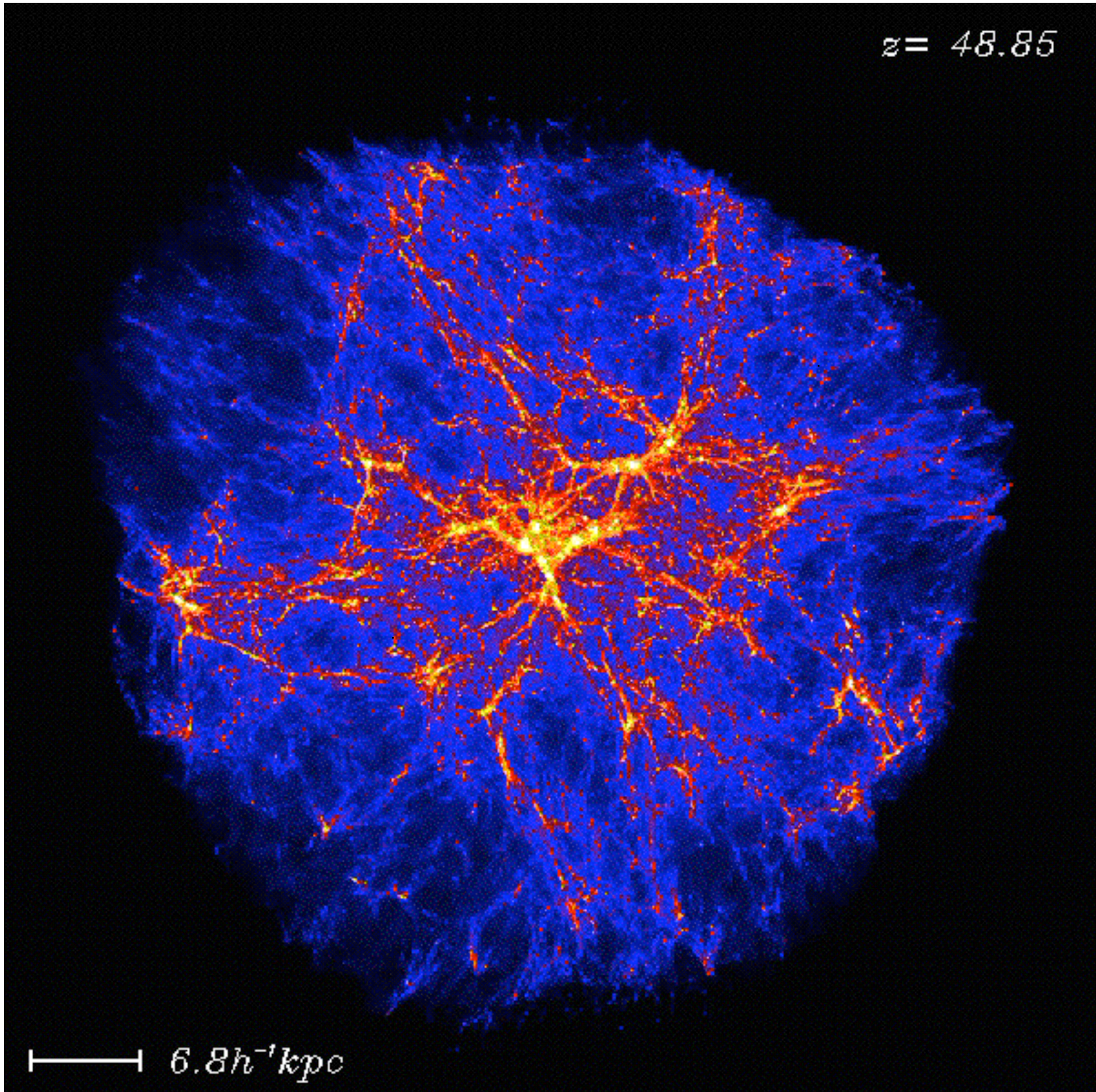


The First Structures in LCDM

MPA **Durham**

L. Gao ∏fl¡¡ A. Jenkins

S. D.M. White C.S. Frenk

V. Springel

Astro-ph/0503003

Outline

- Motivation
- Simulations details.
- Evolution of massive halo structure and their surroundings.
- Large scale structure at high z.
- Implications and Discussion

Motivation

When and where the first stars form? We first need to understand the assembly of the massive dark matter structures at high z.

- Simulate the formation of one of the first dark haloes which probably host the first stars.
- Study internal structure of high z massive objects and their surroundings.
- Examine EPS theory at high z.
- Constraints on the formation of the first stars and galaxies.

Difficulties in simulating the earliest massive objects **CORRECTLY !!!**

Need to resolve very small scale objects ($n_{eff} \sim -3$), which requires:

- Large enough simulation box to provide correct long wave fluctuations.
- As many particles as possible to follow the nonlinear dynamics convincingly.

It is not feasible to do a single large scale simulation.

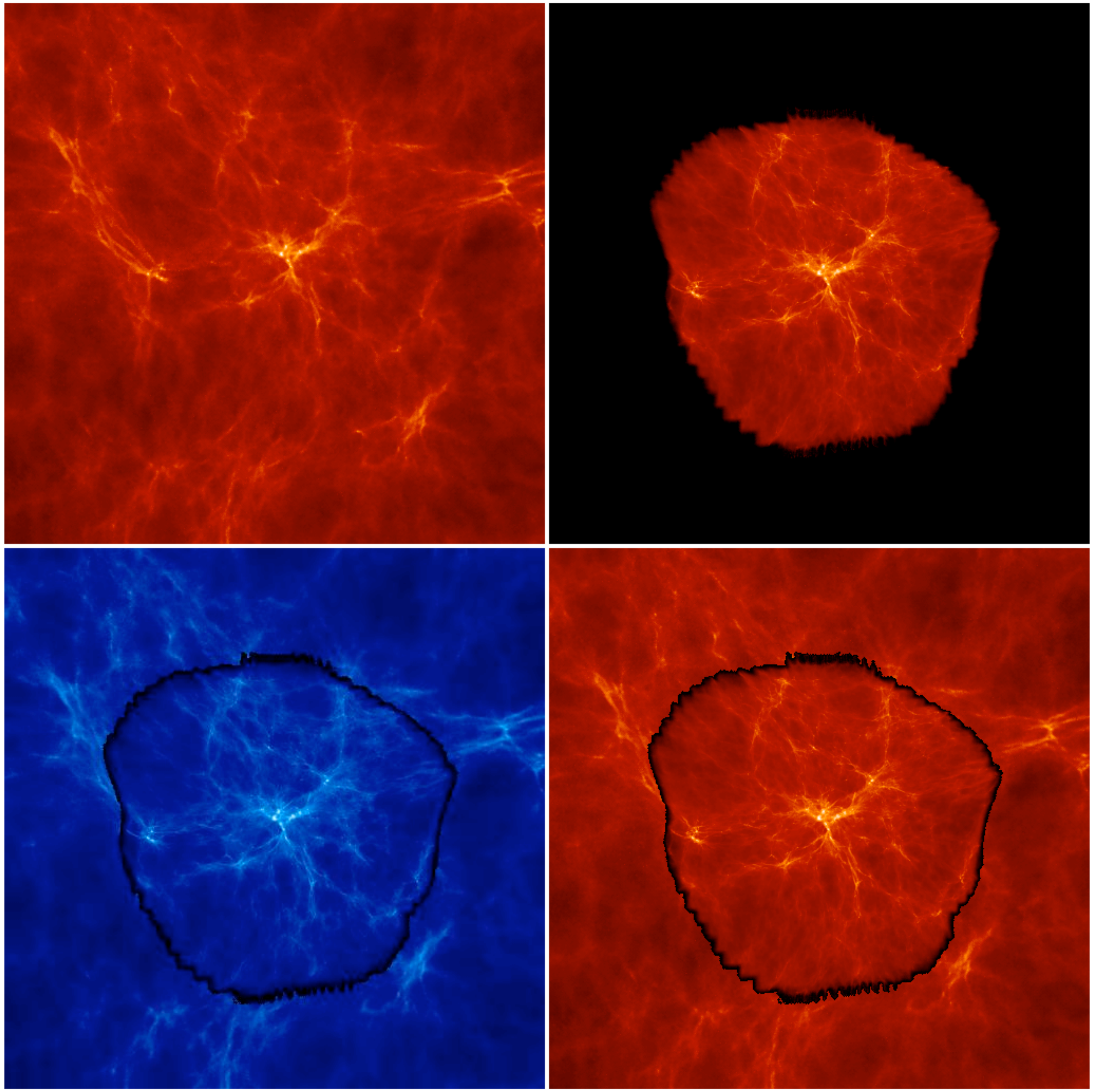
Simulation recipe

1. Identify a rich cluster from a very large scale simulation with boxsize $479 h^{-1}\mathrm{Mpc}$
2. re-simulate this rich cluster with higher mass and force resolution.
3. Identify the most massive object at earlier time in high resolution region when it contains around 10000 particles within virial radius.
4. re--simulate the identified object with higher mass and force resolution with about 2 million particles inside virial radius.
5. repeat 3 again and again up to desired redshift and progenitor mass.

