Mass & Mystery in the Local Group
IoA, Cambridge, July 2005

ΛCDM Dark Halos and the Structure of the Local Group

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PLAN

- Does halo formation history depend on present environment?
- Have halo cores been in place since high redshift?
- Are halo cores in equilibrium?
- Do all halos look similar?
- Is significant mass in substructures? Which ones?
- Are substructures as “old” as their host halos?
- Do satellite galaxies follow the subhalo distribution?
- Where are the first stars now?

Early formation and late merging of the giant galaxies
Gao, Loeb, Peebles, White & Jenkins 2004a ApJ 614, 17

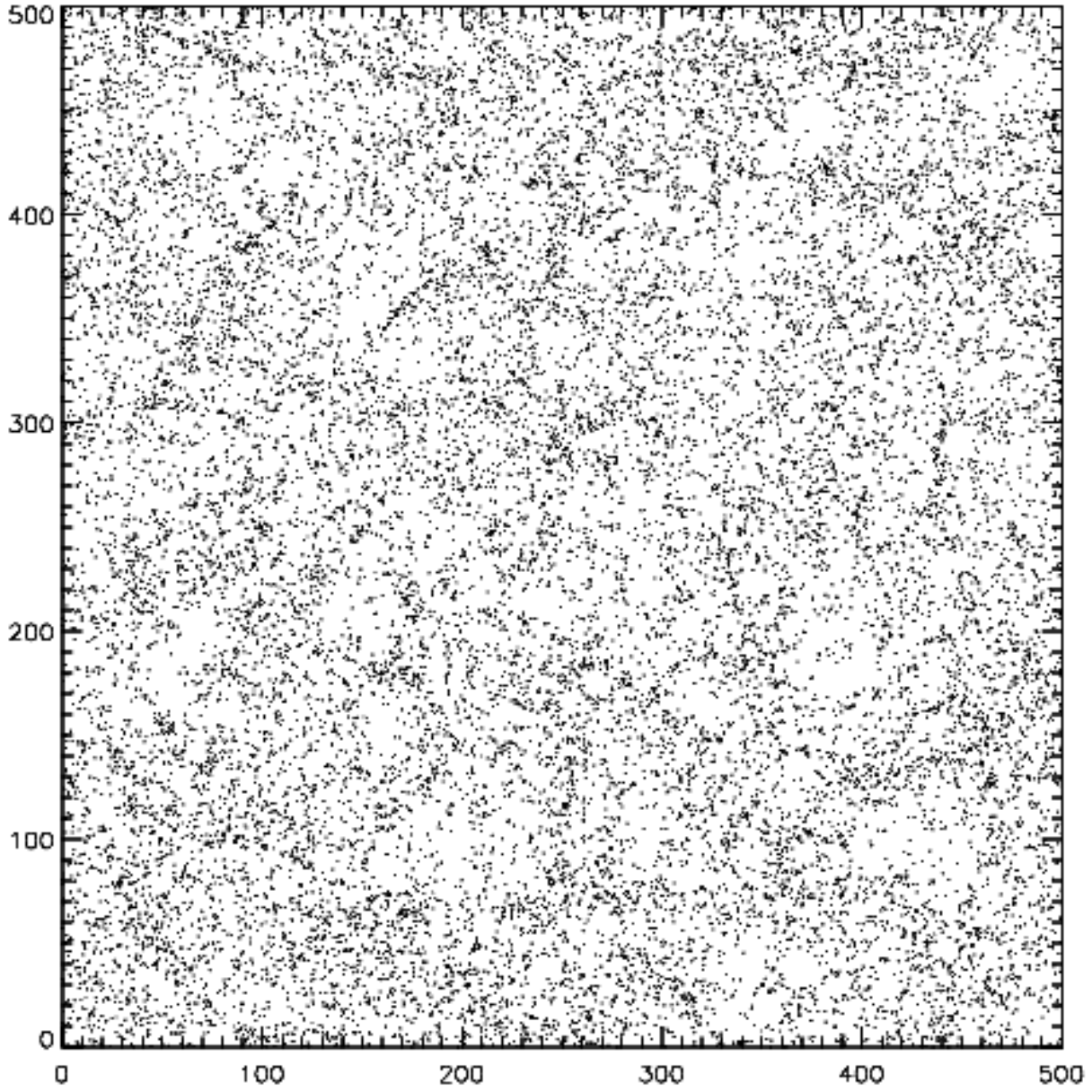
The subhalo populations of ΛCDM dark haloes
Gao, White, Jenkins, Stoehr & Springel 2004b MNRAS 355, 819

Galaxies and subhaloes in ΛCDM galaxy clusters
Gao, De Lucia, White & Jenkins 2004c MNRAS 352, L1

The age dependence of halo clustering
Gao, Springel & White 2005 MNRAS, submitted

Assembly of the inner cores of ΛCDM dark haloes
Gao, White et al 2005, in preparation

Does formation history depend on environment?

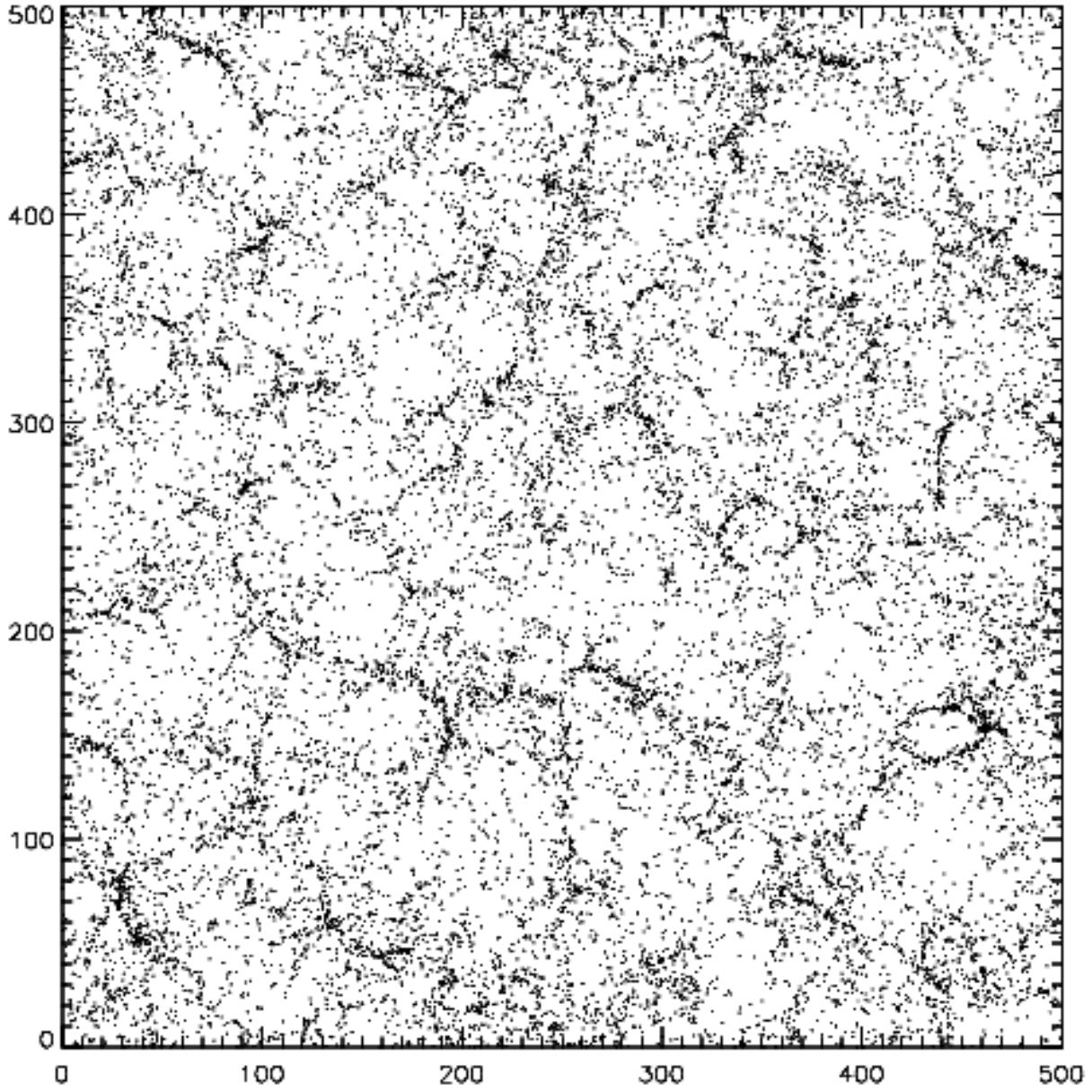


Gao, Springel & White 2005

The 20% of halos with the *lowest* formation redshifts in a 30 Mpc/h thick slice

$$M_{halo} \sim 10^{11} M_{\odot}$$

Does formation history depend on environment?



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The 20% of halos with the *highest* formation redshifts in a 30 Mpc/h thick slice

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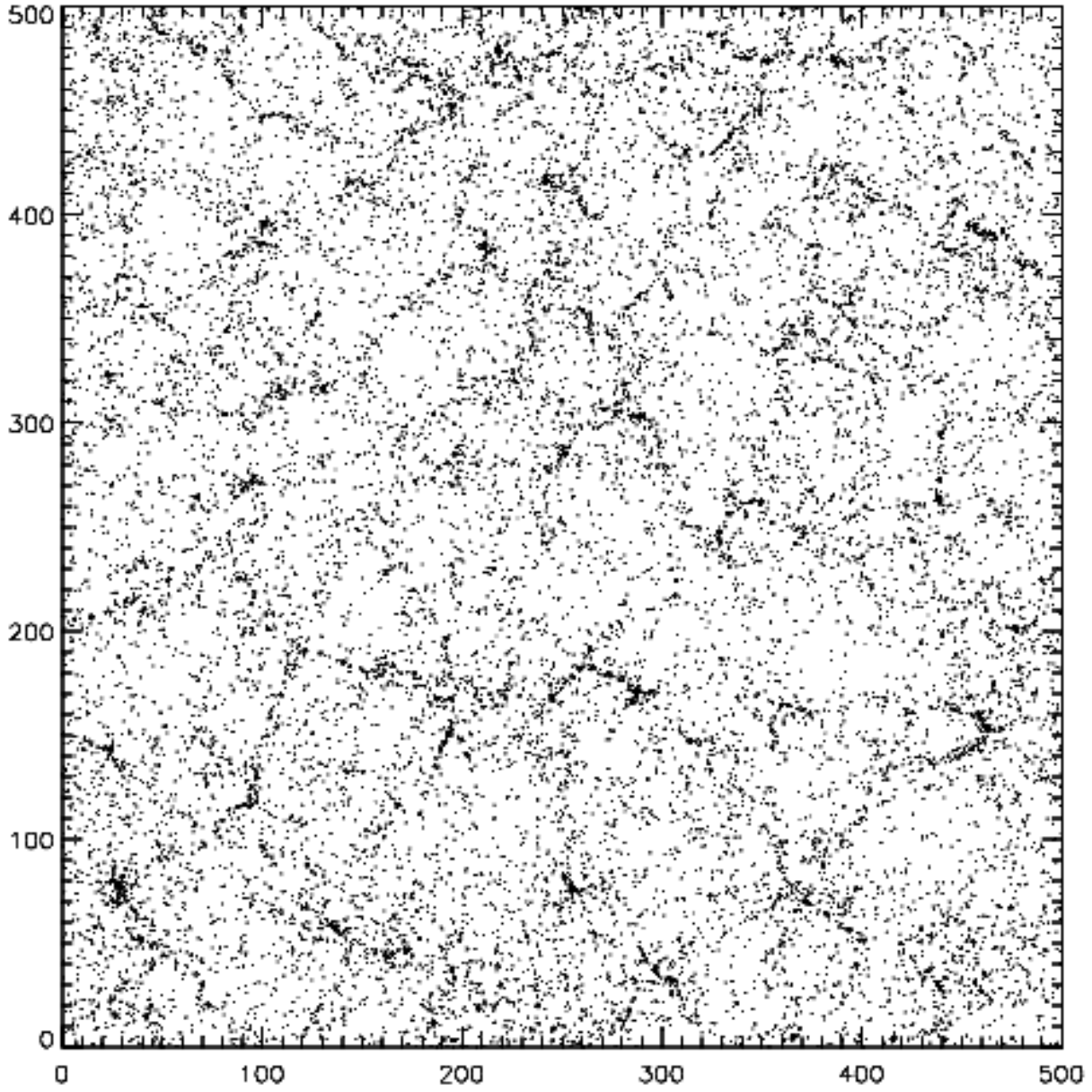
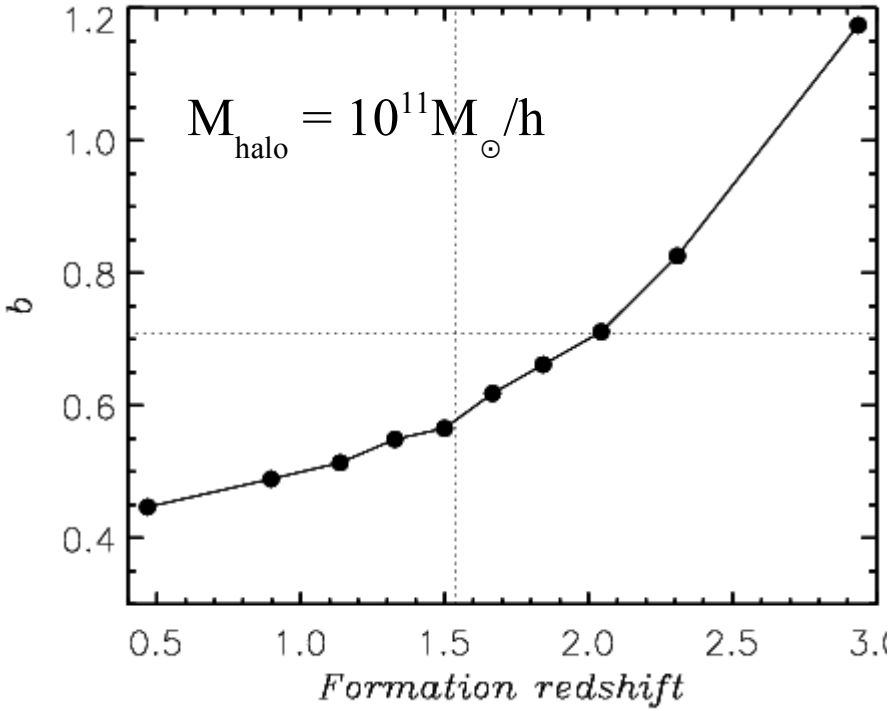


