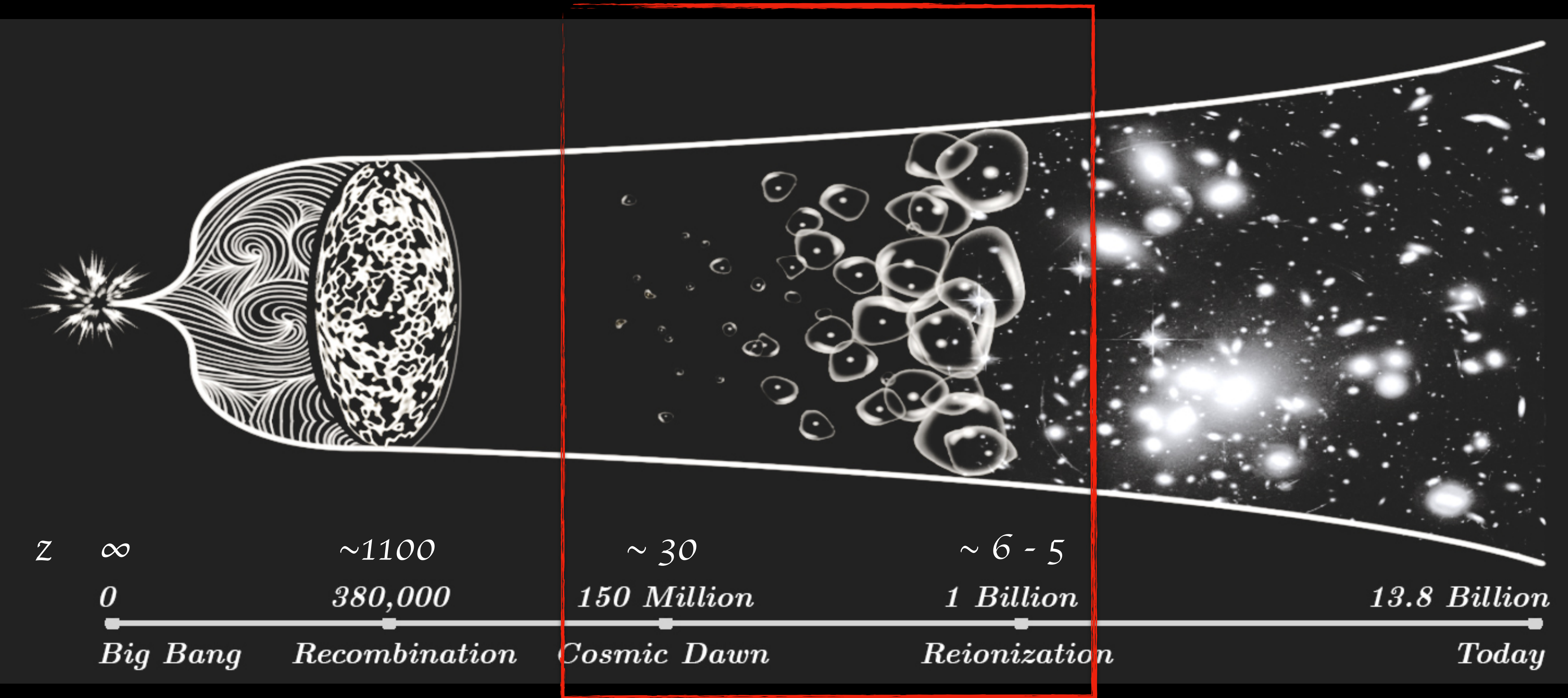
09th June 2025





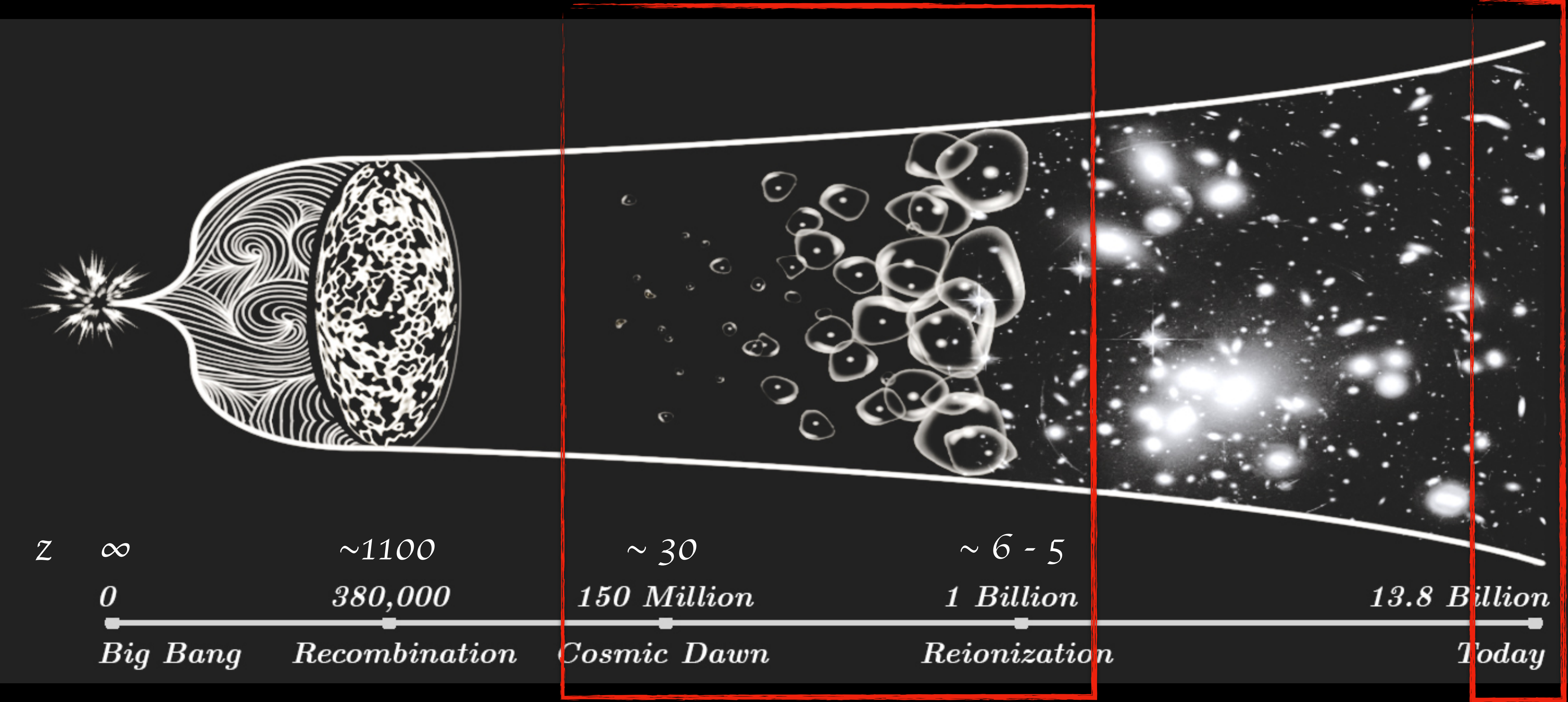
Cosmic Dawn & Epoch of Reionisation

first star formation



Cosmic Dawn & Epoch of Reionisation

first star formation

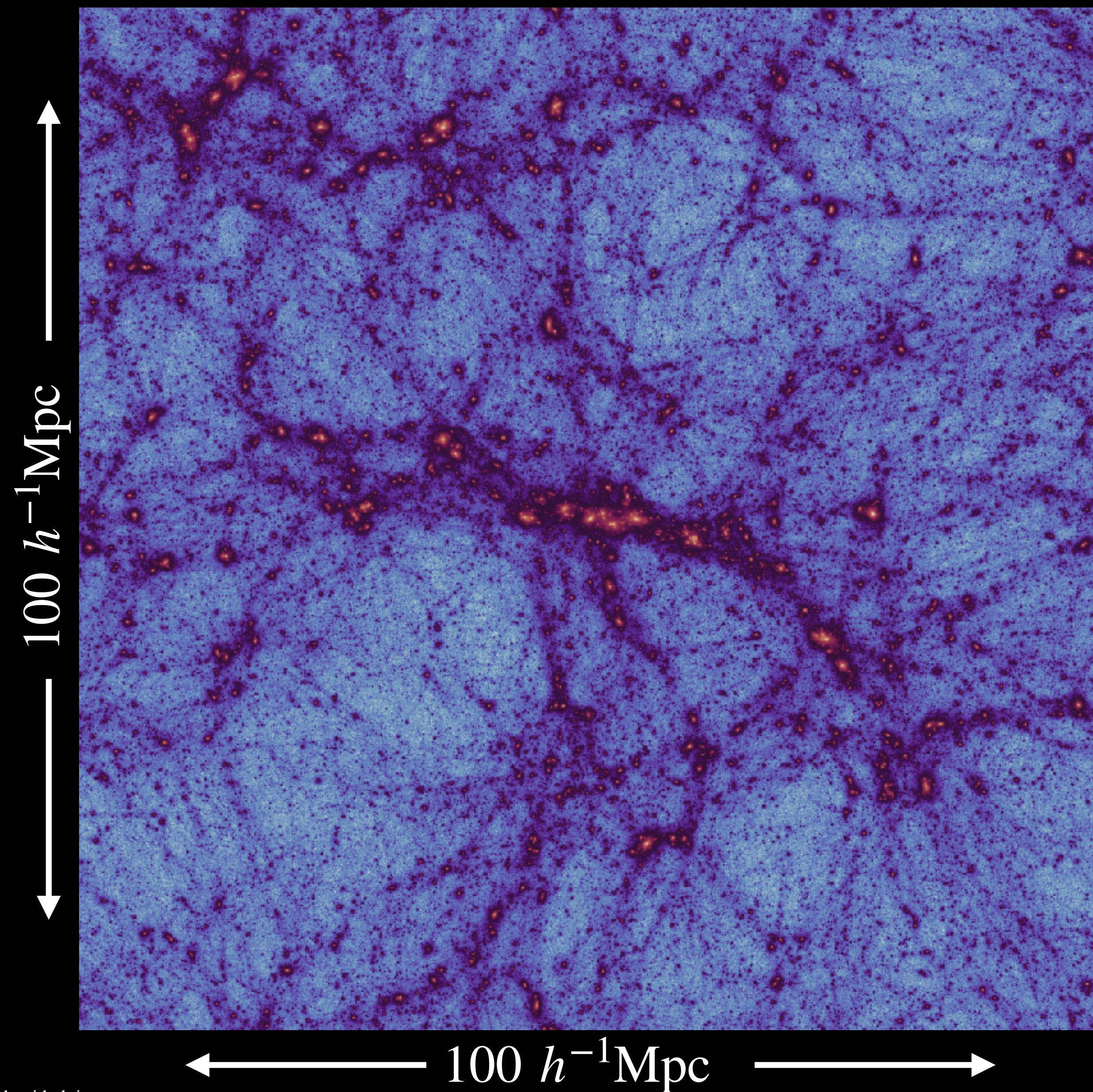


- Observed kinematics and the inferred dynamics
 - integrated interaction history of these objects with the Milky Way
 - how and where they assembled in the early Universe

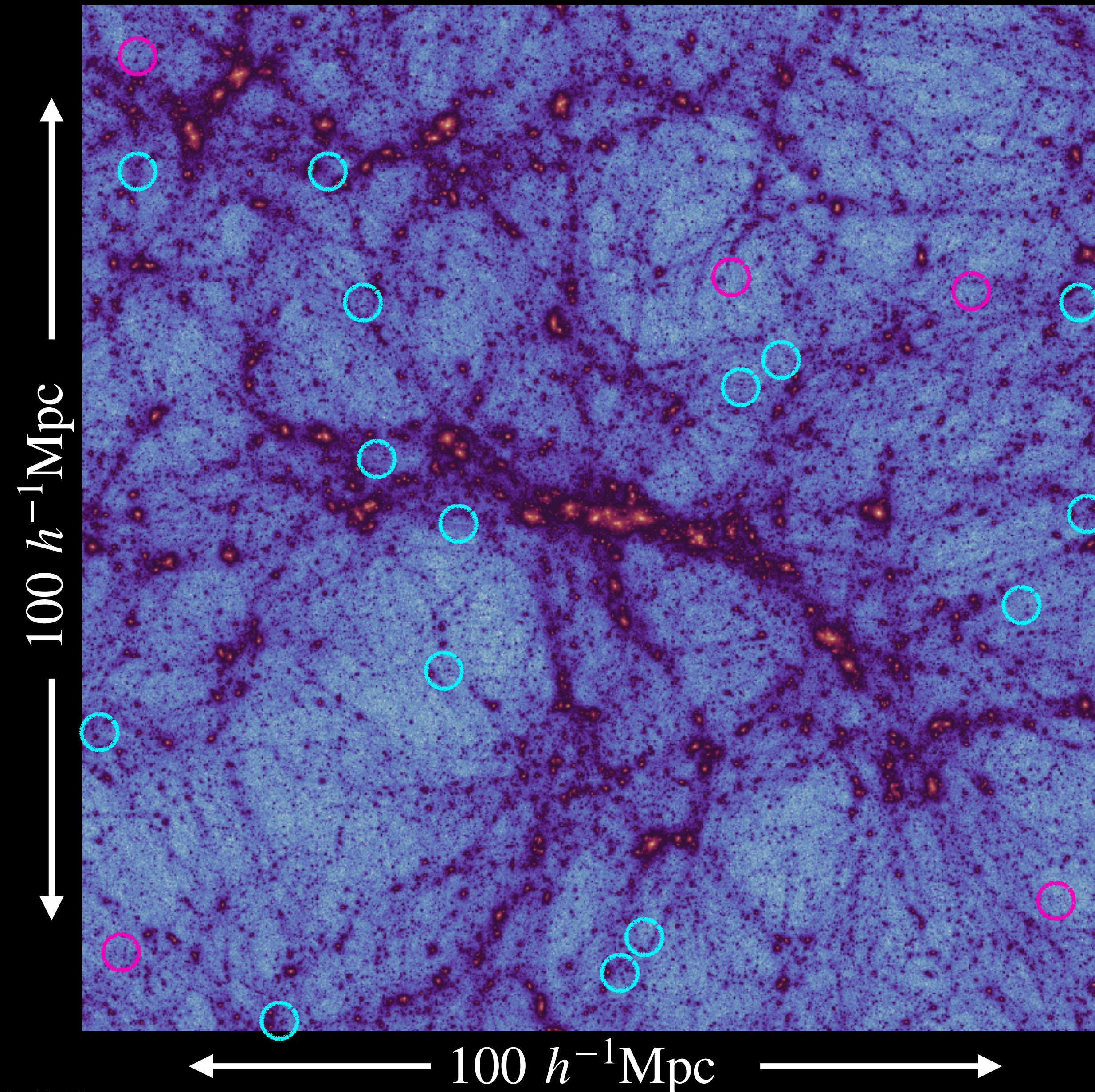
see Freeman & Bland-Hawthorn 2002; Frebel & Norris 2015; Bullock & Johnston 2005; Diemand+2005; Madau+2008; Springel+2008, etc

- Observed kinematics and the inferred dynamics
 - integrated interaction history of these objects with the Milky Way
 - how and where they assembled in the early Universe
- But how much is this affected by the peculiarities of the Milky Way?
 - Relatively isolated nature of the Local Group
 - Proximity of Andromeda
 - Assumptions we make about how galaxy formation proceeds at early times.

