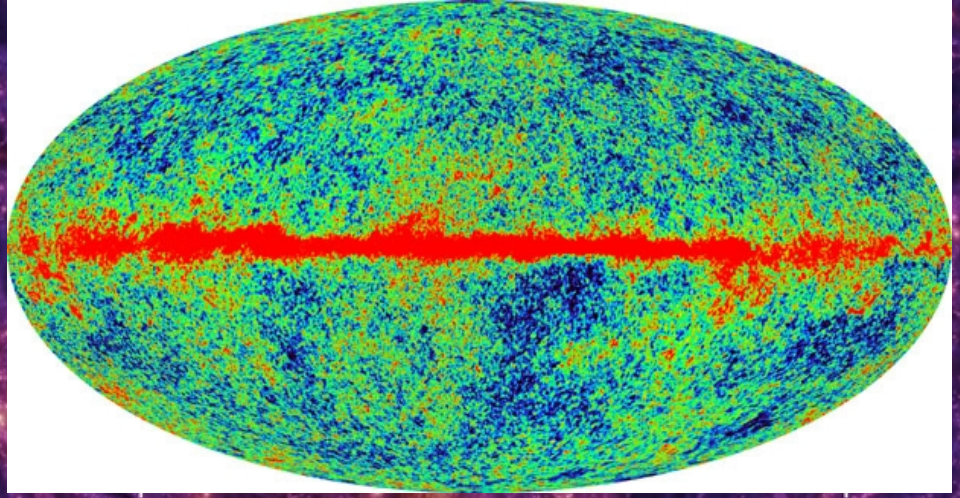


Cosmic Frontiers
Durham
August 2006

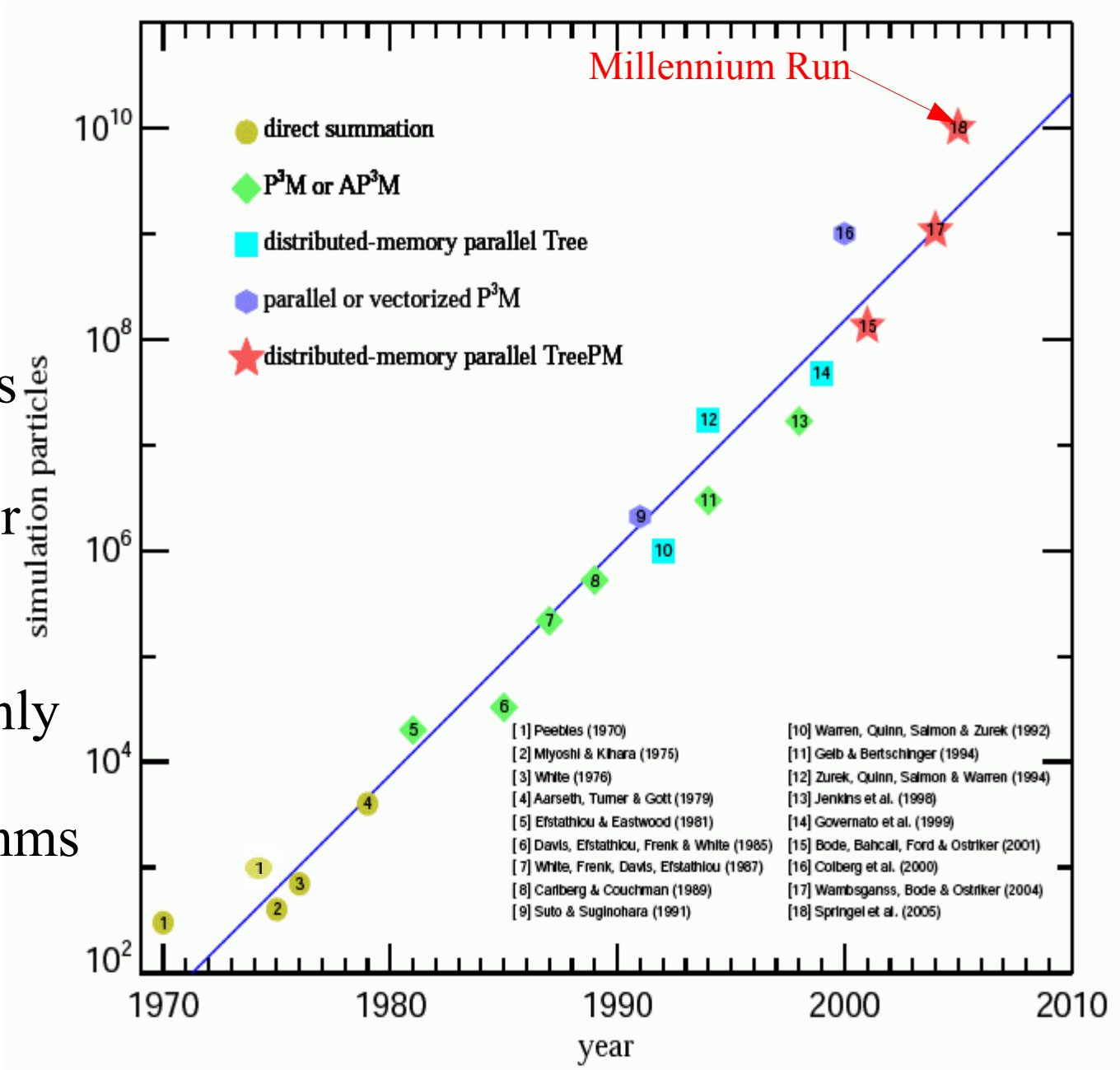
Large-scale Structure: Insights from the Millenium Simulation

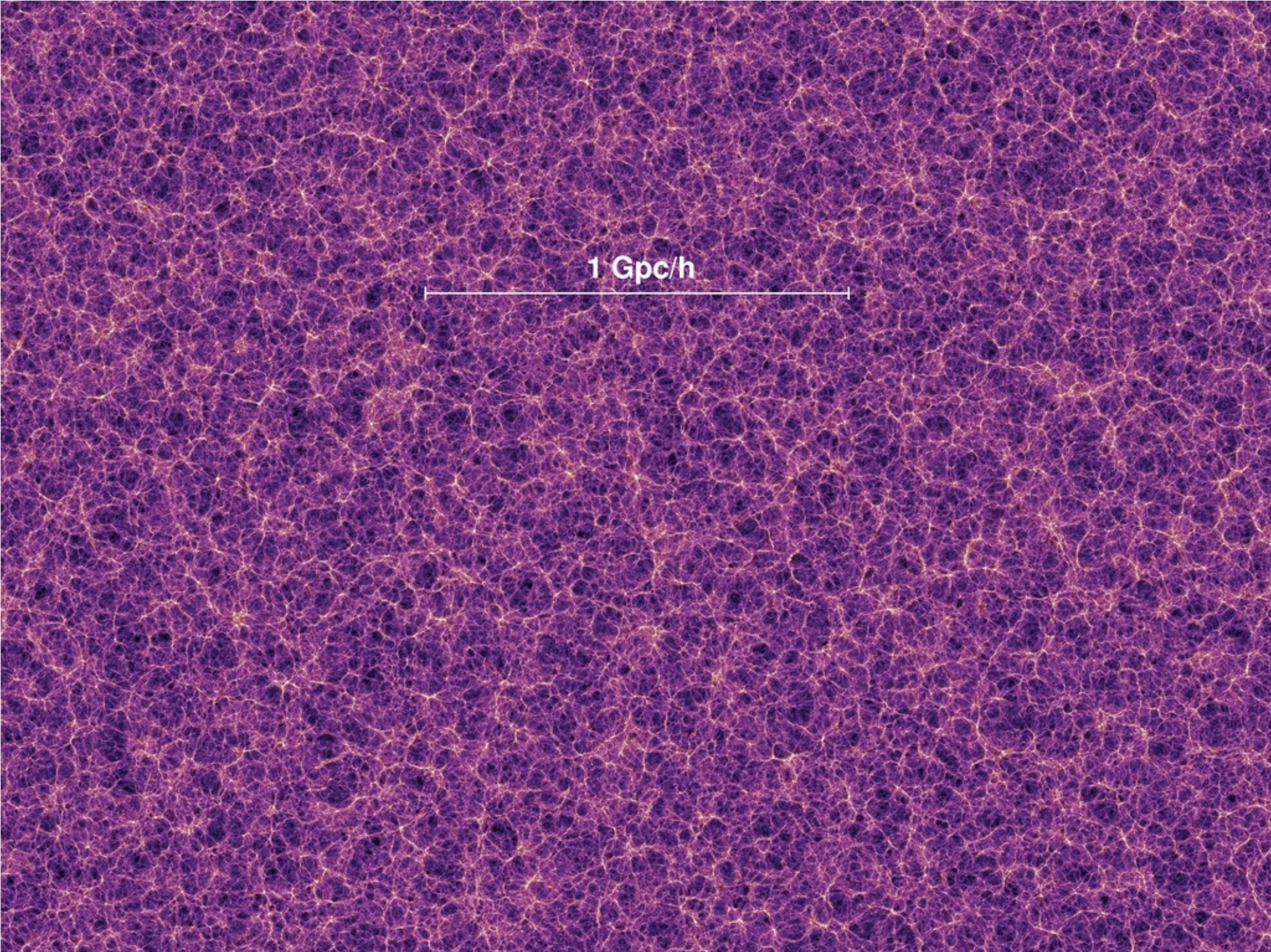
Simon White
Max Planck Institute for Astrophysics

