IAP, Paris, July 2005

The Assembly History of ΛCDM Halos

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PLAN

- Does halo assembly depend on present environment?
  YES → HOD -- R.I.P.
- Were halos built from inside to outside?
  Mass is added late to many halo cores
- Are halo cores in equilibrium?
  Many are not at the centres of their halos
- Is the substructure mass function universal?
  YES -- but *not* when scaled to halo mass
- Is significant mass in low mass substructures?
  NO -- the most massive subhalos dominate
- Are substructures as "old" as their host halos?
  NO -- most fell in at $z<0.5$, *after* typical DM particles
- Do satellite galaxies follow the subhalo distribution?
  NO -- they follow the *mass* distribution more closely

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

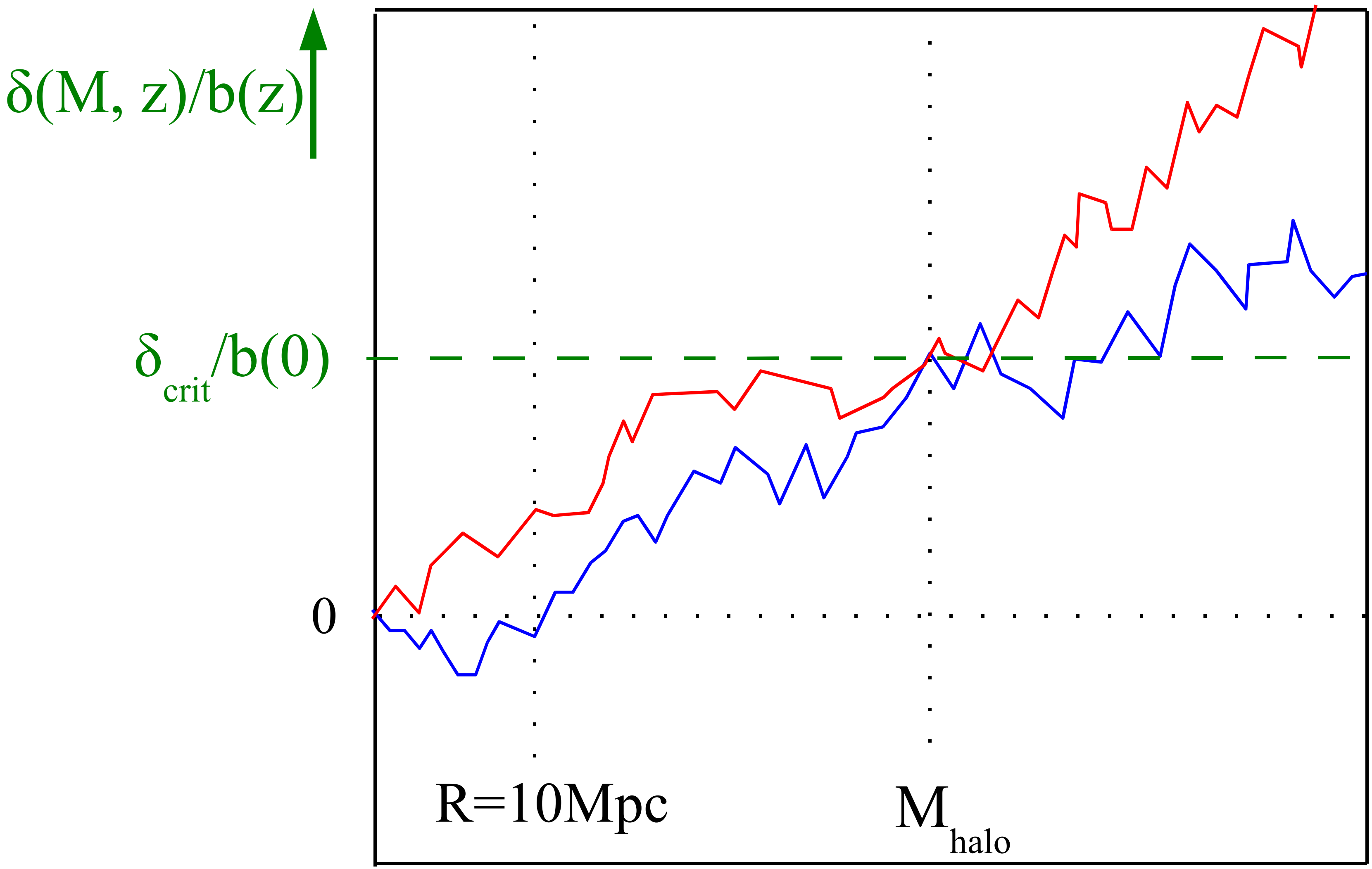
The age dependence of halo clustering

Gao, Springel & White 2005 MNRAS, submitted

Assembly of the inner cores of ΛCDM dark haloes

Gao, White et al 2005, in preparation

Excursion-set model for structure evolution



Bond et al (1991)

Lacey & Cole (1993)

Mo & White (1996)

Sheth, Mo & Tormen (2000)

Sharp k-filter → Markov random walk

→ Halo environment is independent of halo formation history at given mass

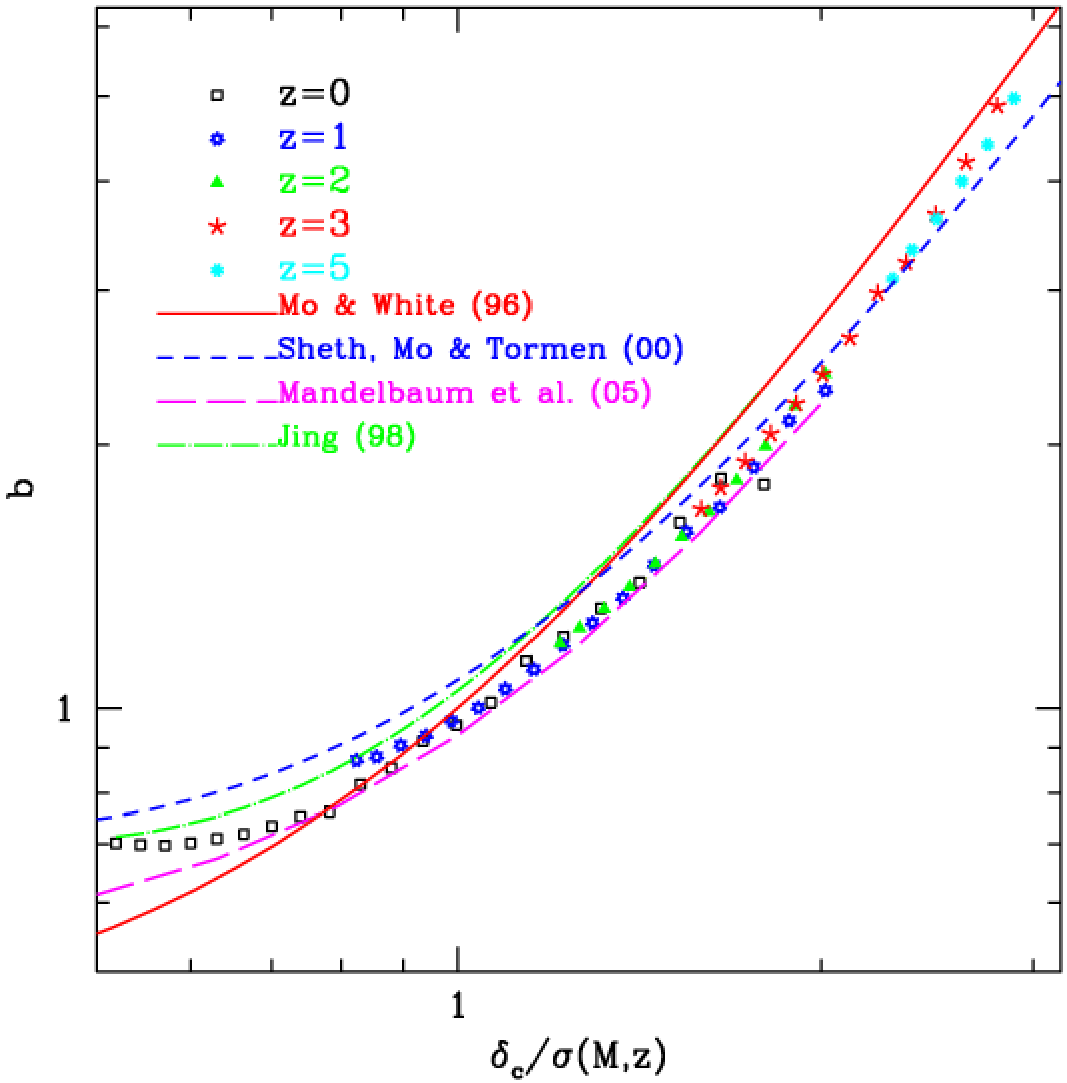
$\sigma(M, z=0)$ →

[k_{smooth} →

← M_{smooth}]