ΛCDM

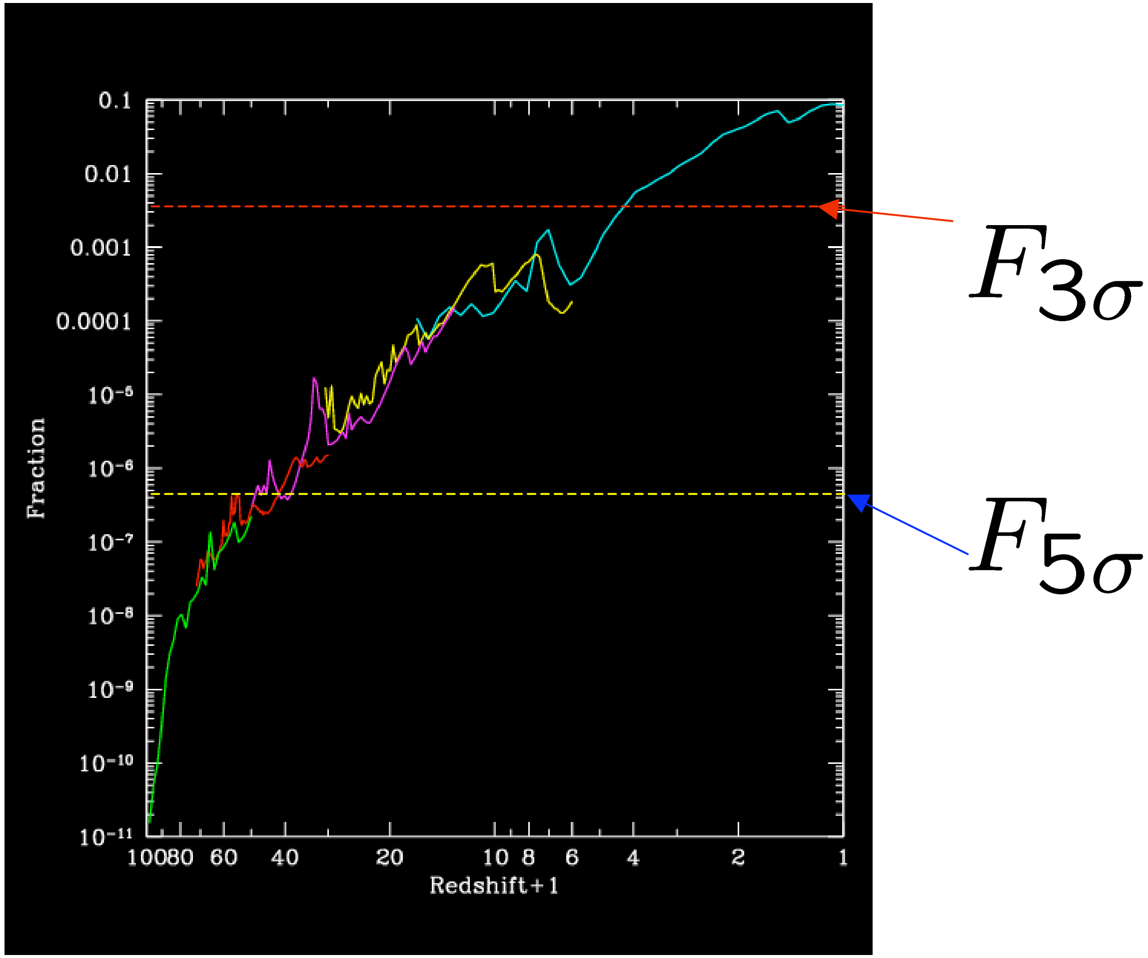
transfer function: CMBFAST

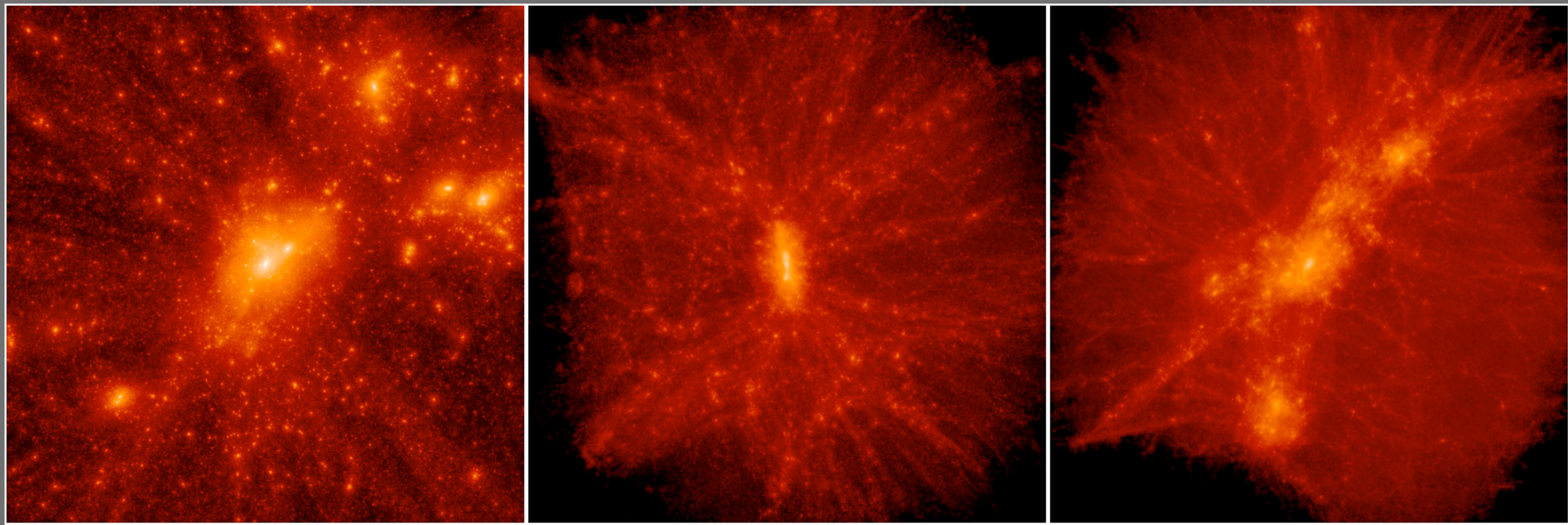
	$R1$	$R2$	$R3$	$R4$	$R5$
N_p	8457516	5804755	8658025	41226712	73744737
$M_p[h^{-1}M_\odot]$	5.05e8	2.2e6	1.24e4	29.5	0.545
$\epsilon[h^{-1}kpc]$	5.0	0.8	0.15	0.017	0.0048
$M_{200}[h^{-1}M_\odot]$	0.8e15	3.4e12	2.0e10	5.2e7	1.2e5
Z_{start}	39	149	249	399	599
Z_{end}	0	5	12	29	48