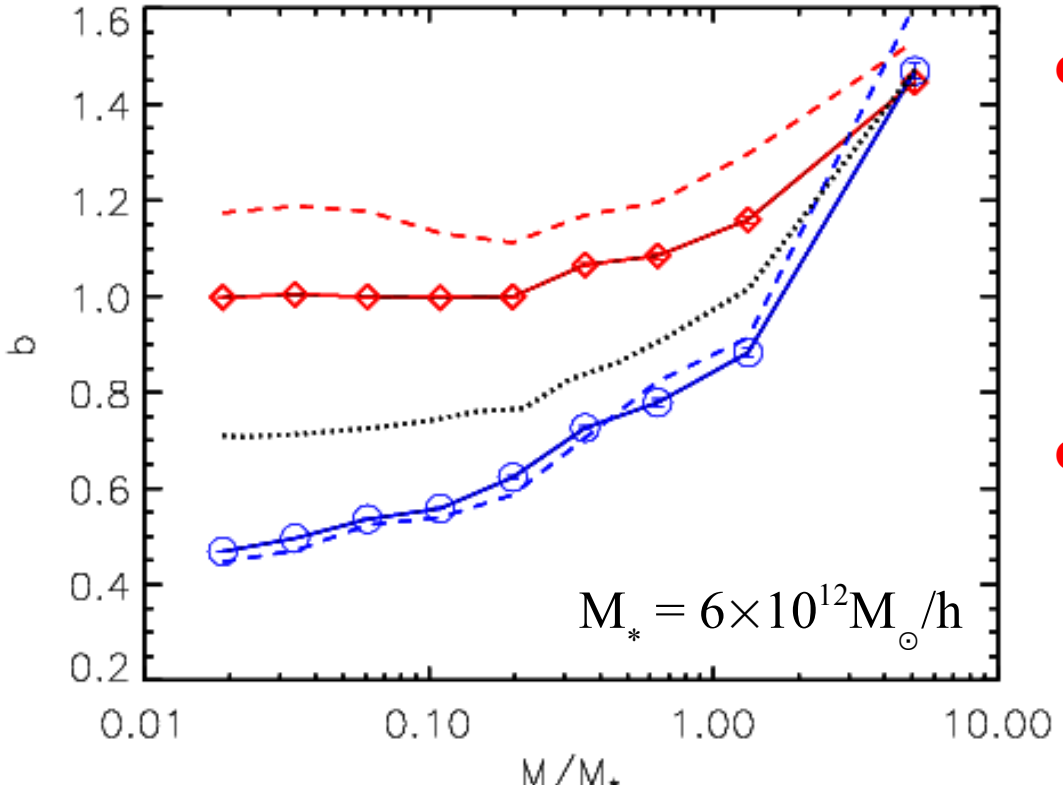
Gao, Springel & White 2005

An equal number of randomly chosen DM particles

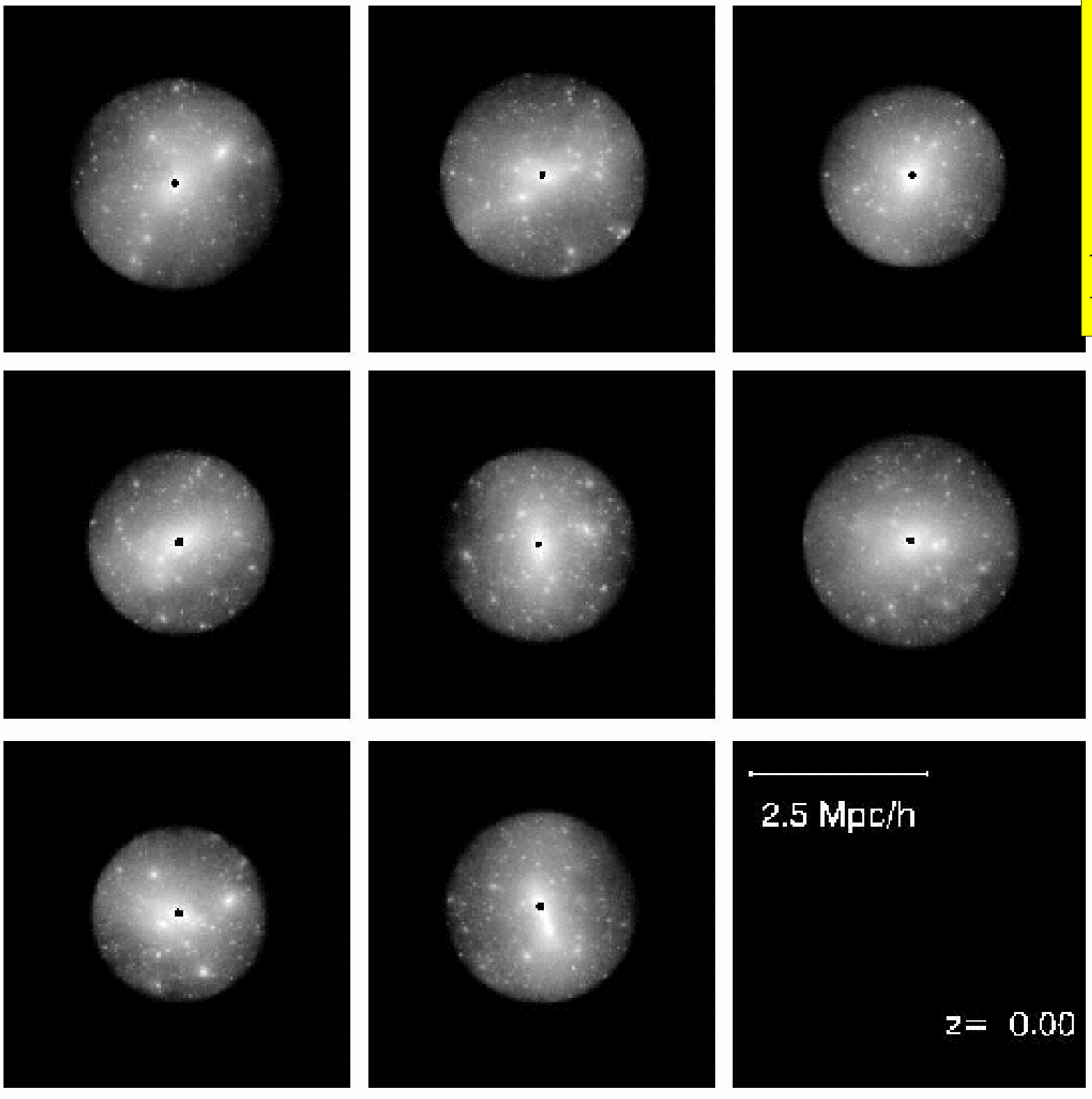
Halo bias as a function of mass and formation time

Gao, Springel & White 2005





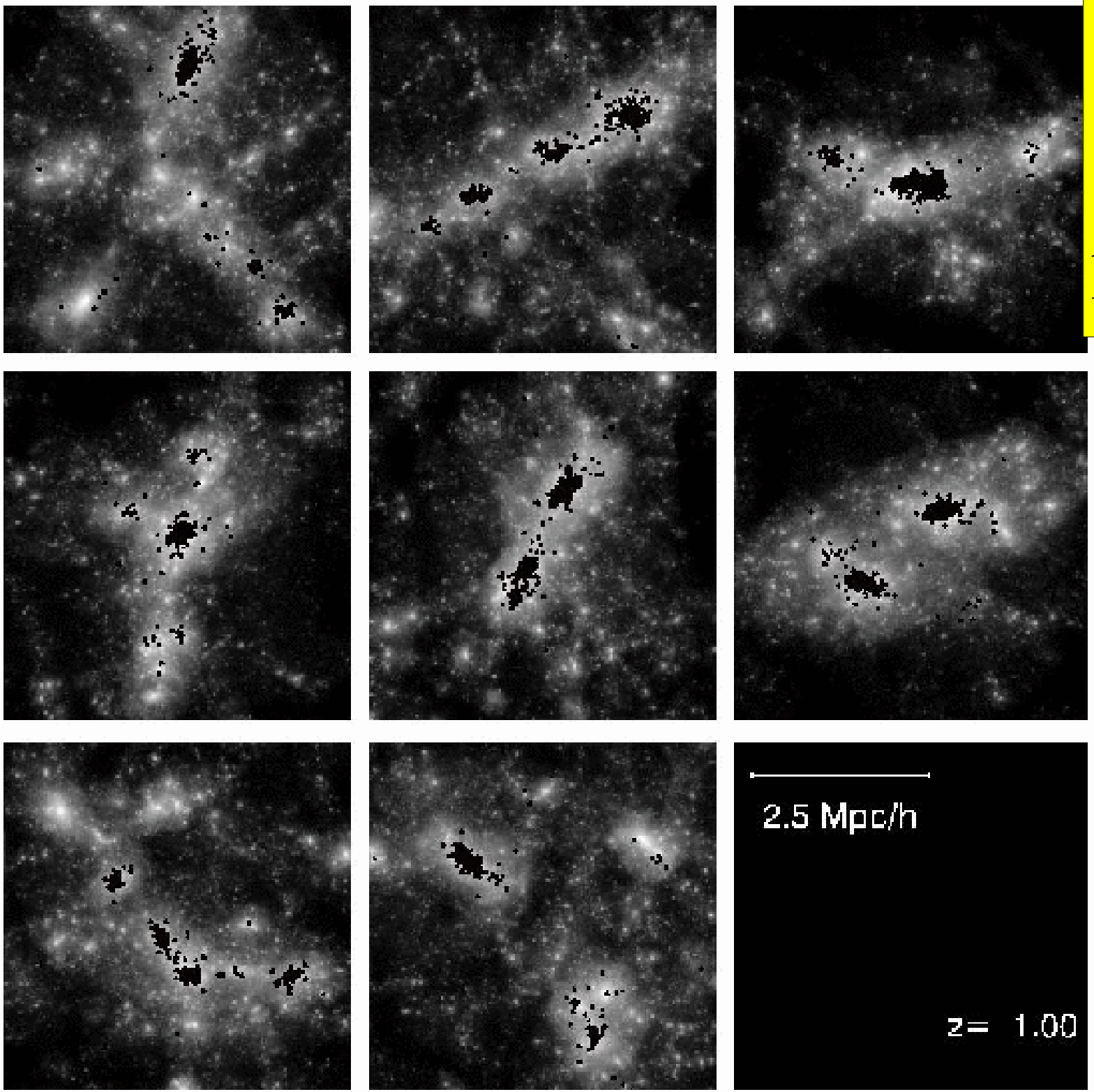
- Bias increases smoothly with formation redshift
- The dependence on formation redshift is strongest at low mass
- This dependence is consistent *neither* with excursion set theory *nor* with HOD models



Have halo cores been in place since high redshift?