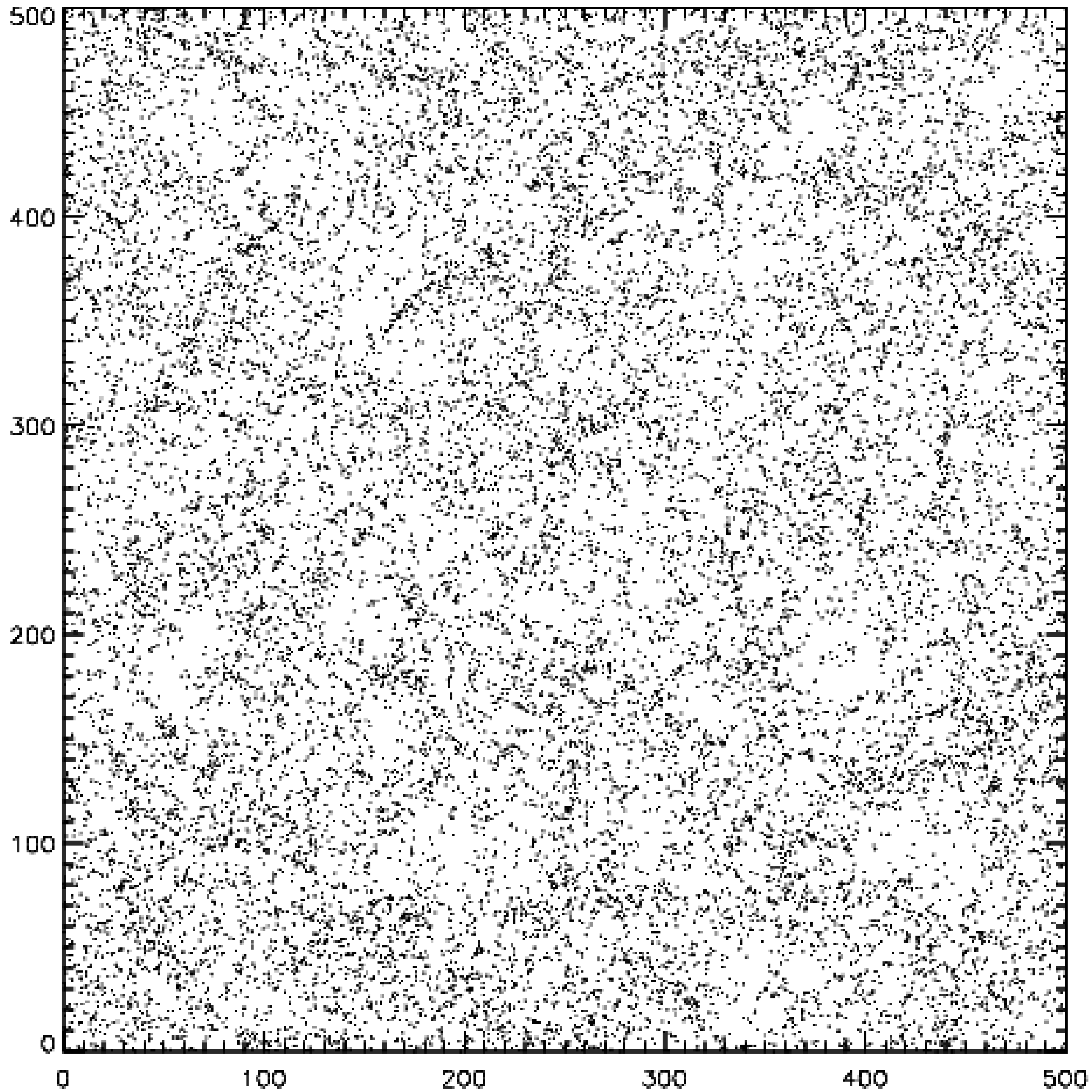
Mean halo bias as a function of mass

Gao, Springel & White 2005



- Massive halos cluster more strongly than low mass halos
- Different simulators agree on the strength of the effect to ~ 10%

Distribution of $10^{11}M_\odot$ halos in the Millennium Run



Gao, Springel & White 2005

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

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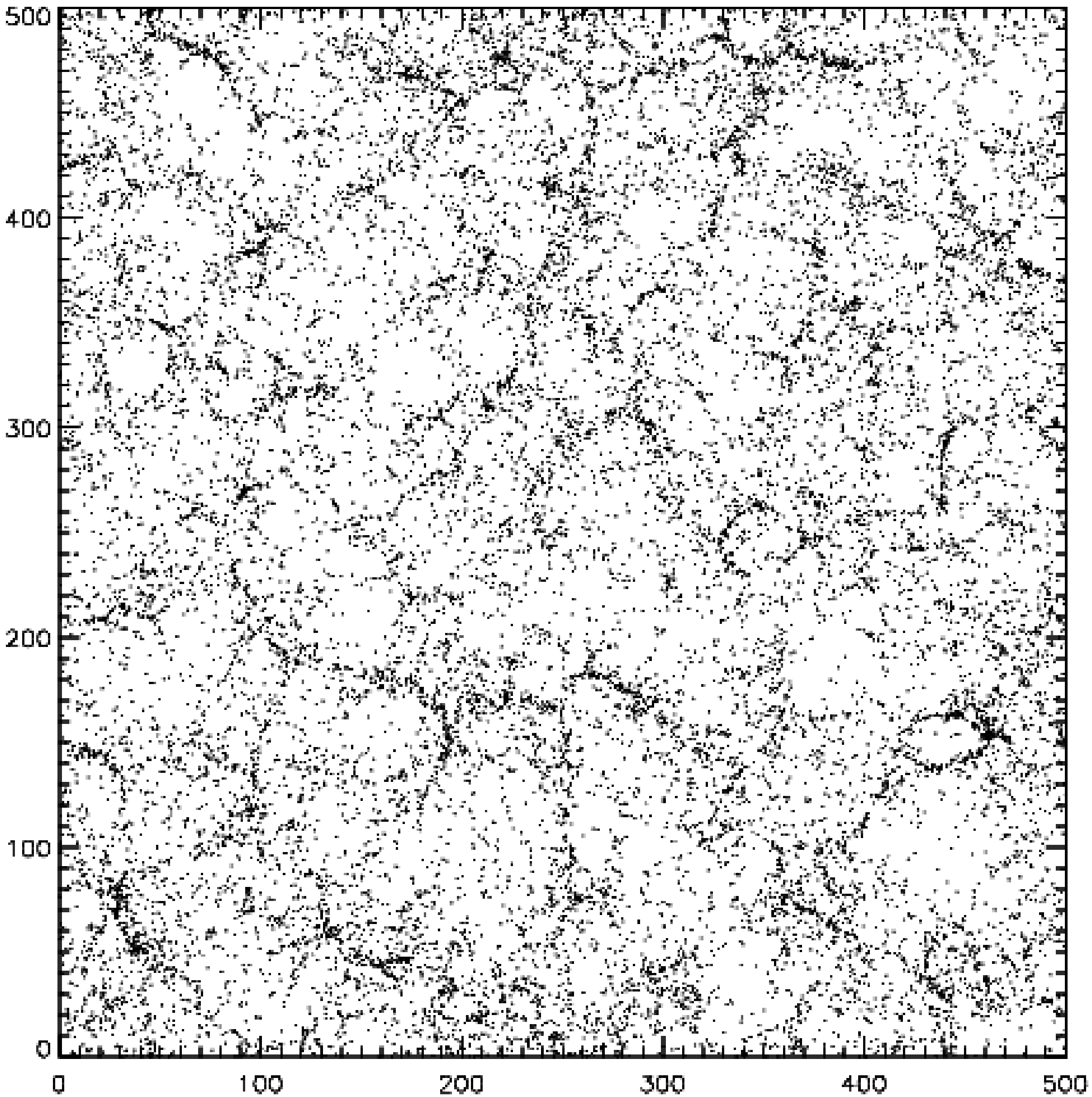

Gao, Springel & White 2005

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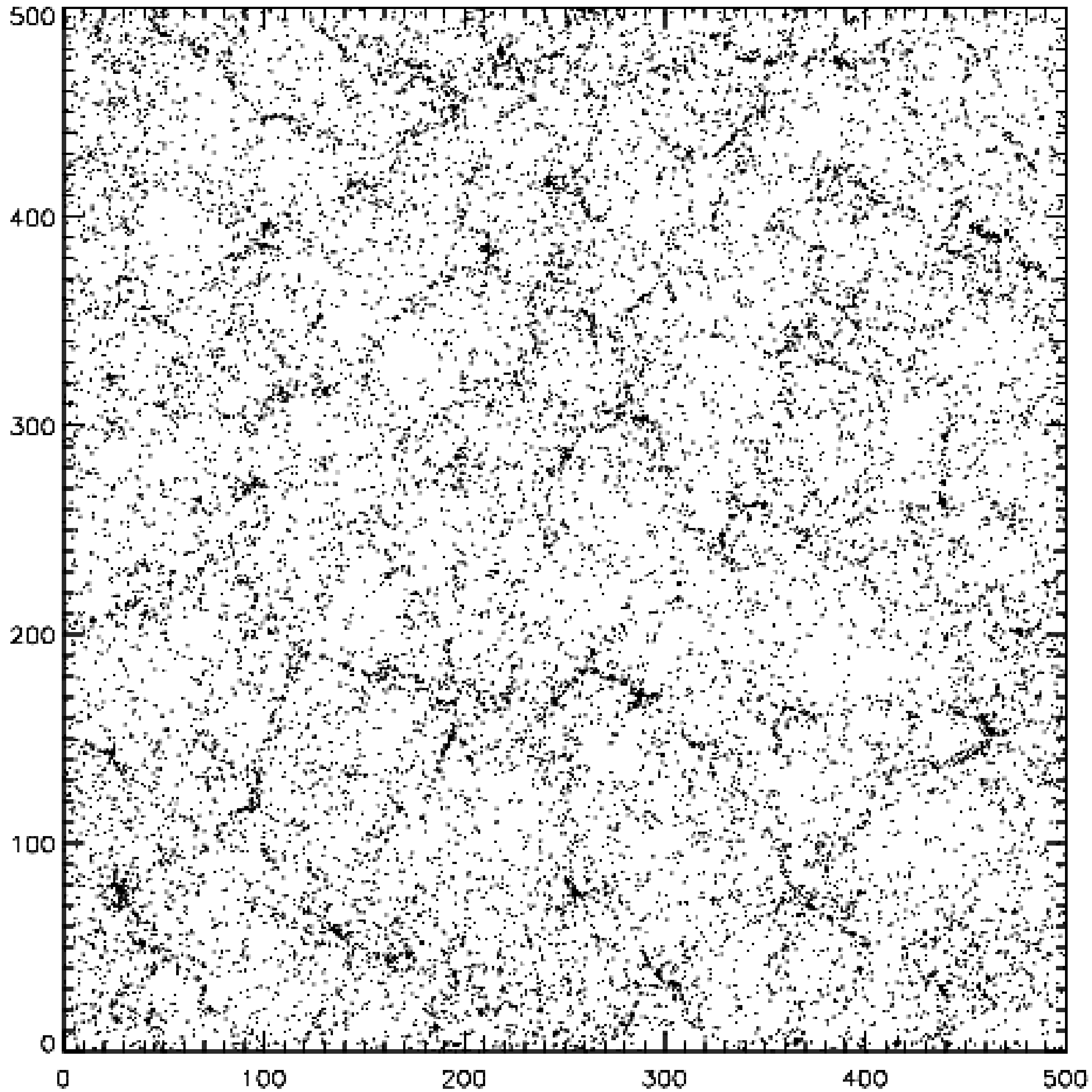
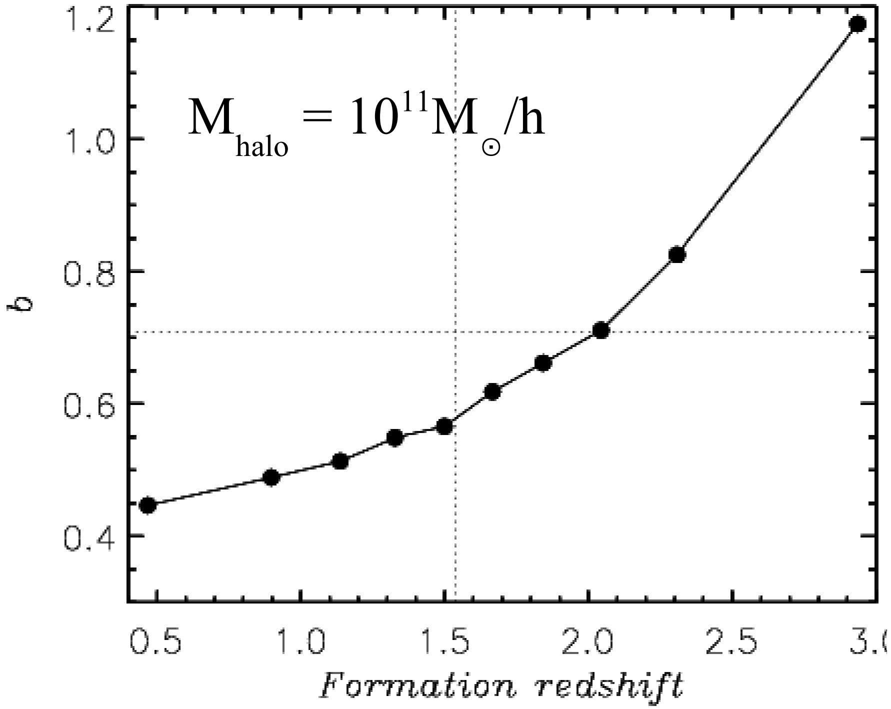