see Freeman & Bland-Hawthorn 2002; Frebel & Norris 2015; Bullock & Johnston 2005; Diemand+2005; Madau+2008; Springel+2008, etc



- *DORCHA is Irish Gaelic for *dark*
 - /'dɔr.ə.xə/; roughly DOR-uh-khuh
- $L = 100 h^{-1} \text{Mpc}$
- $m_p \simeq 6.45 \times 10^8 h^{-1} M_{\odot}$
- AREPO; SubFind-HBT



- $1 \lesssim \frac{M_{\text{halo}}}{10^{12} h^{-1} M_{\odot}} \lesssim 2$

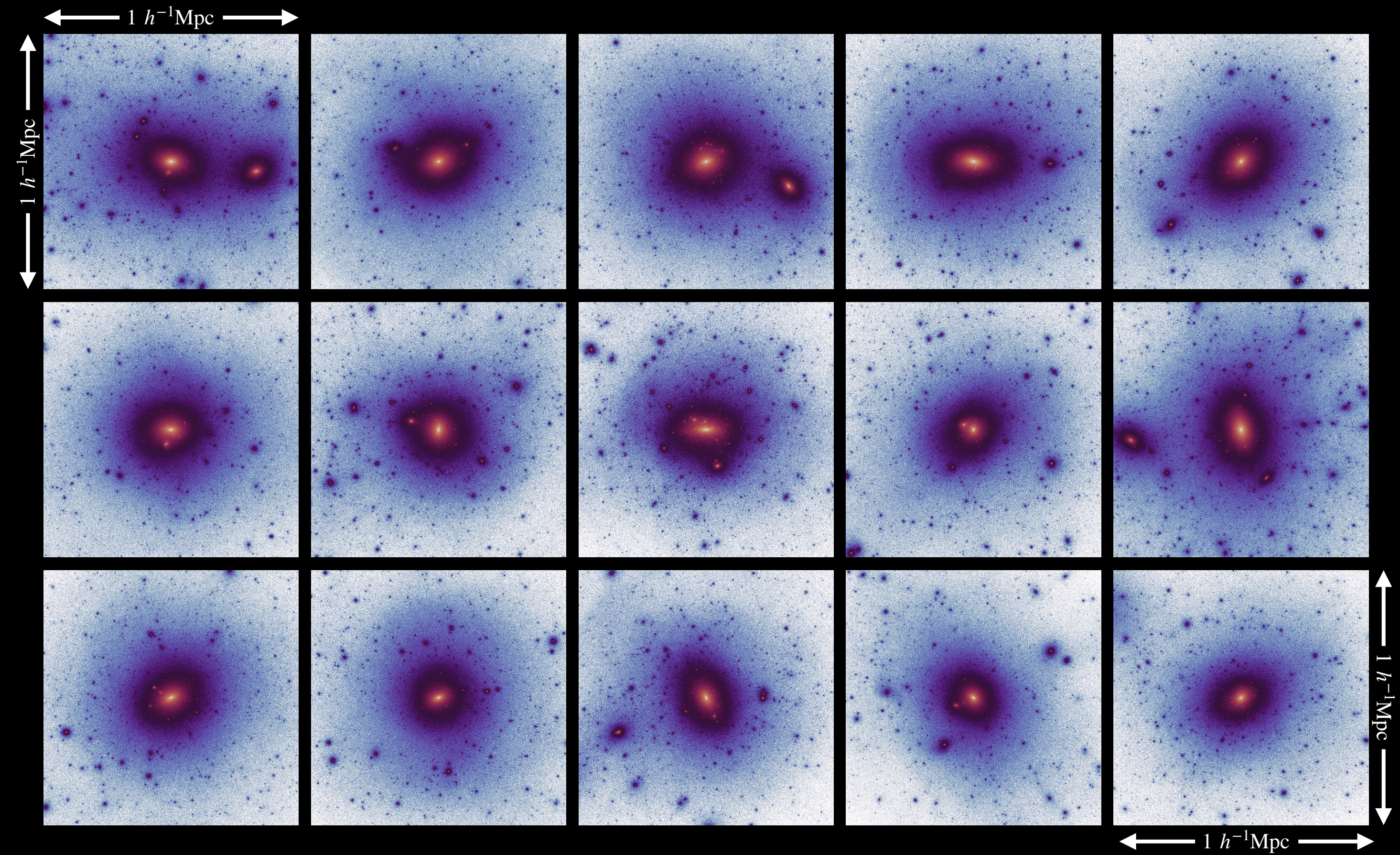
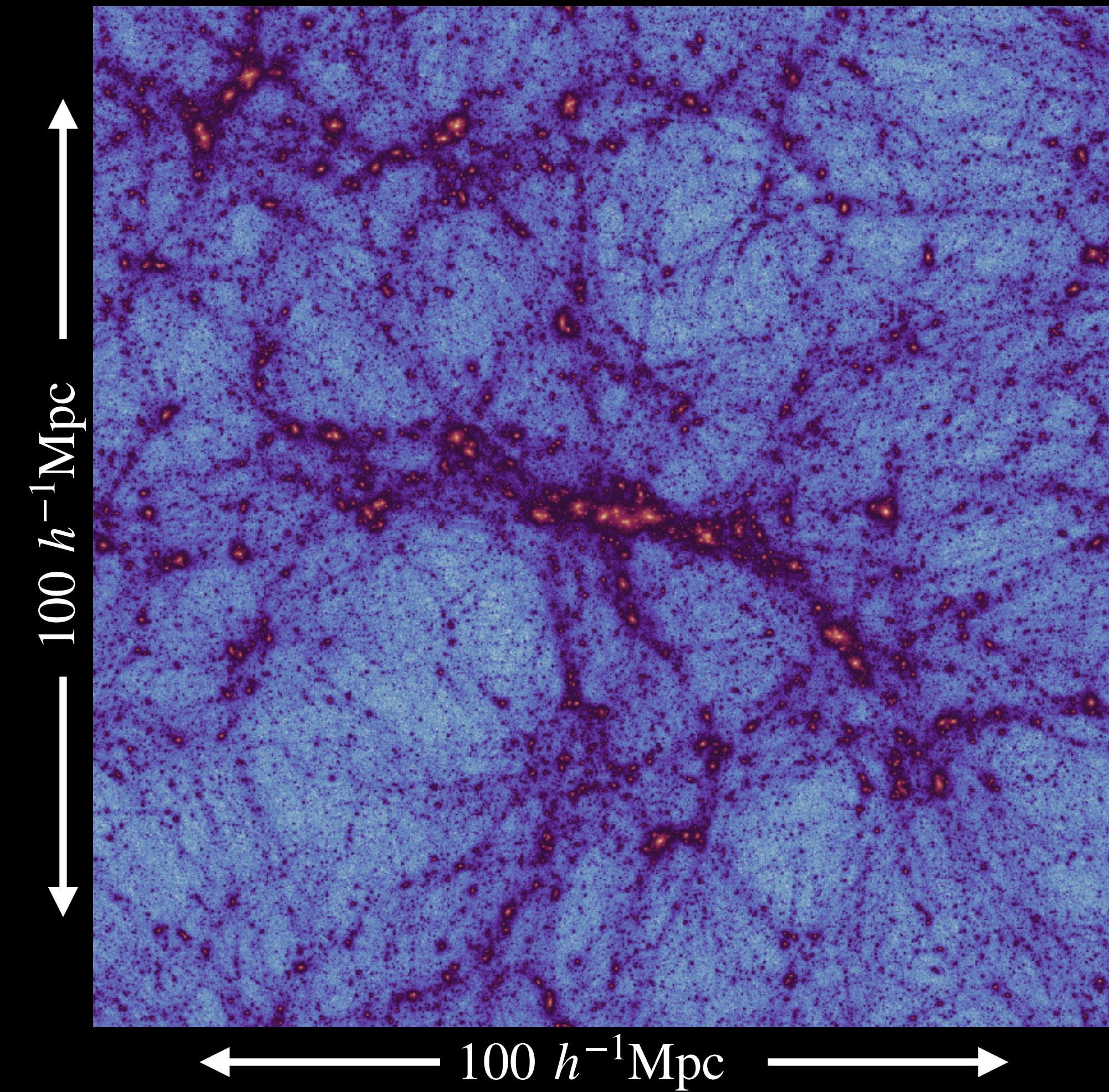
- For MW systems:

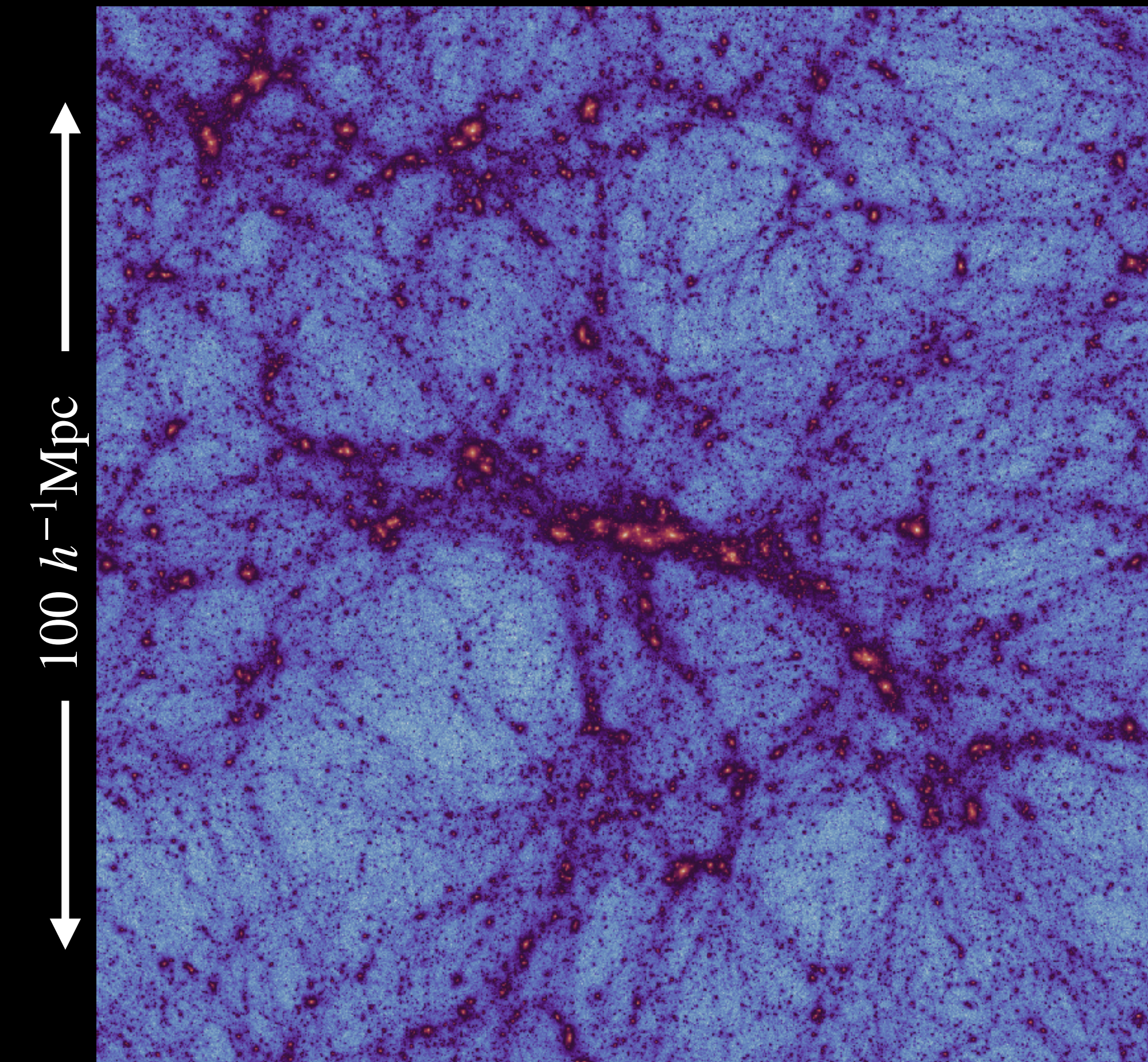
$$r_{\text{iso,cut}} = 1.4 h^{-1} \text{Mpc}$$

- For MW-M31 systems:

- MW systems within 1 h^{-1} Mpc

- $r_{\text{iso,cut}} = 0.5 h^{-1} \text{Mpc}$

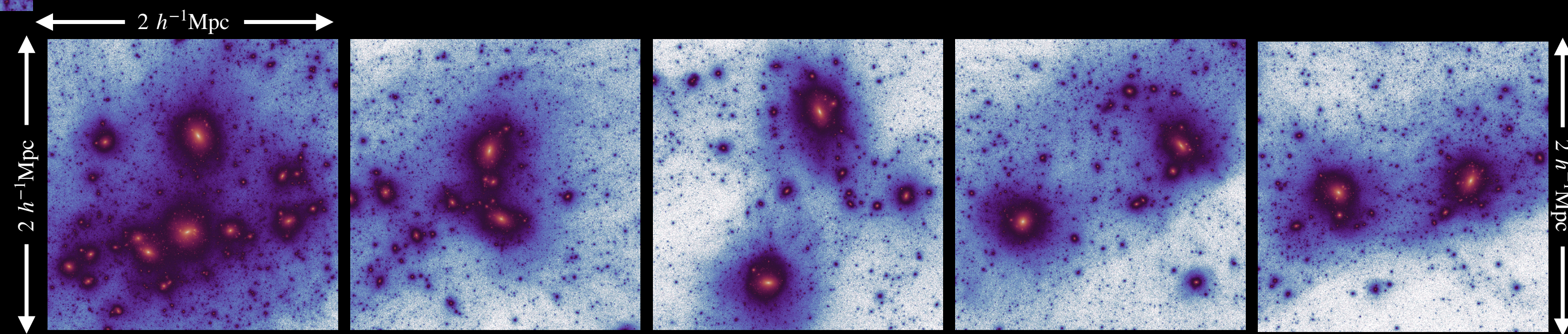
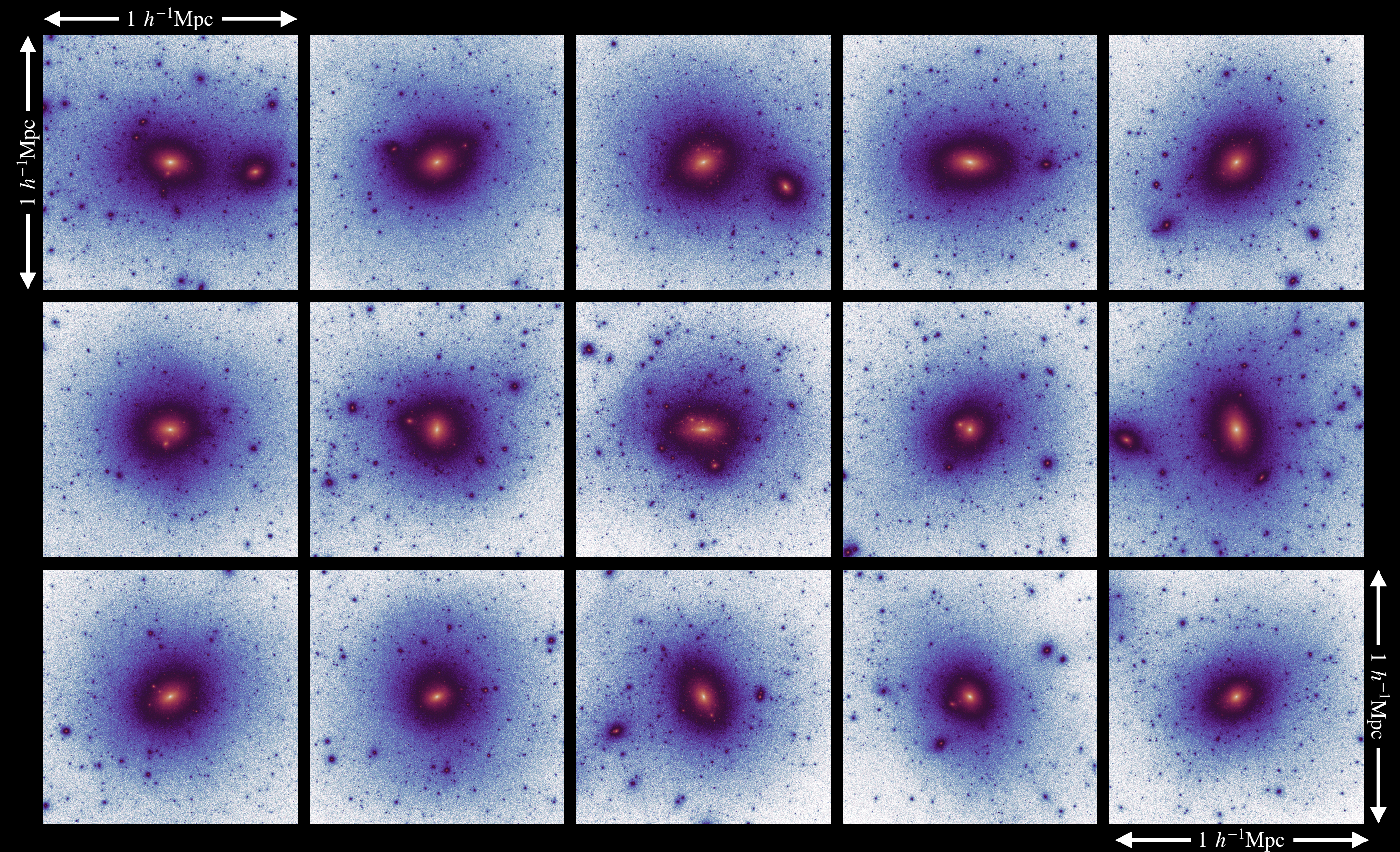