- 'Concordance' cosmology
- Final cluster mass ~10^{15} $M_{\odot}$
- DM within 20kpc at $z = 0$ is shown black

Gao et al 2004a



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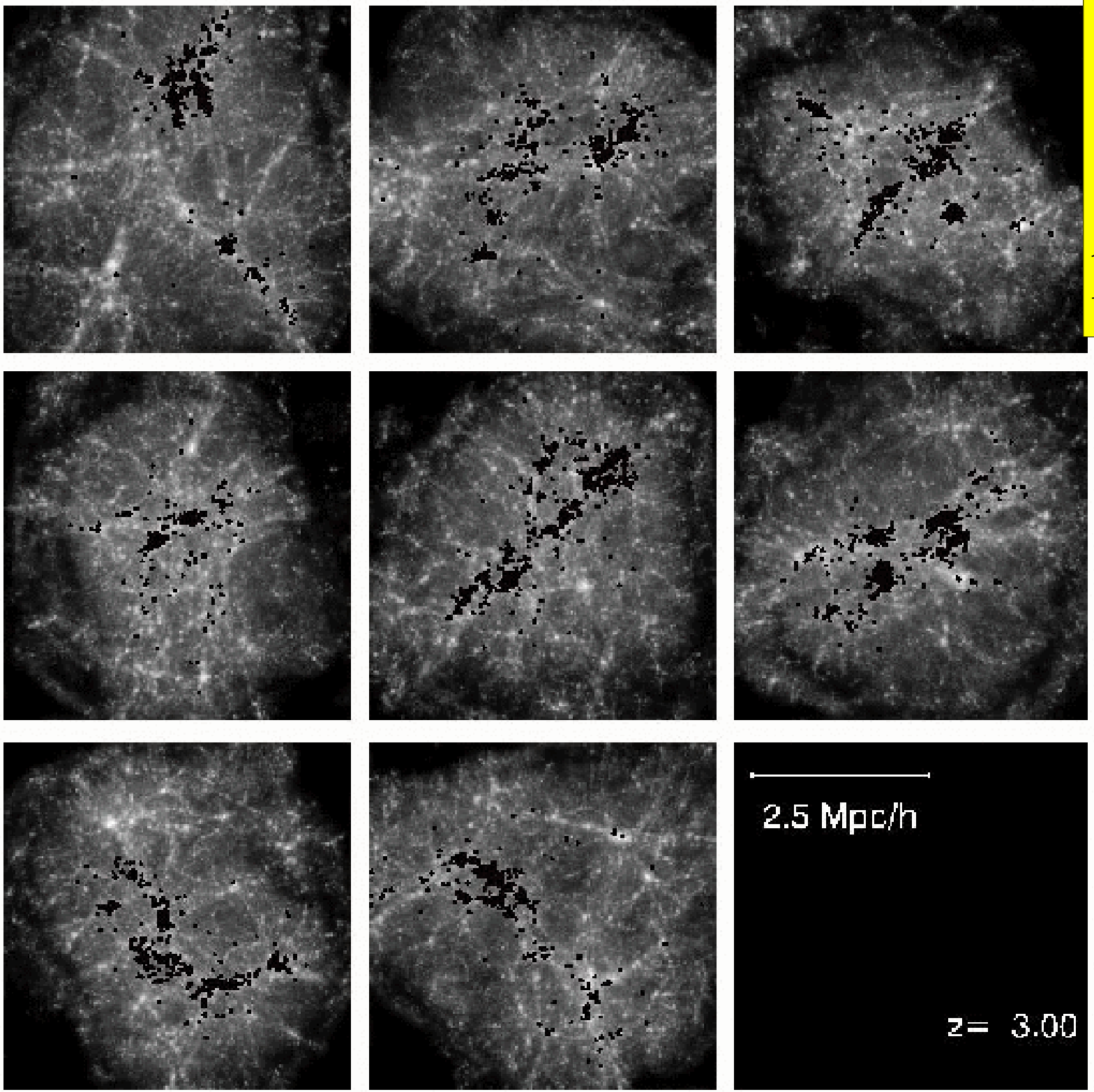

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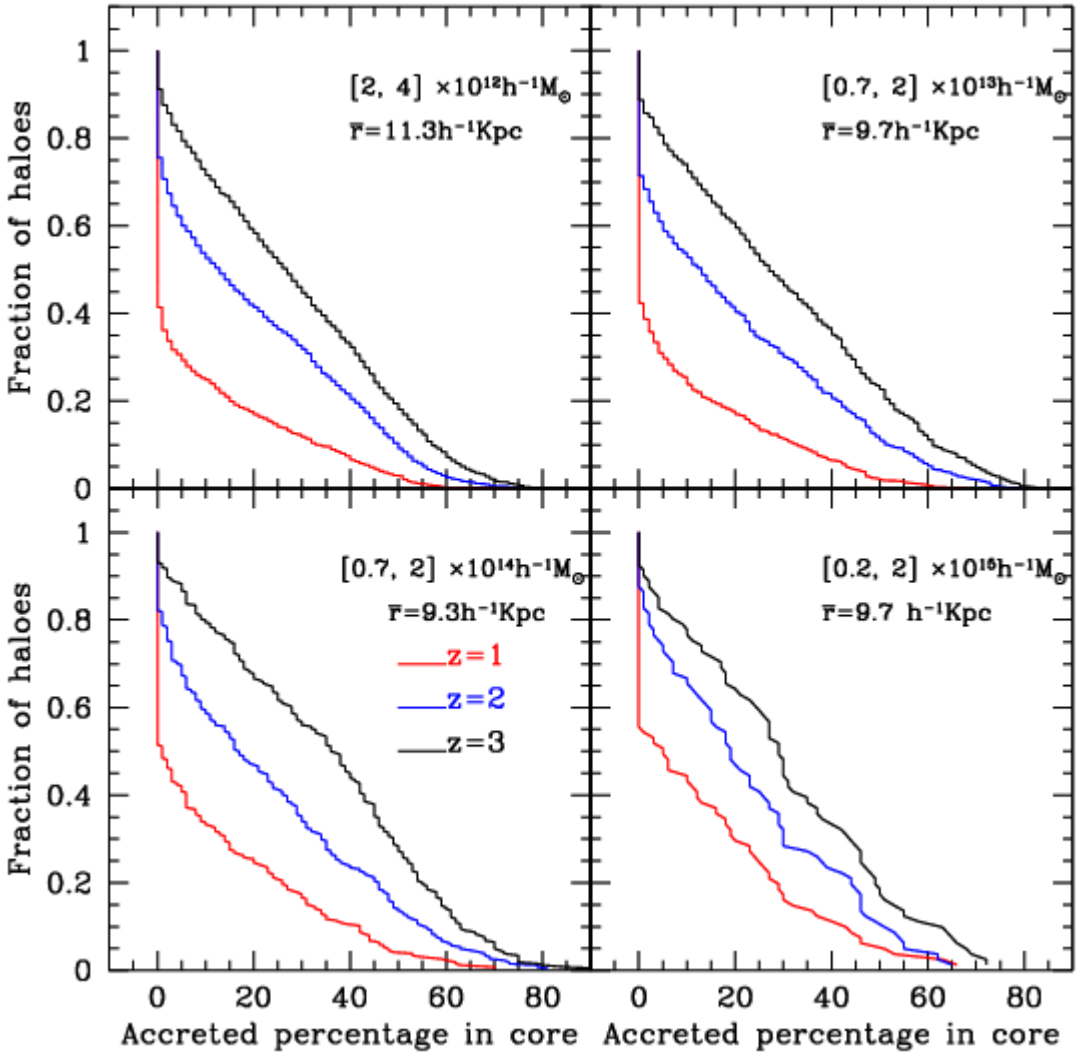
Gao et al 2004a

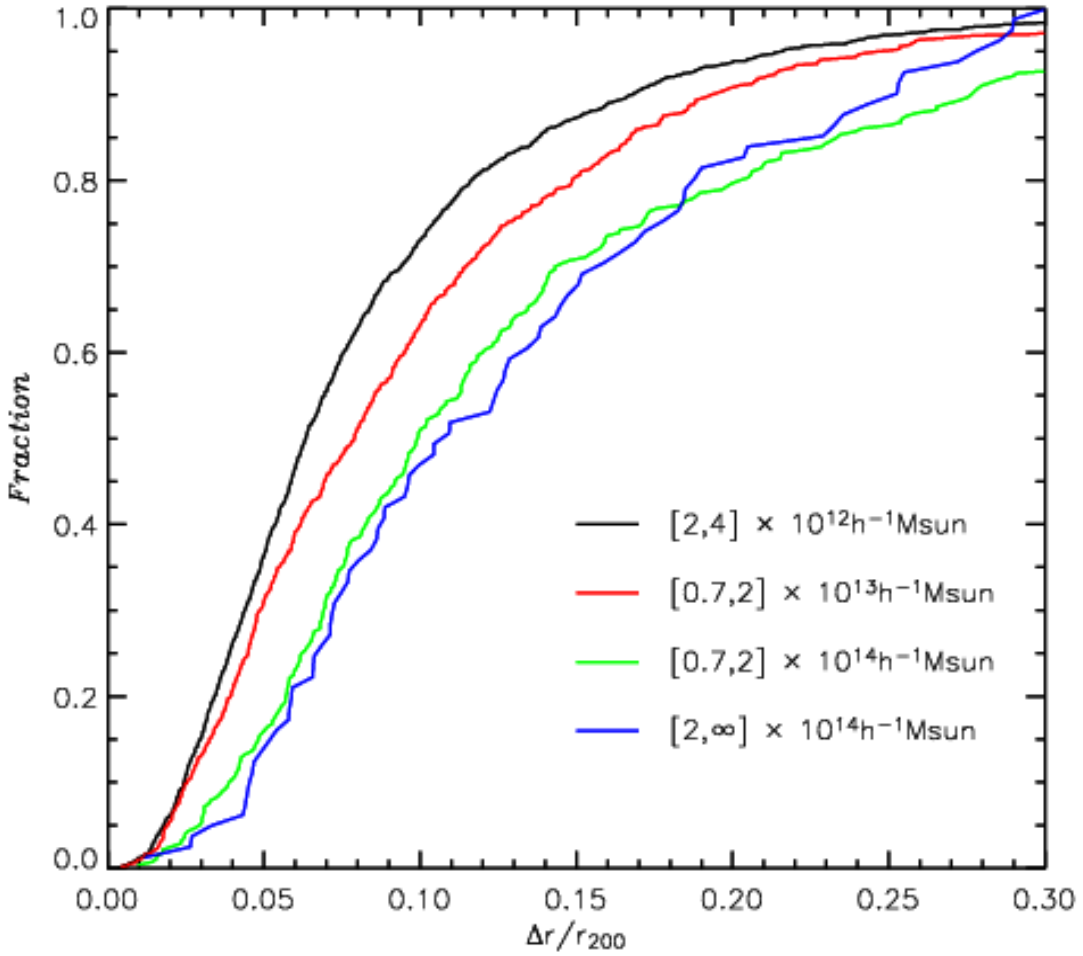
Late accretion onto the visible cores of galaxies

Gao et al 2005, in prep.



- 40% of galaxy mass halos have at least a few percent accretion onto their inner core since z=1
- 17% have accreted more than 20% of their inner core since z=1
- 40% have accreted more than 20% of their inner core since z=2

Are halo cores in equilibrium?