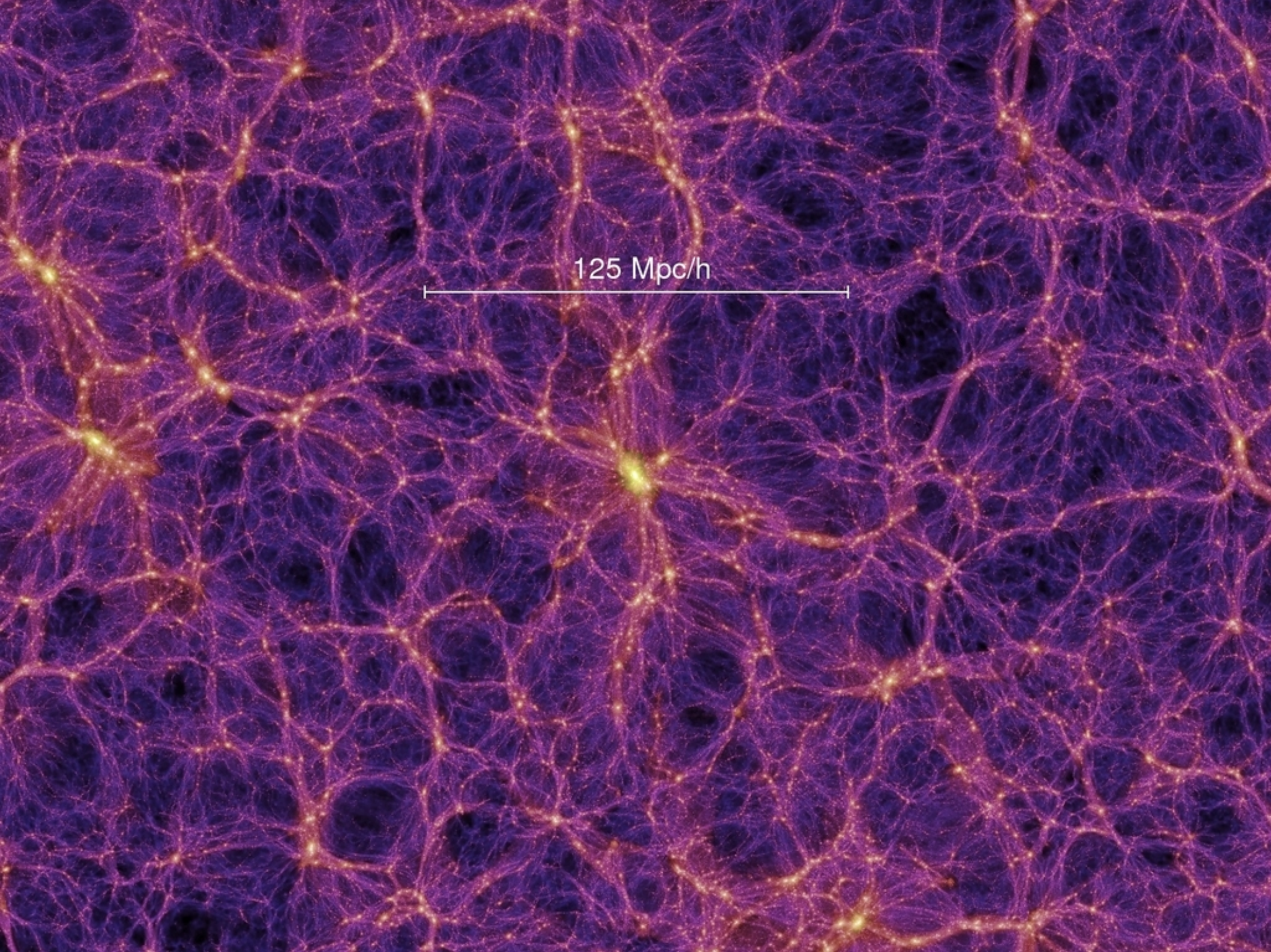
Moore's Law for Cosmological N-body Simulations

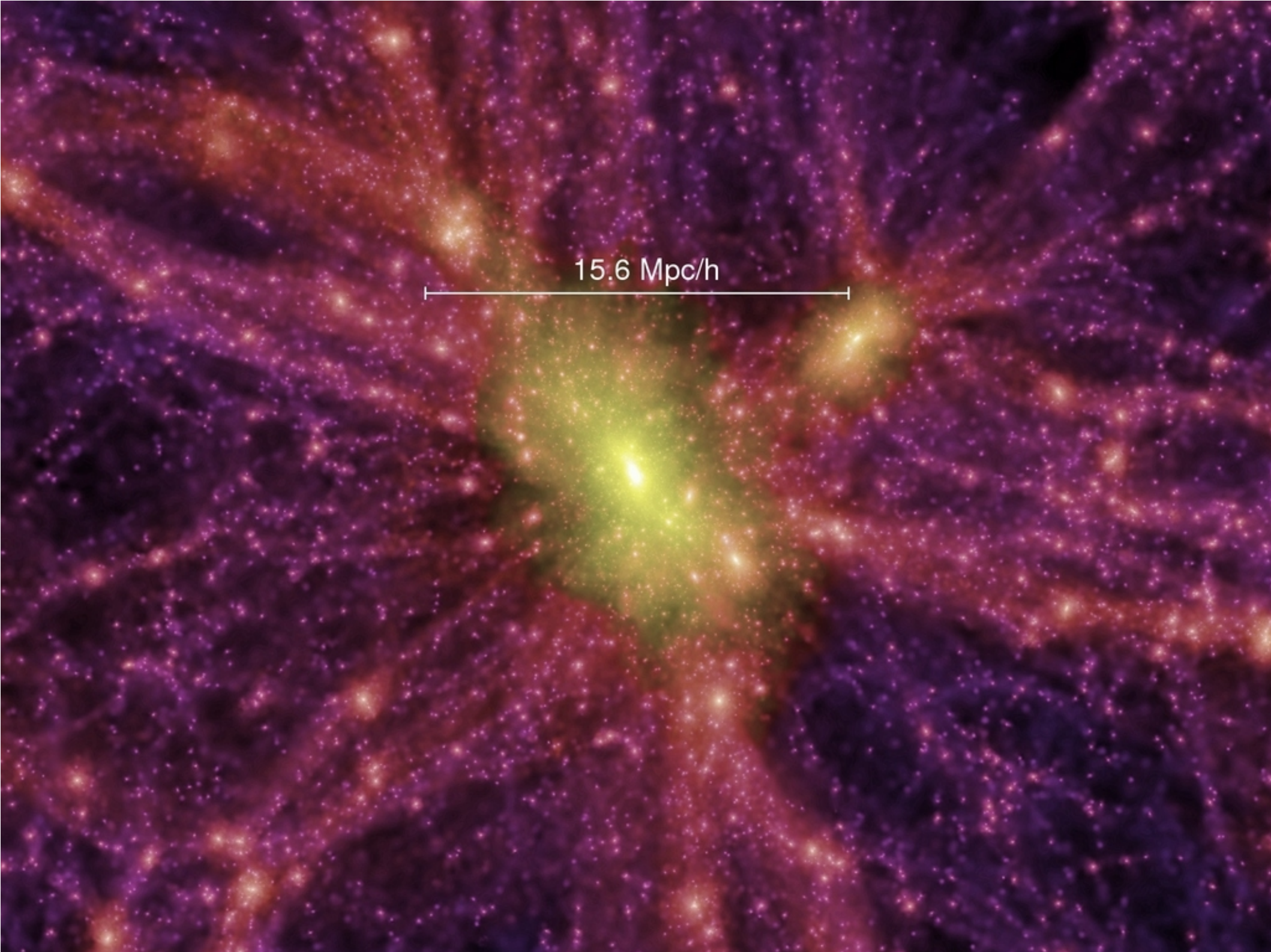
Springel et al 2005

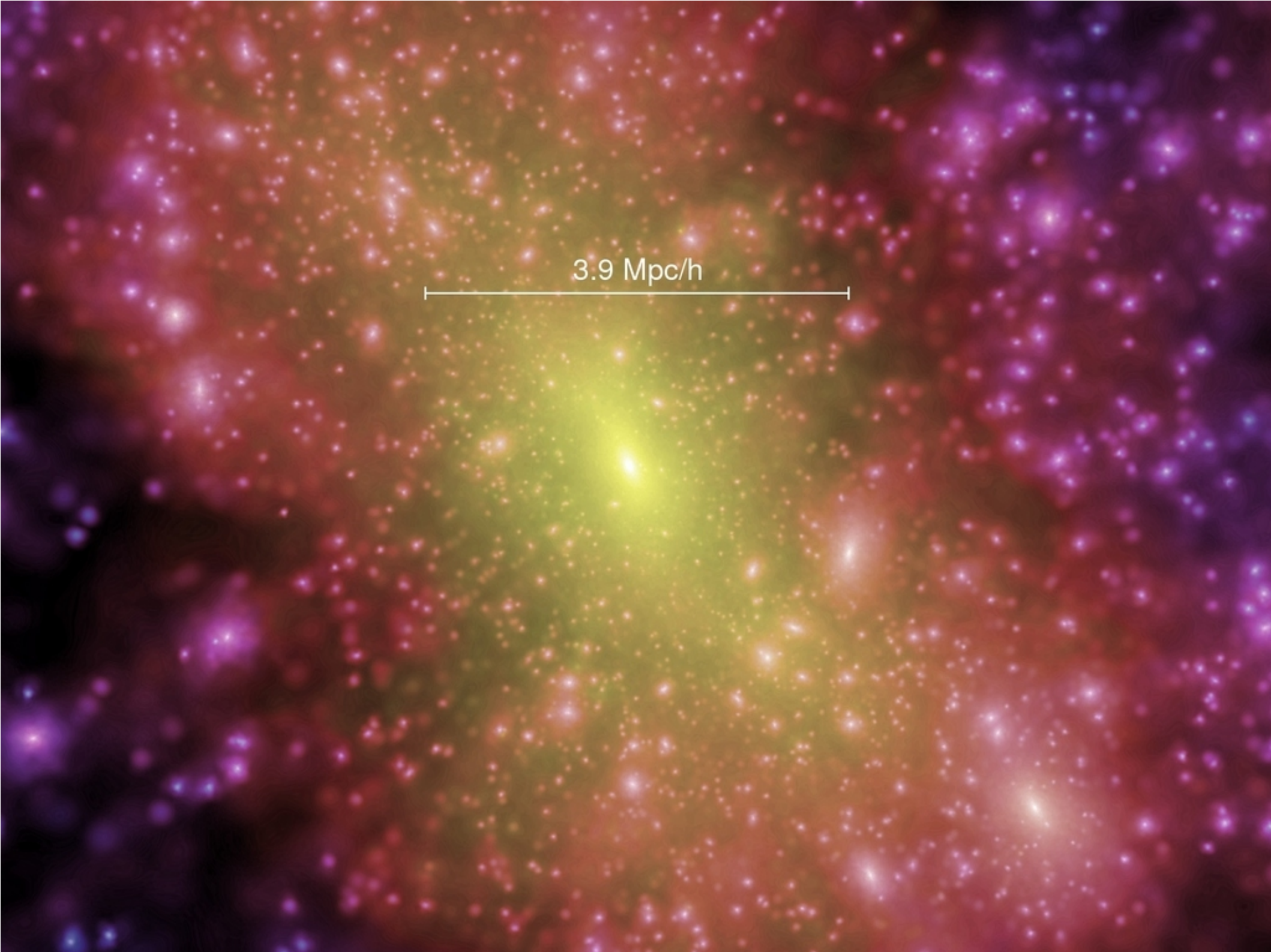
- Computers double their speed every 18 months
- A naive N-body force calculation needs N^2 op's
- Simulations double their size every 16.5 months
- Progress has been roughly equally due to hardware and to improved algorithms