100 h^{-1} Mpc

$$m_p \simeq 1.57 \times 10^5 h^{-1} M_{\odot}$$

see also ELVIS(Garrison-Kimmel+2014); Caterpillar(Griffen+2018); Milky Way-est(Buch+2024), etc



- Tag most-bound 10% particles of all the sub haloes in progenitor FoF groups.
- @ $z \in [25, 20, 15, 10, 8, 5]$



- Tag most-bound 10% particles of all the sub haloes in progenitor FoF groups.
 - @ $z \in [25, 20, 15, 10, 8, 5]$
- Also,
 - “old”: collated list from above for $z \geq 10$
 - “new”: accreted onto halo after $z \leq 5$

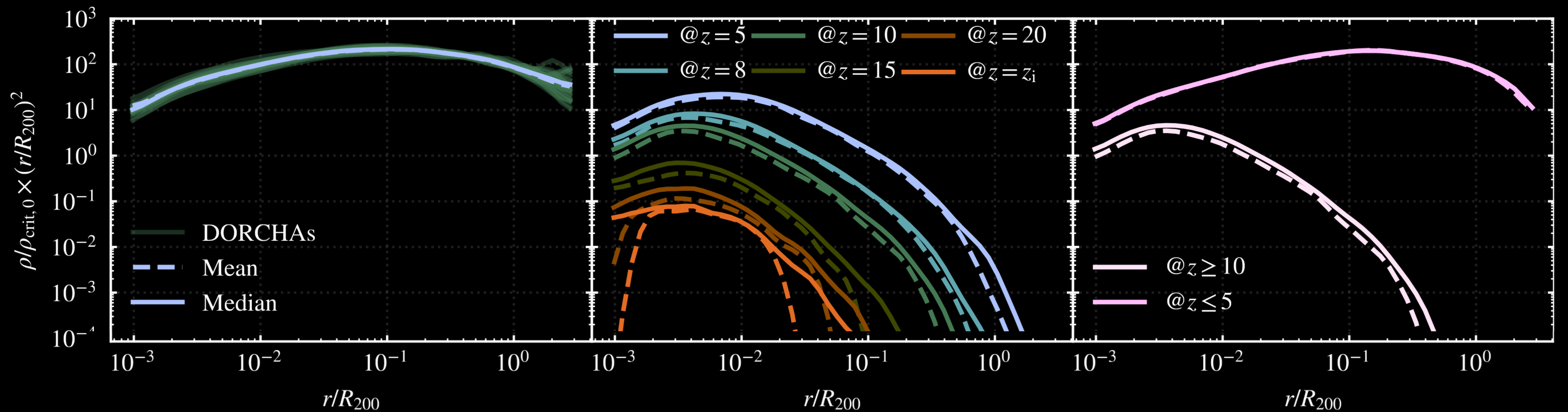


What is their kinematical and dynamical trends at $z = 0$?