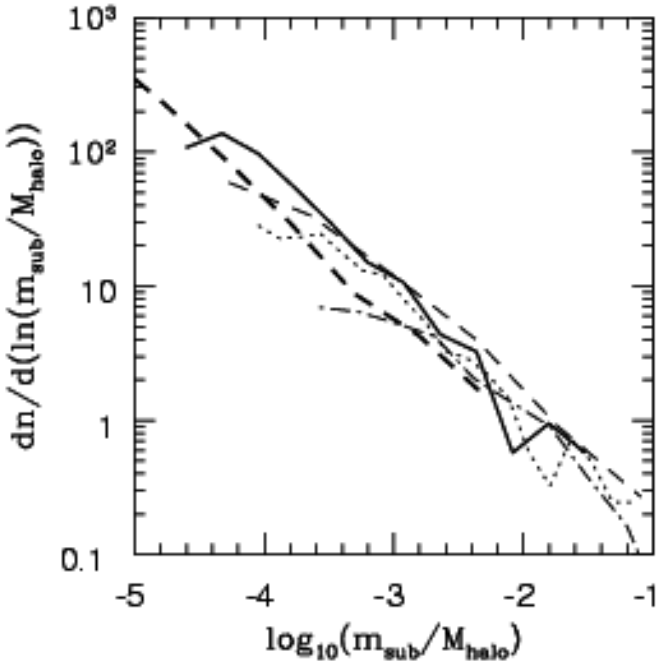


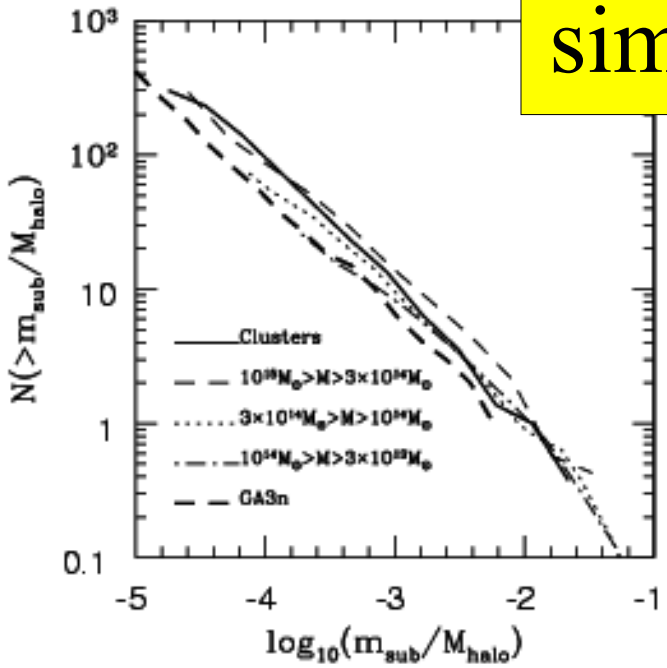
Gao et al 2005, in prep.

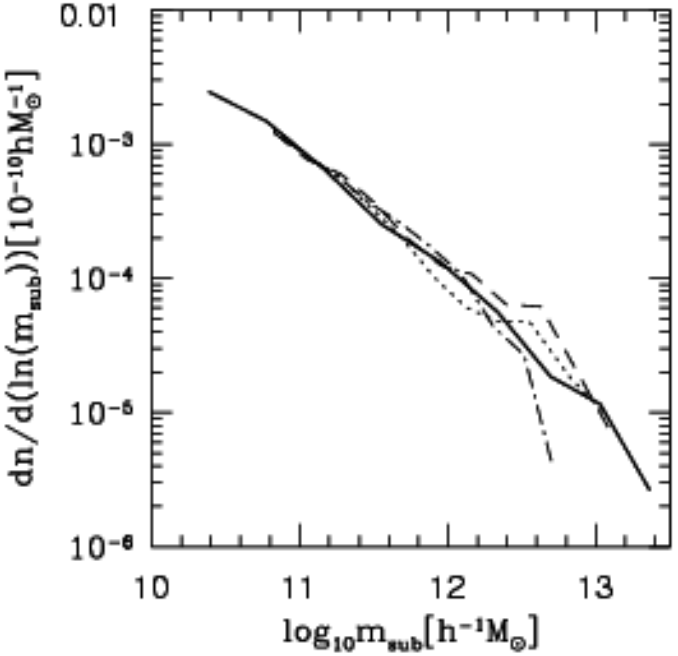
- At z=0 about 20% of Milky Way like halos have their potential centre offset from their barycentre by more than 0.1 r_{200} ~ 0.2 $r_{1/2}$
- Offsets are typically larger for more massive halos
- Offsets are likely to be associated with lop-sidedness and warps

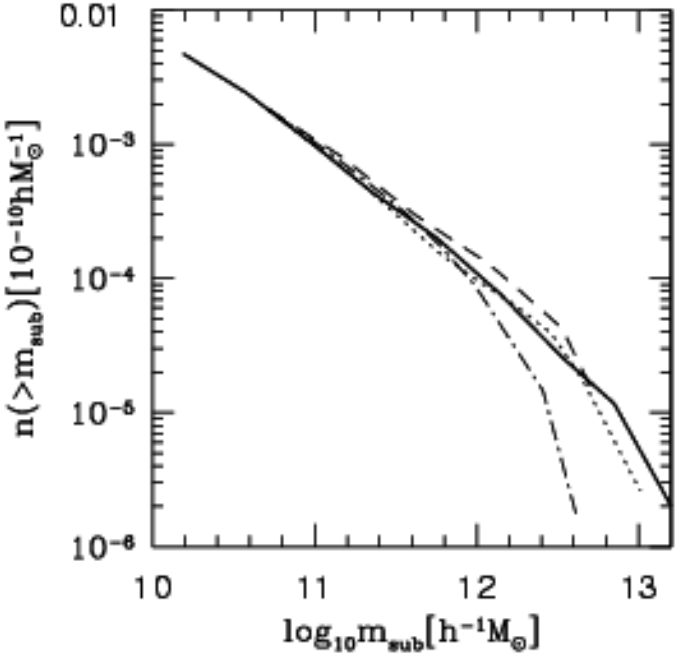
Gao et al 2004b

Do all halos have similar substructure?







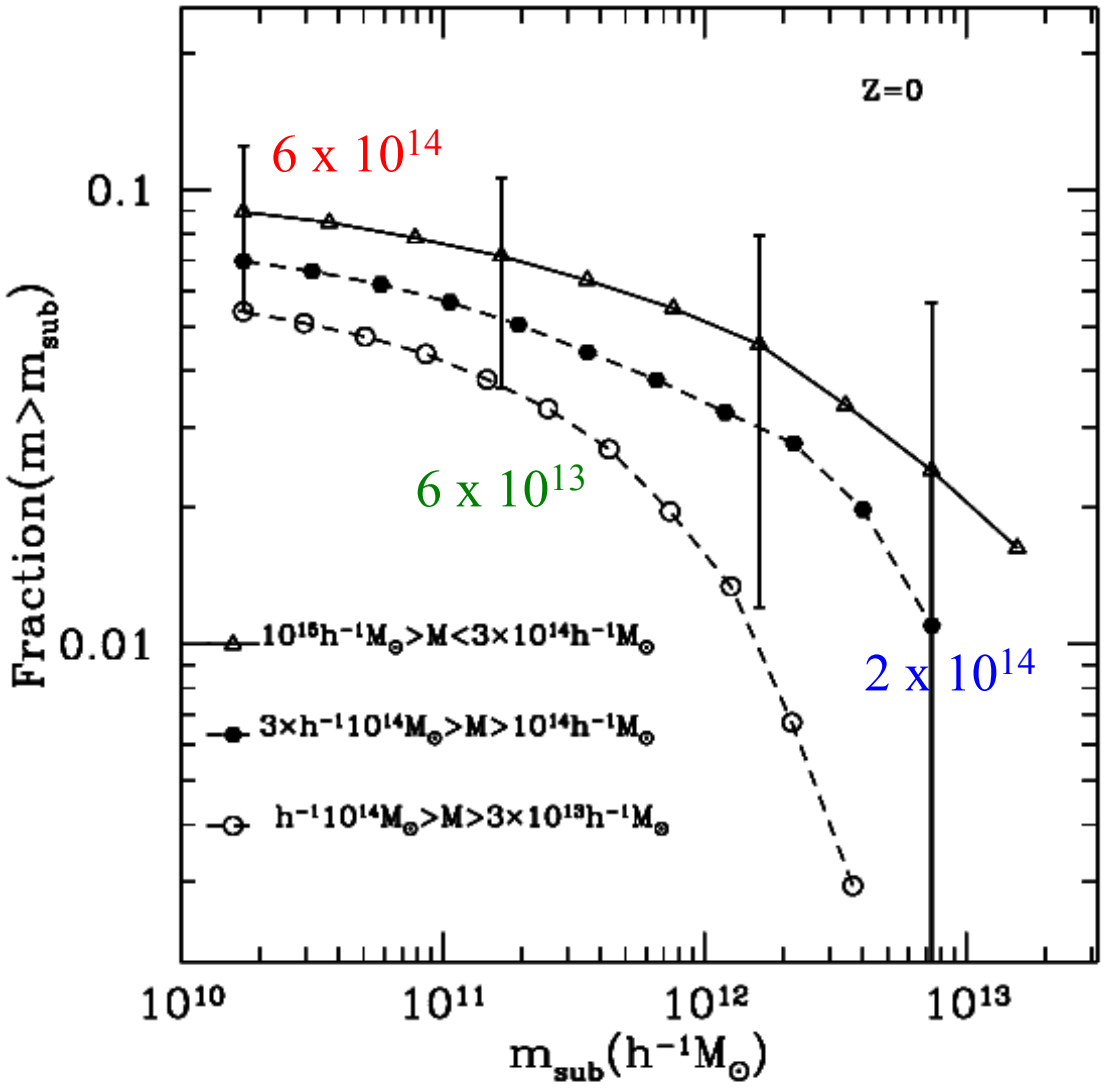


Scaling subhalo mass functions to the mass of the parent halo gives systematics with M_{halo}

Counting subhalos per unit parent halo mass *without* scaling gives much better agreement at low mass + a cut-off at high m_{sub}/M_{halo}