1 Gpc/h

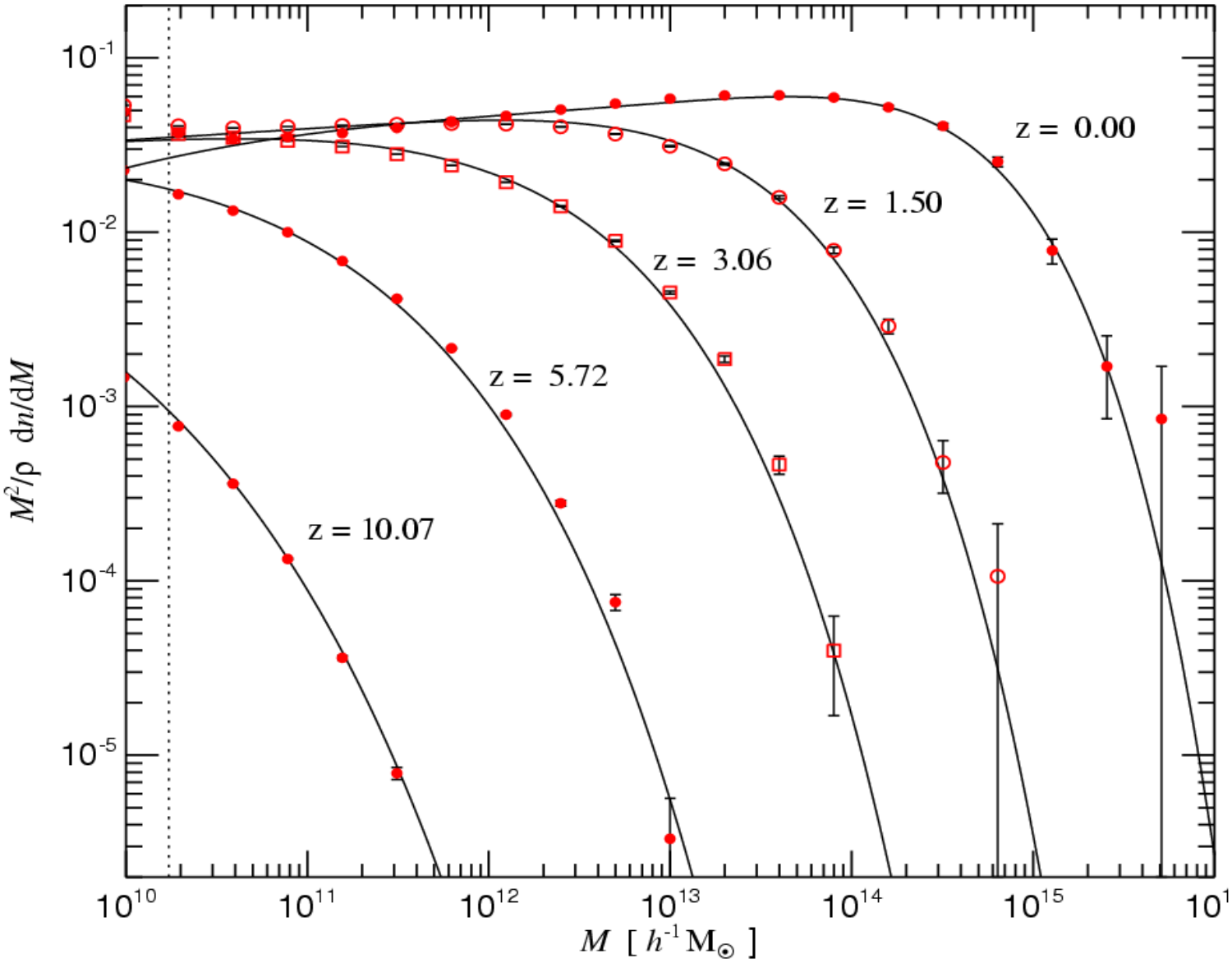

125 Mpc/h


15.6 Mpc/h


3.9 Mpc/h

Halo Mass Functions in the MS

Springel et al 2005

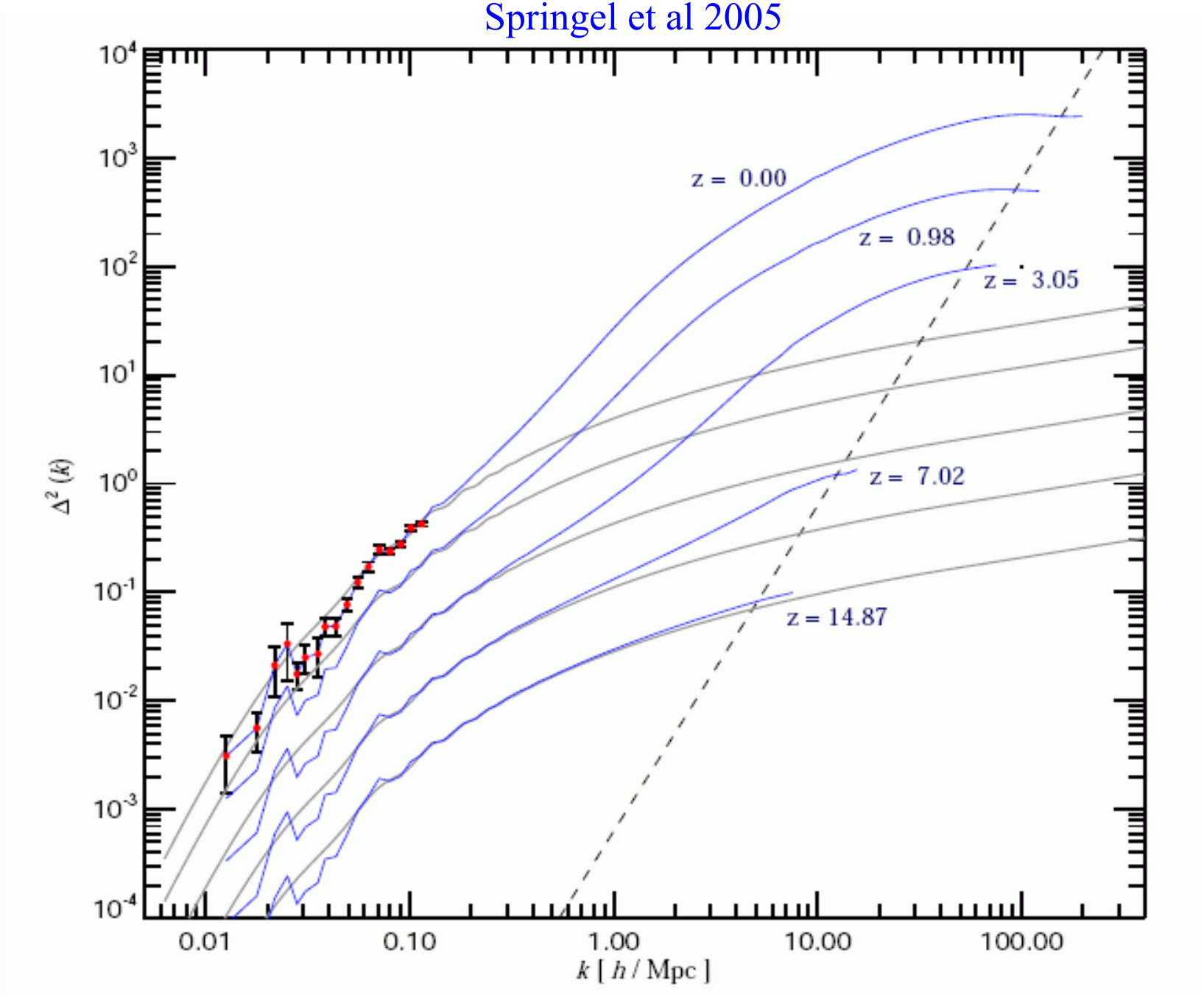


Solid curves are the empirical fitting formula from Jenkins et al 2001 with no parameters adjusted