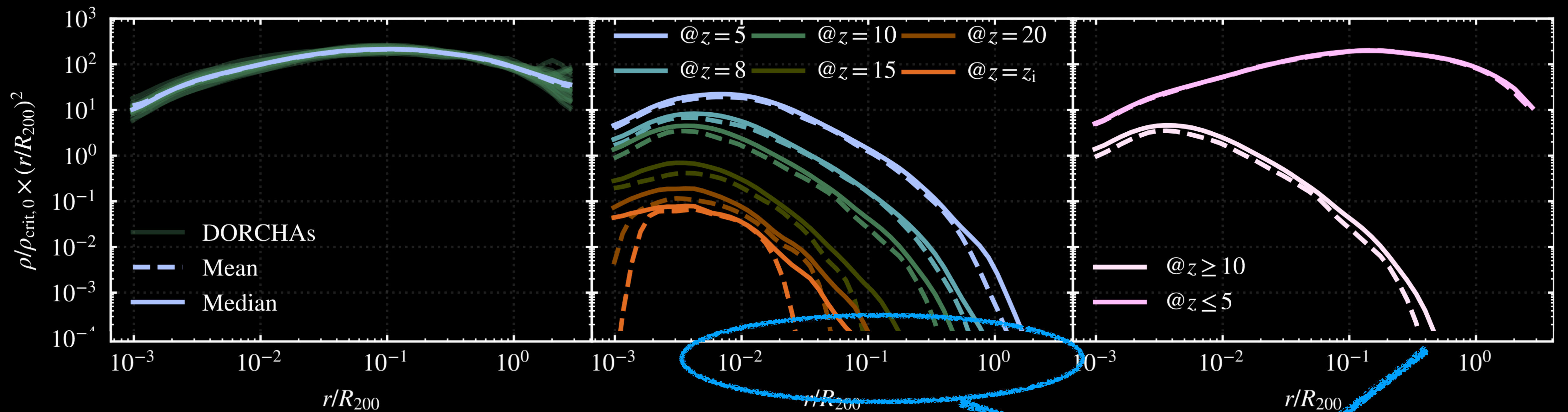
Radial profiles

radial density profiles



Radial profiles

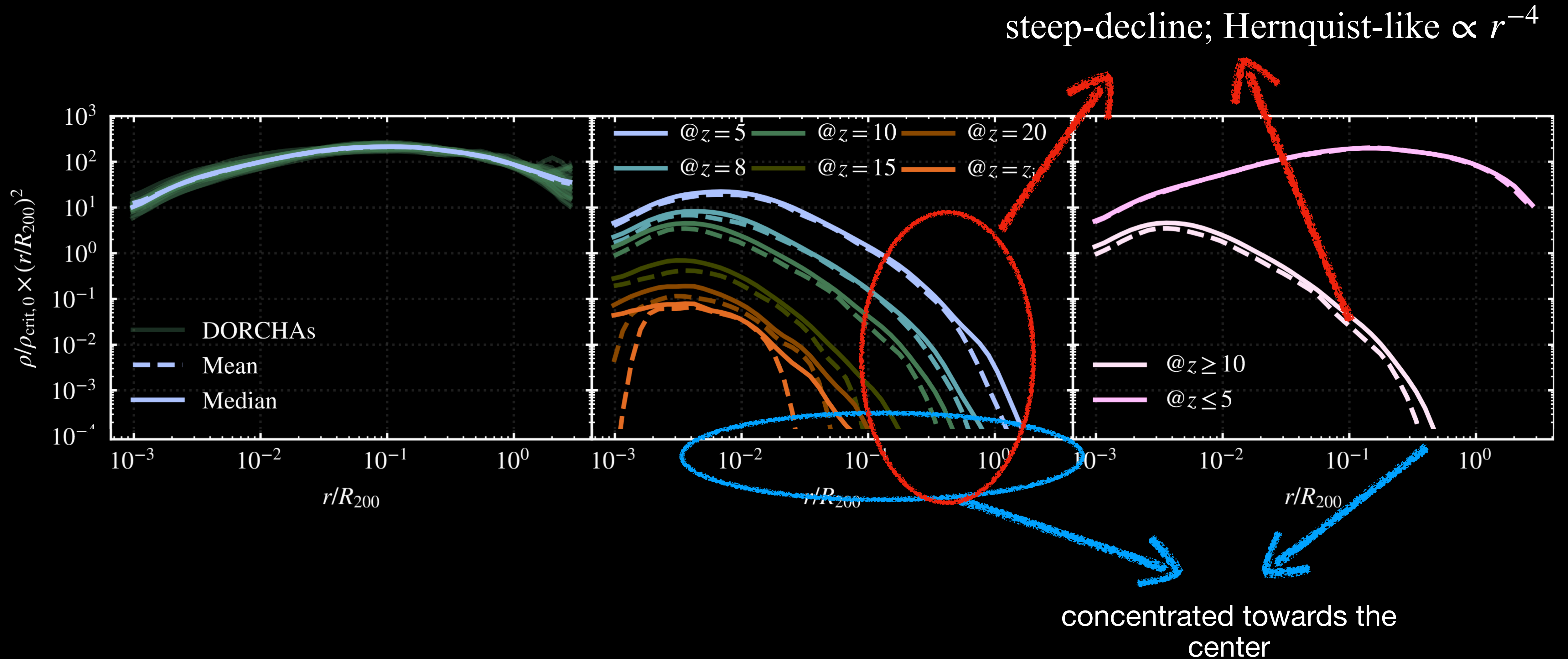
radial density profiles



concentrated towards the center

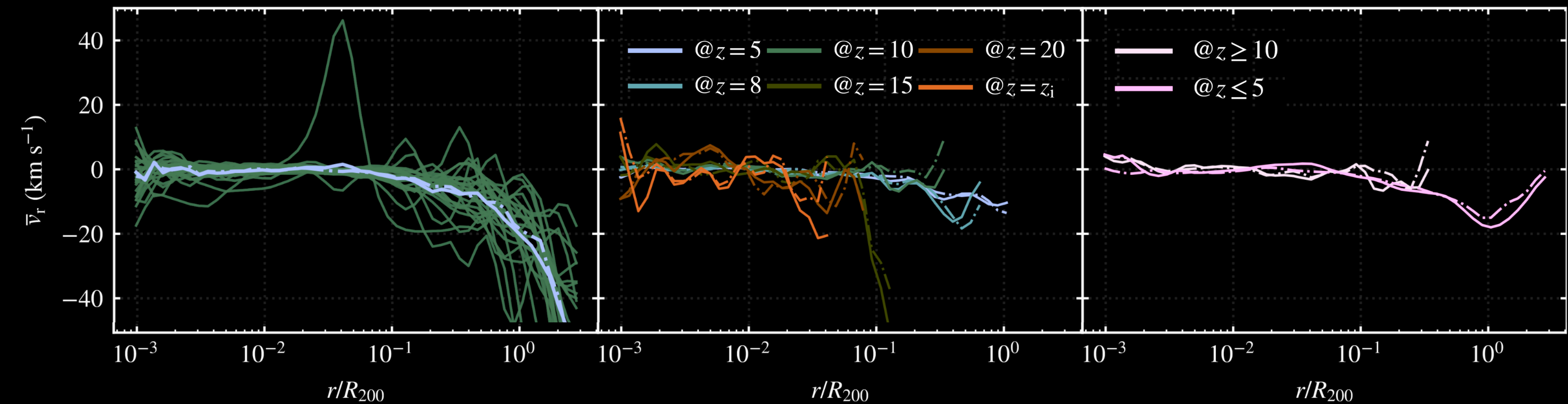
Radial profiles

radial density profiles



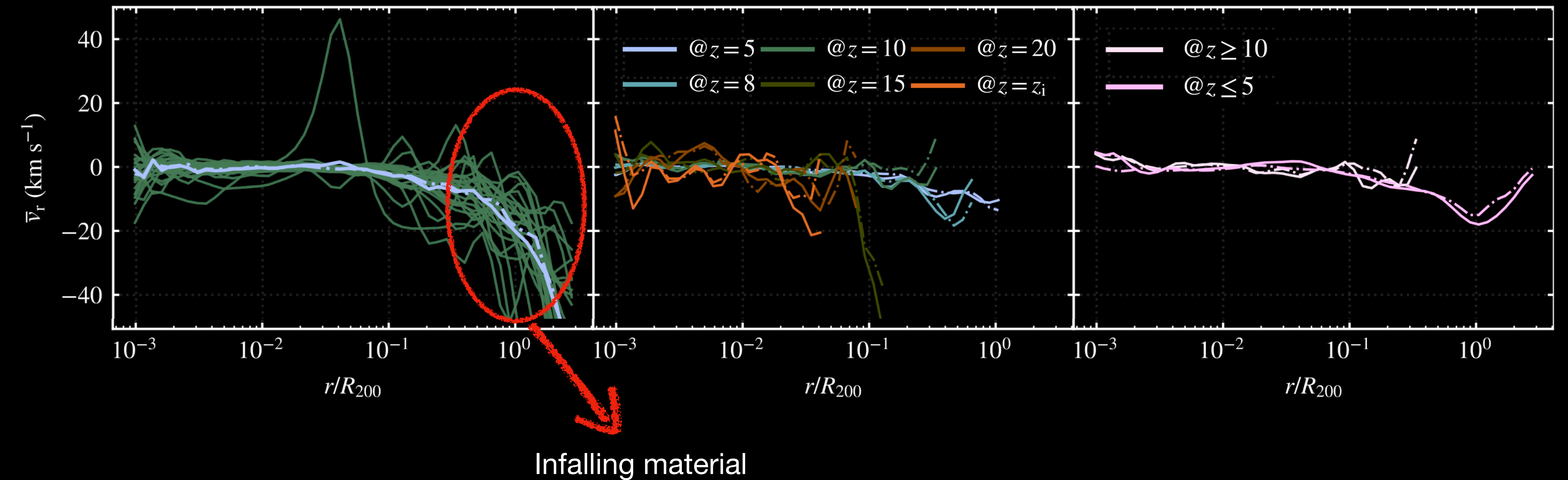
Radial profiles

mean radial velocity



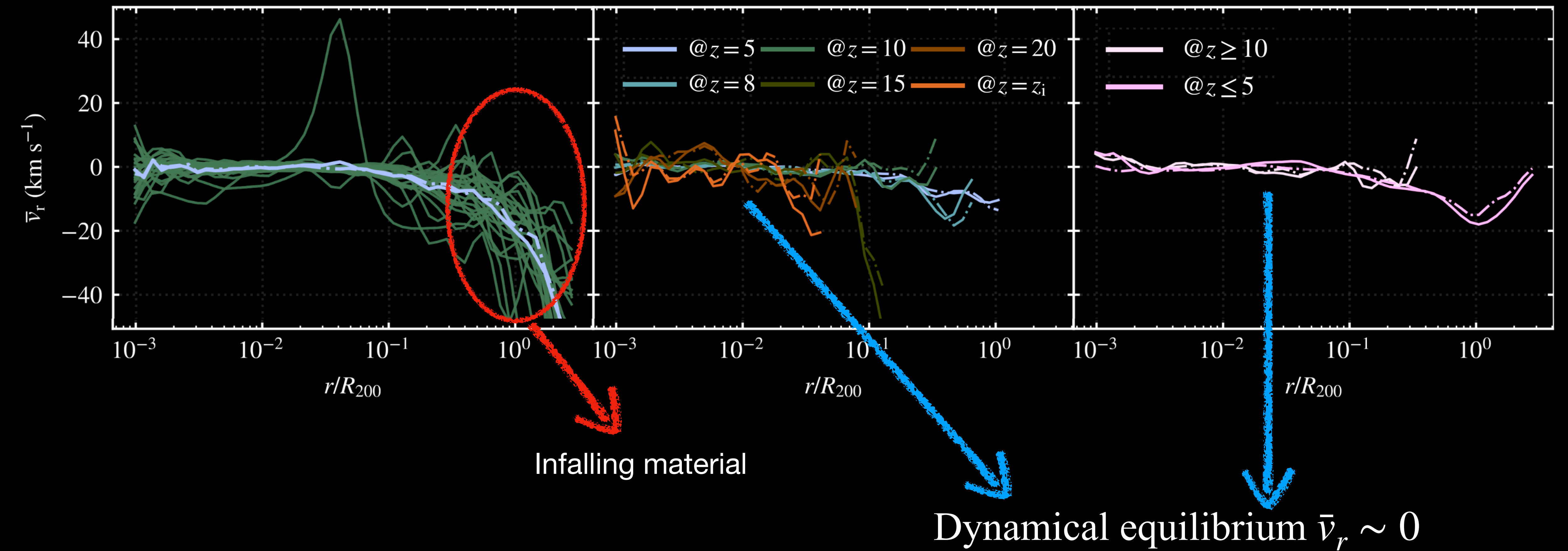
Radial profiles

mean radial velocity



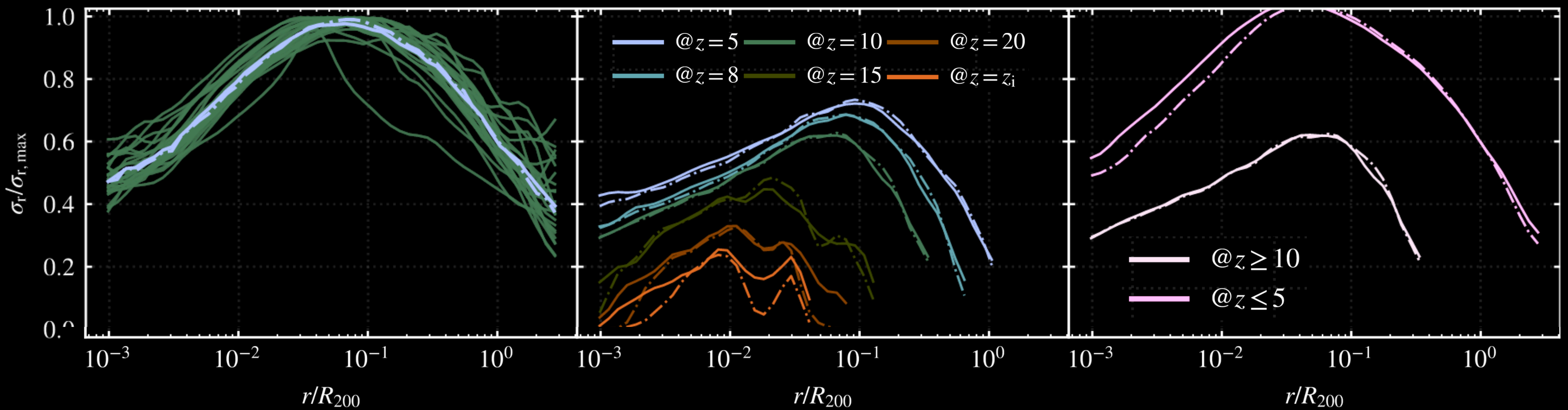
Radial profiles

mean radial velocity



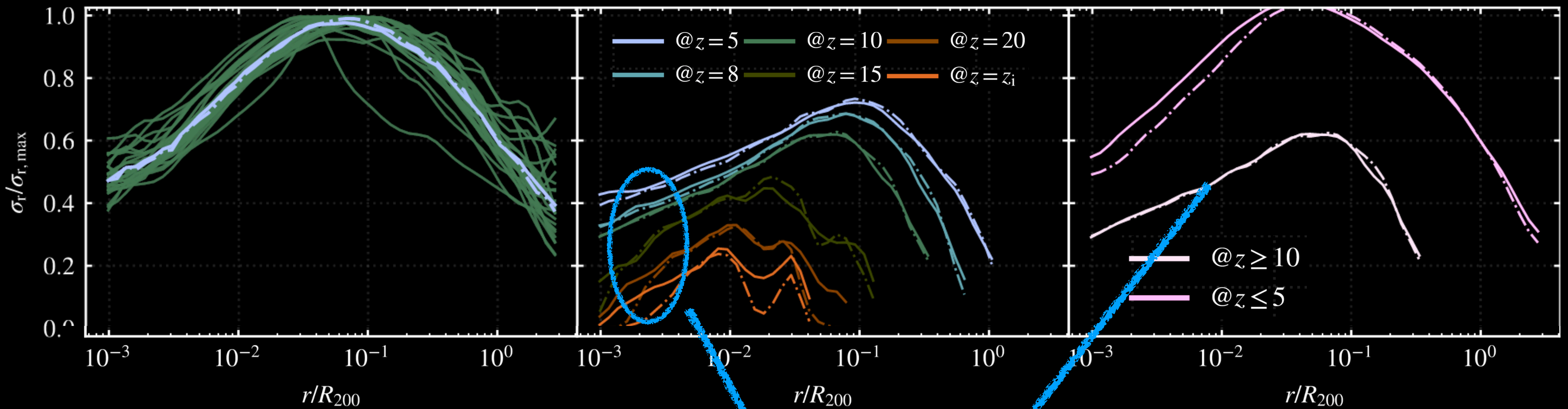
Radial profiles

velocity dispersion



Radial profiles

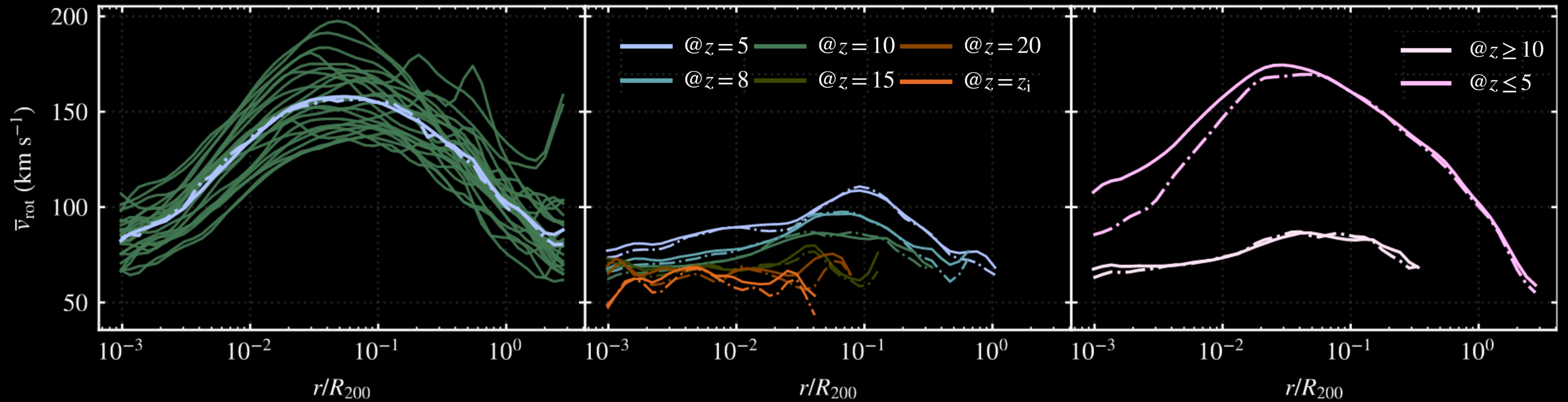
velocity dispersion



Dynamically colder

Radial profiles

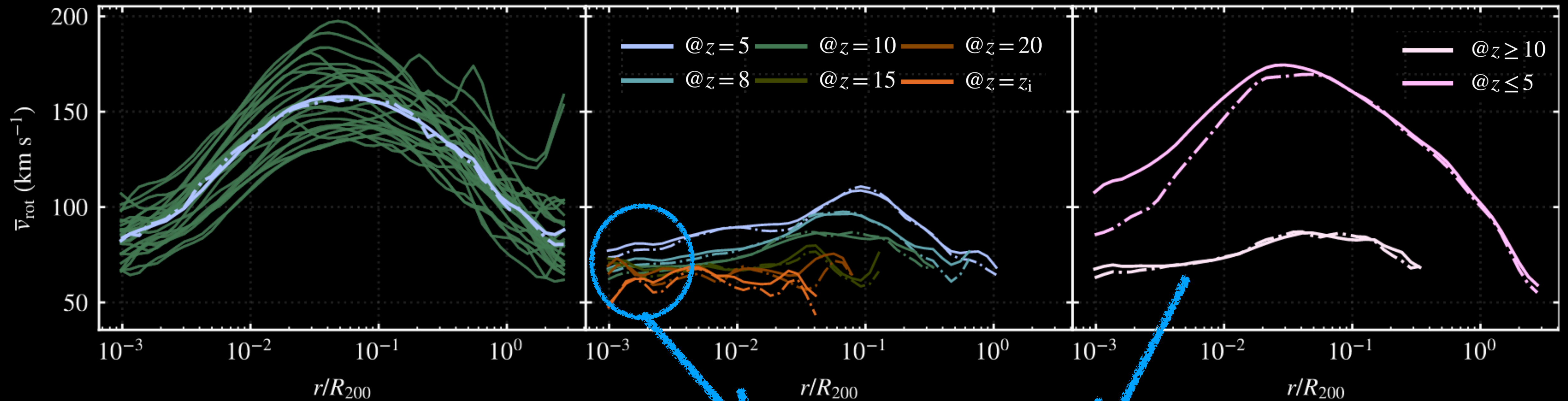
mean rotational velocity



see PIGS survey(Arentsen+2020; Ardern-Arentsen+2024), Starkenburg+2017, etc