Gao, Springel & White 2005

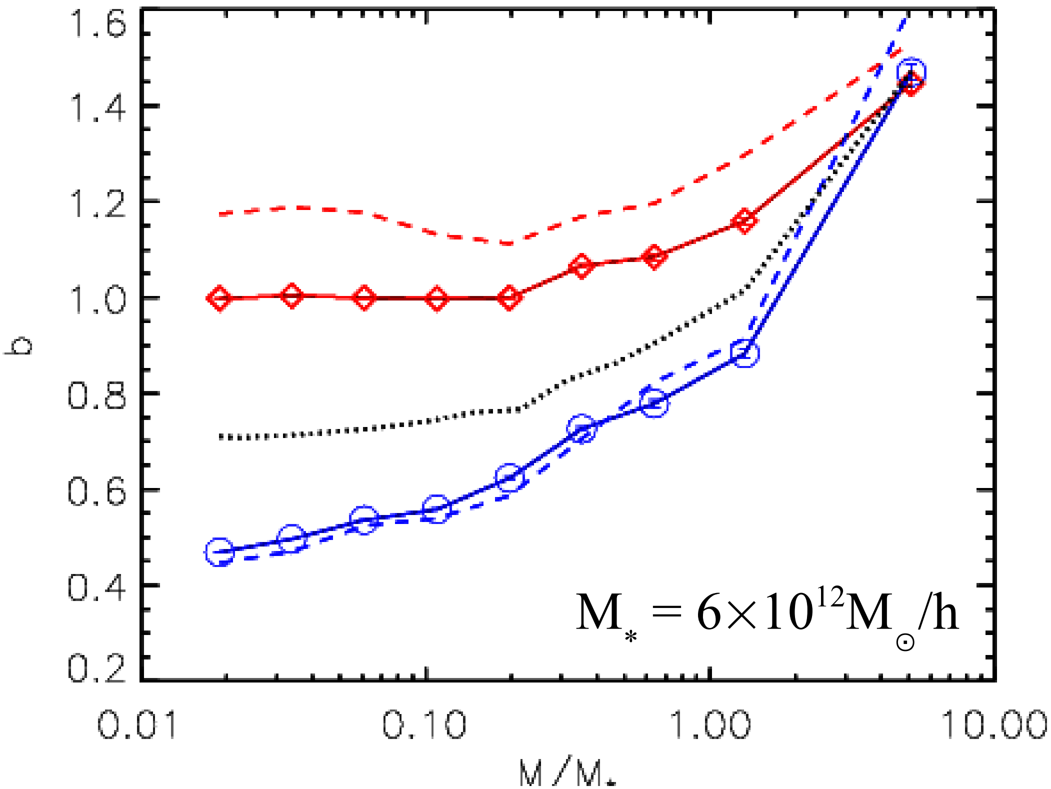
An equal number of randomly chosen DM particles