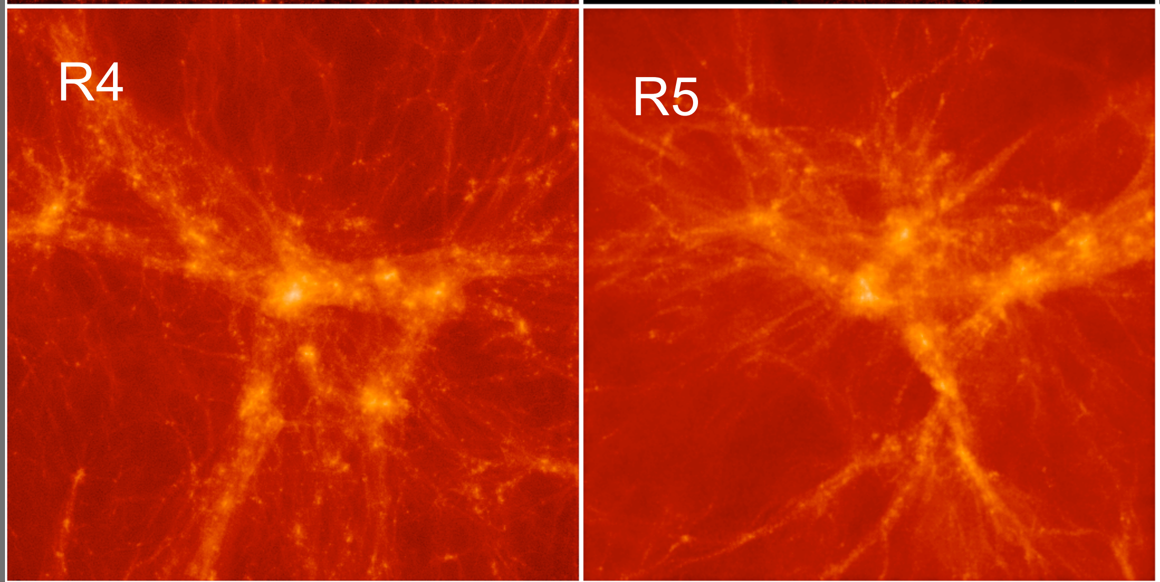


z=120.01
5 Kpc/h

Mass fraction of cosmic mass in the most massive haloes

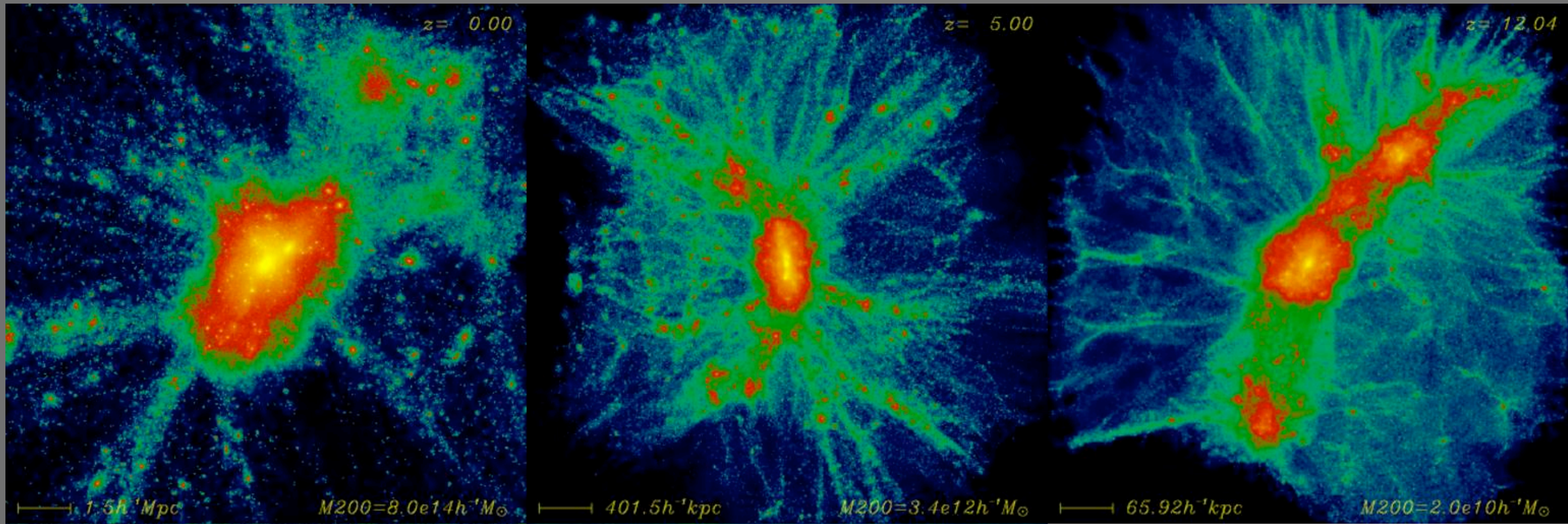


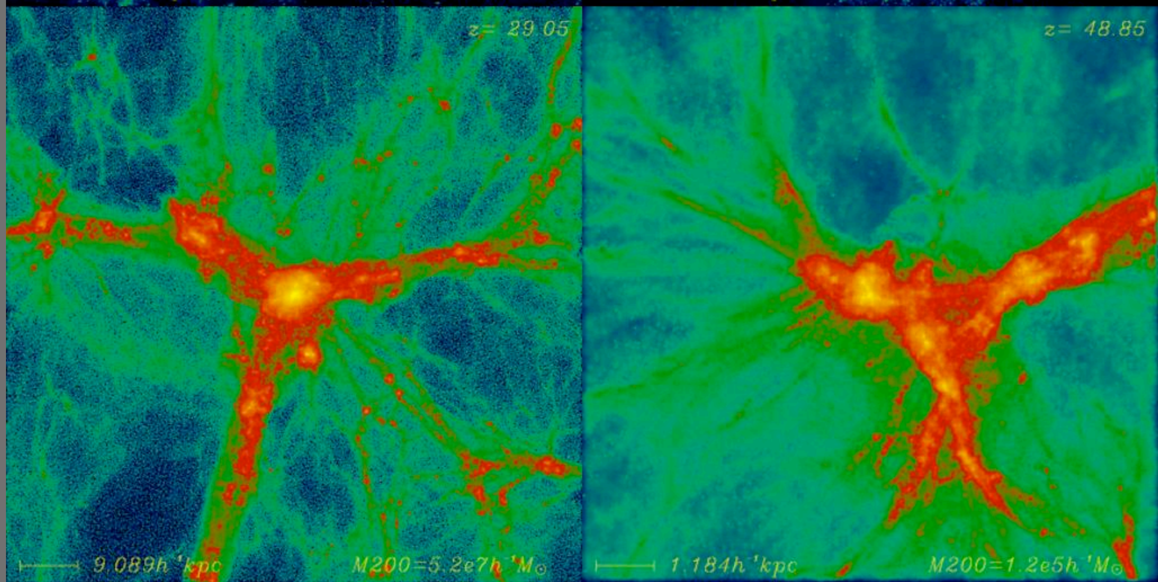




10 R200