Radial profiles

mean rotational velocity



older material have lower rotational signature

see PIGS survey(Arentsen+2020; Ardern-Arentsen+2024), Starkenburg+2017, etc

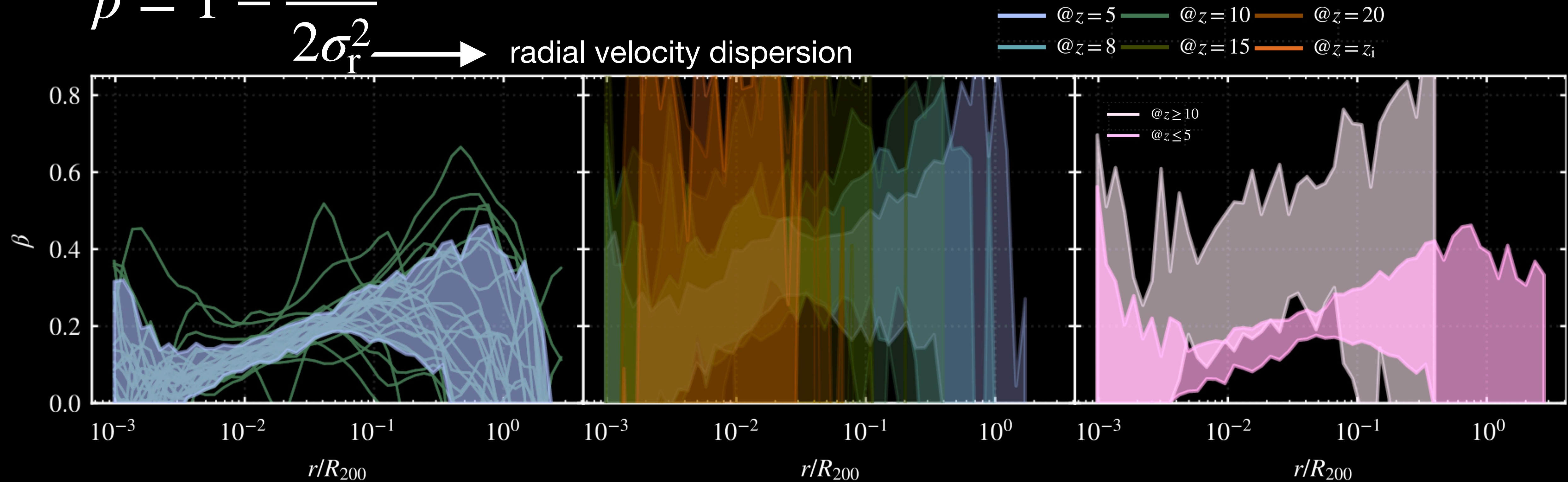
Radial profiles

anisotropy profile

$$\beta = 1 - \frac{\sigma_t^2}{2\sigma_r^2}$$

→ tangential velocity dispersion

→ radial velocity dispersion



$\beta \rightarrow 1$ Preferentially radial orbits

$\beta \rightarrow 0$ Preferentially isotropic

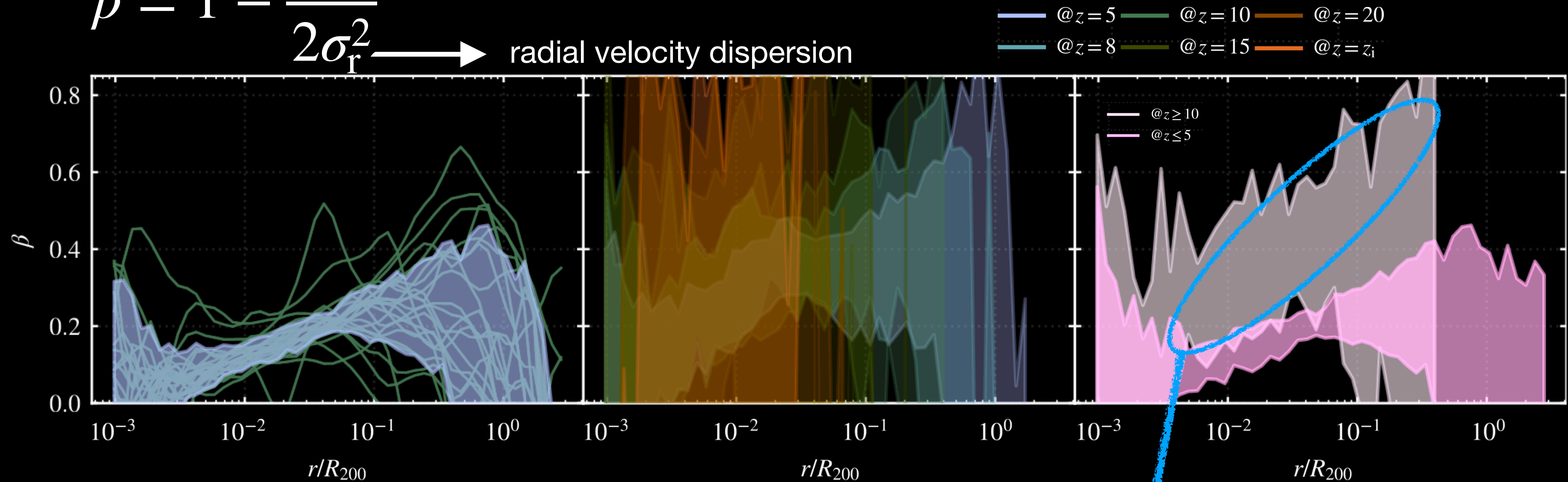
Radial profiles

anisotropy profile

$$\beta = 1 - \frac{\sigma_t^2}{2\sigma_r^2}$$

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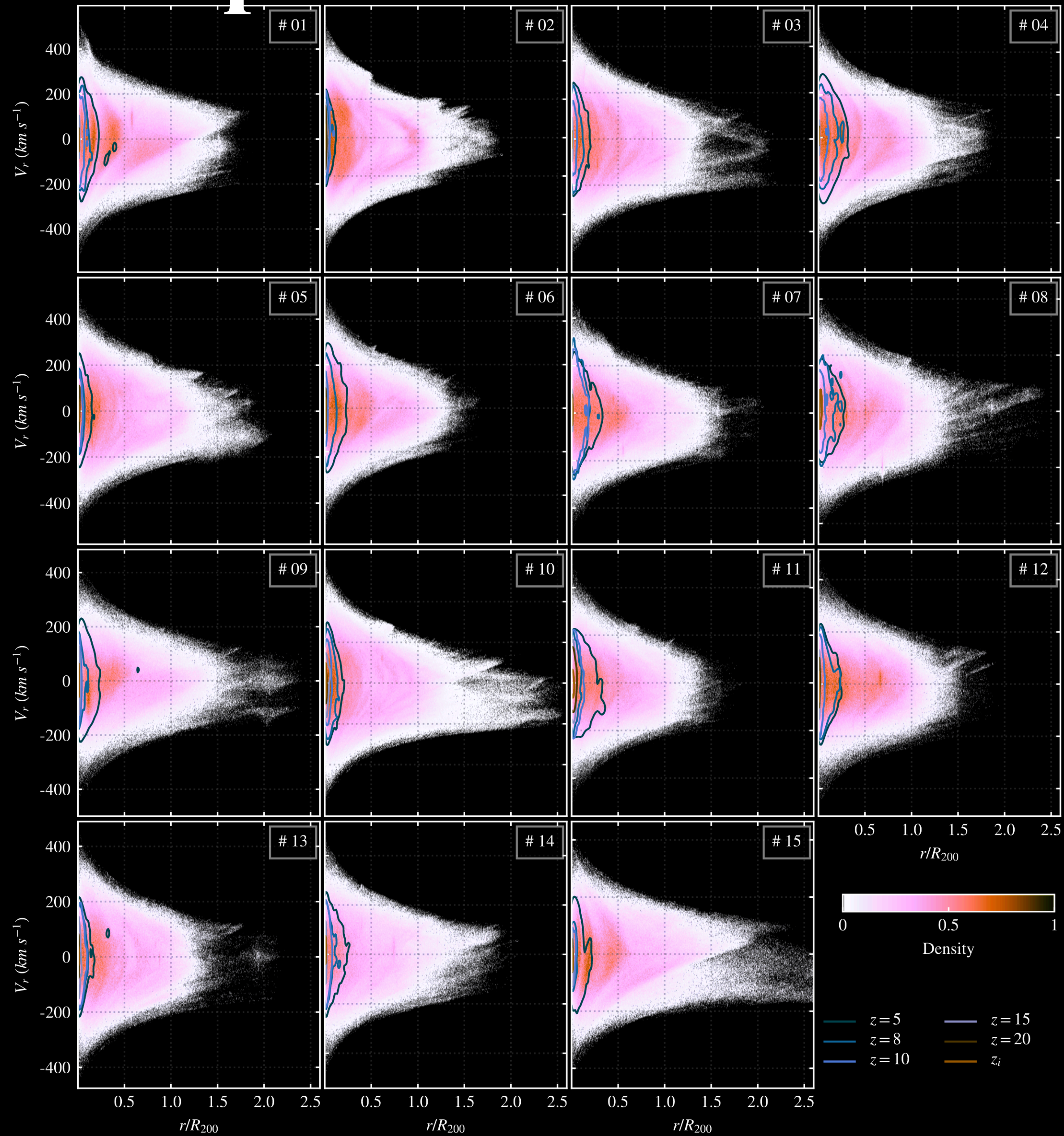


$\beta \rightarrow 1$ Preferentially radial orbits

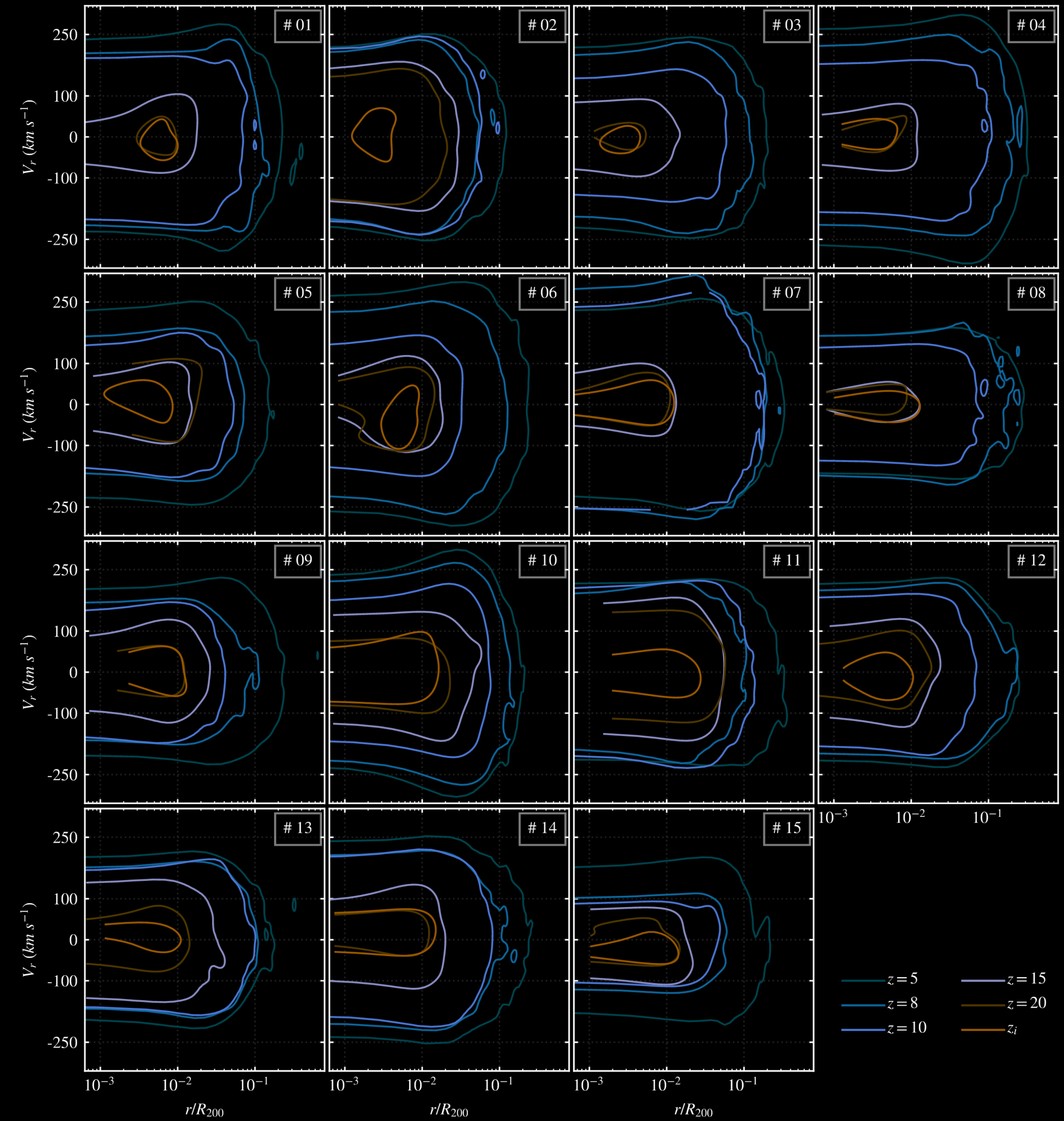
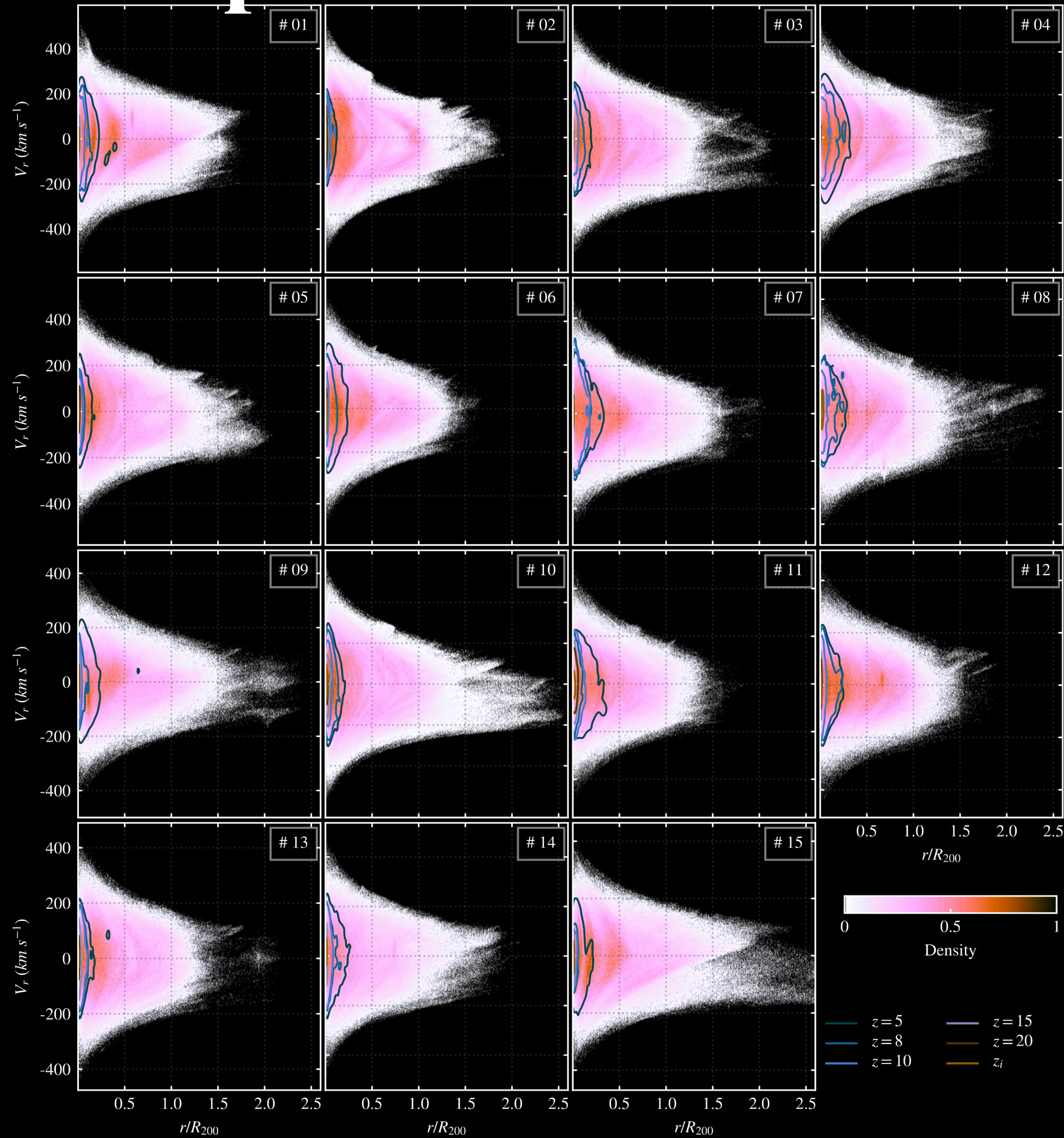
$\beta \rightarrow 0$ Preferentially isotropic