Halo bias as a function of mass and formation time

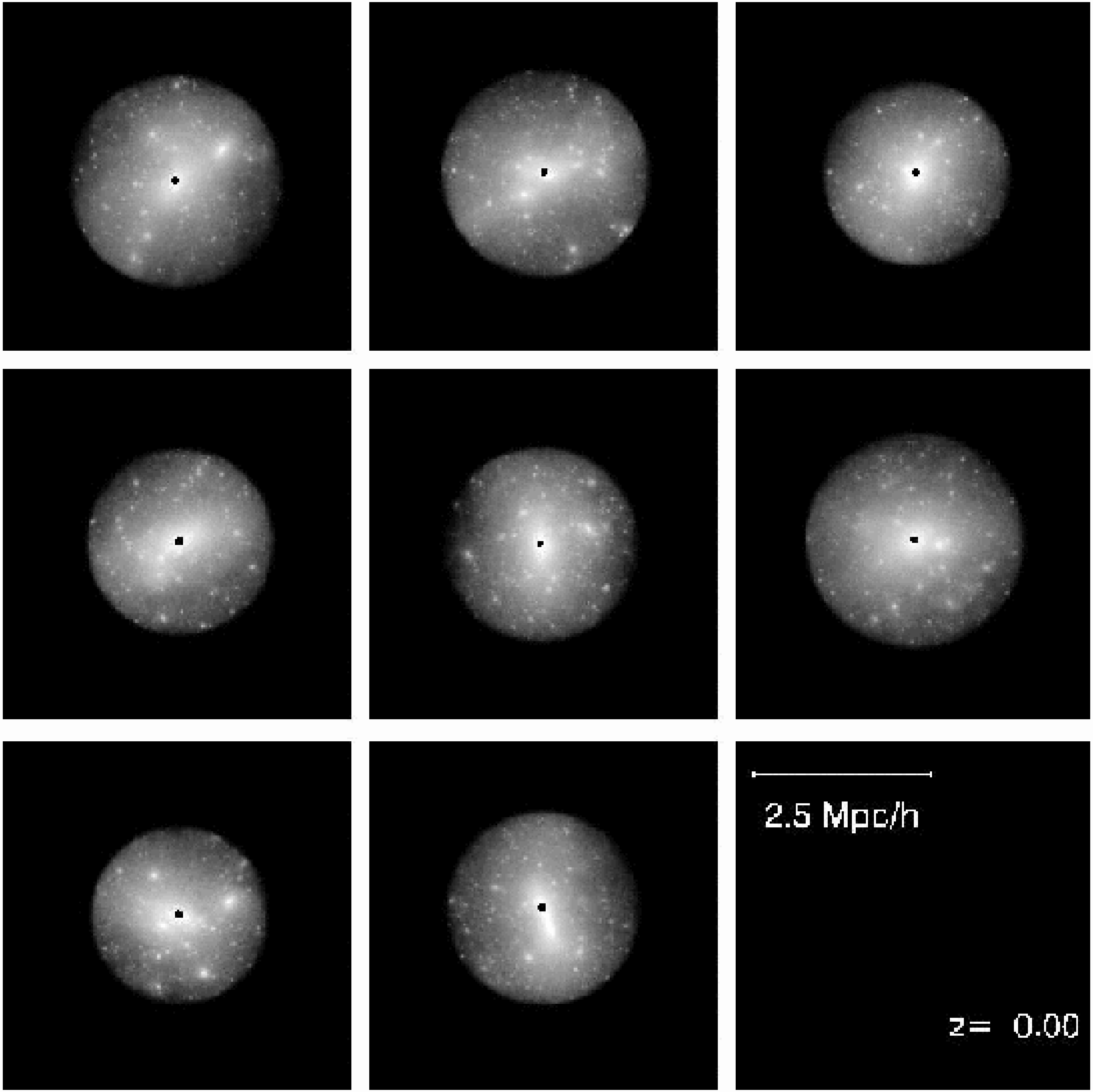
Gao, Springel & White 2005



- Bias increases smoothly with formation redshift



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

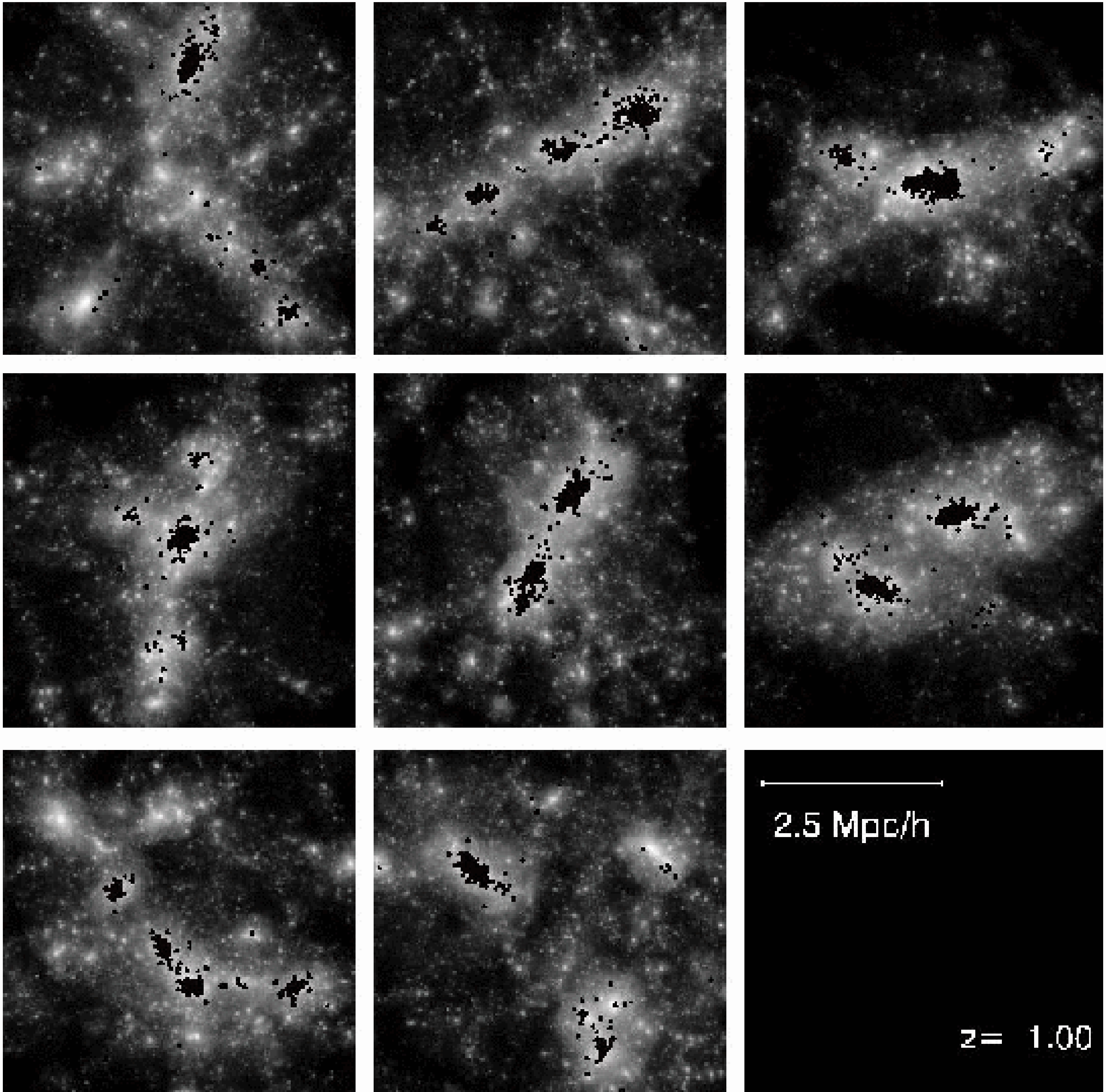


Cluster structure in ΛCDM

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

Gao et al 2004a

Cluster structure in ΛCDM



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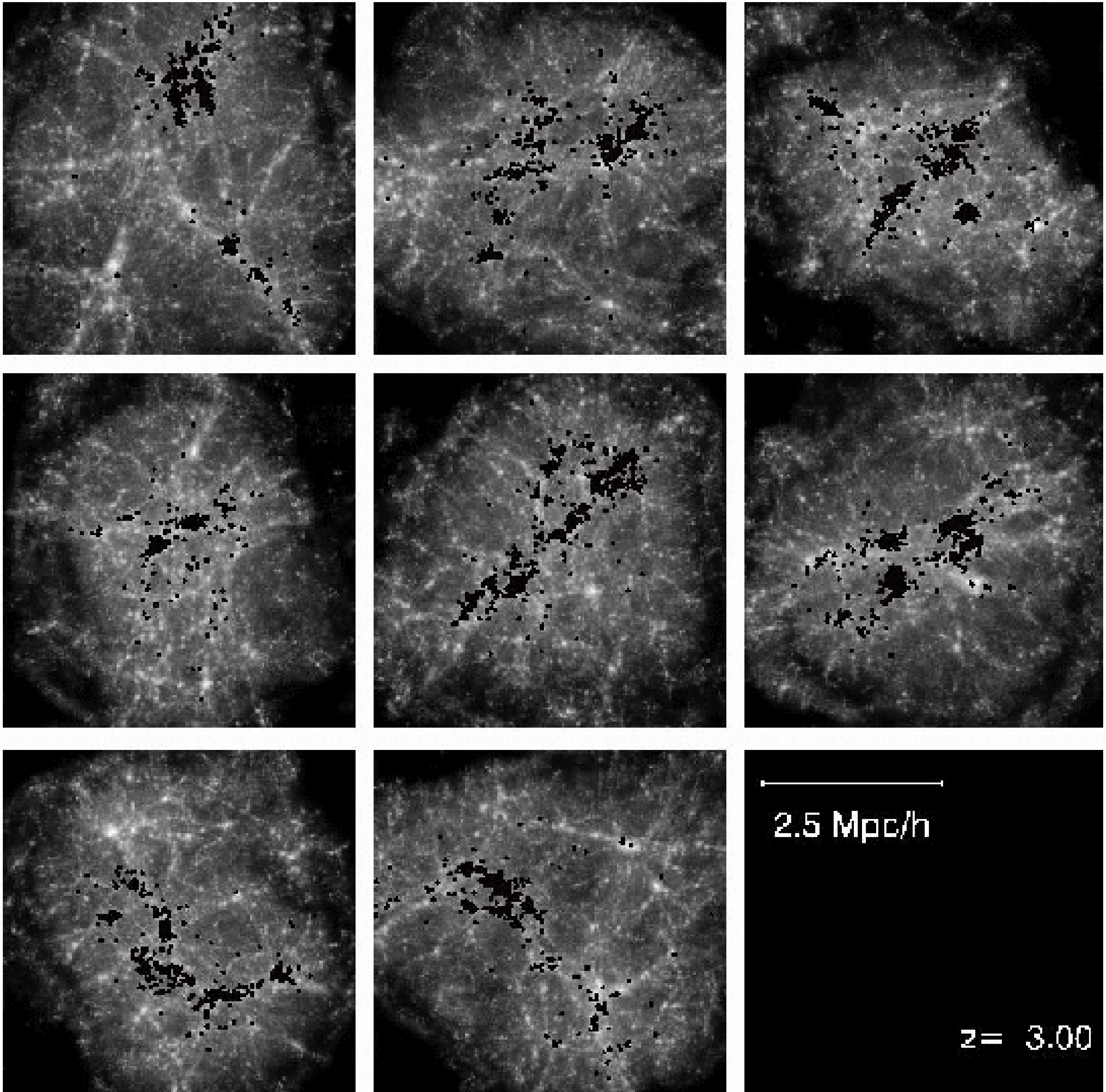

Cluster structure in ΛCDM

- 'Concordance' cosmology
- Final cluster mass $\sim 10^{15} M_{\odot}$
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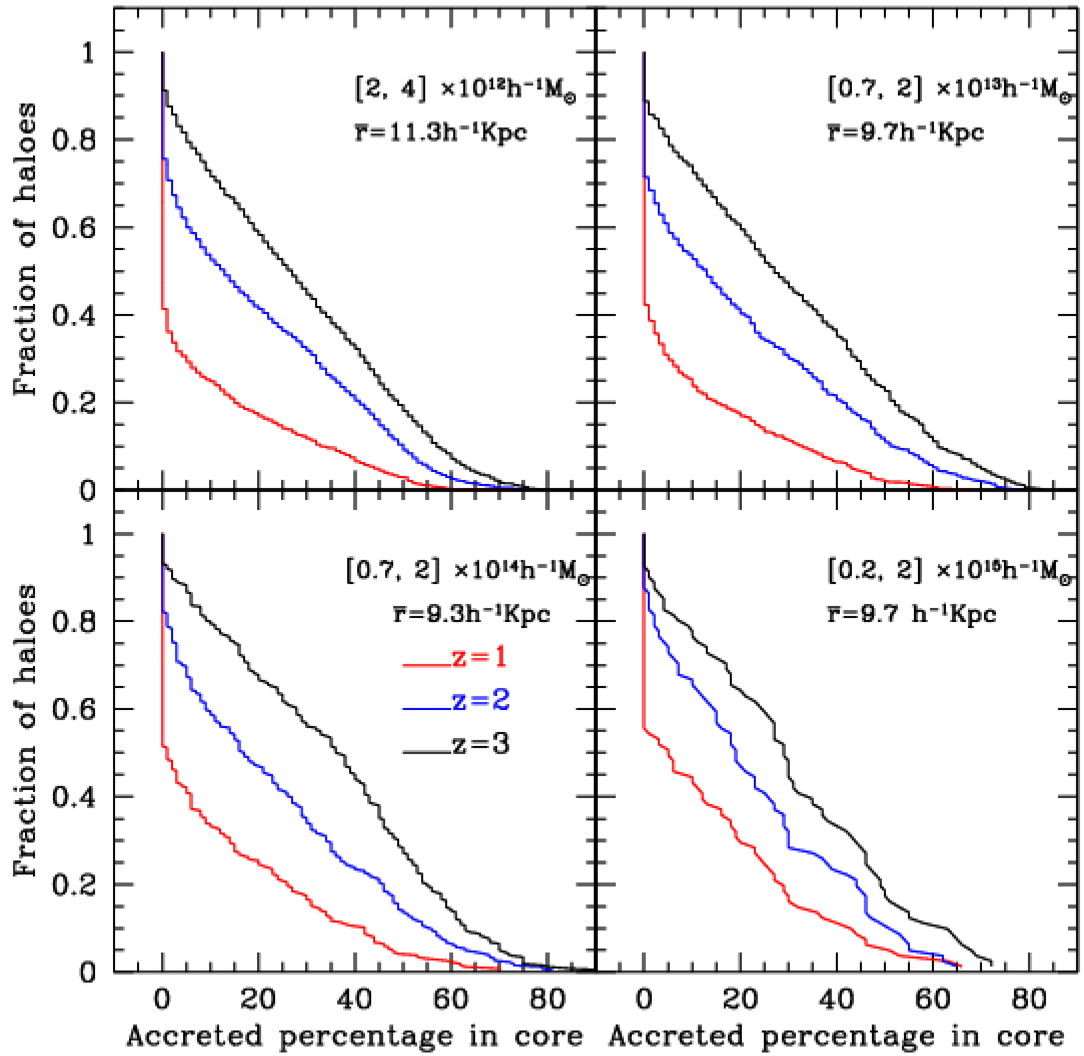
Gao et al 2004a