R4 and R5 are similar and distinct from the others

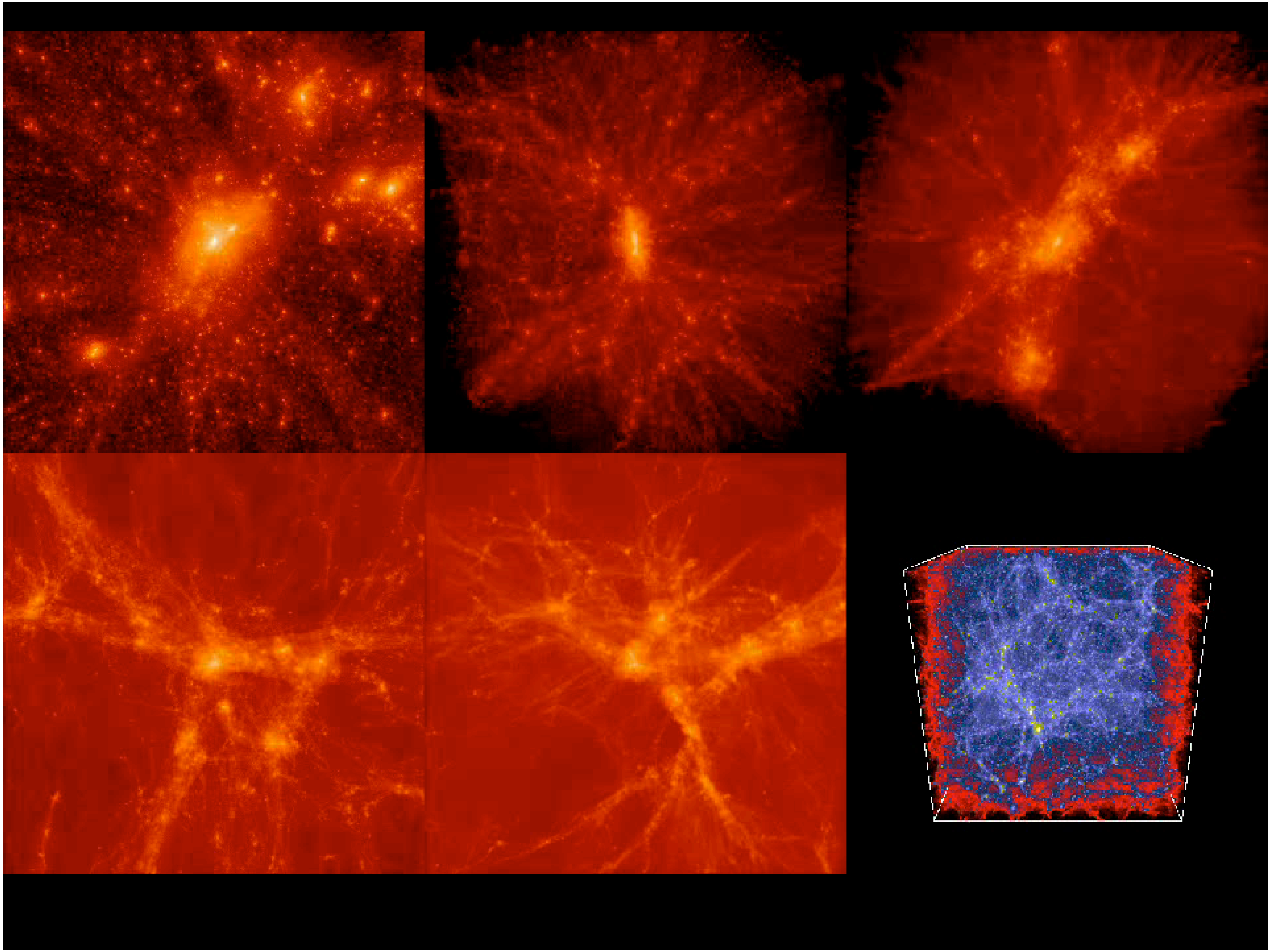


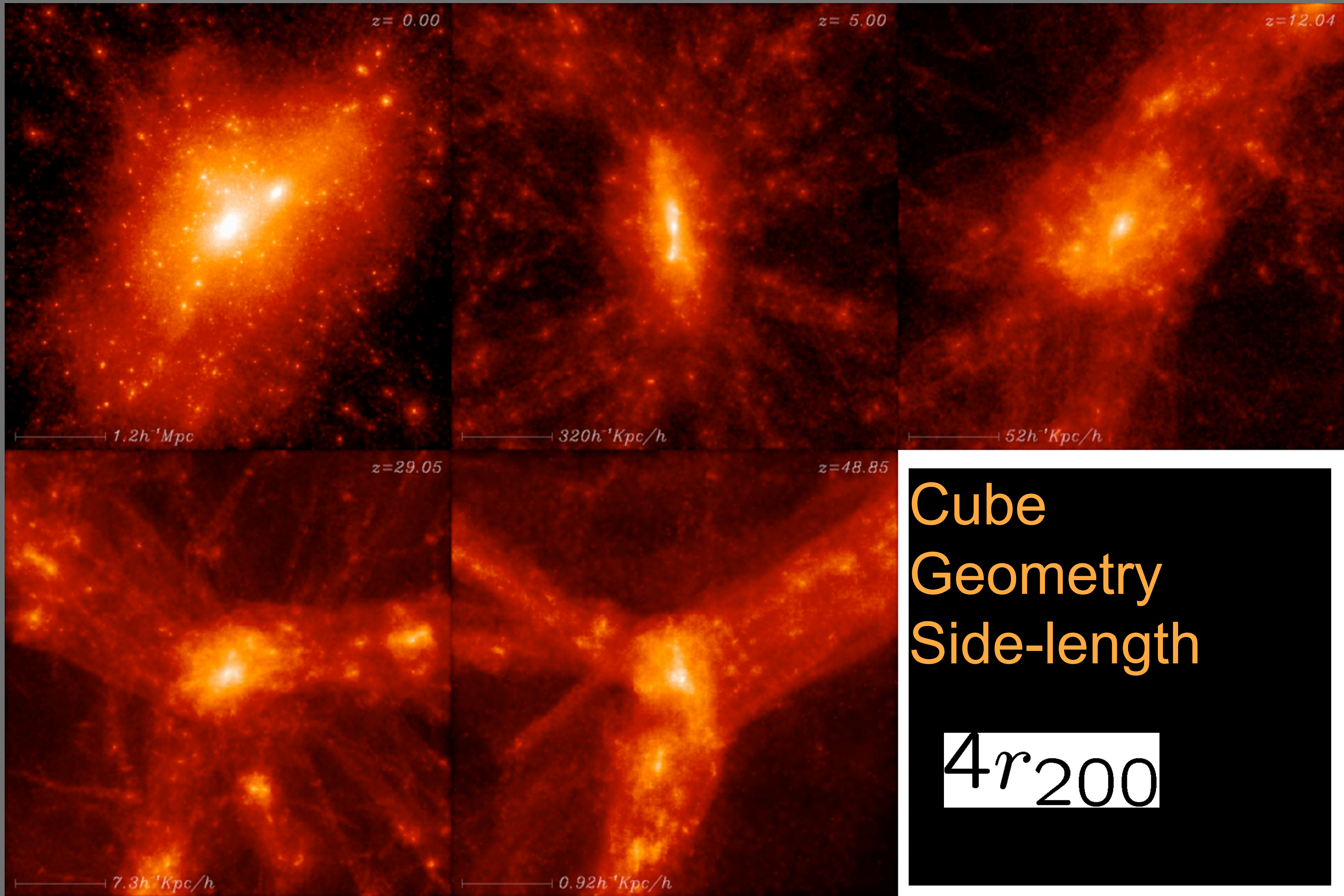


Slice with

Geometry

$$10 \times 10 \times 2 \times r_{200}^3$$

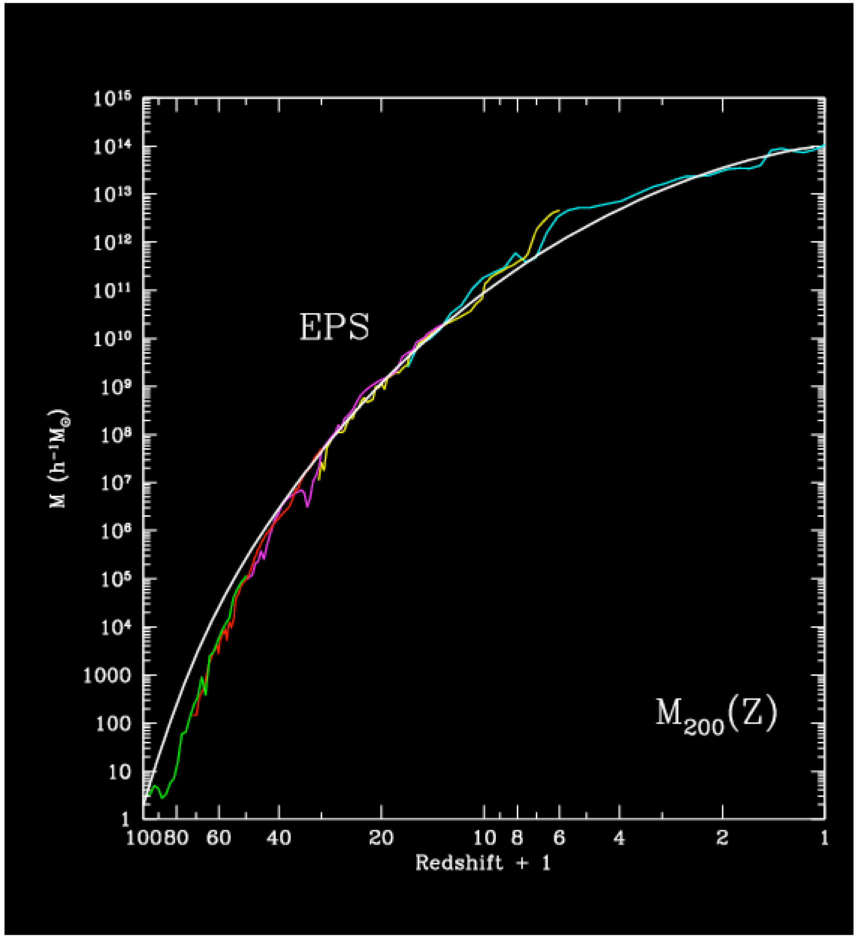