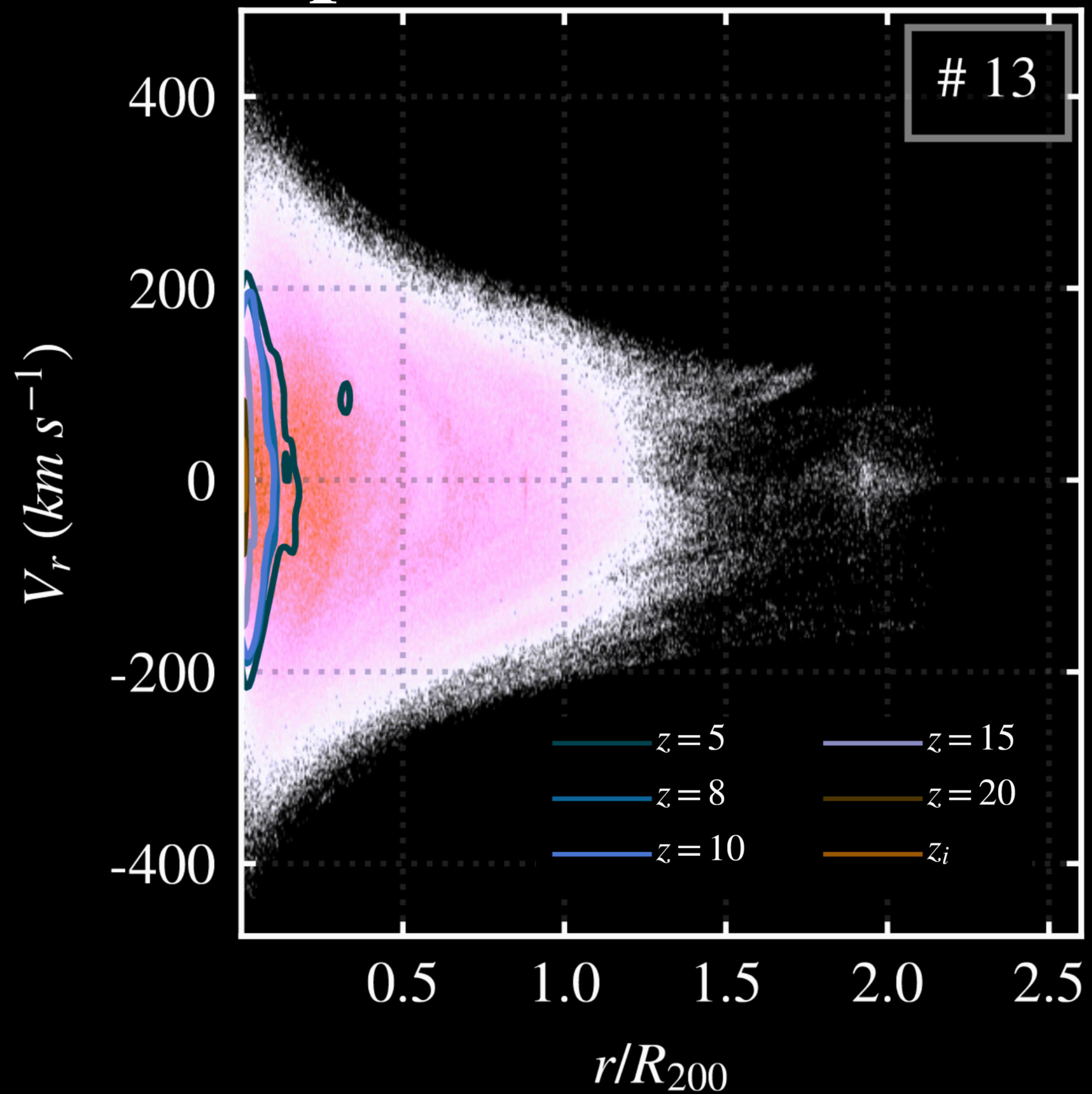
Preferentially radial orbits

Phase space



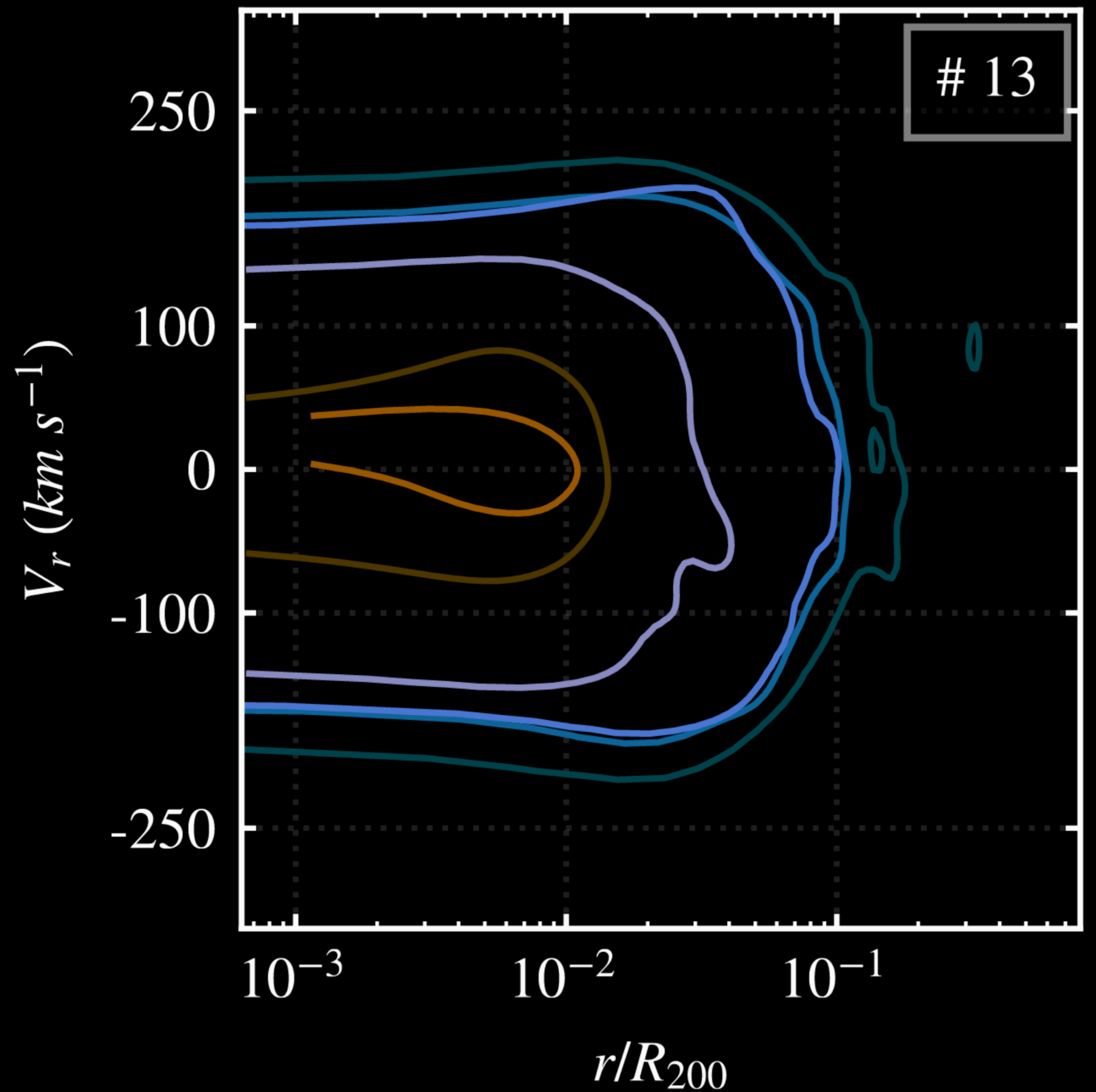
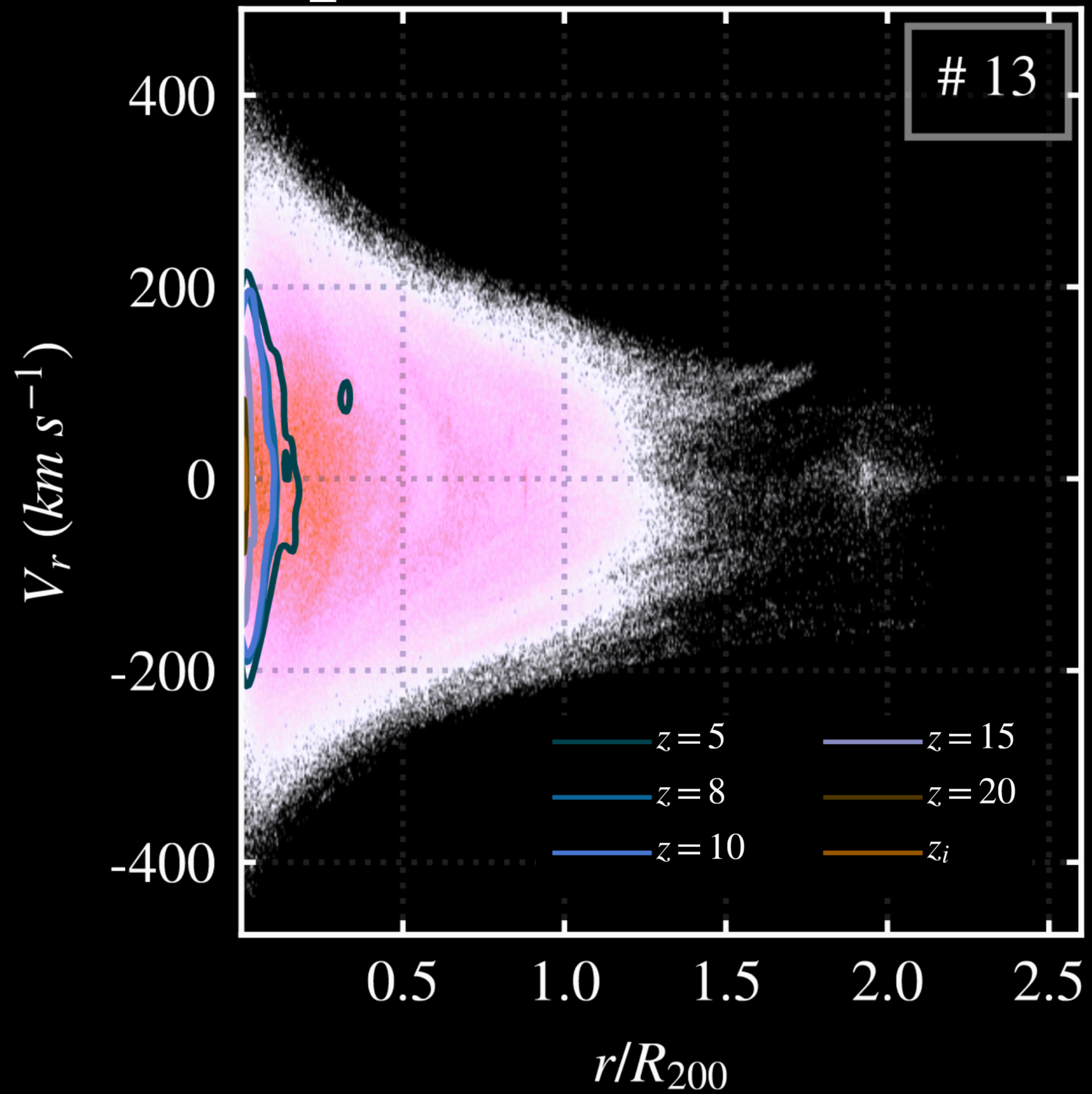
Phase space