At z = 0 half of all DM is in lumps of $M > 2 \times 10^{10} M_\odot$

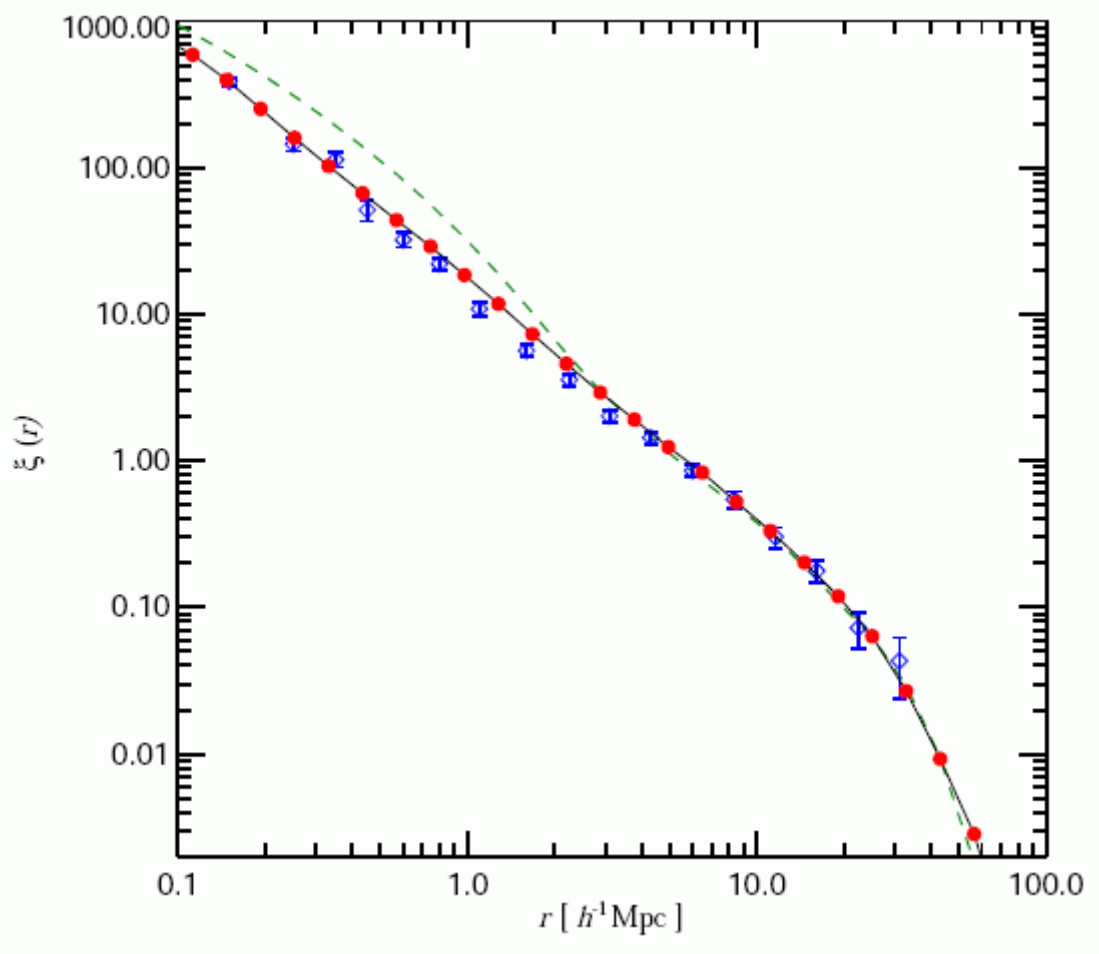
Mass Power Spectra in the MS

Springel et al 2005



Mass/galaxy autocorrelations in the MS

Springel et al 2005

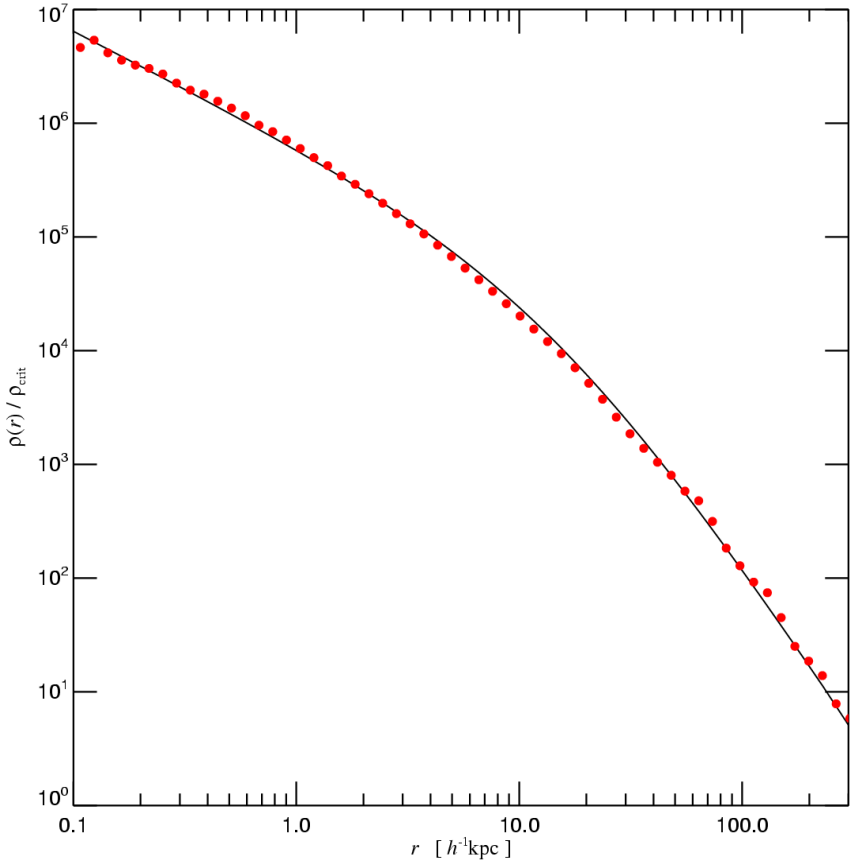


A high-resolution Milky Way halo

Navarro et al 2006

$N_{200} \sim 3 \times 10^7$

600 kpc

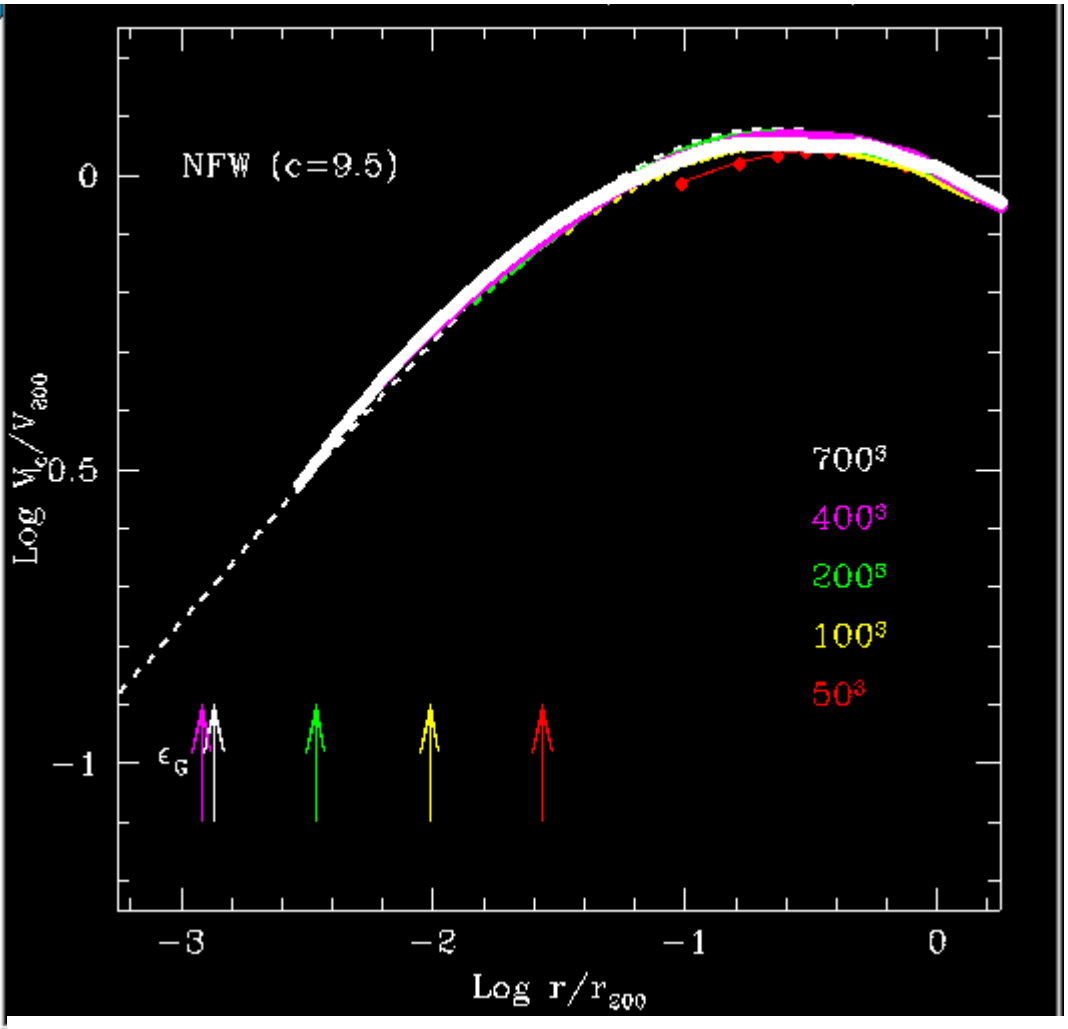


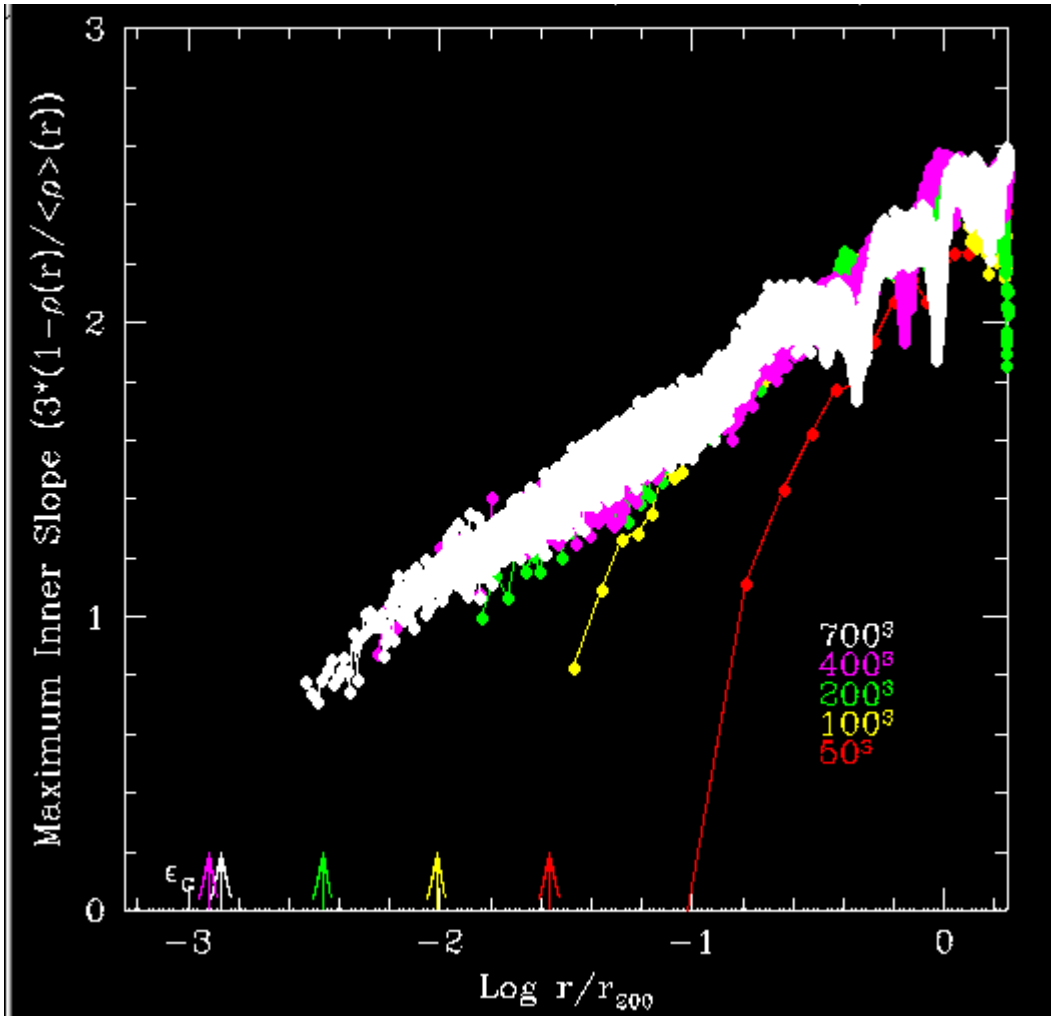
Convergence tests on density profile shape