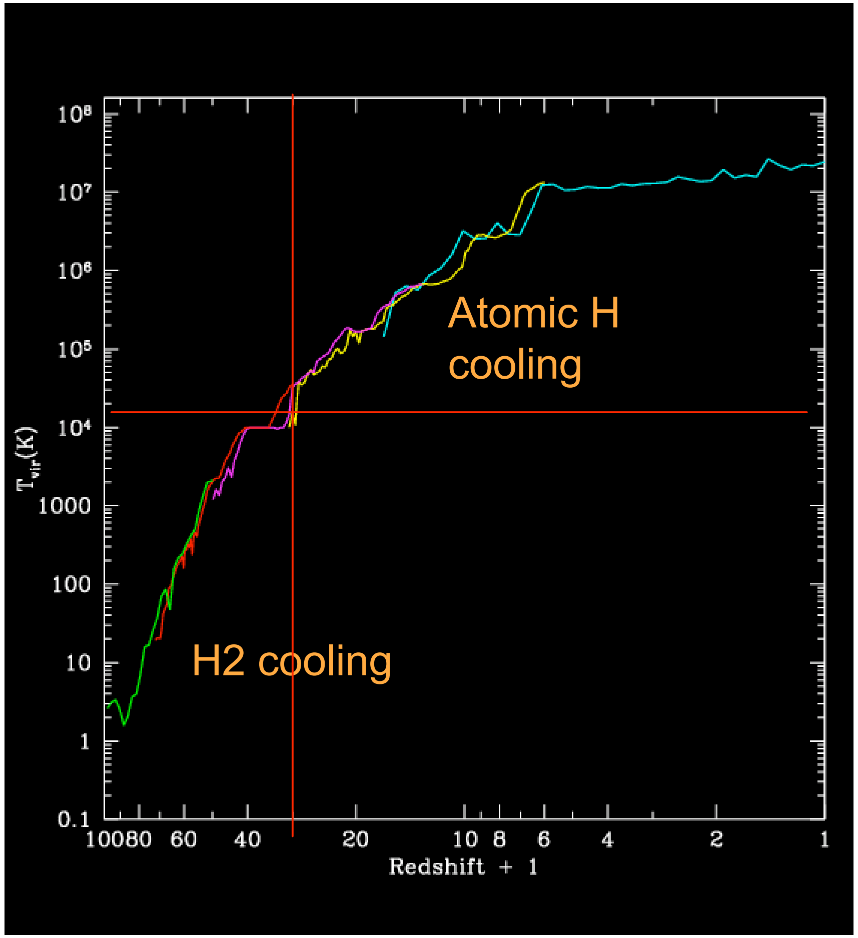


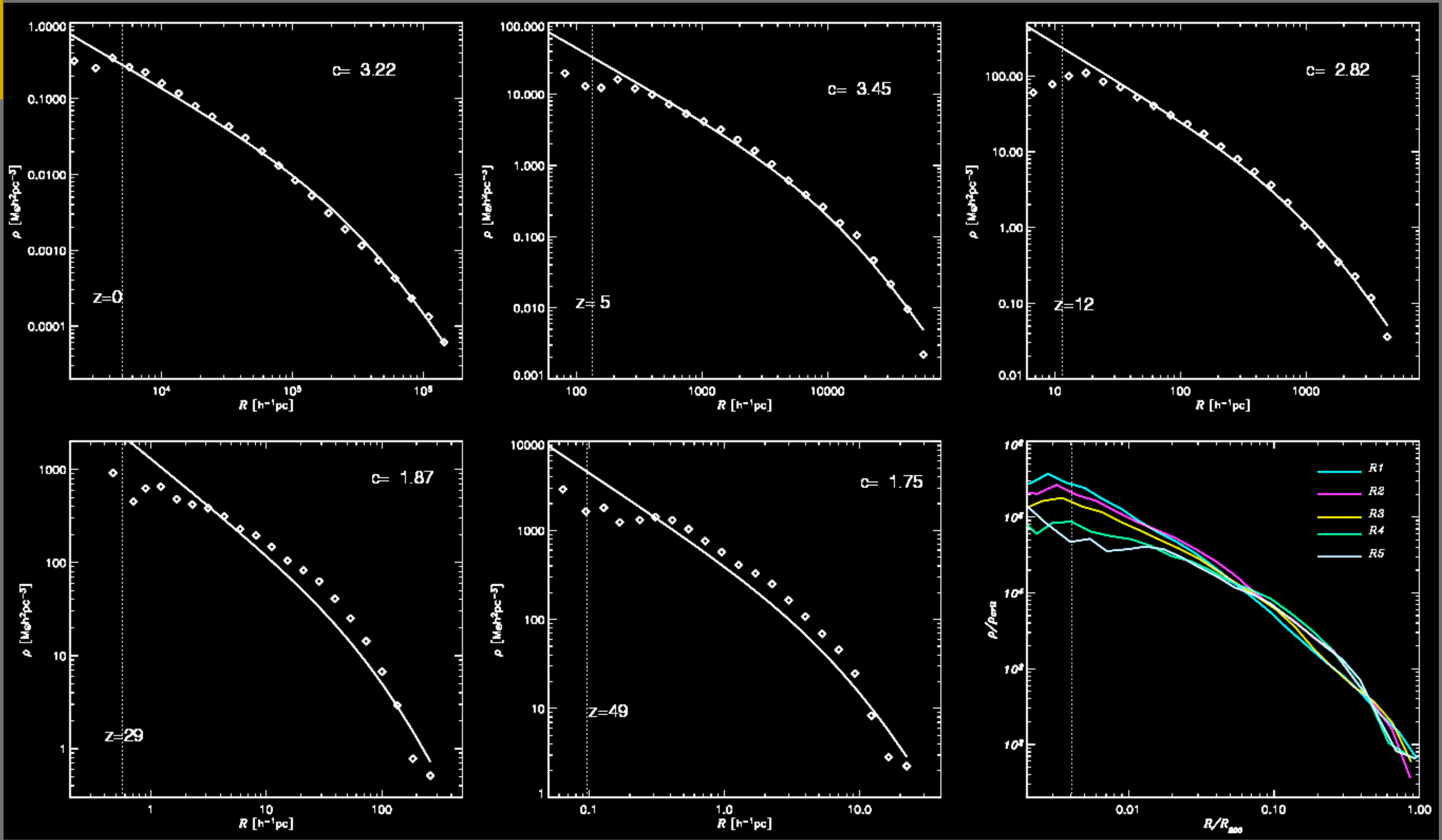
Cube Geometry Side-length

$4r_{200}$

Evolution: Virial mass & temperature





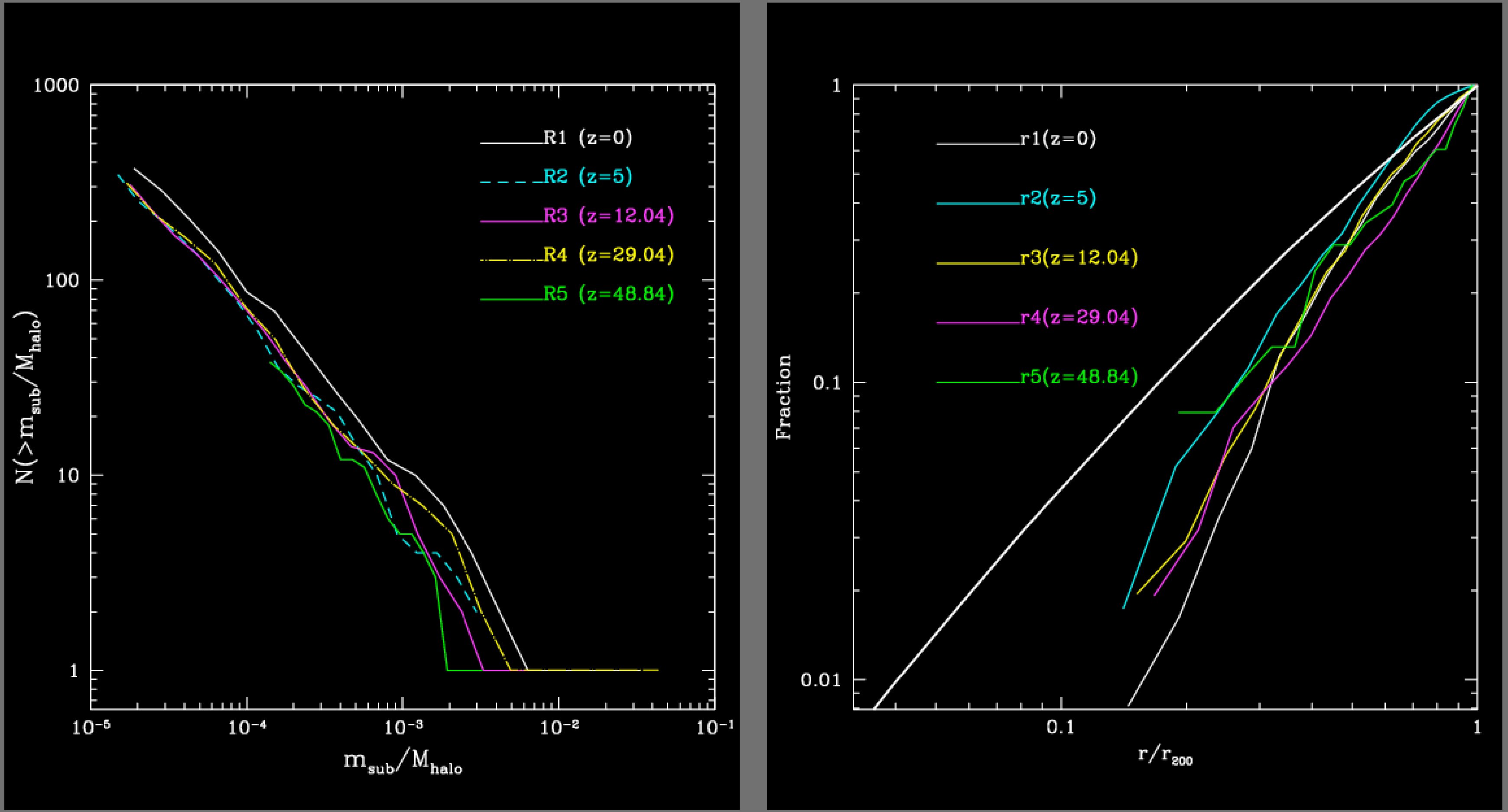