Late accretion onto the visible cores of galaxies

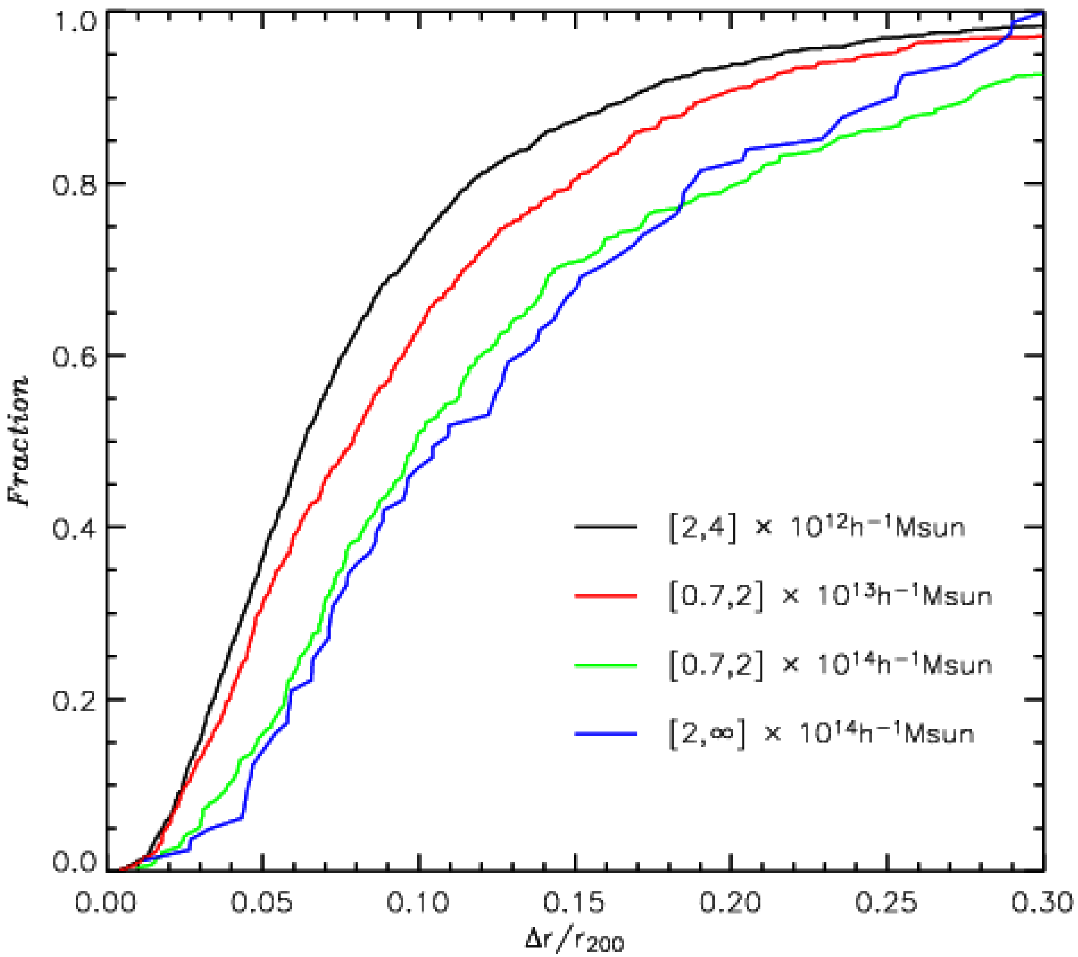
Gao et al 2005, in prep.



- 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

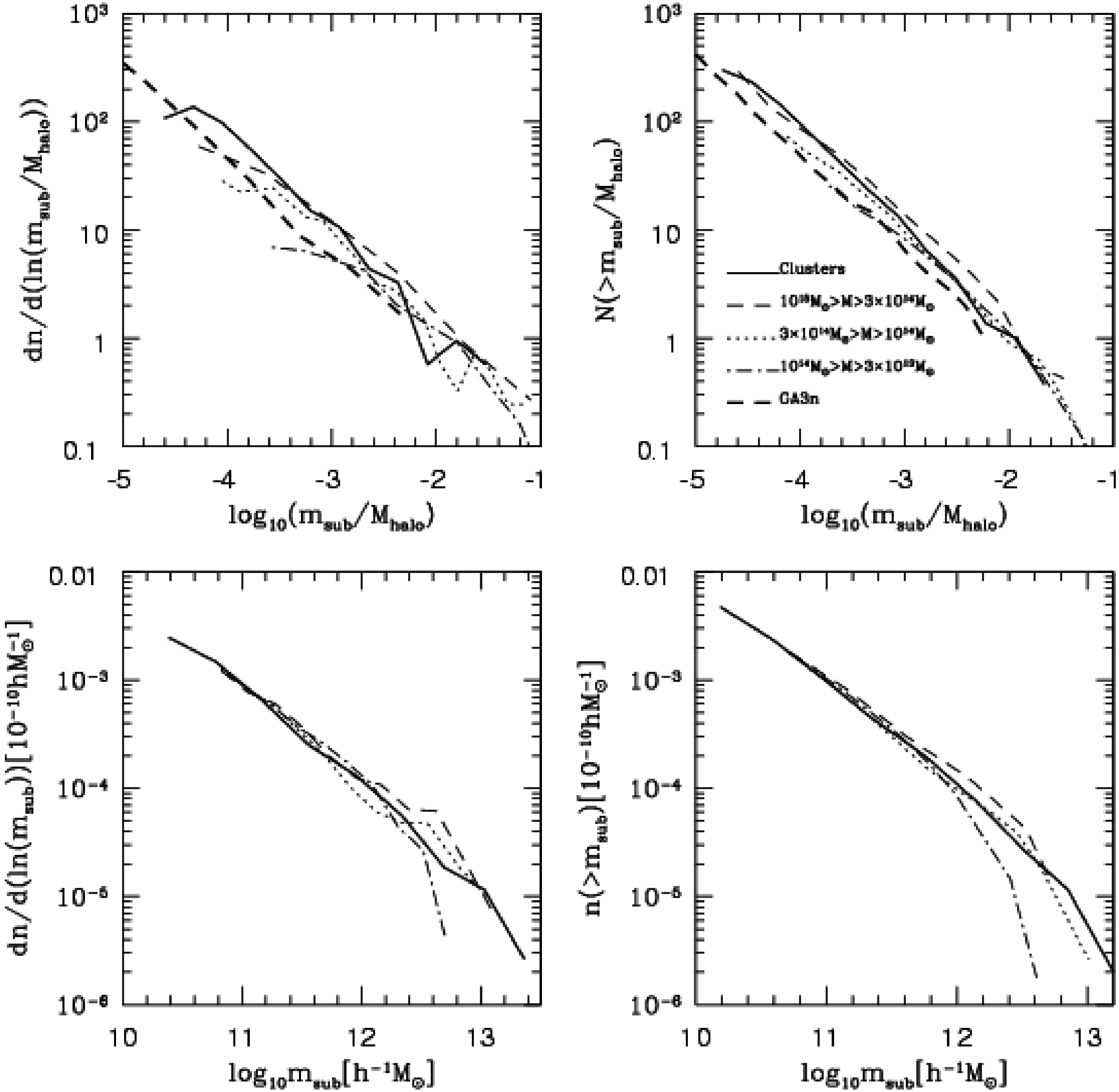
Are halo cores in equilibrium?

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 $r_{200} \sim$ 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



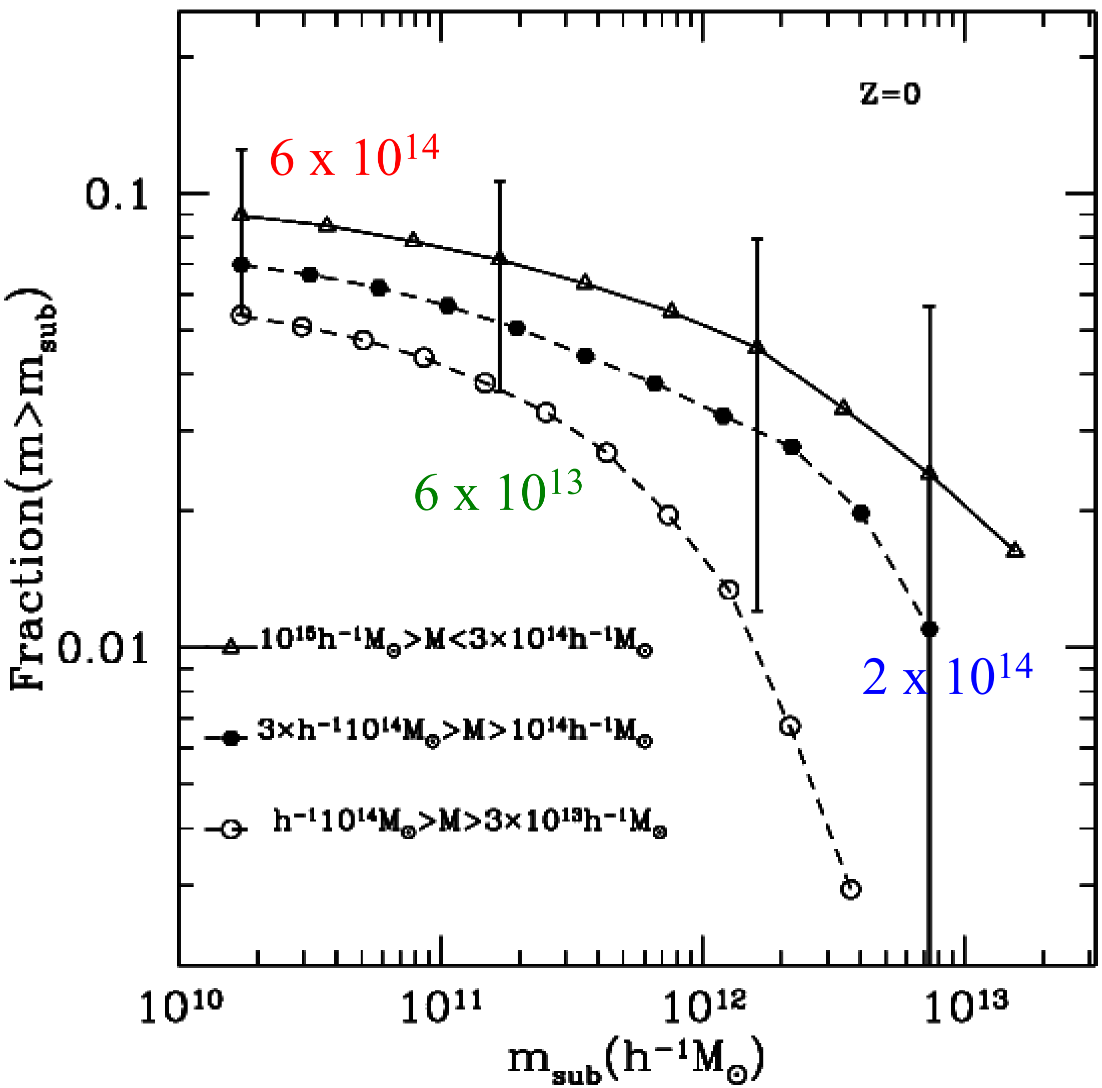
Universal substructure mass functions?