Mass fraction in substructure

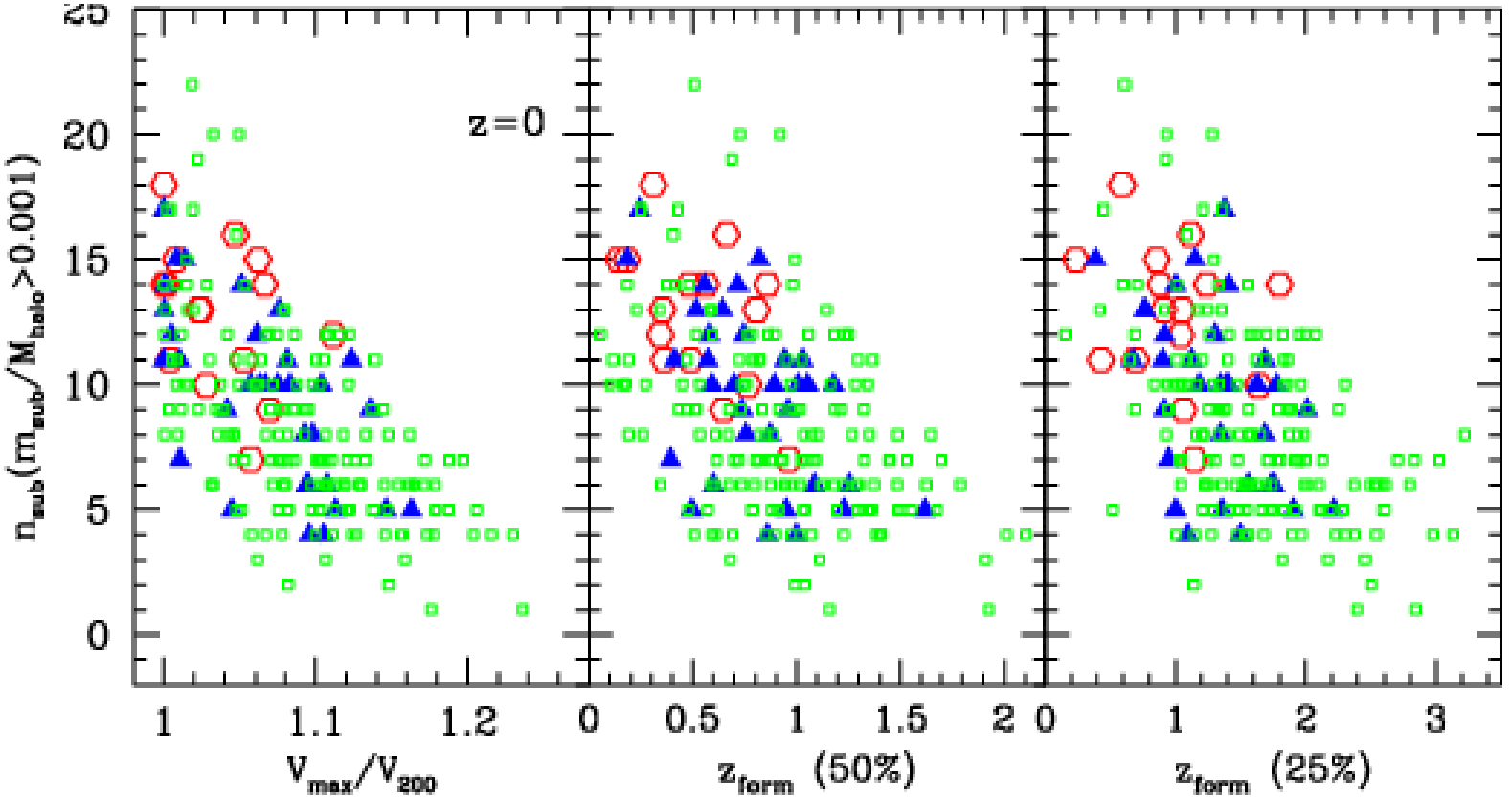
Gao et al 2004b



- Dispersion is large between similar mass objects
- Most of the subhalo mass is in the most massive subhalos
- More massive halos have a larger fraction of their mass in substructure
- Fraction of halo mass in subhalos less massive than ~ 2 x 10^{11} is the same in all the mass groups

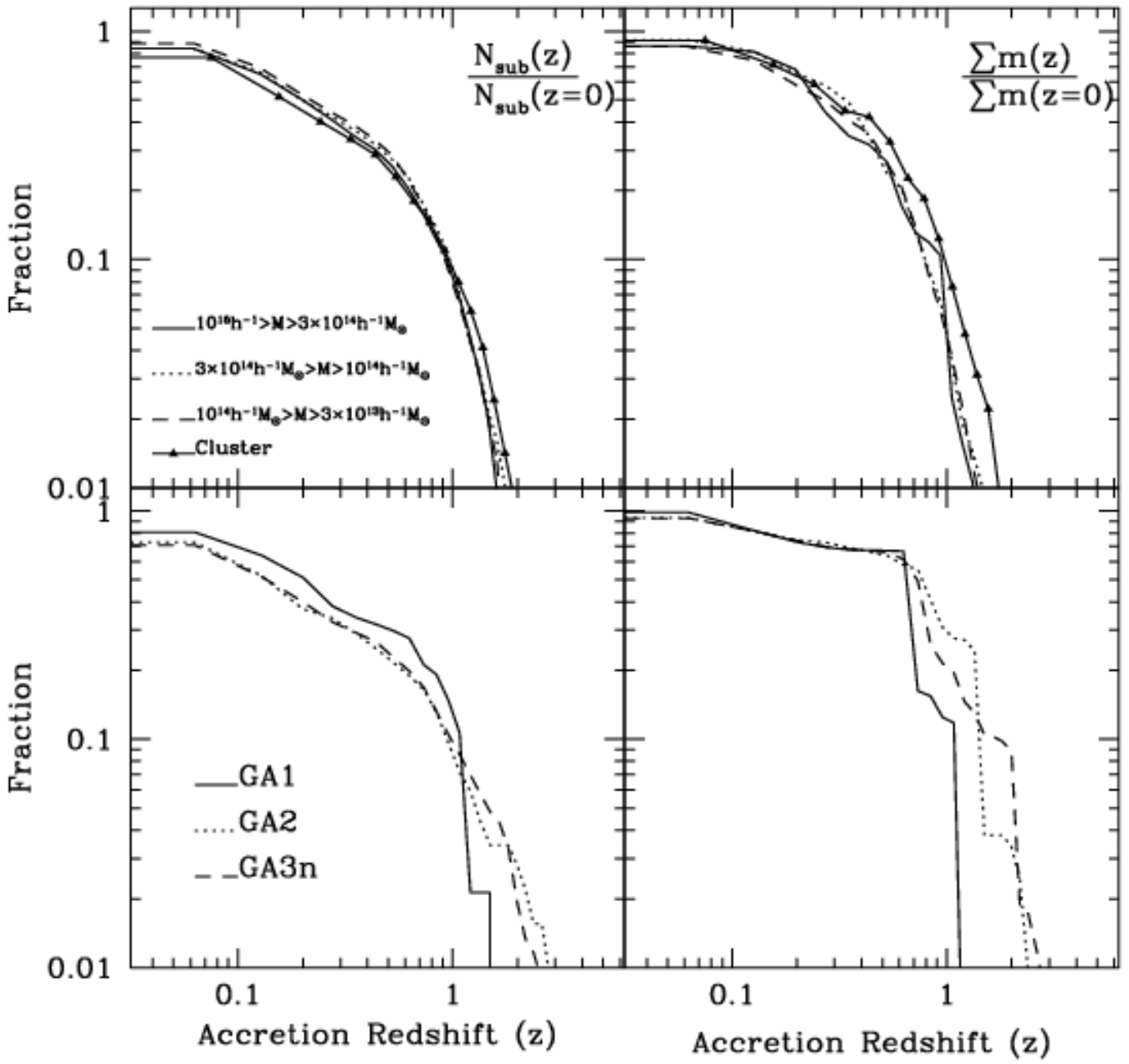
Substructure as a function of other halo properties

Gao et al 2004b



At every mass, halos with lower concentration (V_{max} / V_{200}) or with later formation times have more substructure

Gao et al 2004b



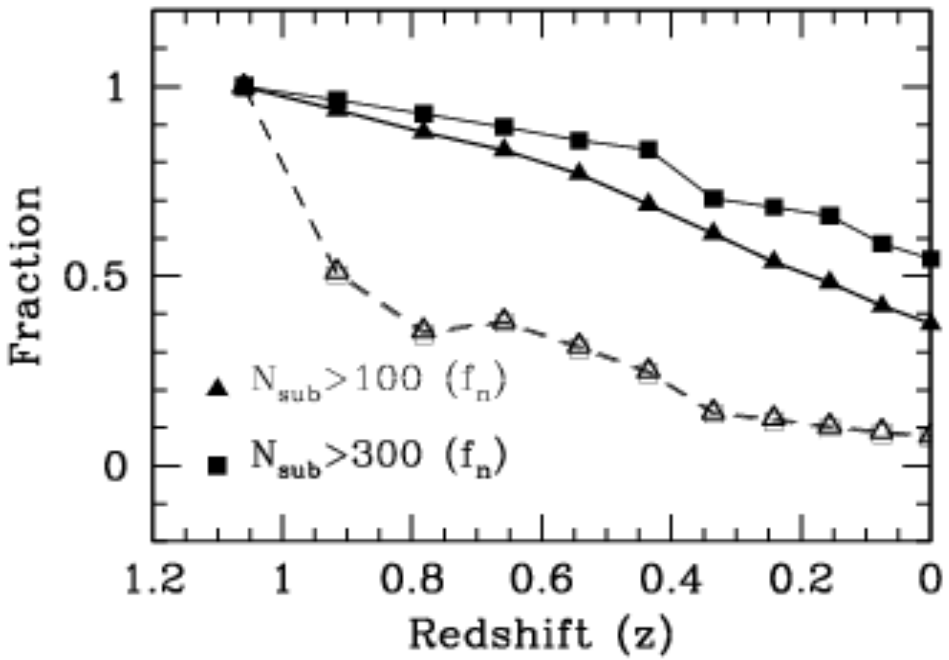
When are sub-halos accreted?

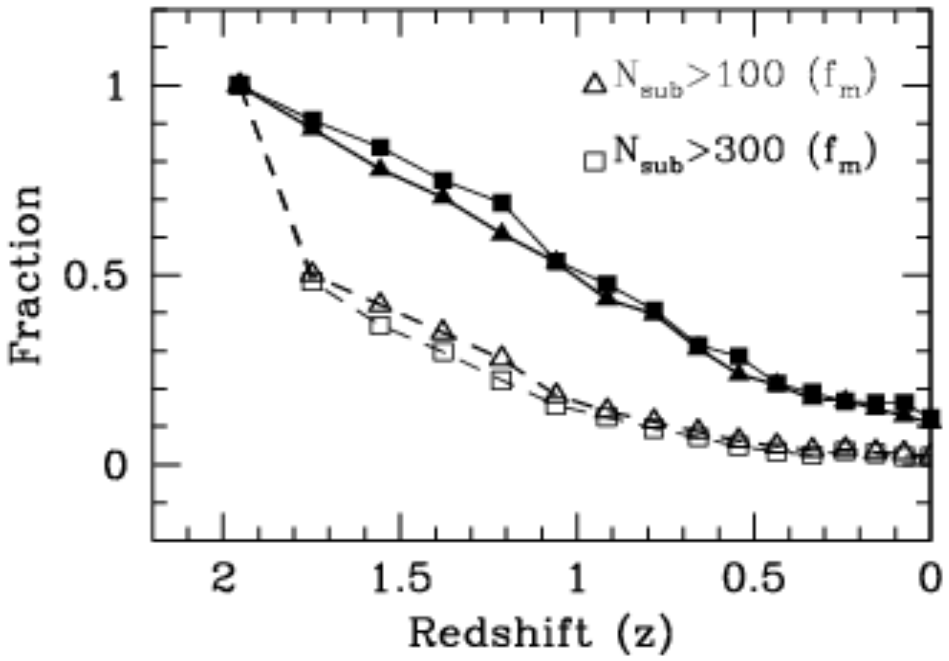
Most of the subhalos (and most of the mass in subhalos) first became a subhalo at *late* times