Navarro et al 2006

DM profiles are converged to a few hundred parsecs

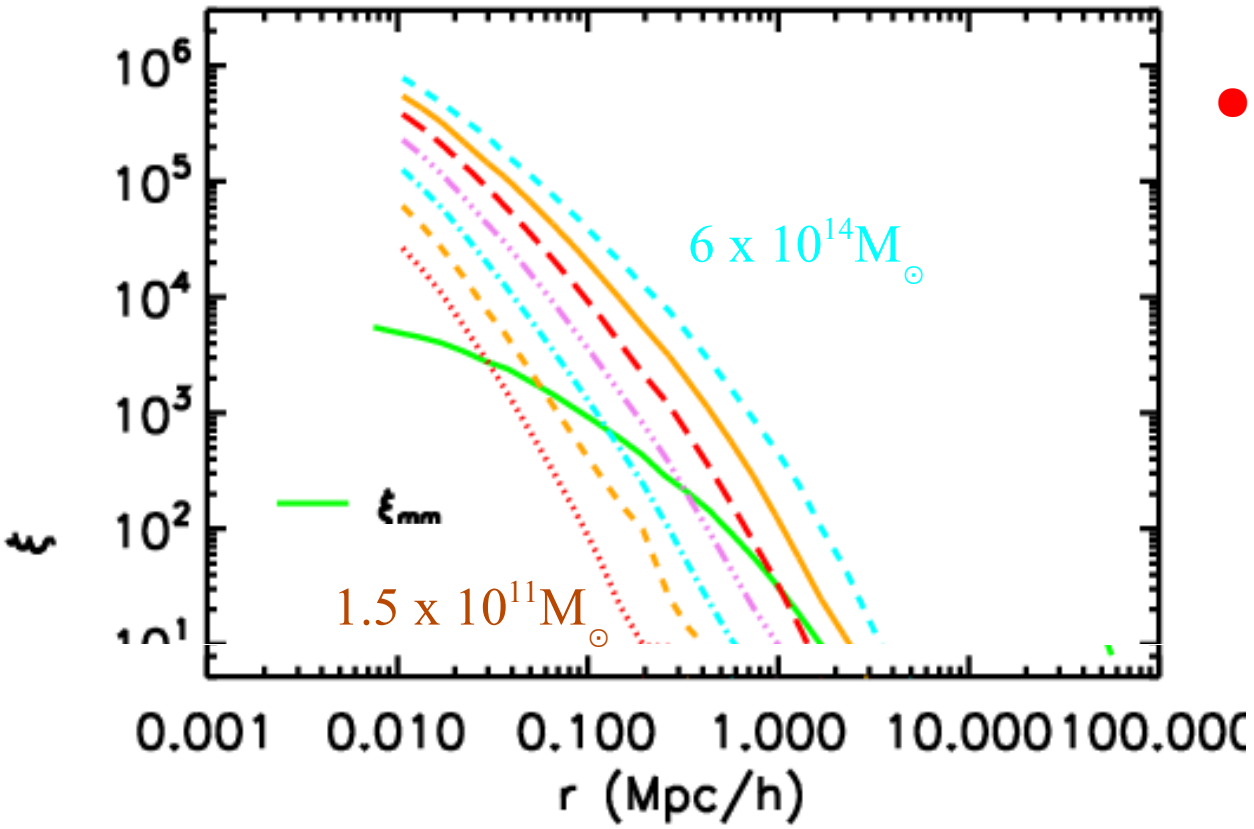
The inner asymptotic slope must be shallower than – 0.9





Density profile shapes at large radii

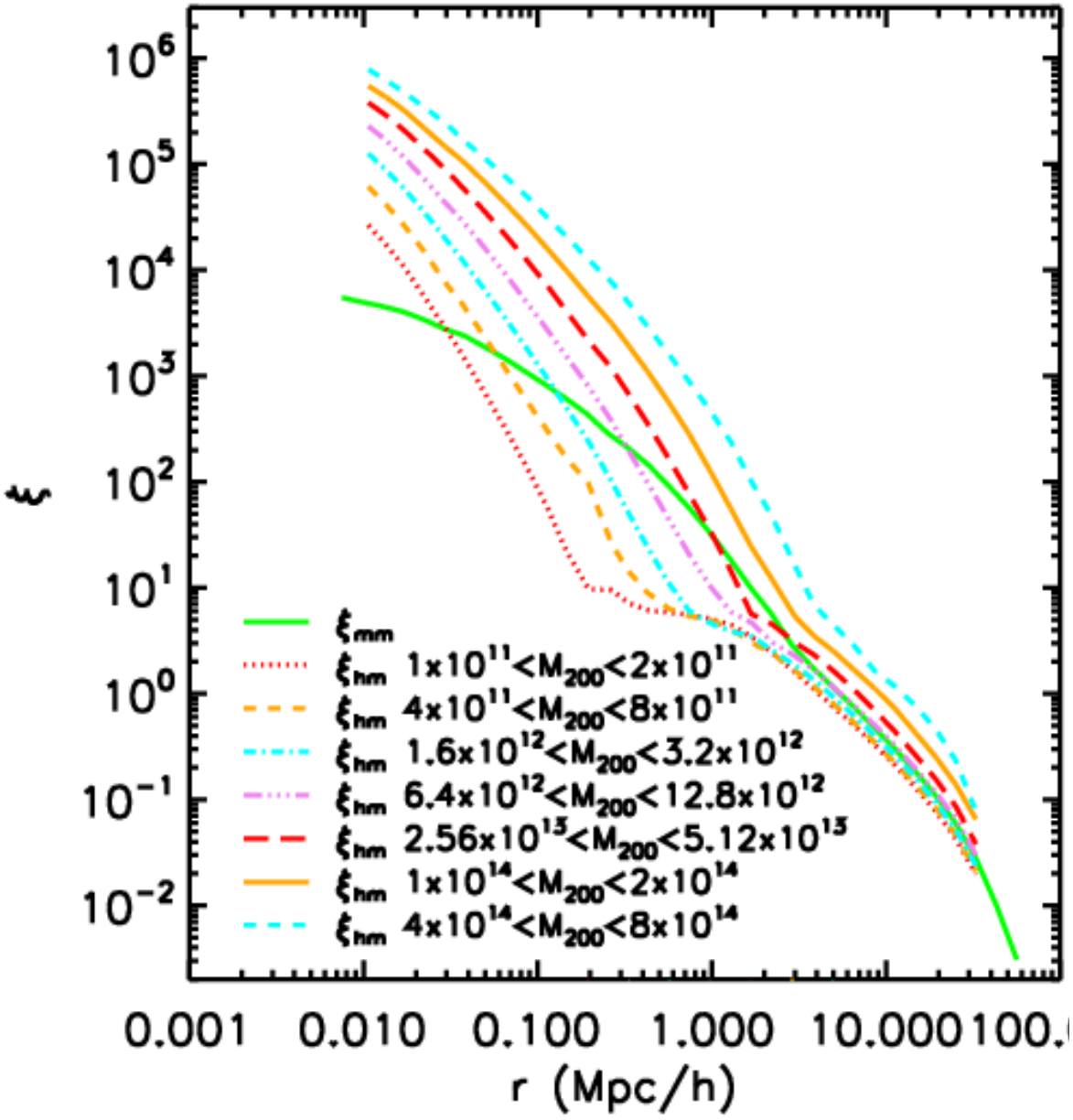
Hayashi et al 2006



- Mean density profiles of halos of given M_{200} are well fit down to overdensities of 10 by the fitting formula of Navarro et al (2004)