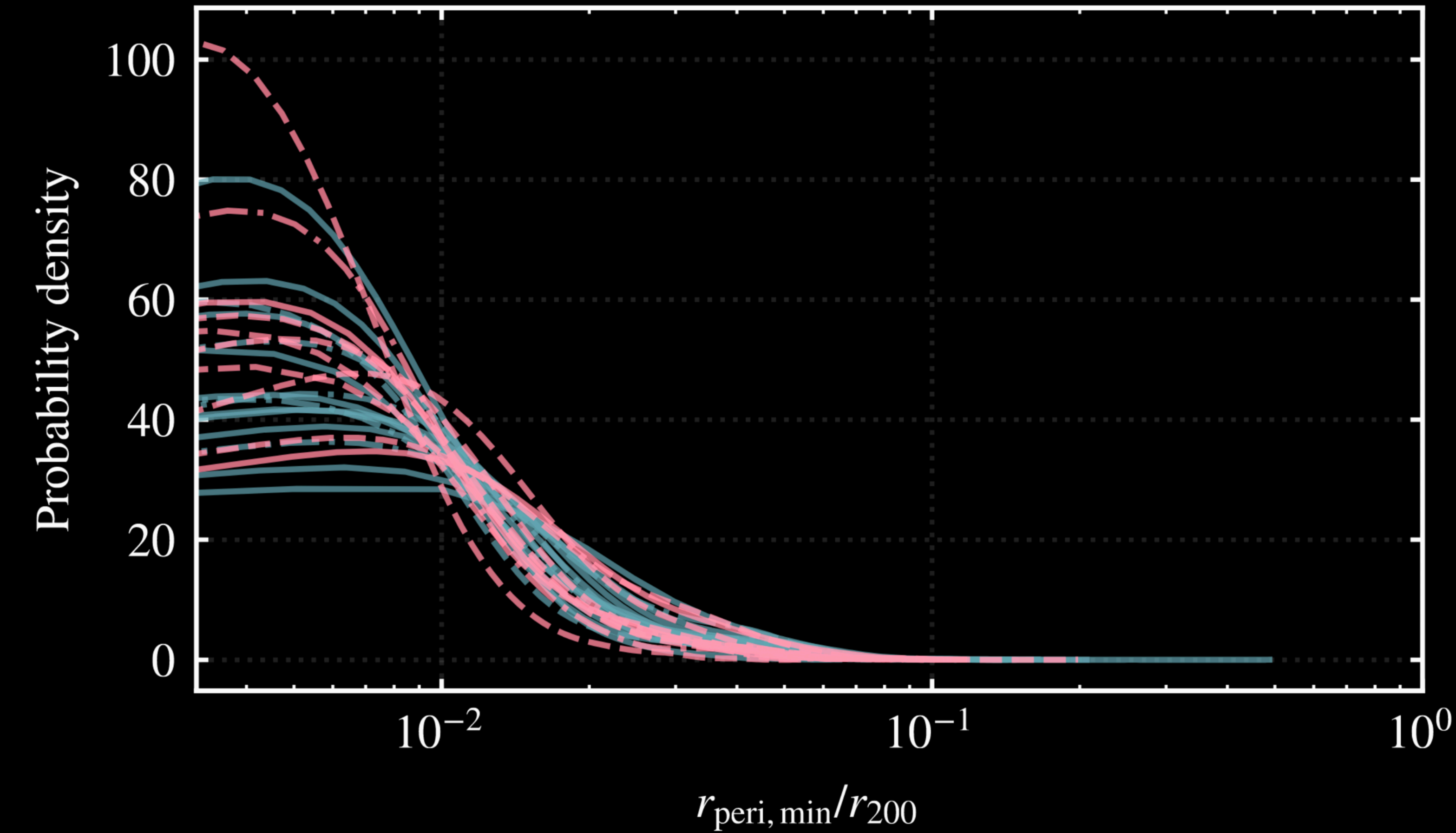
Phase space

DORCHA_13



Pericentric distances

interactions with halo-center

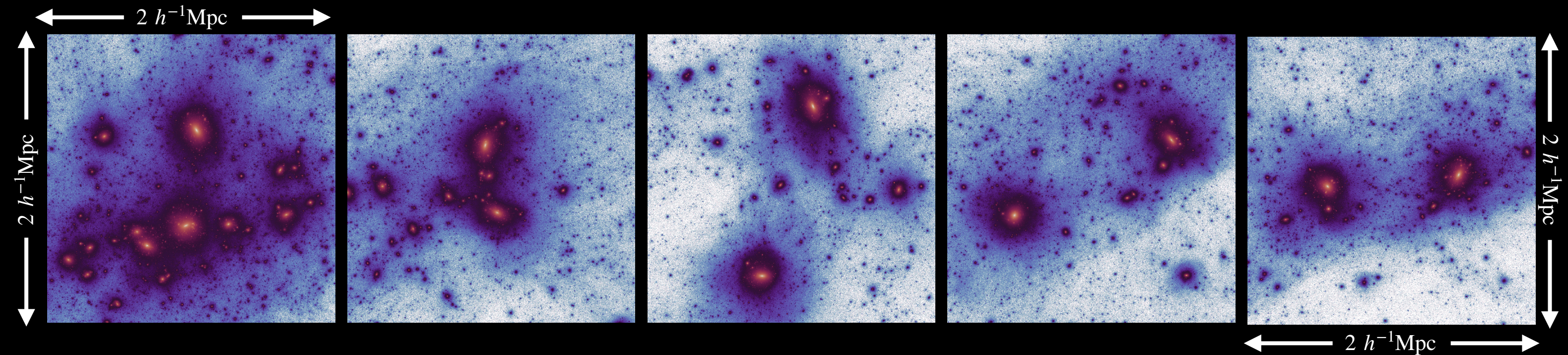
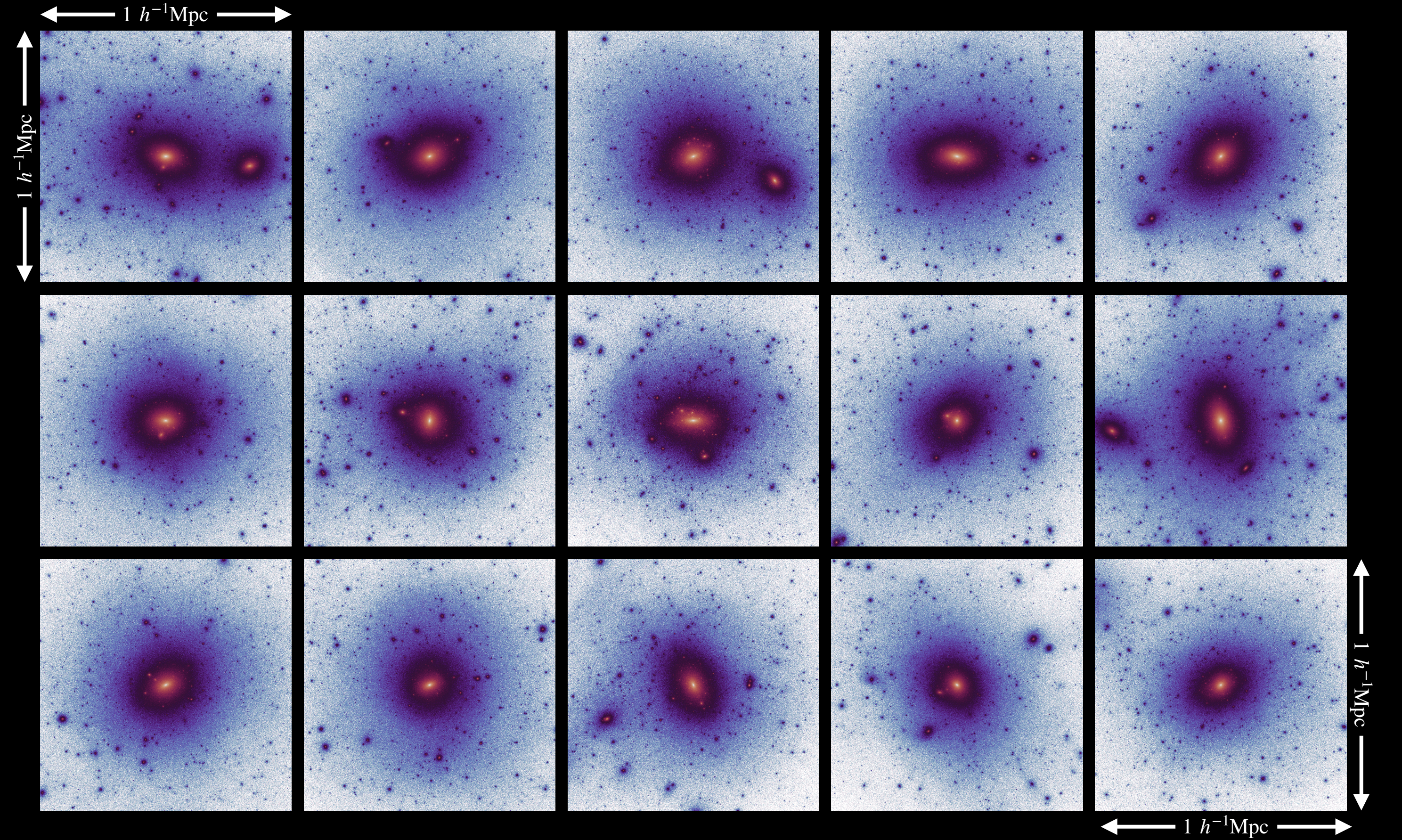
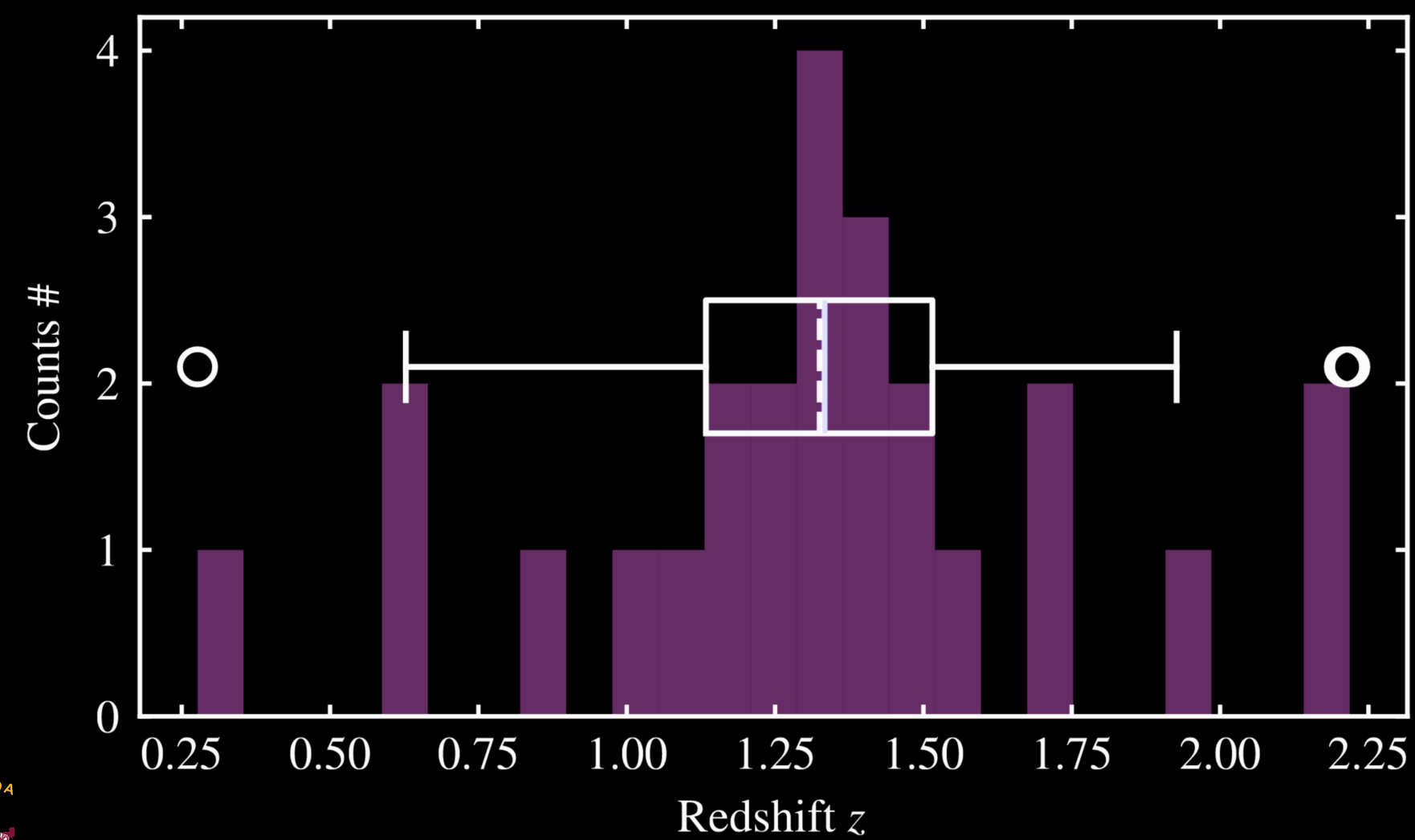
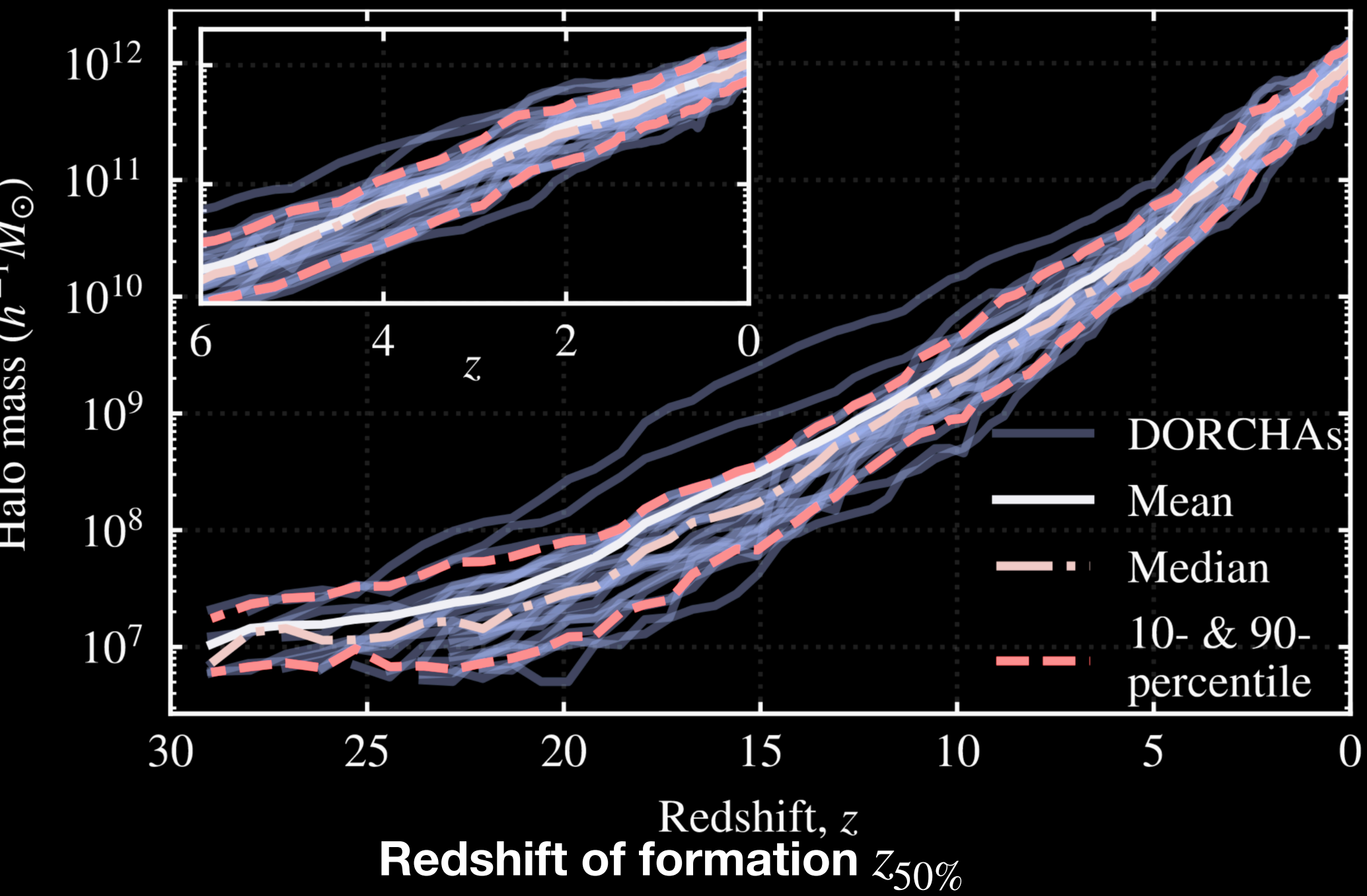


Minimum pericentric distance
for $z \leq 5$ for our “old” particles

Summary

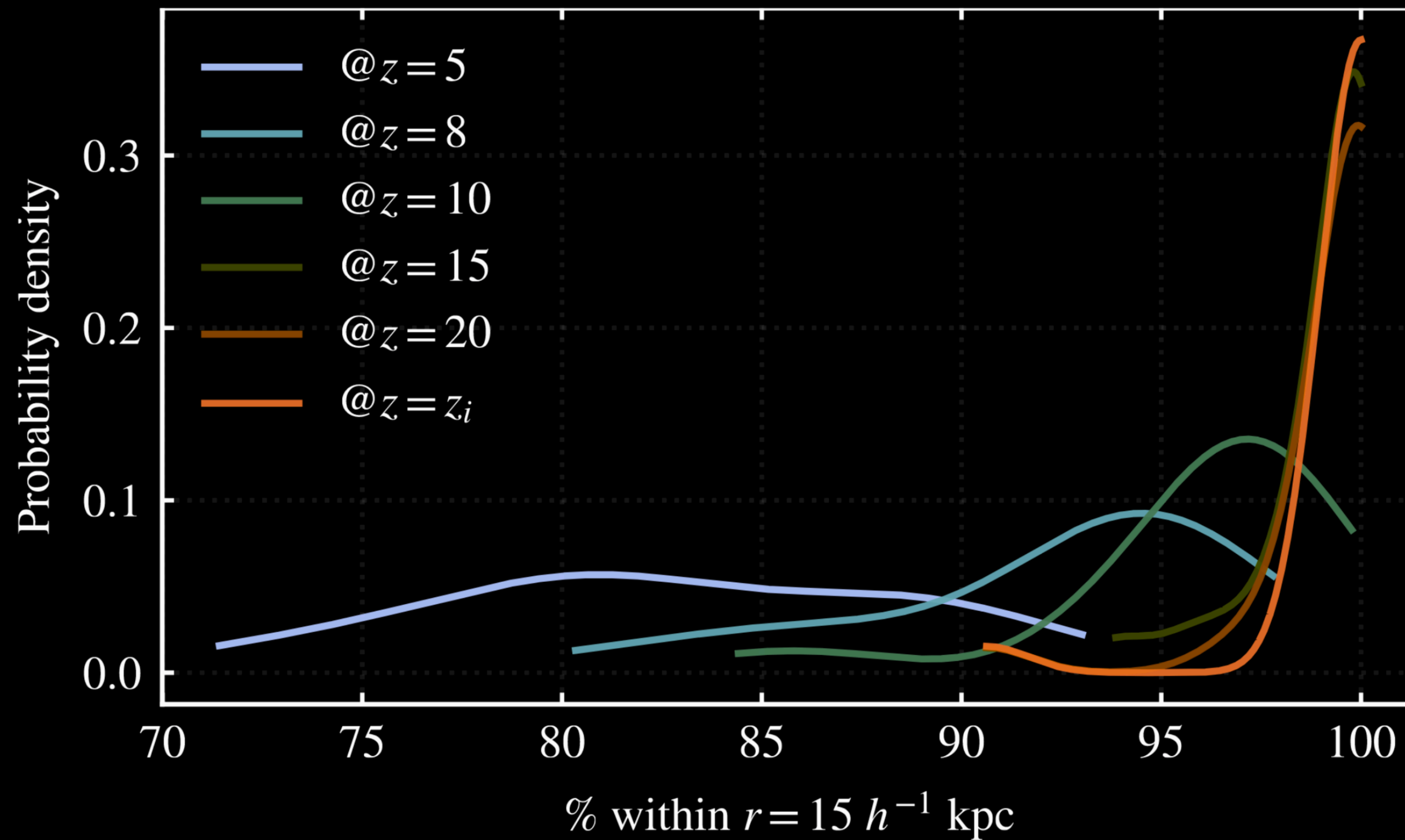
- A new Milky Way analogue DMO zoom suite
 - 25 haloes: 15 isolated & 10 in pairs; data to be made public.
- Most of our tagged particles is concentrated in the inner regions of the main sub-halo.
- Likely tracers of first stars and/or their remnants are mostly centrally concentrated.
- Distinct kinematical features for the old and new components of the Galaxy
 - concentrated in the innermost parts of the halo today; $\propto r^{-4}$
 - dynamical equilibrium $\bar{v}_r \sim 0$;
 - dynamically colder σ_r ; preferentially radial velocity distribution β
- We repeat our analyses by subcategorising the DORCHAs based on paired/isolated and/or formation history. The trends remain.