70% after z = 0.5
90% after z = 1.0

This is much *later* than the accretion time of typical DM particles

Gao et al 2004b



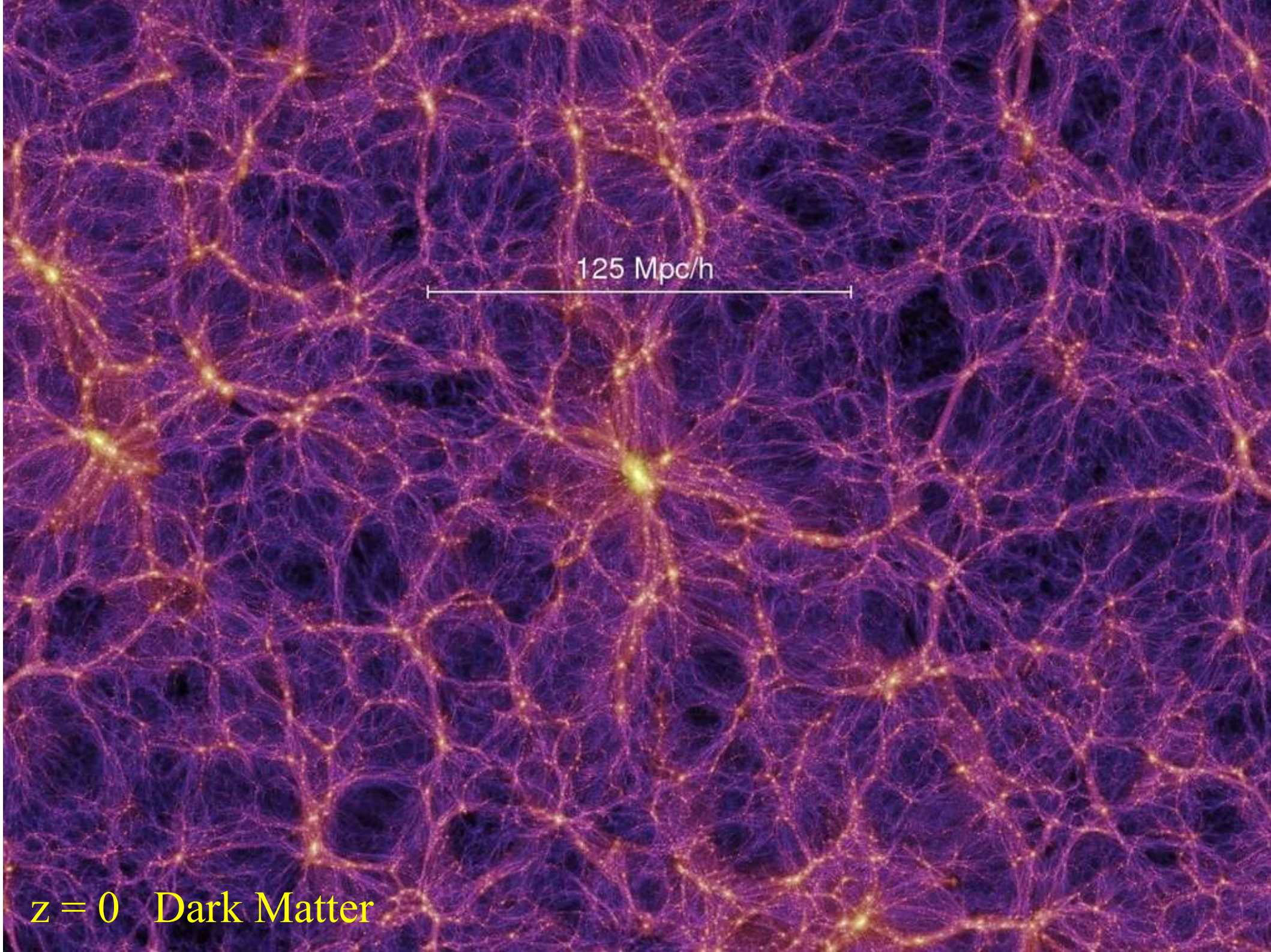


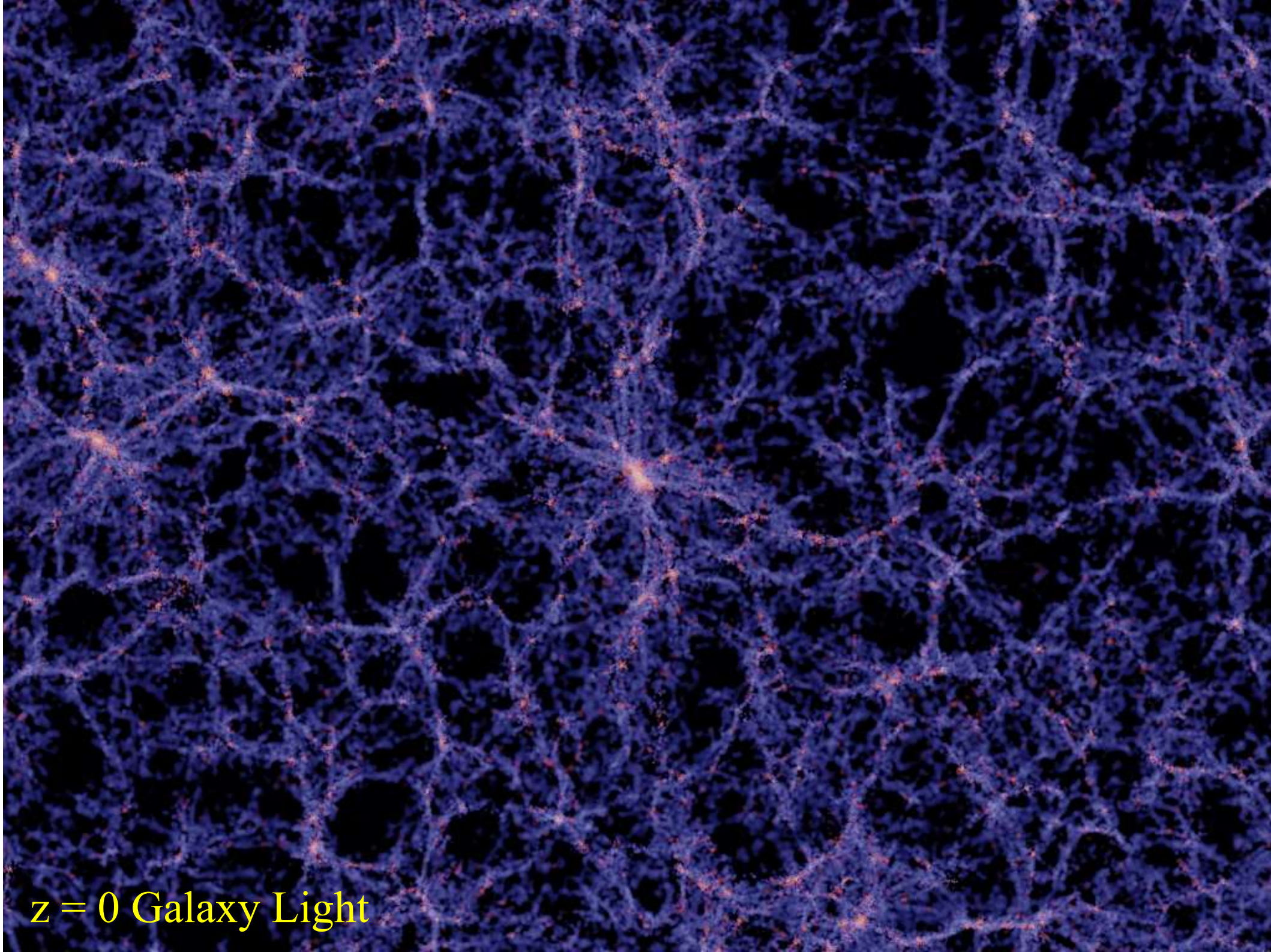
How rapidly do infalling halos lose mass or disrupt

Subhalos accreted at z = 1 lose a factor 2 in number and a factor 12 in mass by z = 0

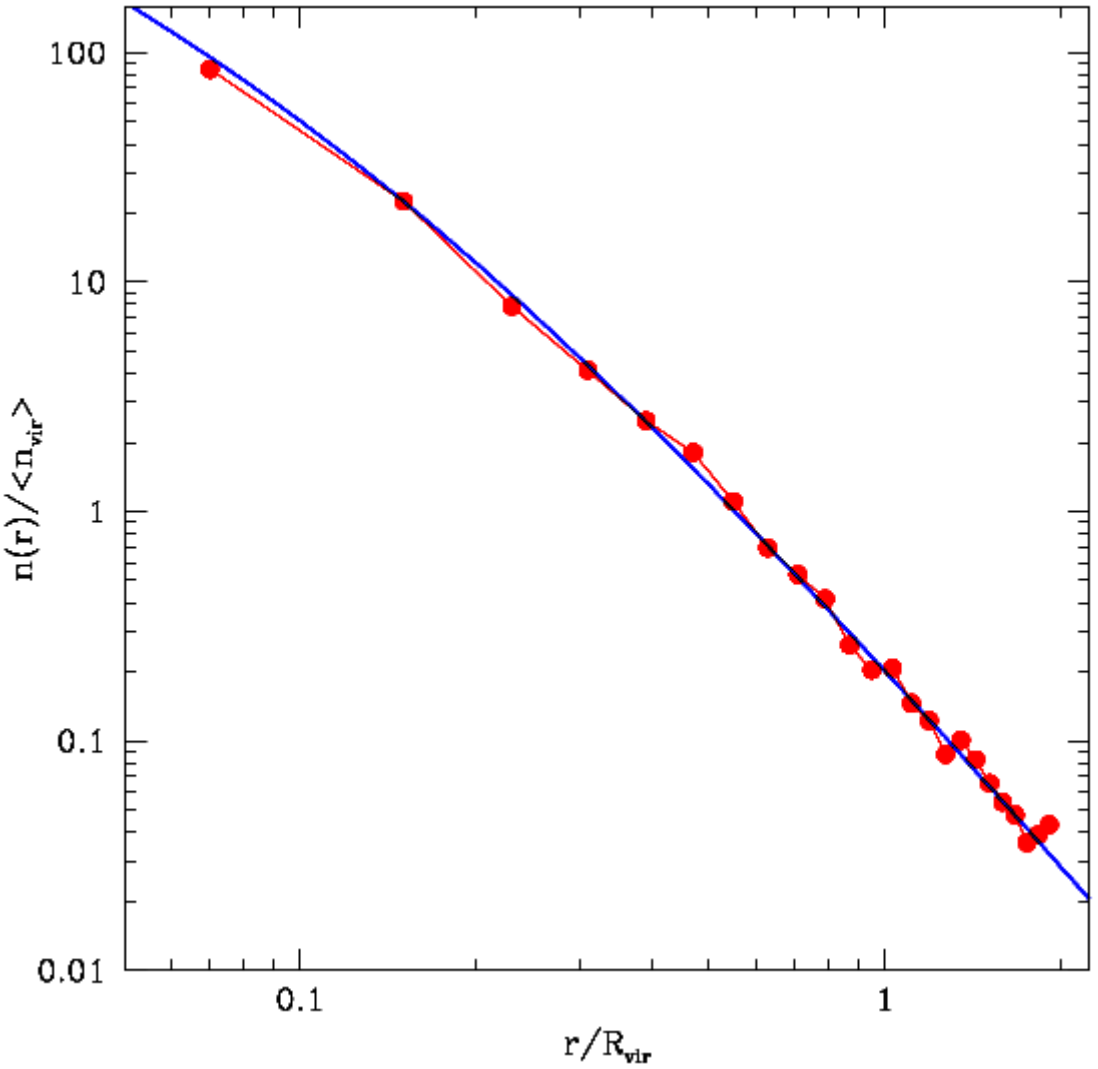
Subhalos accreted at z = 2 lose a factor 8 in number and a factor 50 in mass by z = 0

Although the number reduction is affected by resolution the mass reduction is not


125 Mpc/h
z = 0 Dark Matter


z = 0 Galaxy Light

Do satellites follow the halo mass distribution?