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

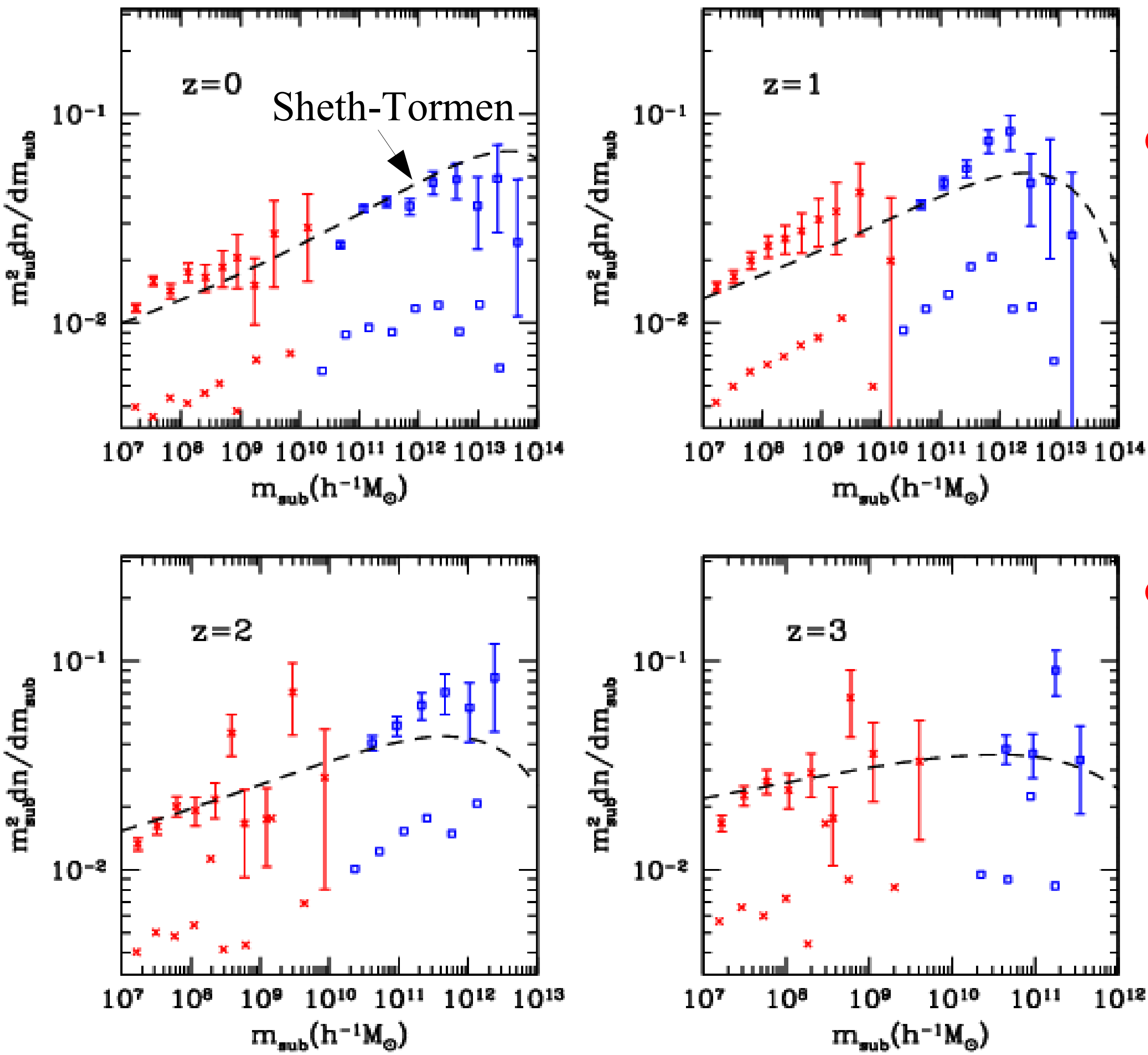
Gao et al 2004b



- Dispersion is large
- Most of 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

Subhalo and halo abundance/mass are parallel

Gao et al 2004b



- Subhalos are bounded at higher density than halos

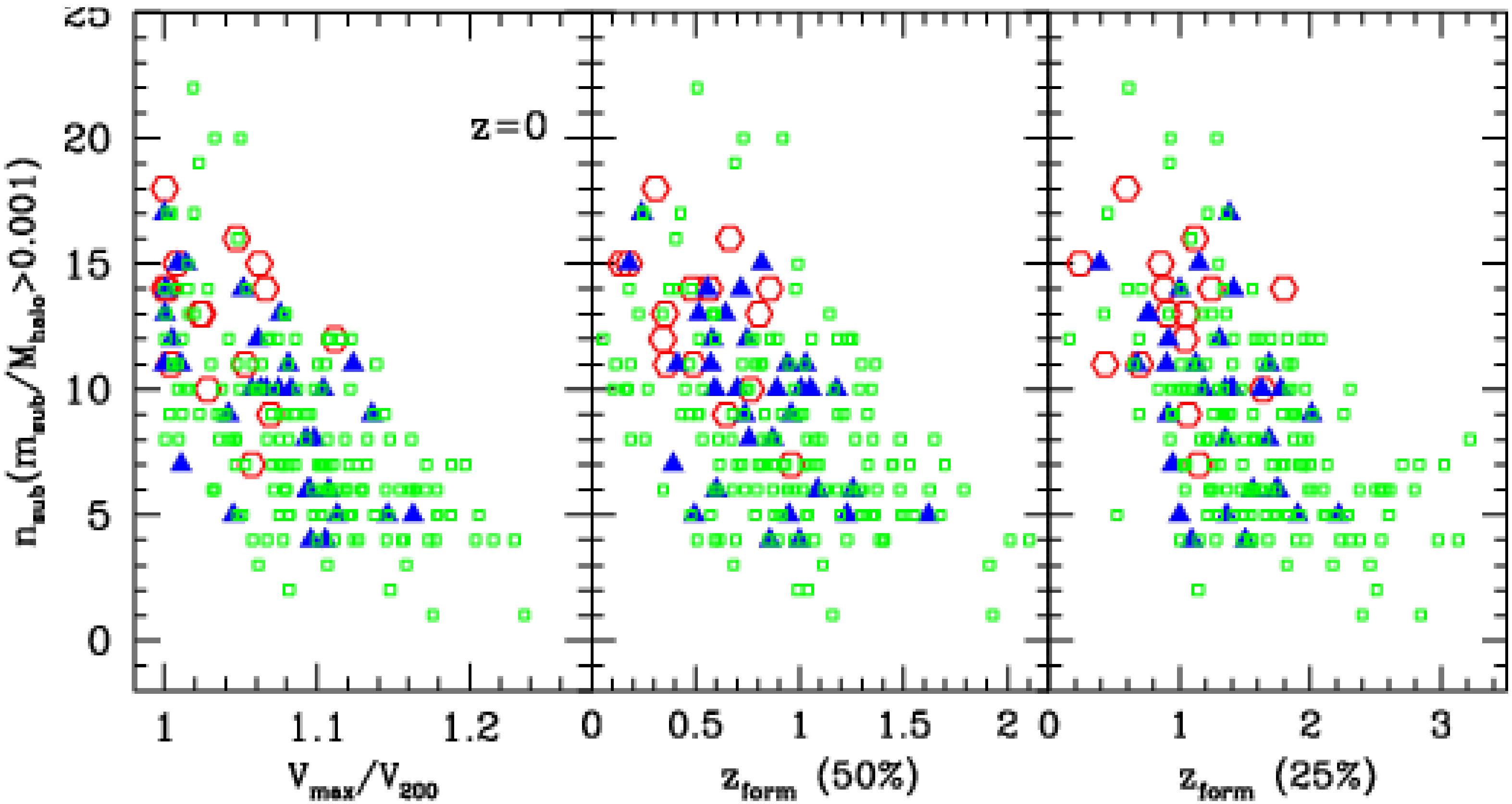
→ ~ half the mass for similar structure

- Doubling the masses we estimate for subhalos

→ subhalo abundance per unit mass in halos is the same as halo abundance per unit mass in the Cosmos