Mass assembly history

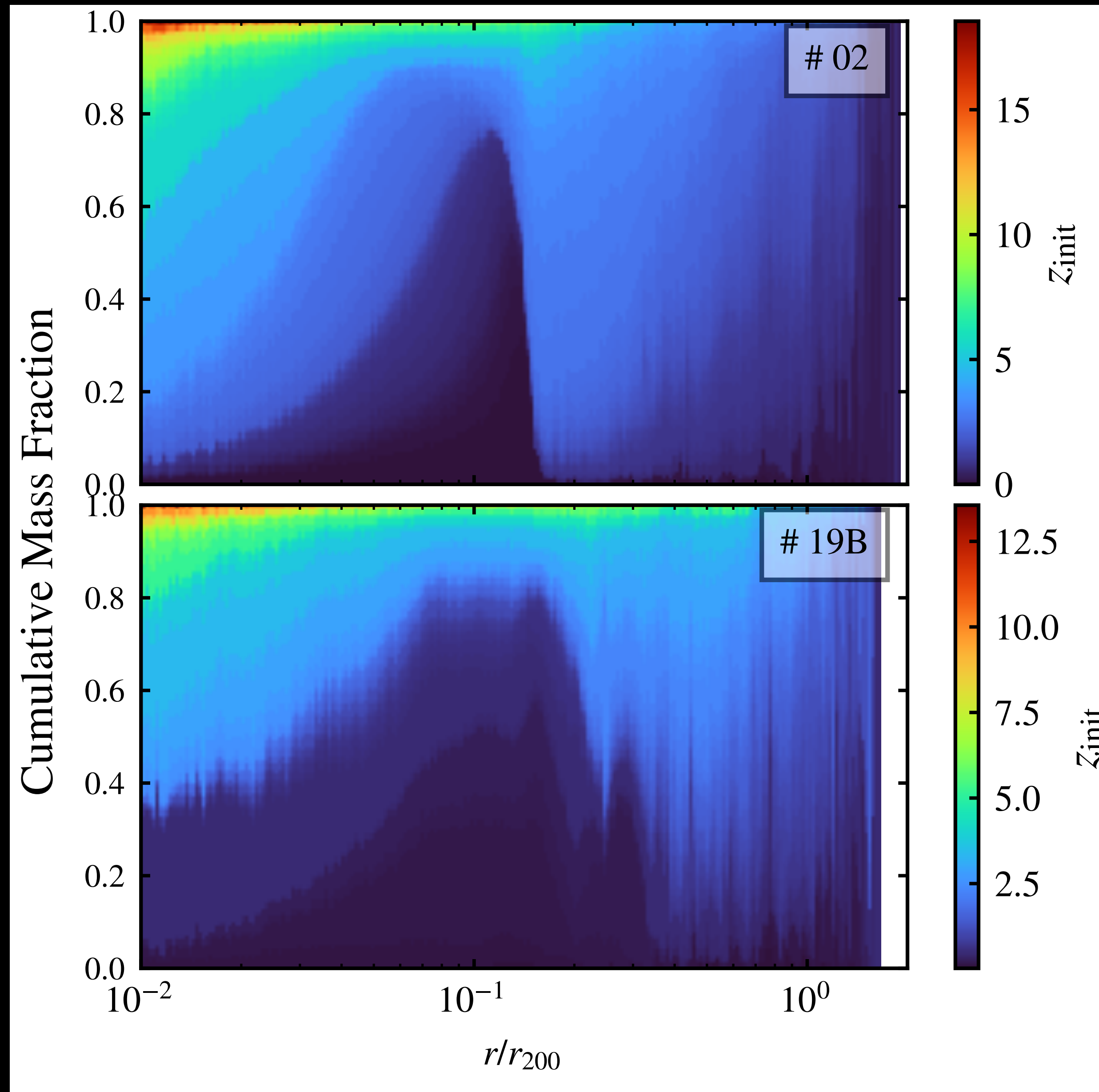


Distribution at $z = 0$ within $15 h^{-1} \text{kpc}$

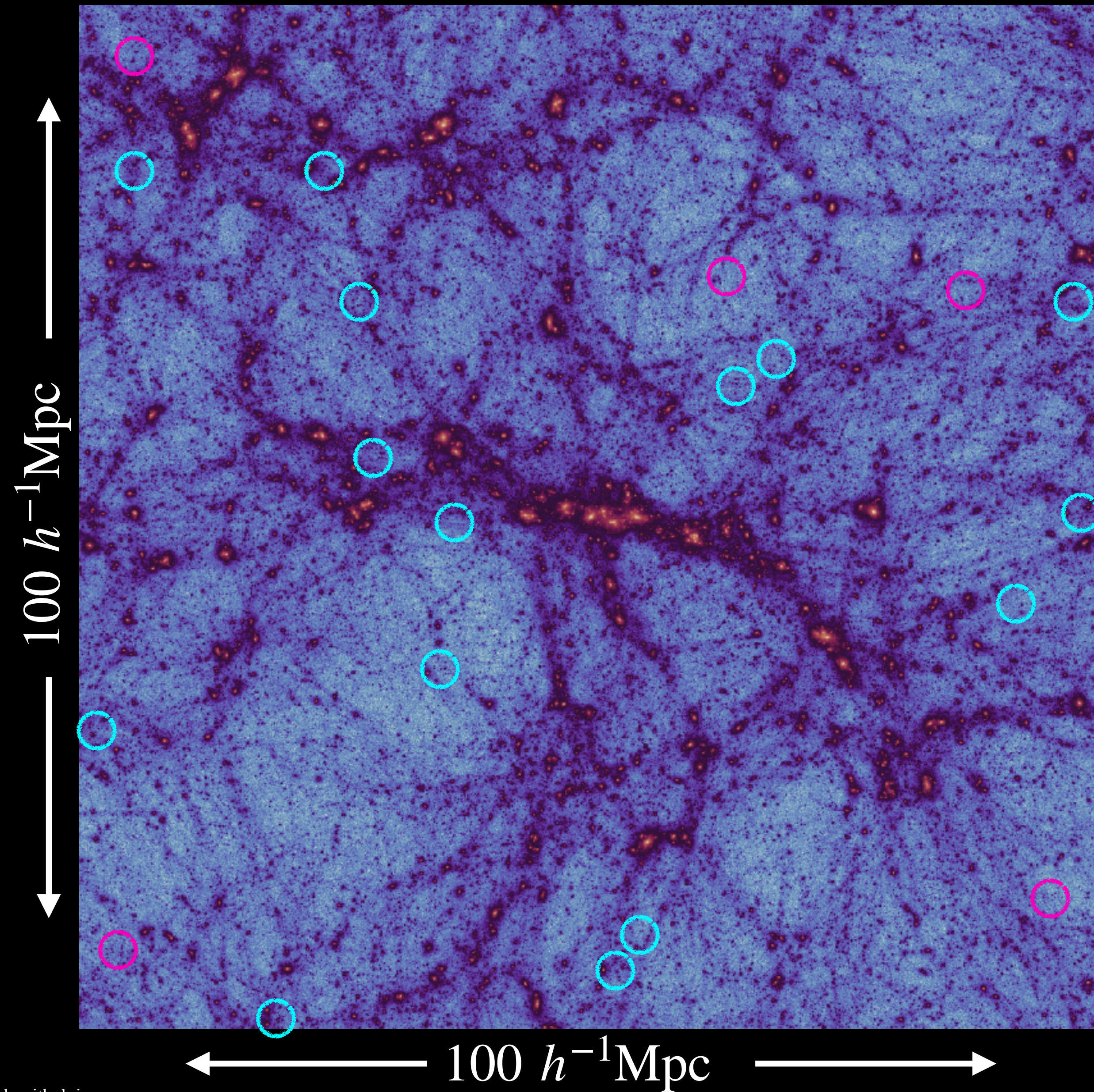
solar neighbourhood



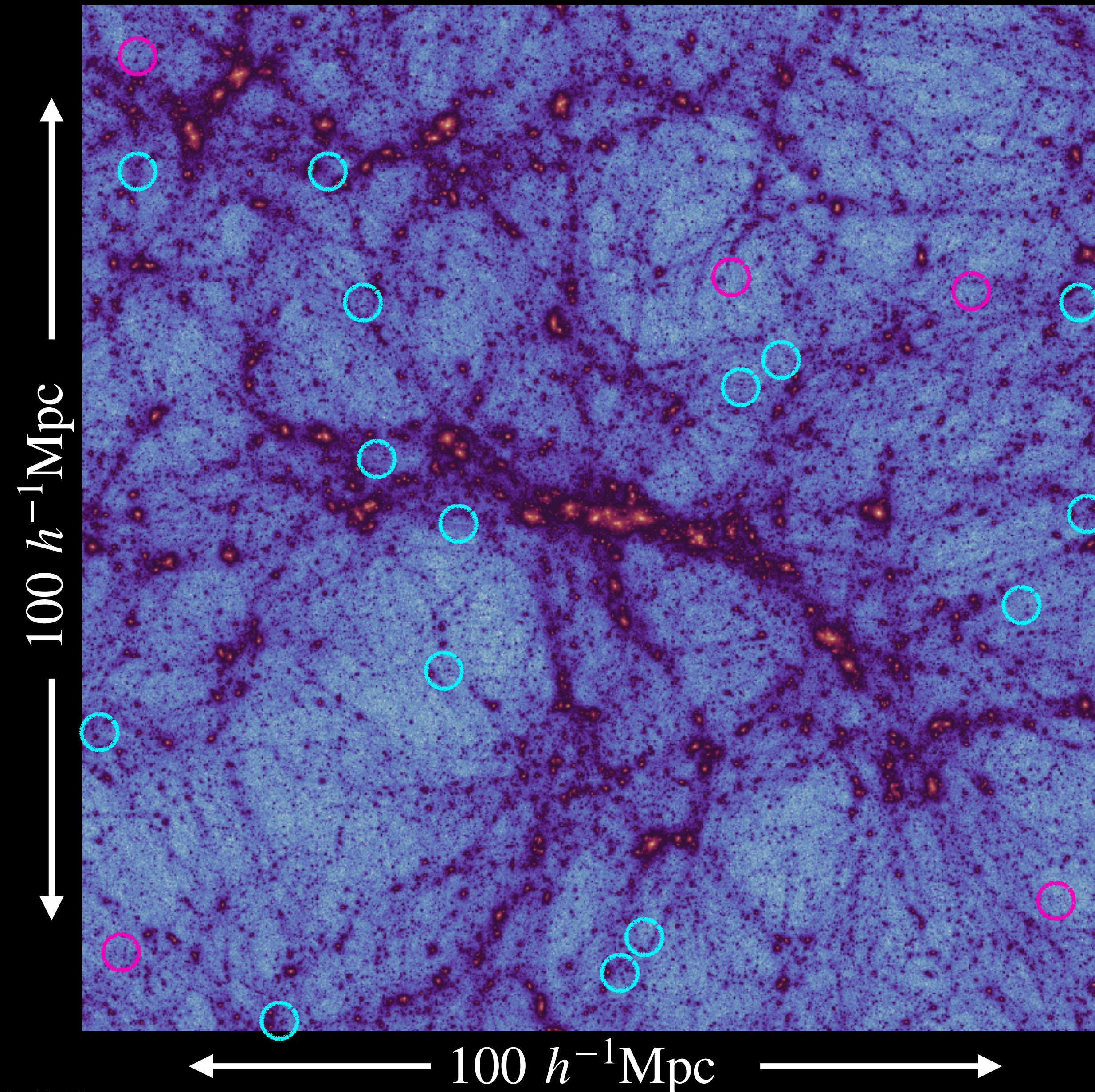
DORCHA suite



DORCHA suite

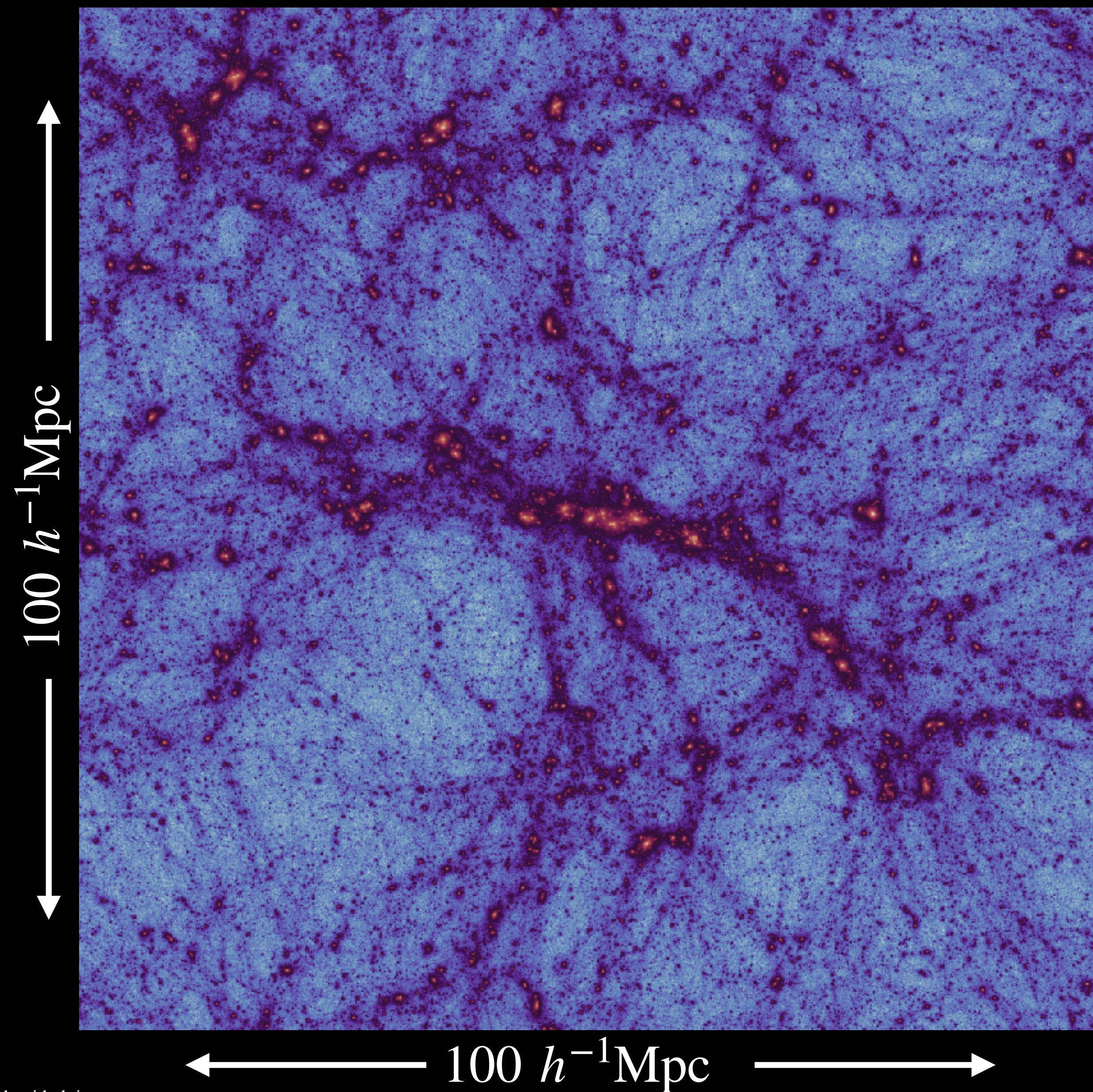


- $m_p \simeq 1.57 \times 10^5 h^{-1} M_{\odot}$



- level_max = 13
 - $N_{\text{eff}} = 8192^3$
- $m_p \simeq 1.57 \times 10^5 h^{-1} M_{\odot}$
- $m_H \simeq 5.04 \times 10^6 h^{-1} M_{\odot}$
- $\ell = 50 h^{-1} \text{pc}$

- Darkmatter-only N -body suite
- AREPO (public version)
- MUSIC for ICs ($@z = 99$)
- 123 snapshot dumps
 - 50 b/w $z = 30$ & 5
 - 73 b/w $z = 5$ & 0
- Halo catalogues & merger trees in post-processing
 - Subfind-HBT (Gadget4)
 - Minimum of 32 particles for halo-finding



- $L = 100 \ h^{-1}\text{Mpc}$
- $N_p = 512^3$
- $m_p \simeq 6.45 \times 10^8 \ h^{-1}M_\odot$
- $m_H \simeq 2.06 \times 10^{10} \ h^{-1}M_\odot$
- $\ell = 10 \ h^{-1}\text{kpc}$