•Concentration decreases with redshift

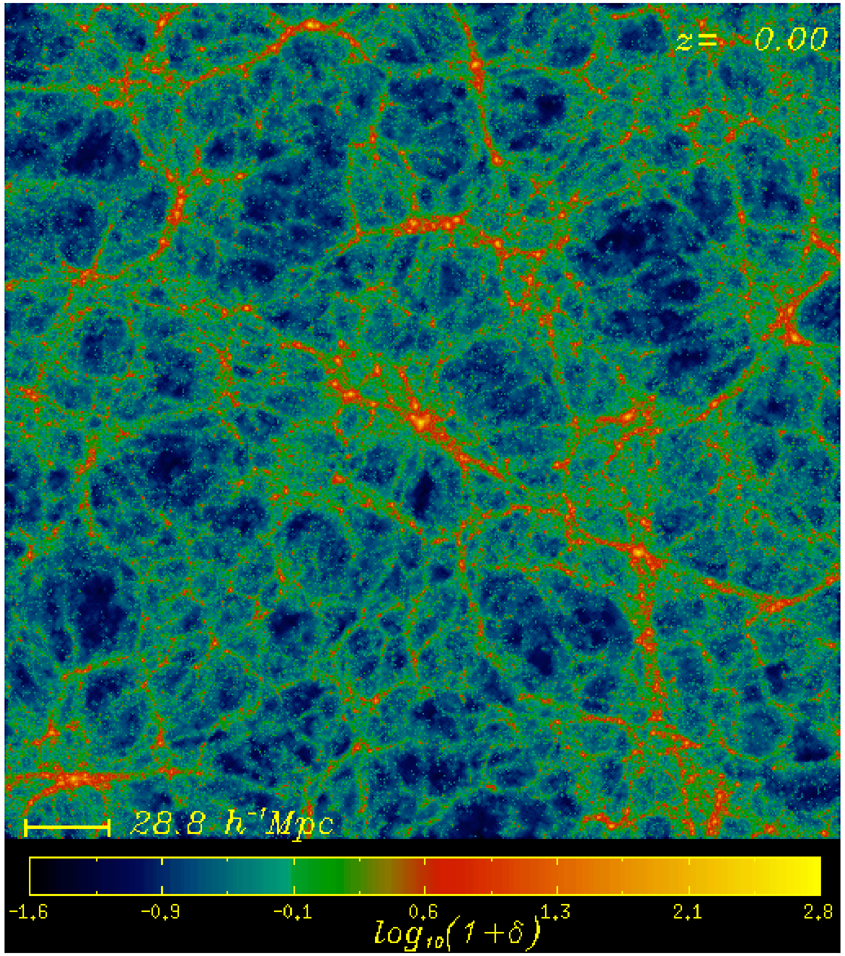
•Inner slope increases with redshift

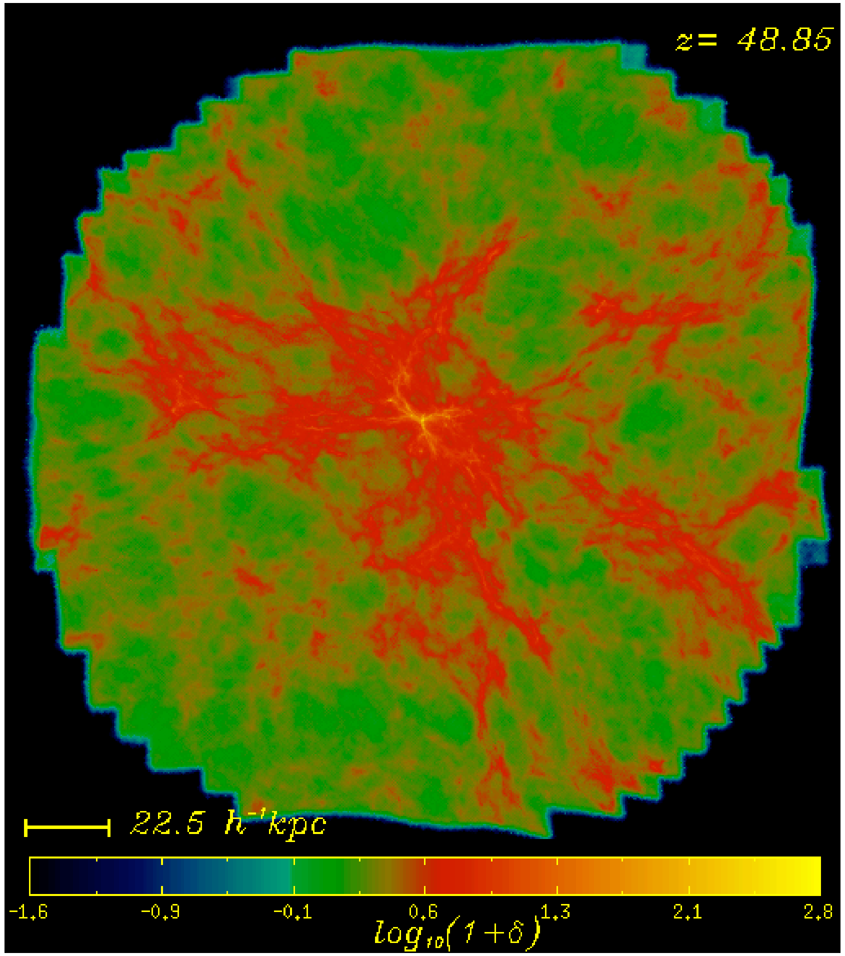
•Density profiles are the same for earlier haloes.