Substructure as a function of other halo properties

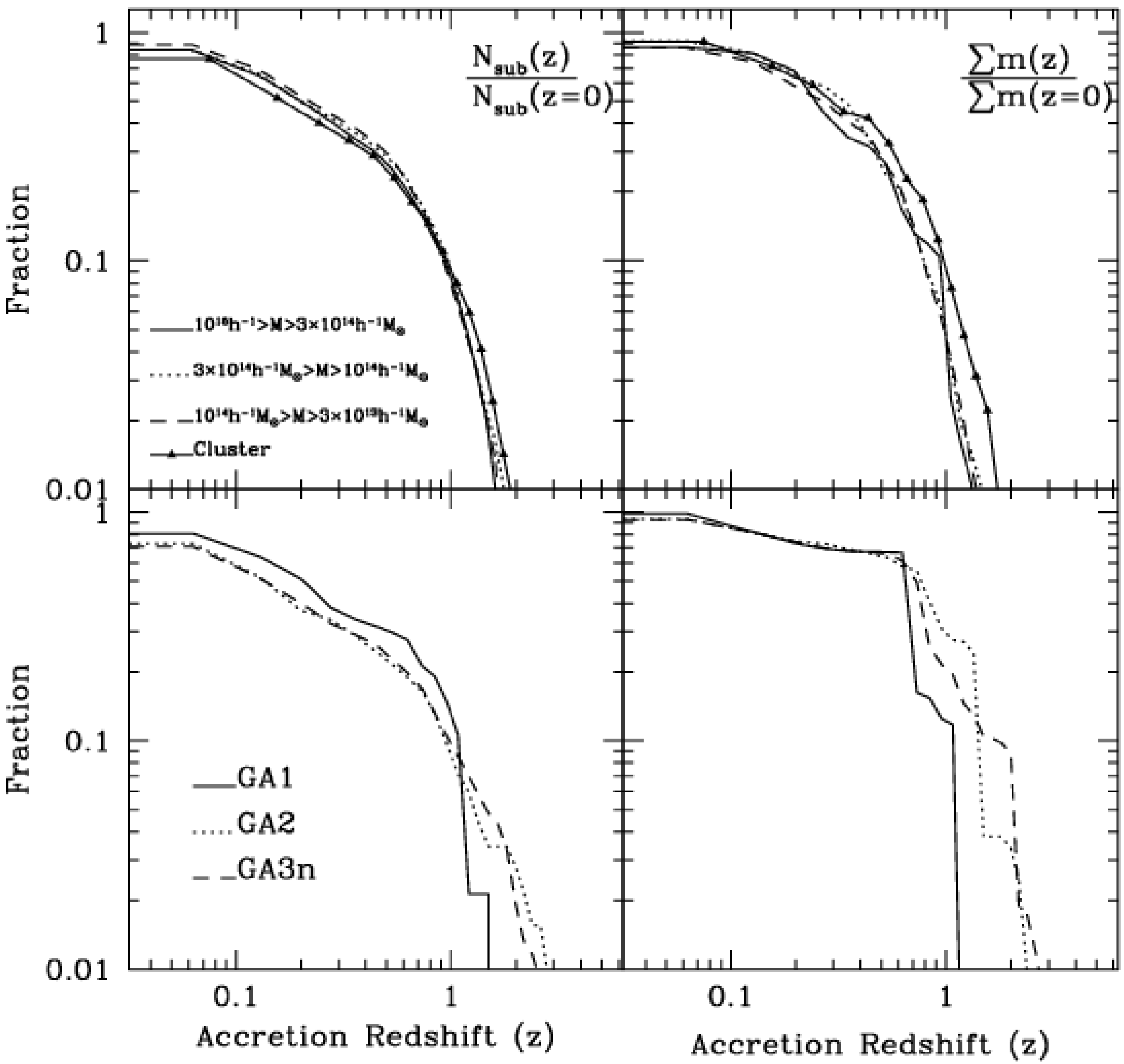
Gao et al 2004b



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

When are sub-halos accreted?

Gao et al 2004b



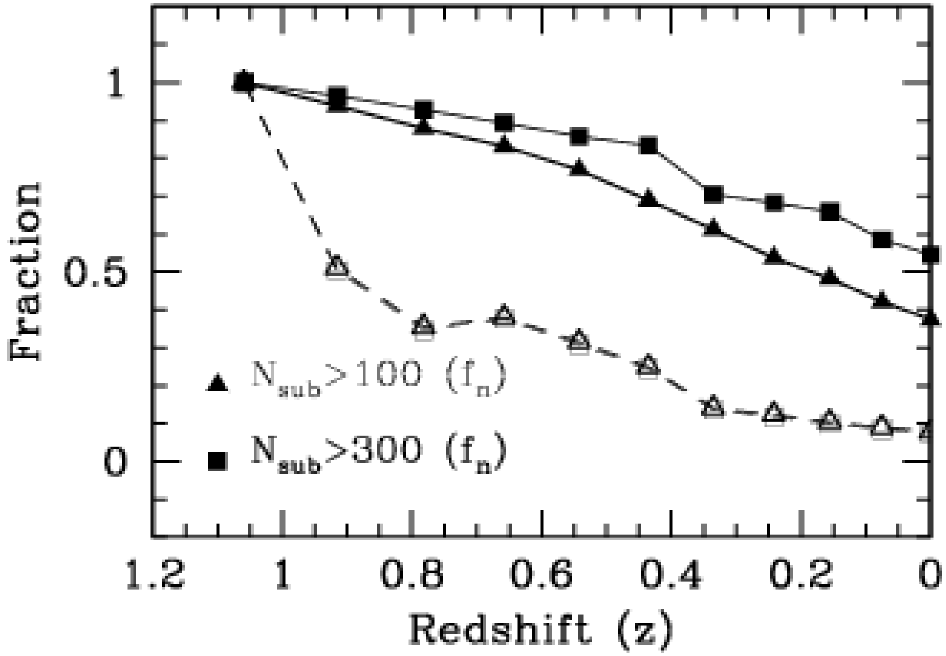
Most of the subhalos (and most of the mass in subhalos) first became a subhalo at *late* times