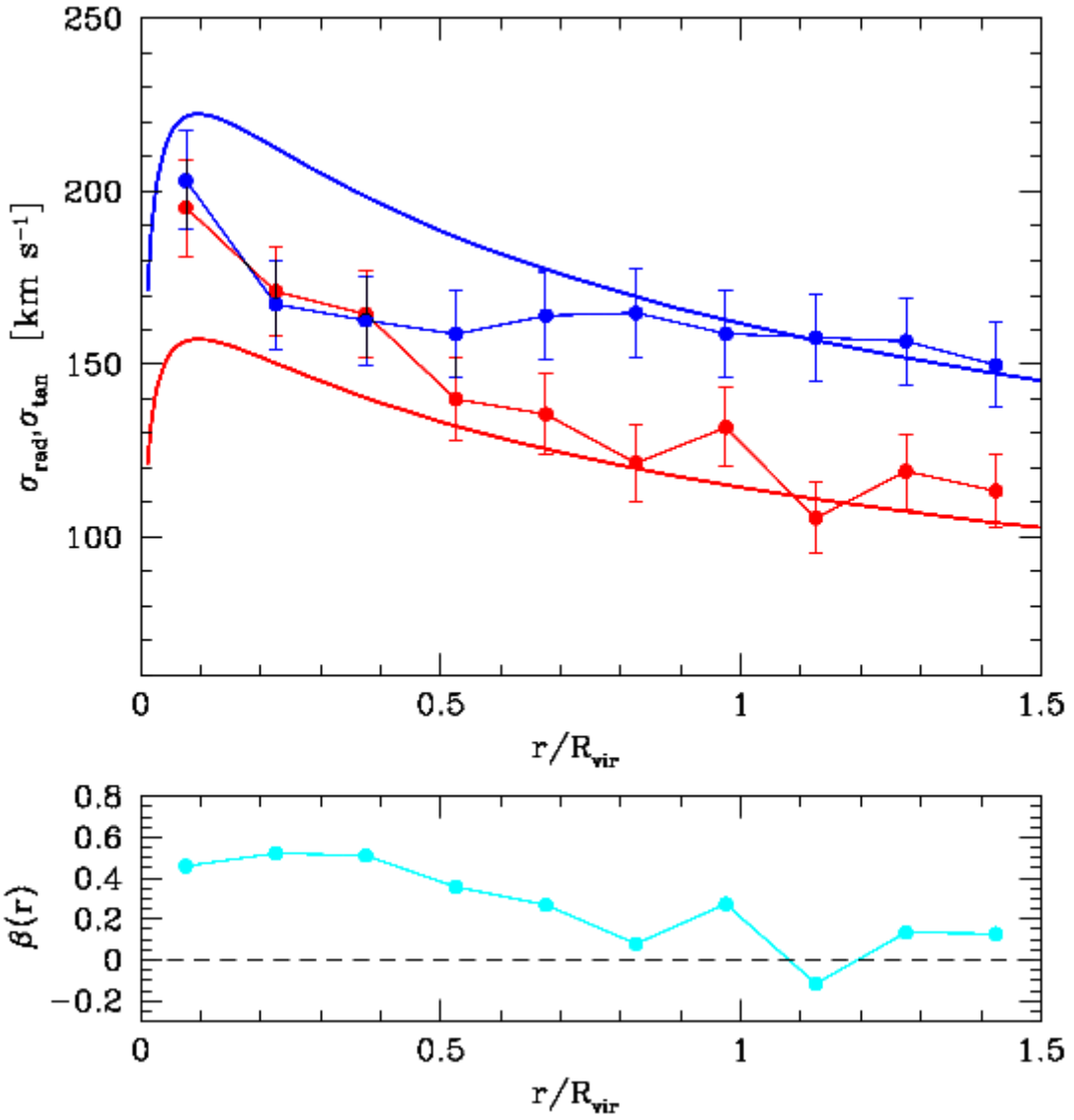


Prada et al 2005

Mean radial number density profile for all satellites with $M_B < -15.6$ surrounding $\sim 10^3$ isolated disk galaxies with $M_B \sim -20.0$

Blue curve is NFW fit to mean halo mass profile

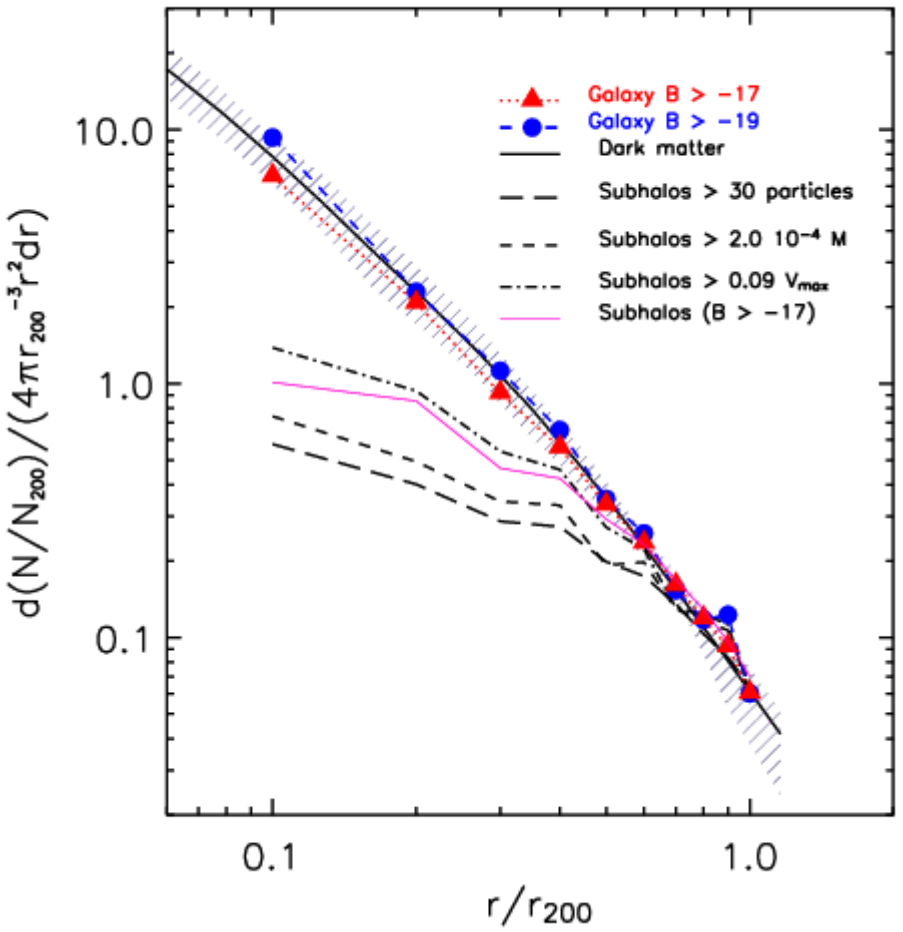
Do satellites follow the halo mass distribution?



Prada et al 2005

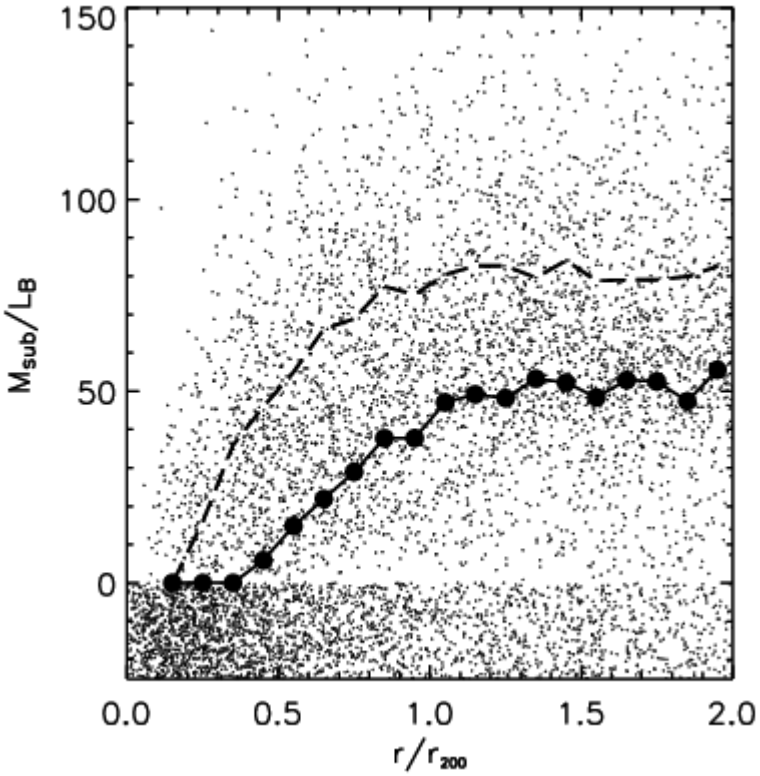
Mean radial and tangential velocity dispersion profiles and local anisotropy parameter for satellites with $M_B < -15.6$ surrounding $\sim 10^3$ isolated disk galaxies with $M_B \sim -20.0$

Gao et al 2004c



Do galaxies follow the subhalo distribution?

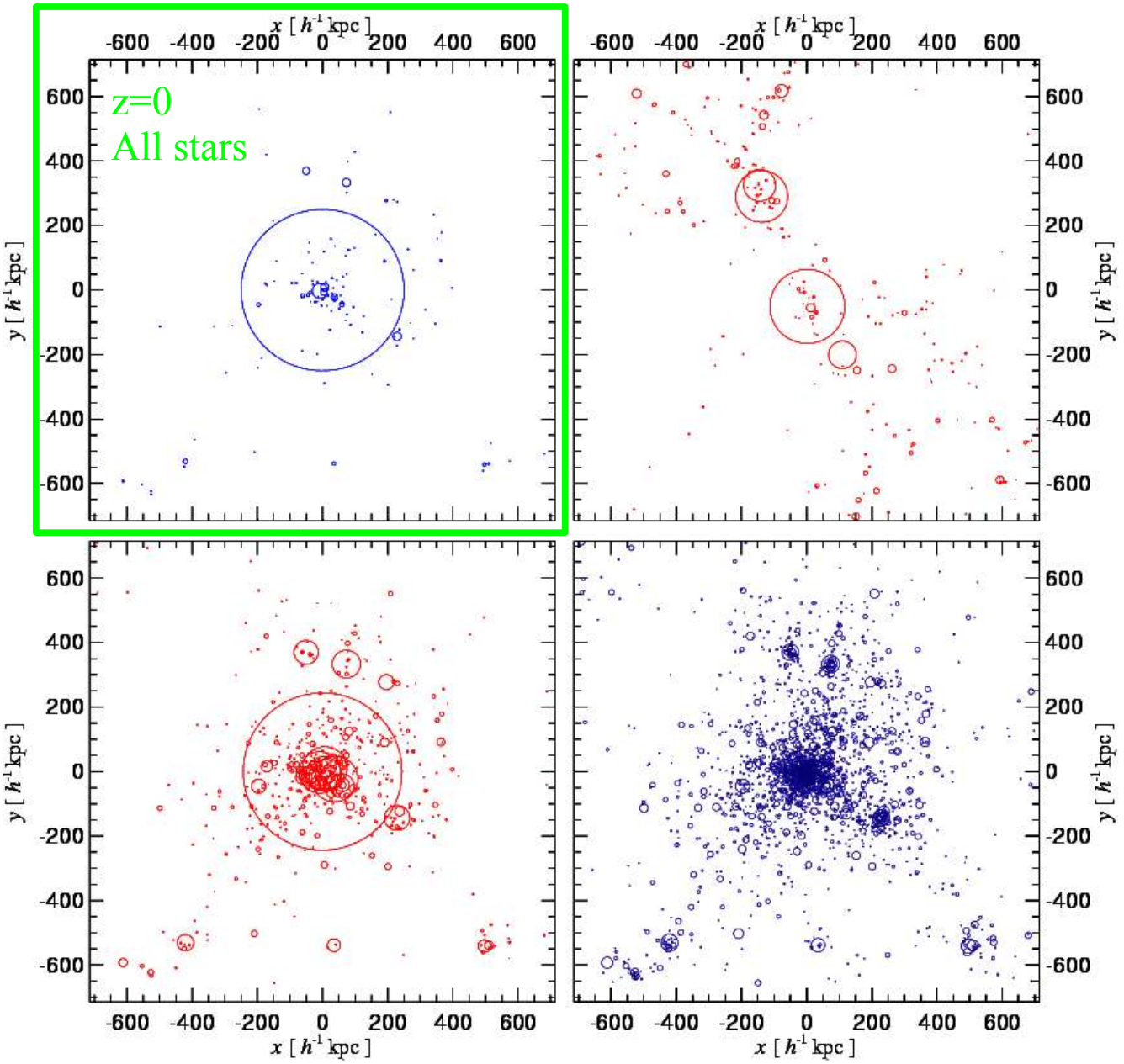
The galaxy population to a magnitude limit is predicted to follow the radial mass profile *not* the subhalo profile to a mass or circular velocity limit



This is because the galaxy M/L is a strong function of r within a halo as a consequence of stripping effects

Where should the first (lowest Z) stars be now?