Substructure: abundance and distribution



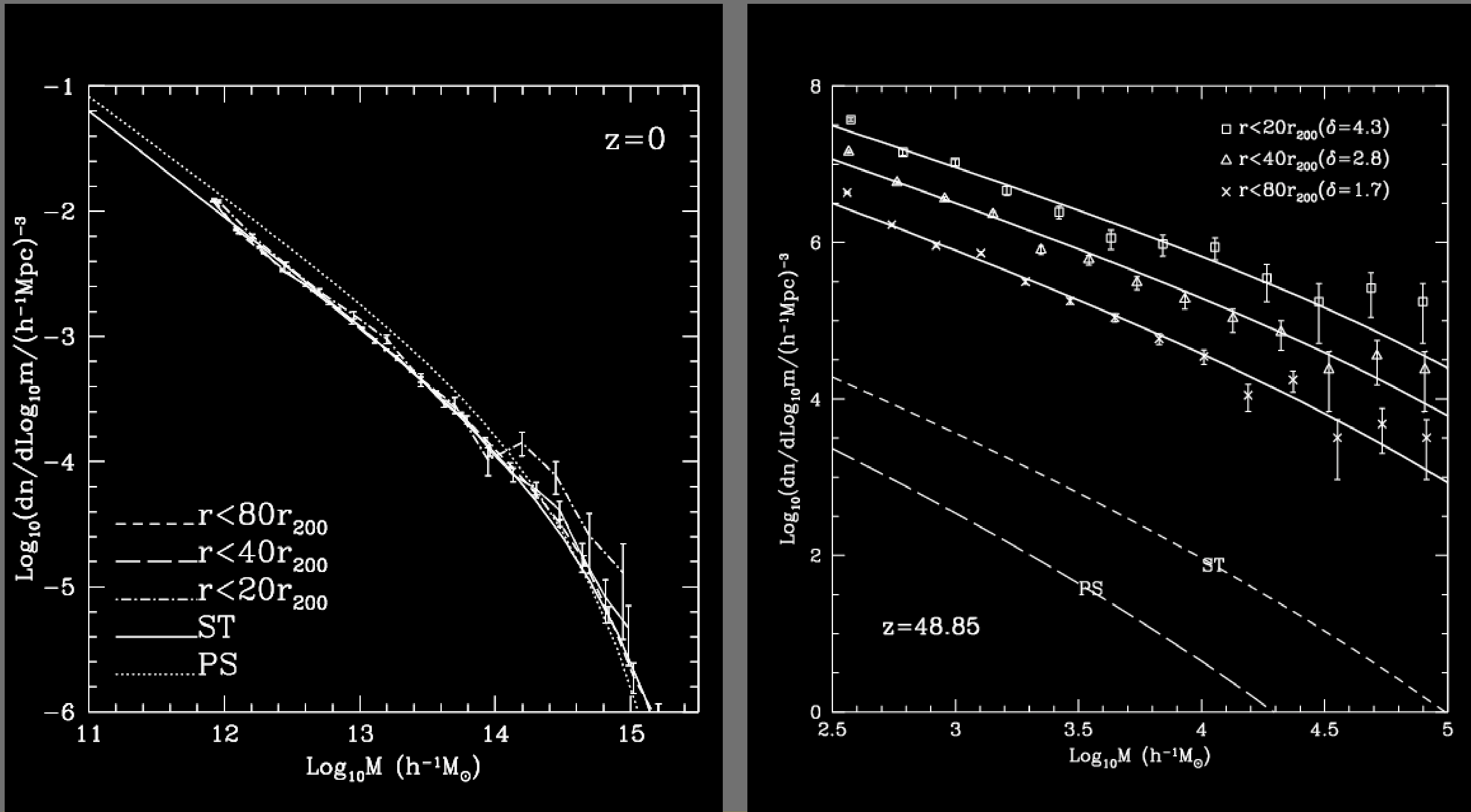
Large scale structure





Geometry $190 \times 190 \times 10r_{200}$

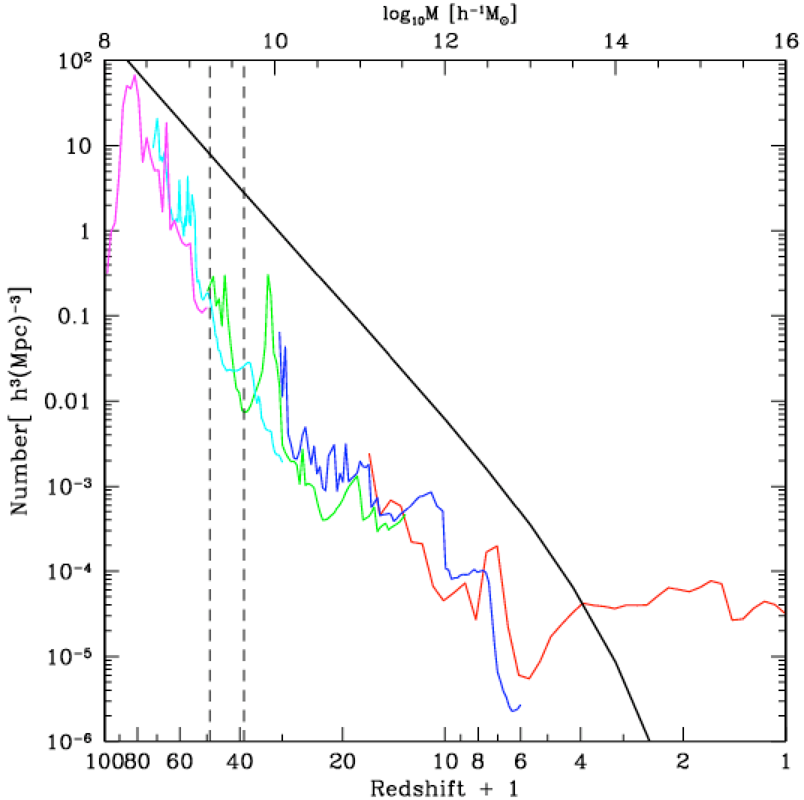
Biased abundance at early redshifts.



Discussion 1: abundance of the critical halos

- The comoving number density of 2000K haloes in which H2 is able to cool efficiently is the same as that of $10^{11}h^{-1}M_{\odot}$ haloes today.

- The comoving number density of 10000K haloes in which effective atomic cooling can take place is the same as that of Milky-Way size halos today.



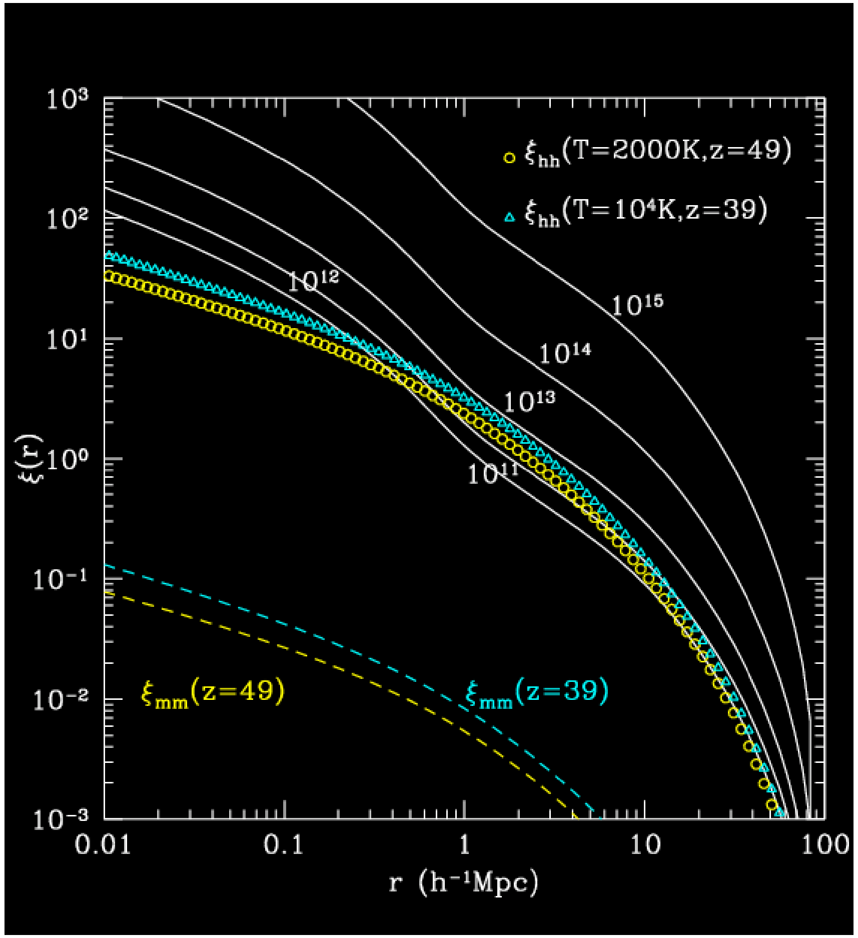
Discussion 2: The spatial clustering of the critical haloes

- Spatial clustering theory by Mo & White 1996

$$\xi_{hh}(r, M, z) = b^2(M, z)\xi_{mm}(r, z)$$

$$b(M, z) = 1 + \frac{\nu^2(M,z)-1}{\delta_c}$$

- At z ~ 49, the clustering strength for the critical haloes is the same as that of Milky-way sized haloes today



Conclusion

- Massive objects at early times accrete mass extremely rapidly and form in regions where the overdensity is high on large scales.
- At early times z>12 the filamentary structure surrounding the massive objects is much stronger than at lower redshifts z<5.
- At very high redshift z~50 large-scale structure is qualitatively different from that in the low redshift universe. In particular the characteristic size of coherent structures is much larger in relation to the typical size of collapsed objects.
- Despite this the internal structure of massive early dark haloes is quite similar to that to their present-day counterparts, both in terms of density profiles and in terms of substructure.

Conclusion

- The number density of haloes in overdense regions at high redshift is surprisingly well described by the extended Press-Schechter model, at least in the redshift interval z=50 -30$ that we study here.
- By z~49, the object we follow has virial temperature ~2000K and should be capable of forming sufficient molecular hydrogen for its central baryonic material to condense into a massive star. Pockets of star formation may thus have appeared much earlier than previously thought. At z~49 such haloes have a comoving number density comparable to that of $10^{11}h^{-1}\mathrm{M}_{\odot}$ haloes today, but by z=40 this has already increased by almost two orders of magnitude. By z~39 gas in our main halo could cool efficiently by atomic processes.