Density profile shapes at large radii

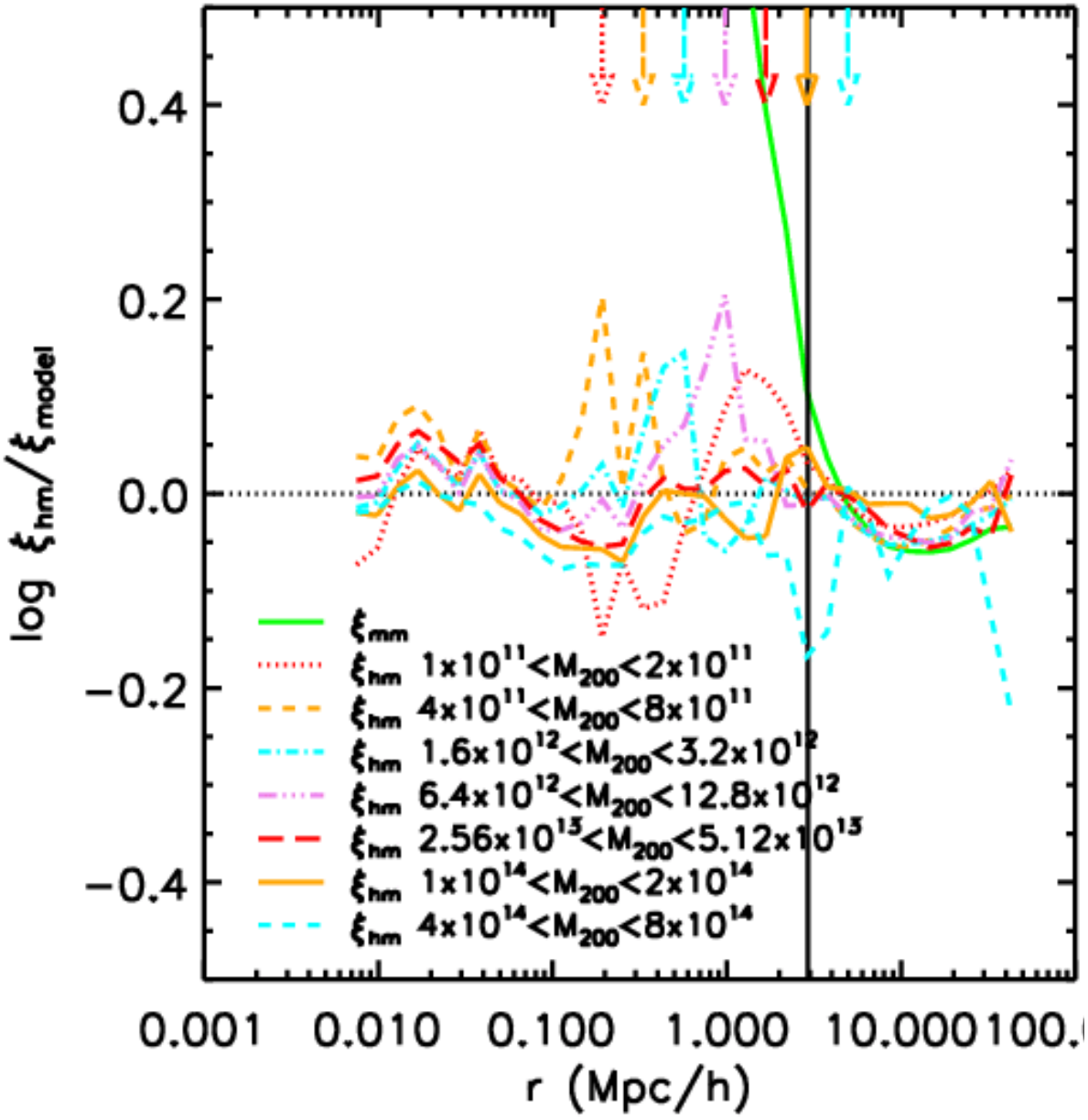
Hayashi et al 2006



- Mean density profiles of halos of given M_{200} are well fit down to overdensities of 10 by the fitting formula of Navarro et al (2004)
- At lower overdensities they are well fit by the *linear* mass correlation function with bias from Sheth, Mo, Tormen (2001)

Density profile shapes at large radii

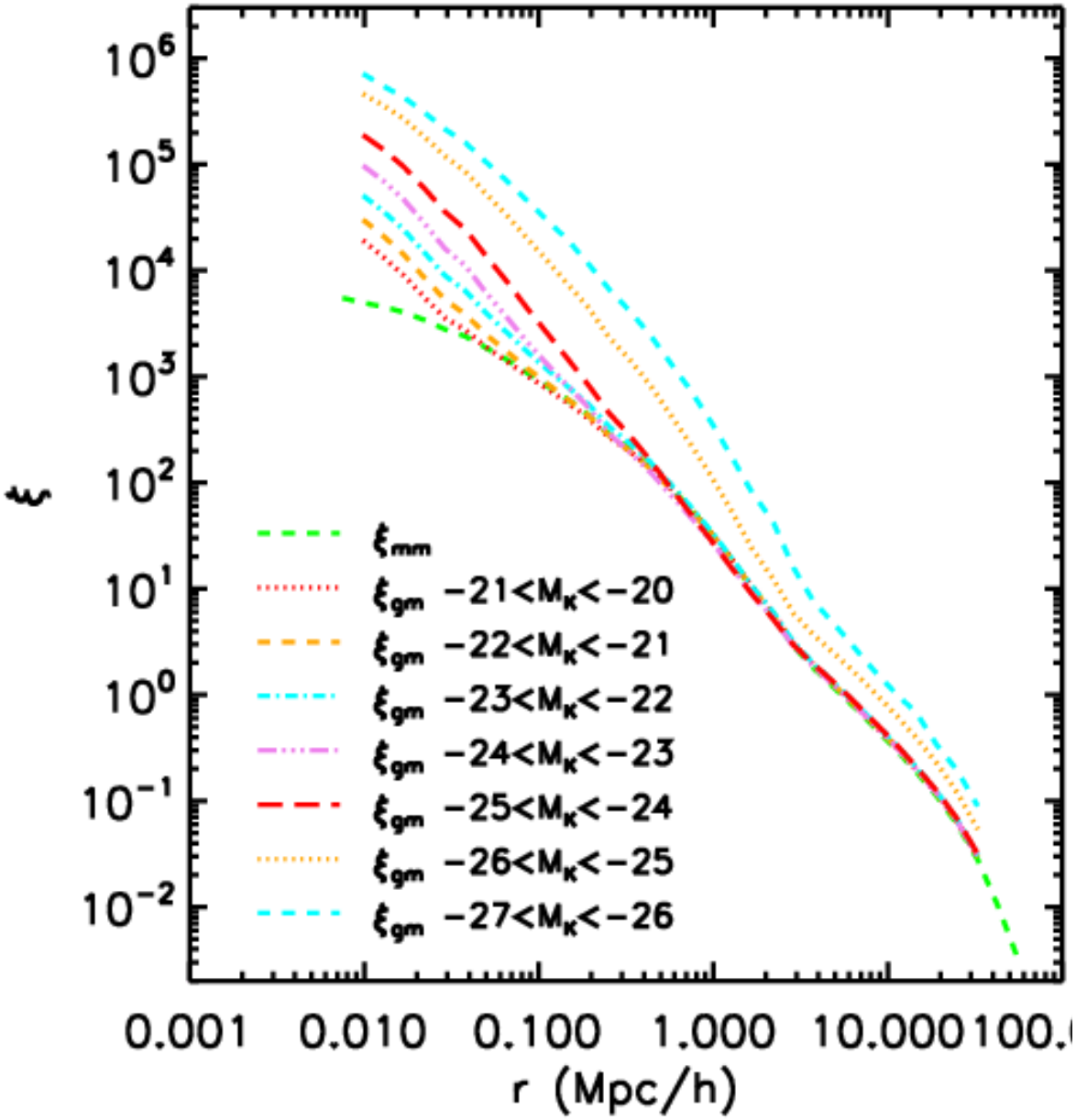
Hayashi et al 2006



- Mean density profiles of halos of given M_{200} are well fit down to overdensities of 10 by the fitting formula of Navarro et al (2004)
- At lower overdensities they are well fit by the *linear* mass correlation function with bias from Sheth, Mo, Tormen (2001)

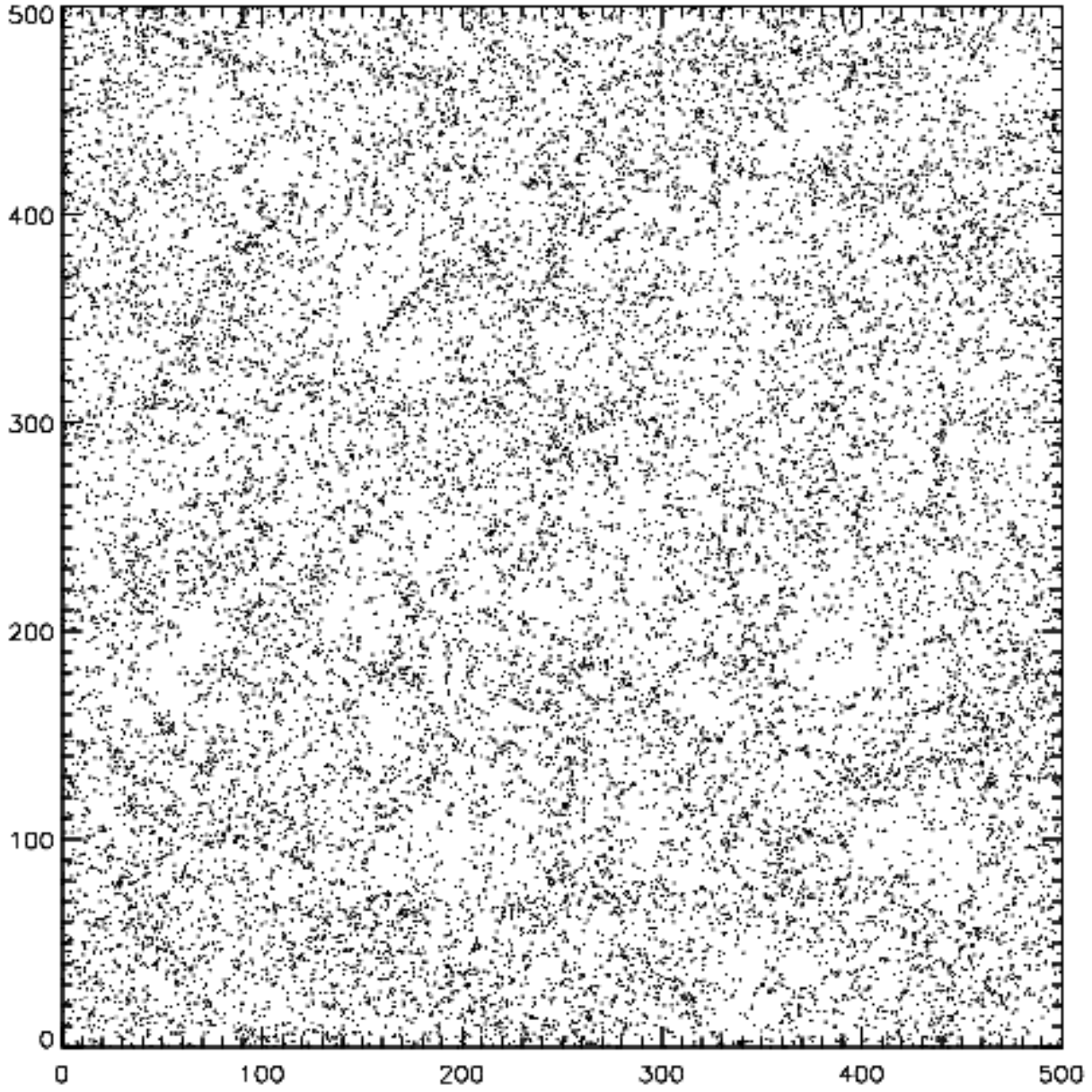
Galaxy-mass cross-correlations to large radii

Hayashi et al 2006



- Galaxy mass cross-correlations are directly measurable through galaxy-galaxy lensing
- They can be predicted from an HOD model and mean halo mass profiles
- Here they are predicted with the Croton et al gal. formation simulation
- On large scale they follow the *nonlinear* ξ_{mm}

Does halo clustering depend on formation history?