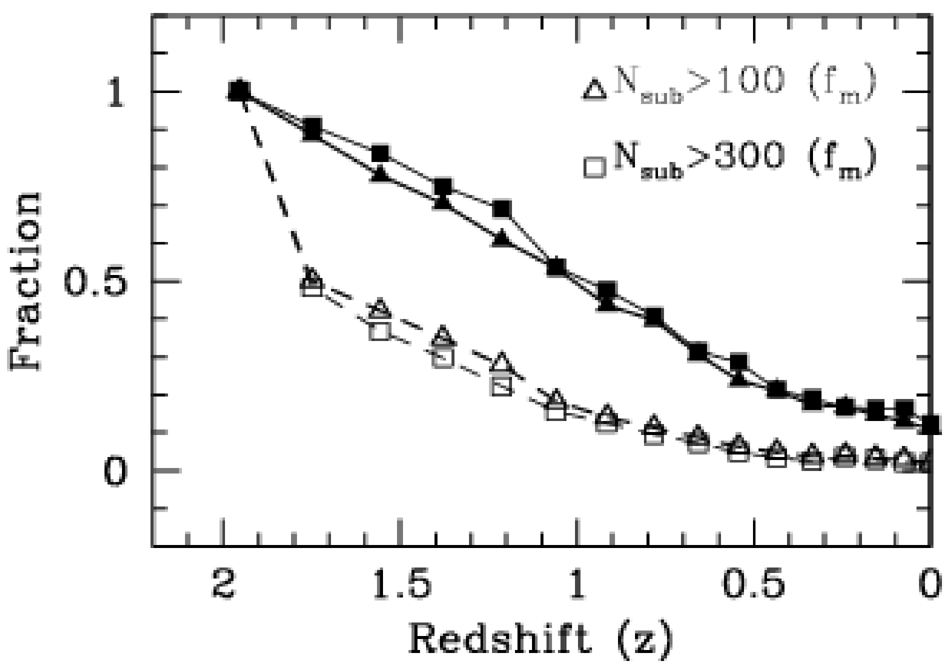
70% after z = 0.5
90% after z = 1.0

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

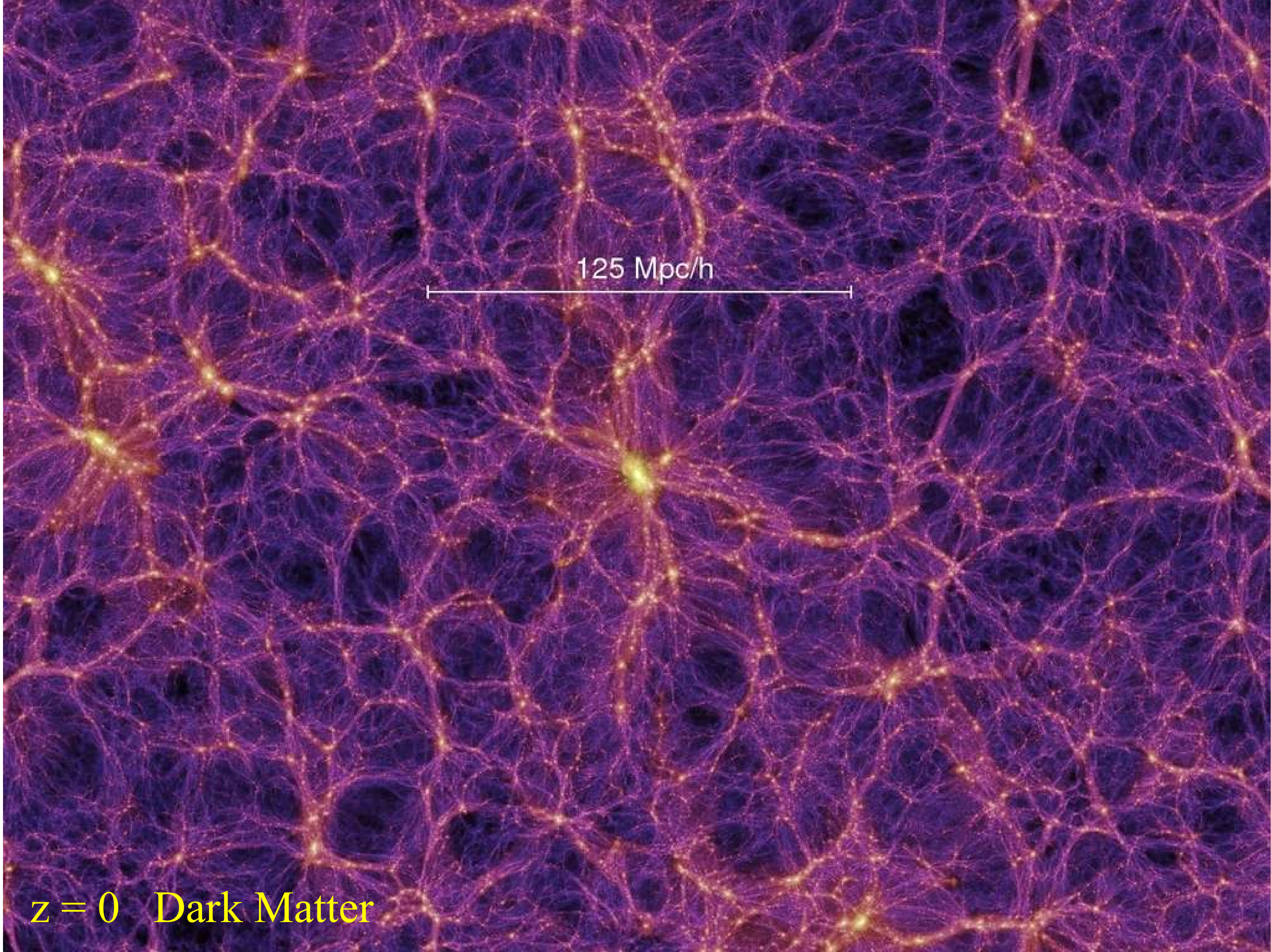


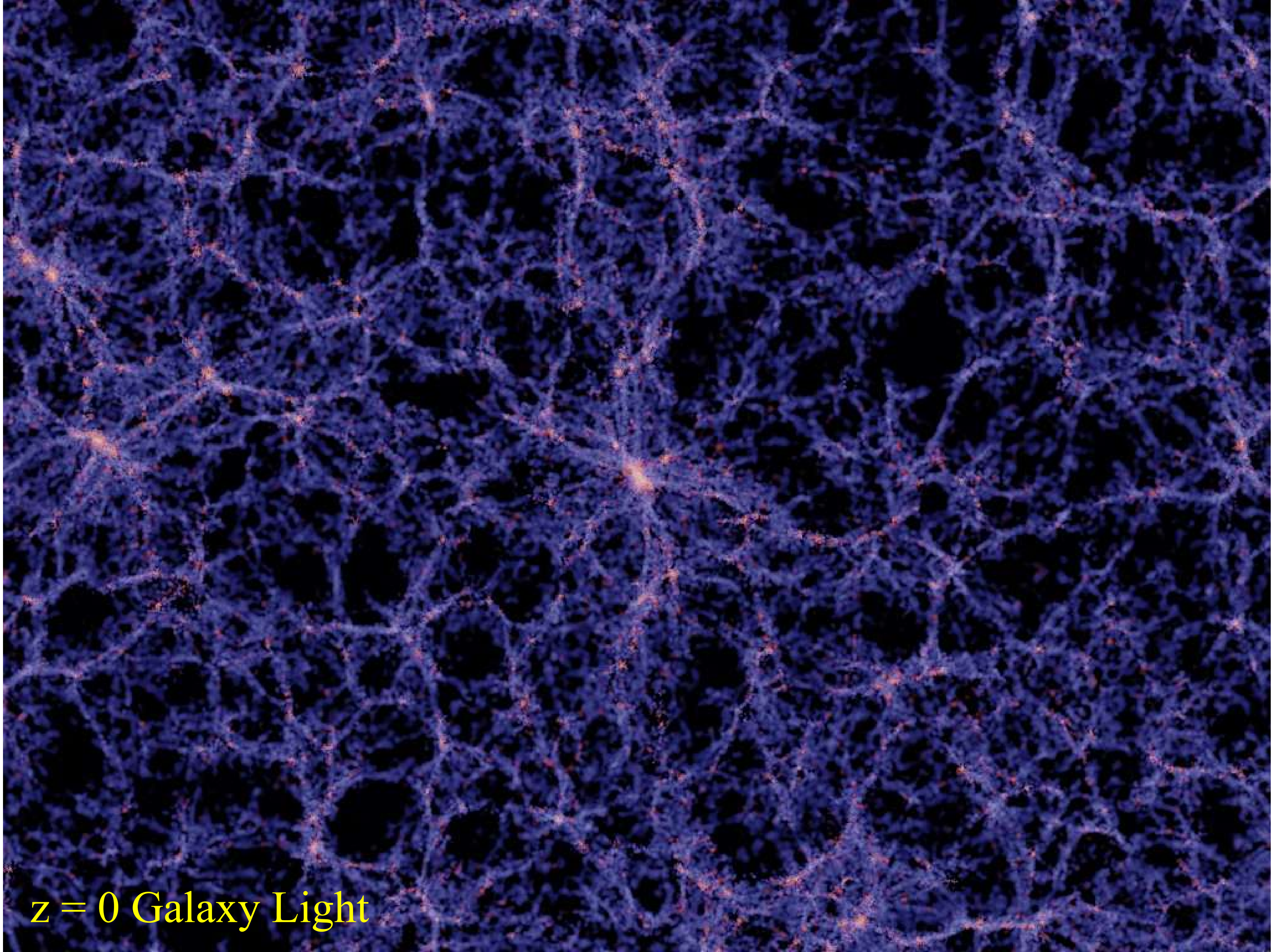


Subhalos accreted at z = 1 lose a factor 2 in number and a factor 12 in mass by z = 0

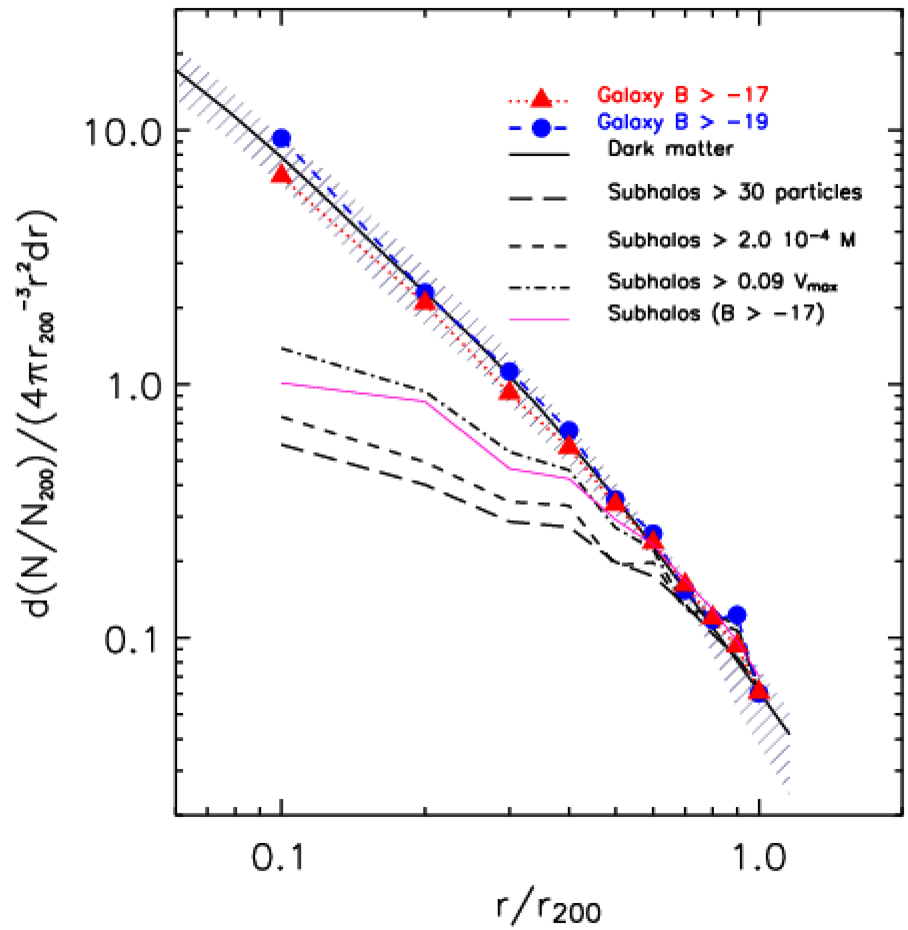
Subhalos accreted at z = 2 lose a factor 8 in number and a factor 50 in mass by z = 0

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


125 Mpc/h
z = 0   Dark Matter

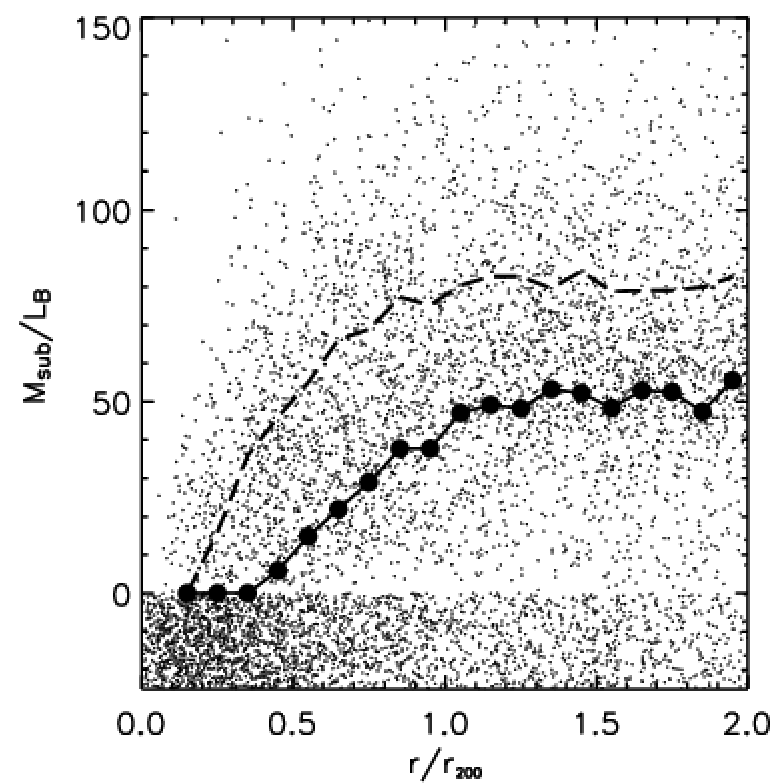

z = 0 Galaxy Light

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

CONCLUSIONS

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