White & Springel 1999



$M_{halo}(z=0) = 2 \times 10^{12} M_{\odot}$

At z = 0 the stars within the virial radius are:

80% in the disk
16% in the bulge
2% in biggest satellite
2% in other satellites

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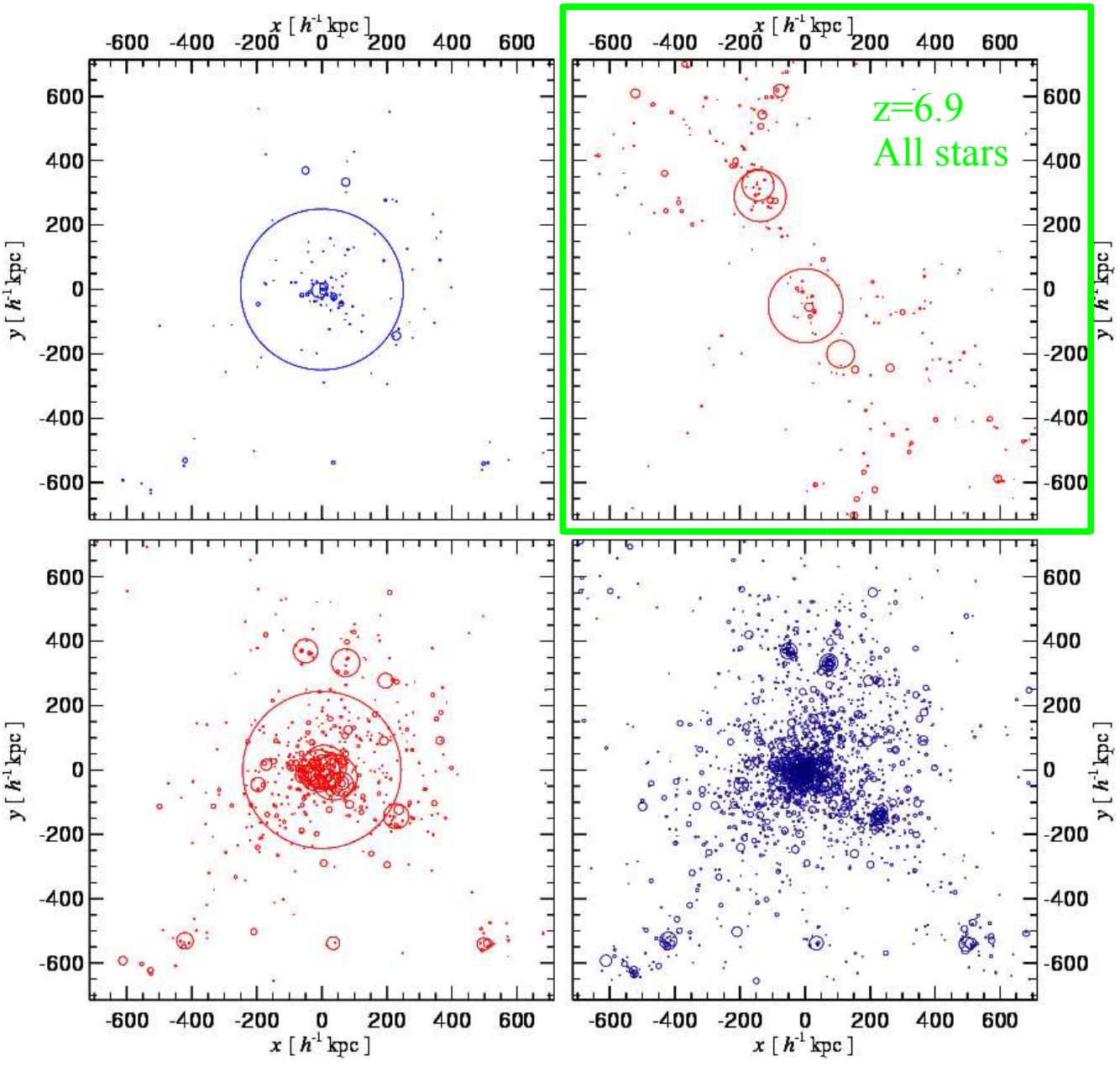


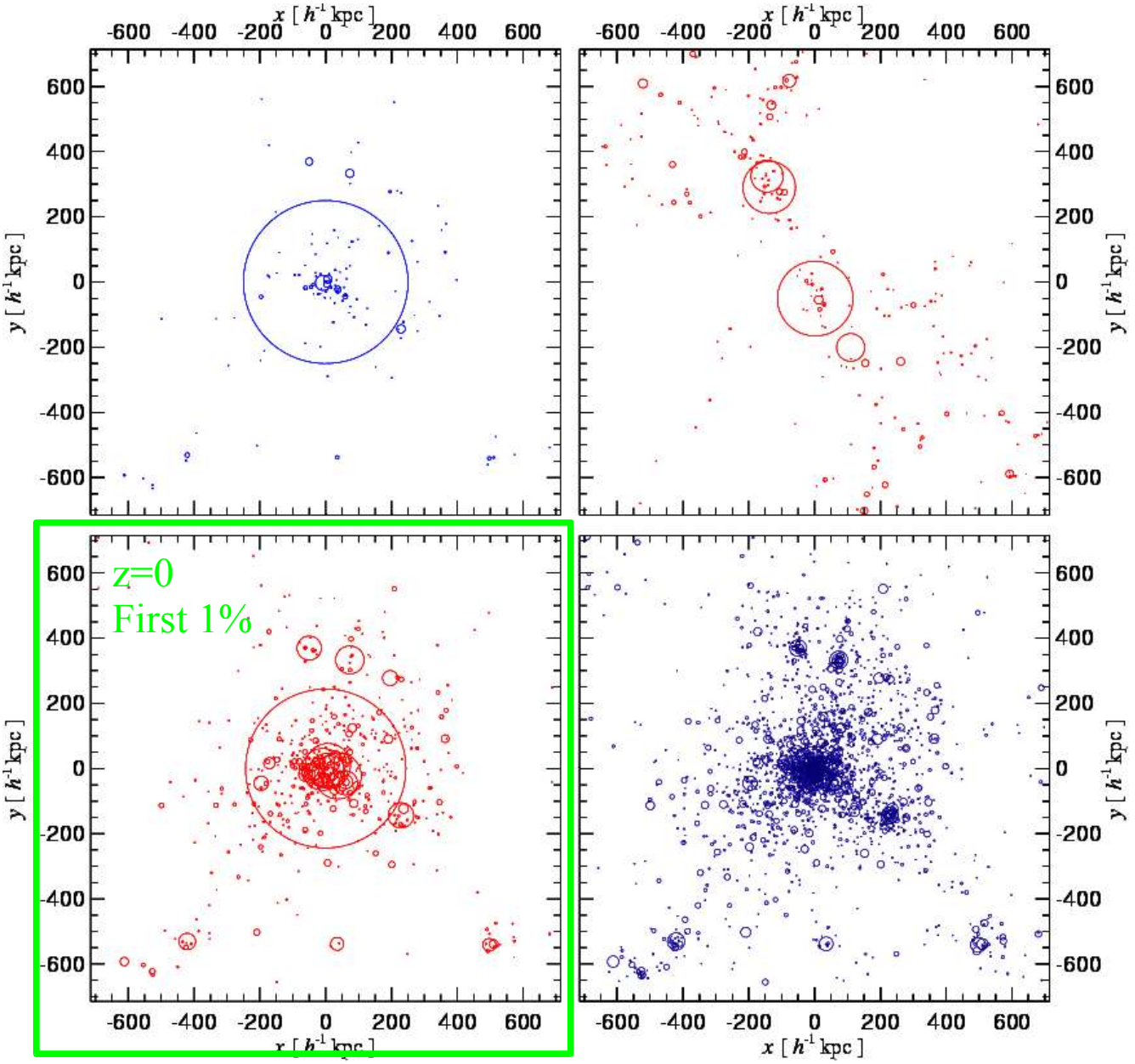
$M_{halo}(z=0) = 2 \times 10^{12} M_{\odot}$

At z = 6.9 one percent of the stars have already formed

Most are in a small number of big progenitors

Where should the first (lowest Z) stars be now?

White & Springel 1999



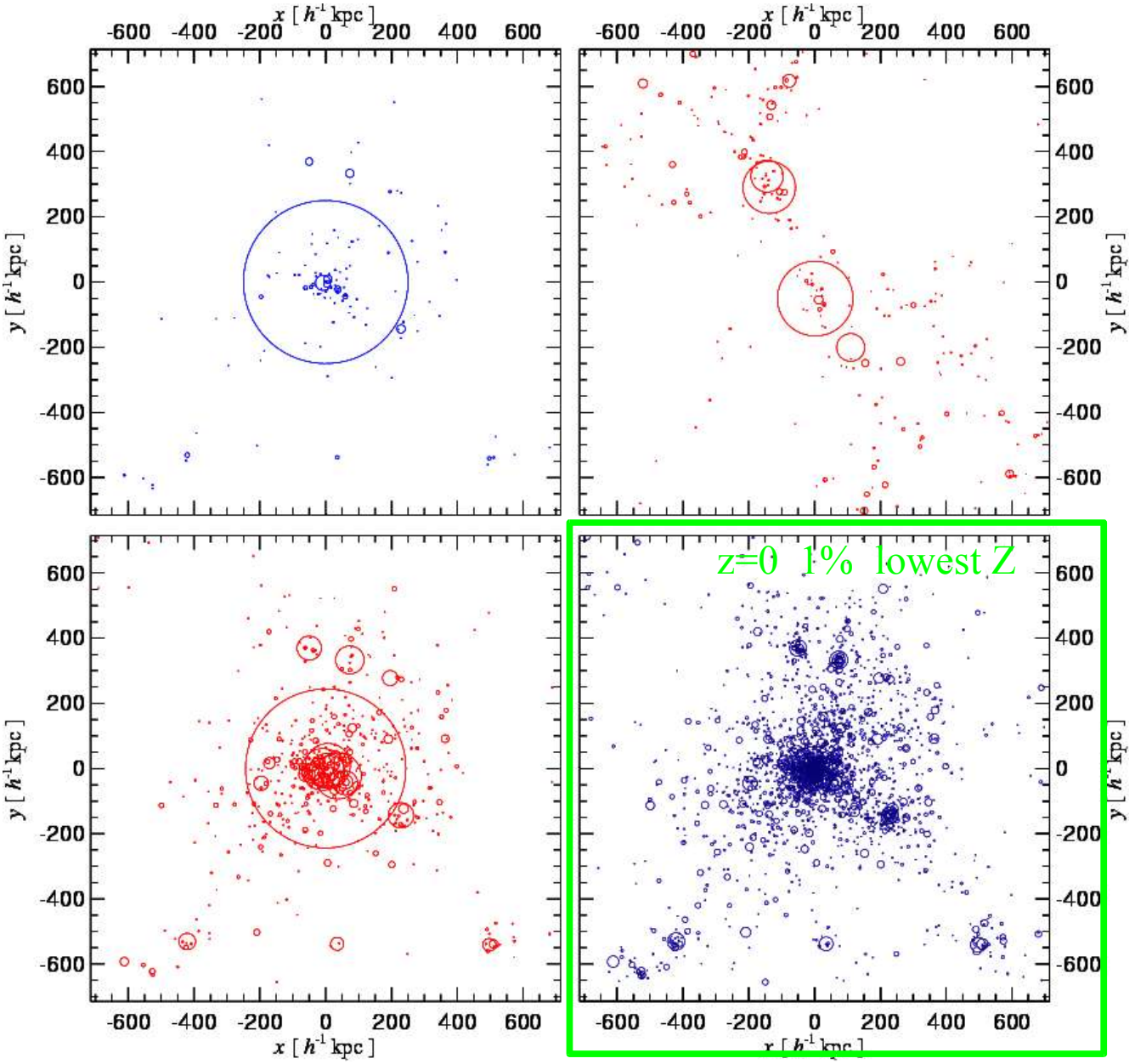
$M_{halo}(z=0) = 2 \times 10^{12} M_{\odot}$

At z = 0 this first 1% of stars are mostly (60%) in the bulge

Older stars are even more concentrated to the centre

Where should the first (lowest Z) stars be now?

White & Springel 1999



$M_{halo}(z=0) = 2 \times 10^{12} M_{\odot}$

At z = 0 the 1% of stars which formed in the lowest mass halos are much more broadly distributed.

These could plausibly be the lowest metallicity stars

PLAN

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- Do all halos look similar?
- Is significant mass in substructures? Which ones?
- Are substructures as “old” as their host halos?
- Do satellite galaxies follow the subhalo distribution?
- Where are the first stars now?

CONCLUSIONS

- Does halo formation history depend on present environment?
  YES
- Have halo cores been in place since high redshift?
  Substantial mass was recently added to many
- Are halo cores in equilibrium?
  Many are off-set from halo barycentre
- Do all halos look similar?
  YES, but with a large dispersion
- Is significant mass in substructures? Which ones?
  Most subhalo mass is in the most massive subhalos
- Are substructures as "old" as their host halos?
  NO – most were accreted after $z = 0.5$
- Do satellite galaxies follow the subhalo distribution?
  NO – they follow the mass distribution
- Where are the first stars now?
  In the bulge