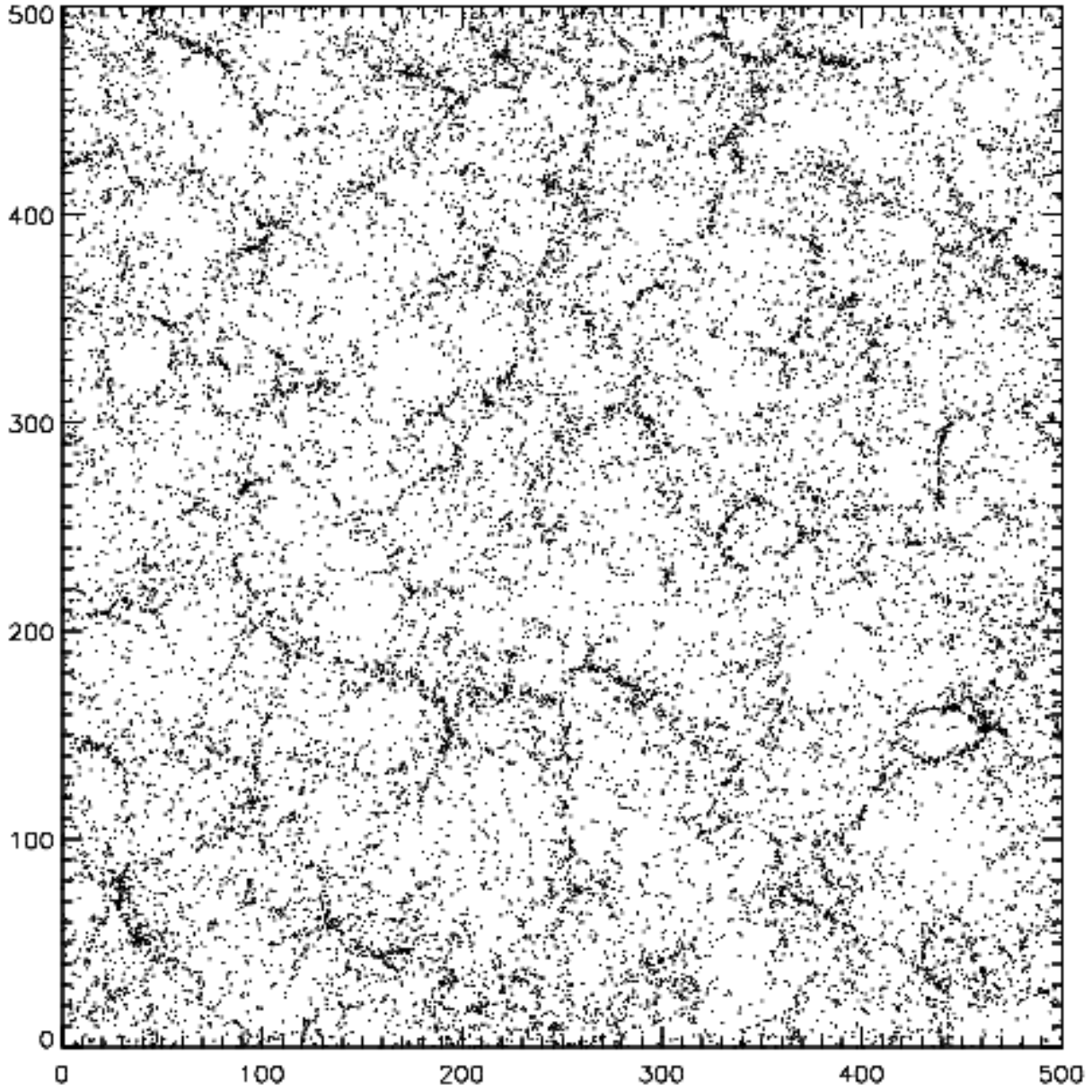


Gao, Springel & White 2005

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

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

Does halo clustering depend on formation history?

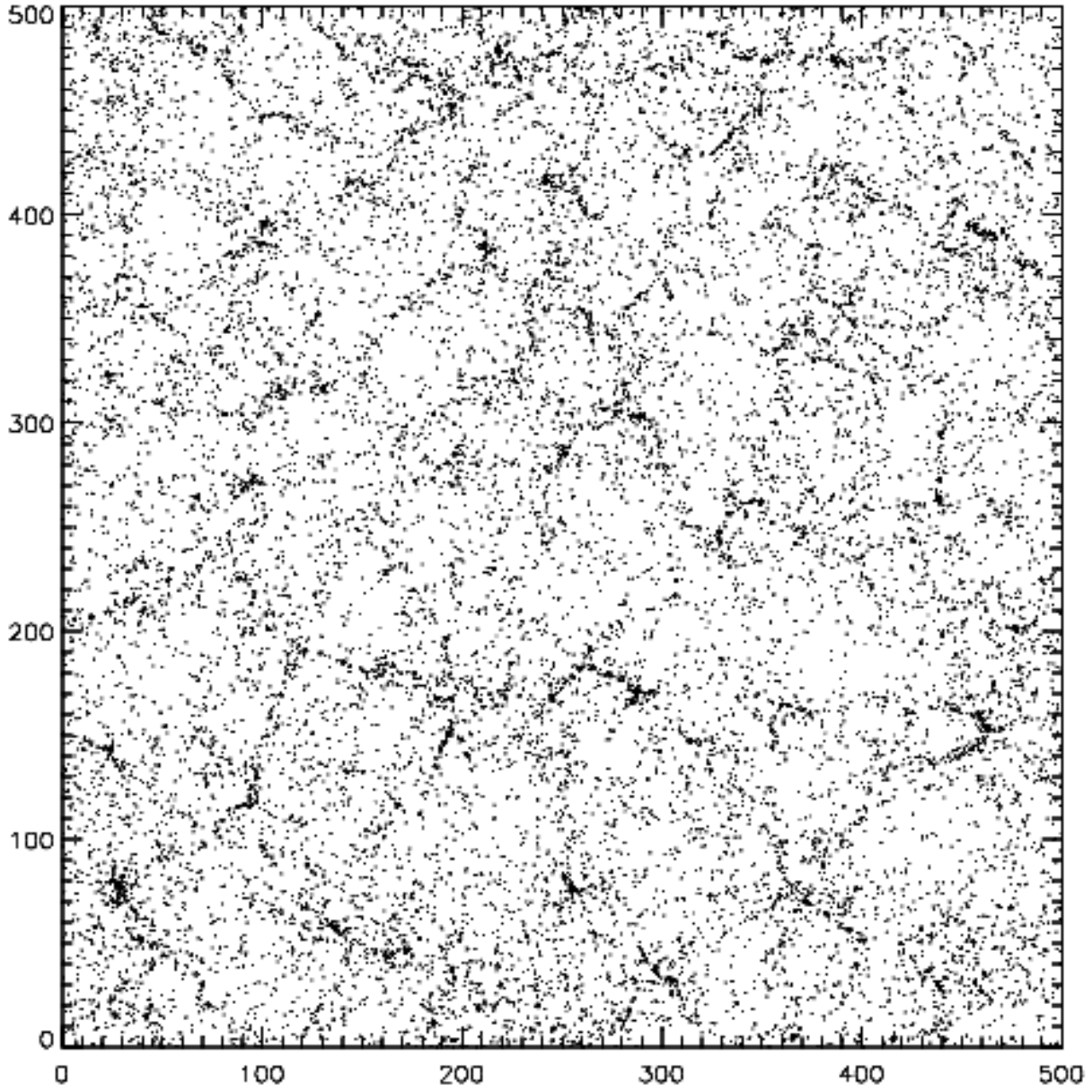


Gao, Springel & White 2005

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

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

Does formation history depend on environment?