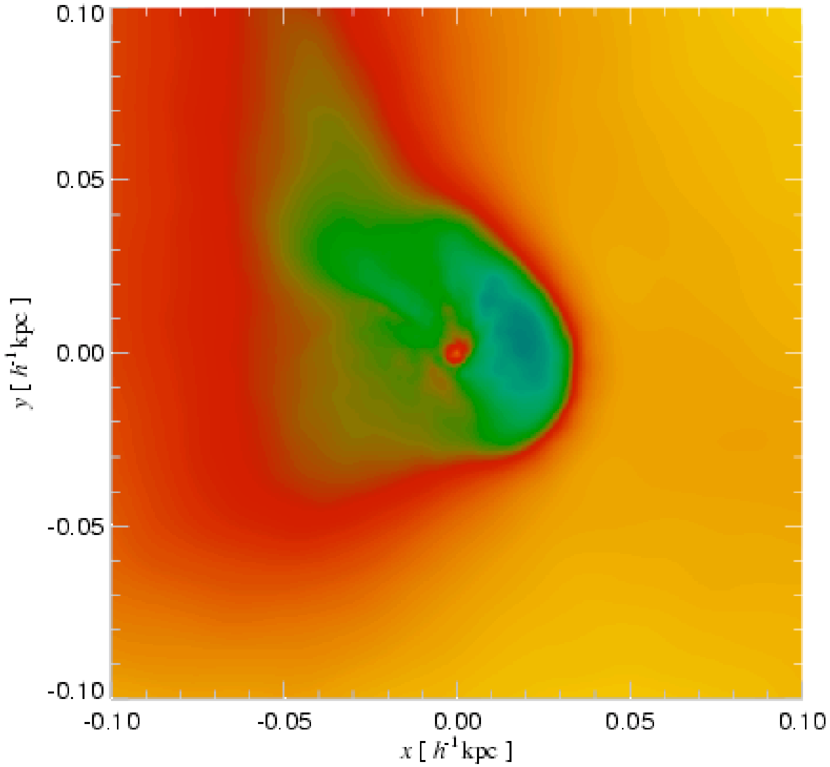
Conclusion

- Over the redshift range 30<z< 50 haloes like the one we have simulated have a comoving correlation length of about $2.5h^{-1}\mathrm{Mpc}$ almost as large as that of present-day dwarf galaxies. The ionisation and dissociation structures their associated stars produce may thus have considerable large-scale structure.

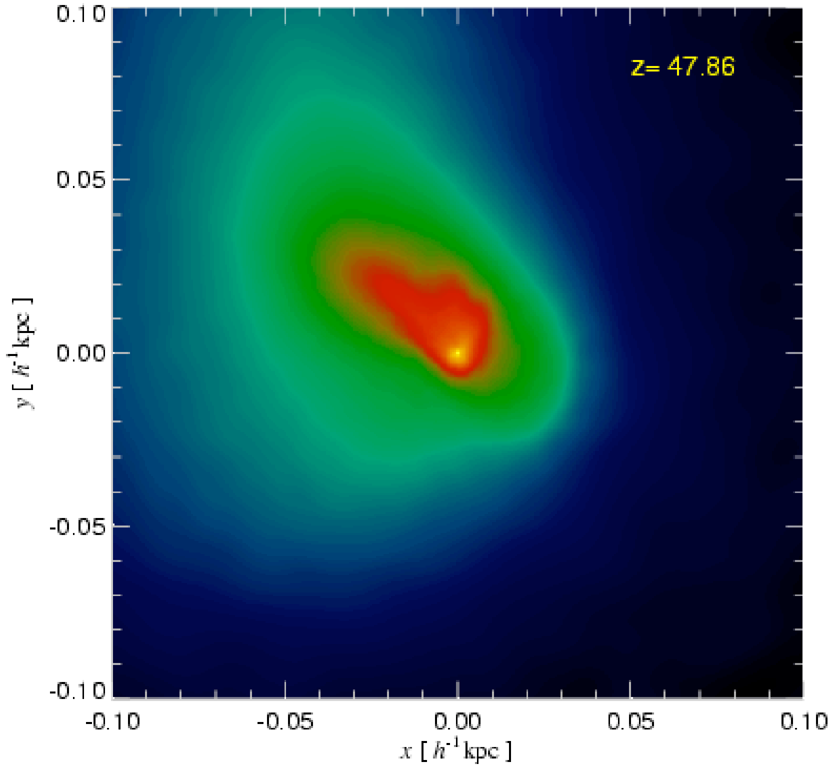
R5 with Hydro + non-equilibrium Chemistry

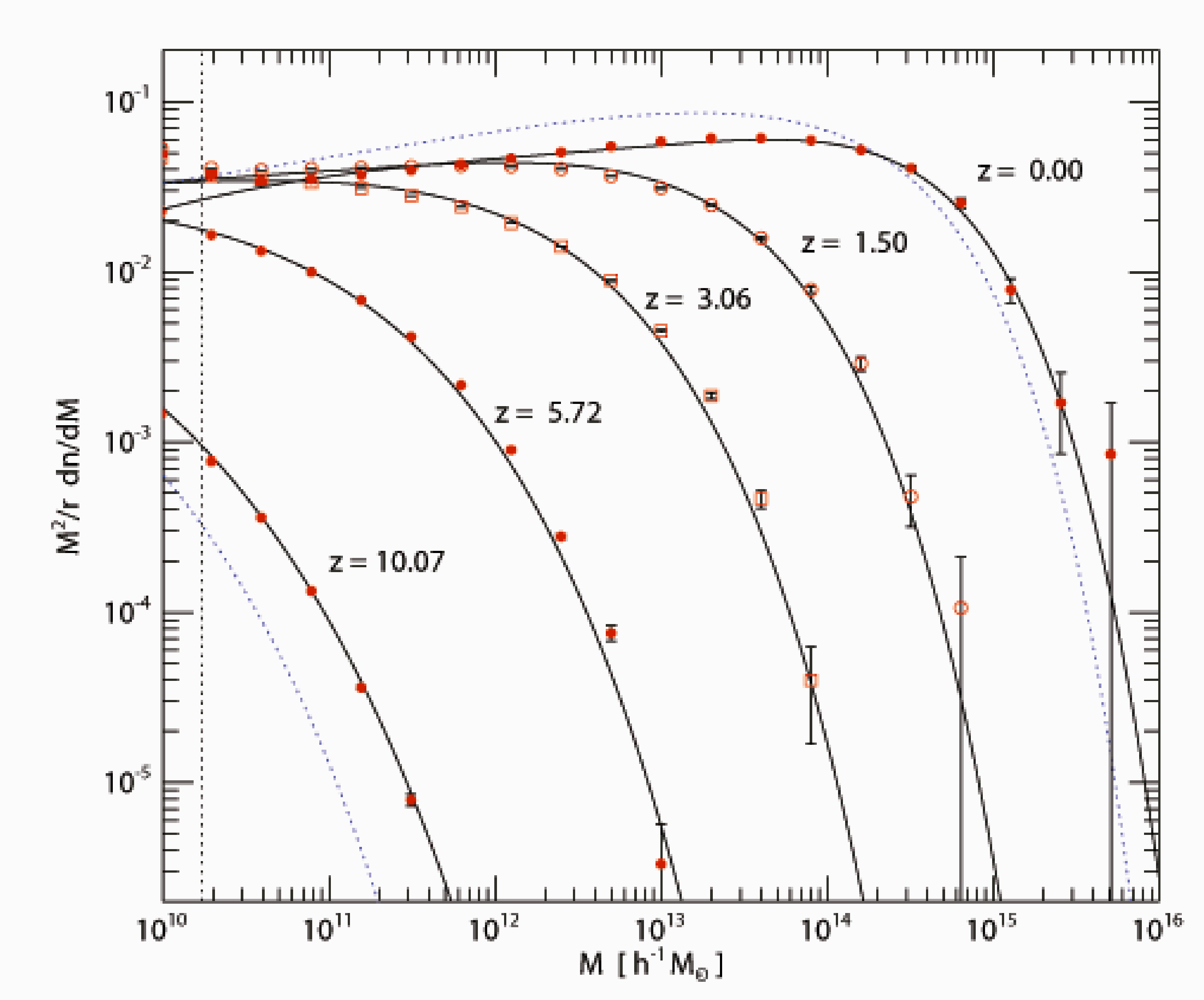
$M_{GAS} \sim 0.15 M_{\odot}$

Temperature map



Density map





Springel et al. 2005, Nature

Thank you!

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Grazie£°

Dank fuer Ihre Aufmerksamkeit!