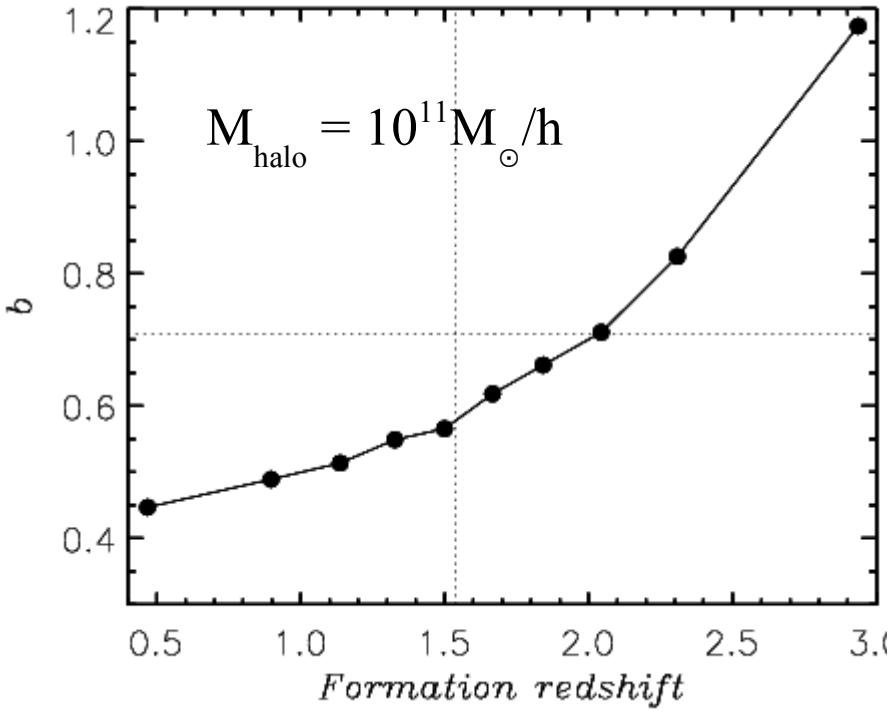


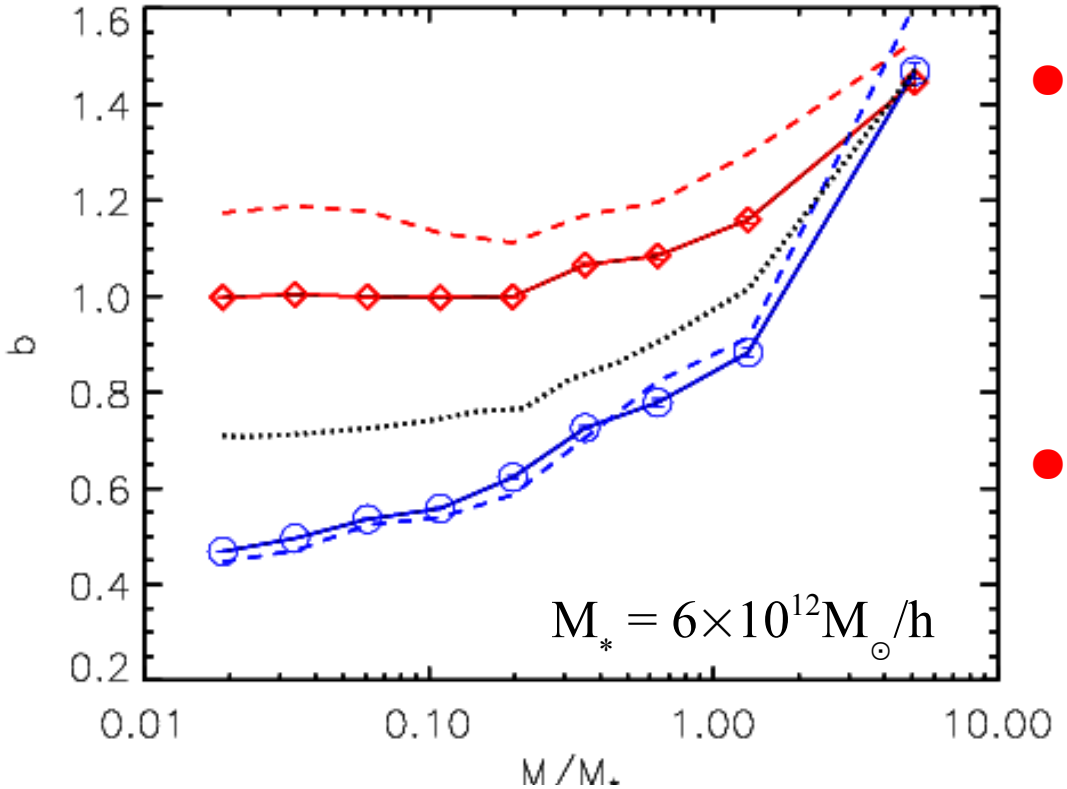
Gao, Springel & White 2005

An equal number of randomly chosen DM particles

Halo bias as a function of mass and formation time

Gao, Springel & White 2005

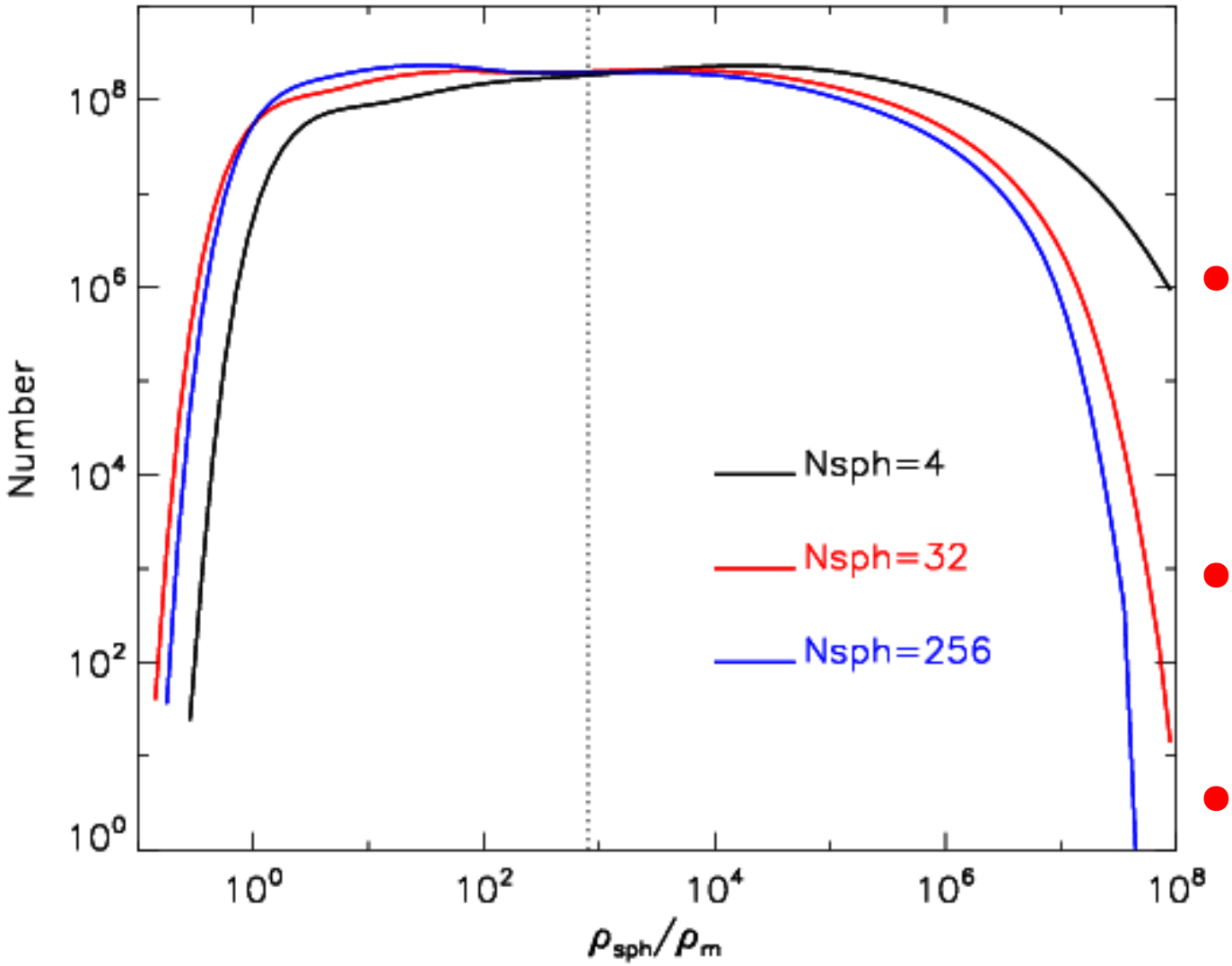




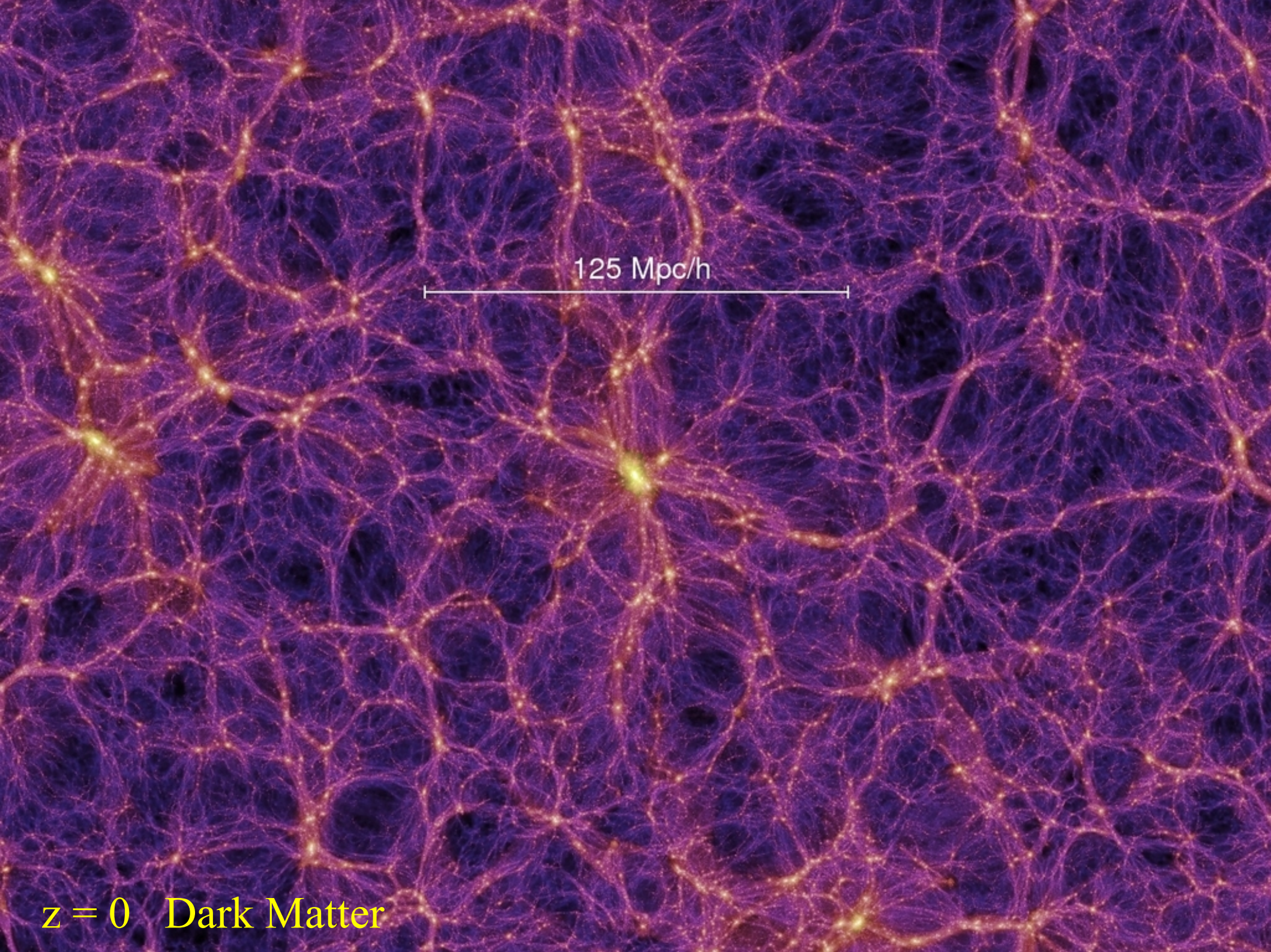
- Bias increases smoothly with formation redshift
- The dependence on formation redshift is strongest at low mass
- This dependence is consistent *neither* with excursion set theory *nor* with HOD models

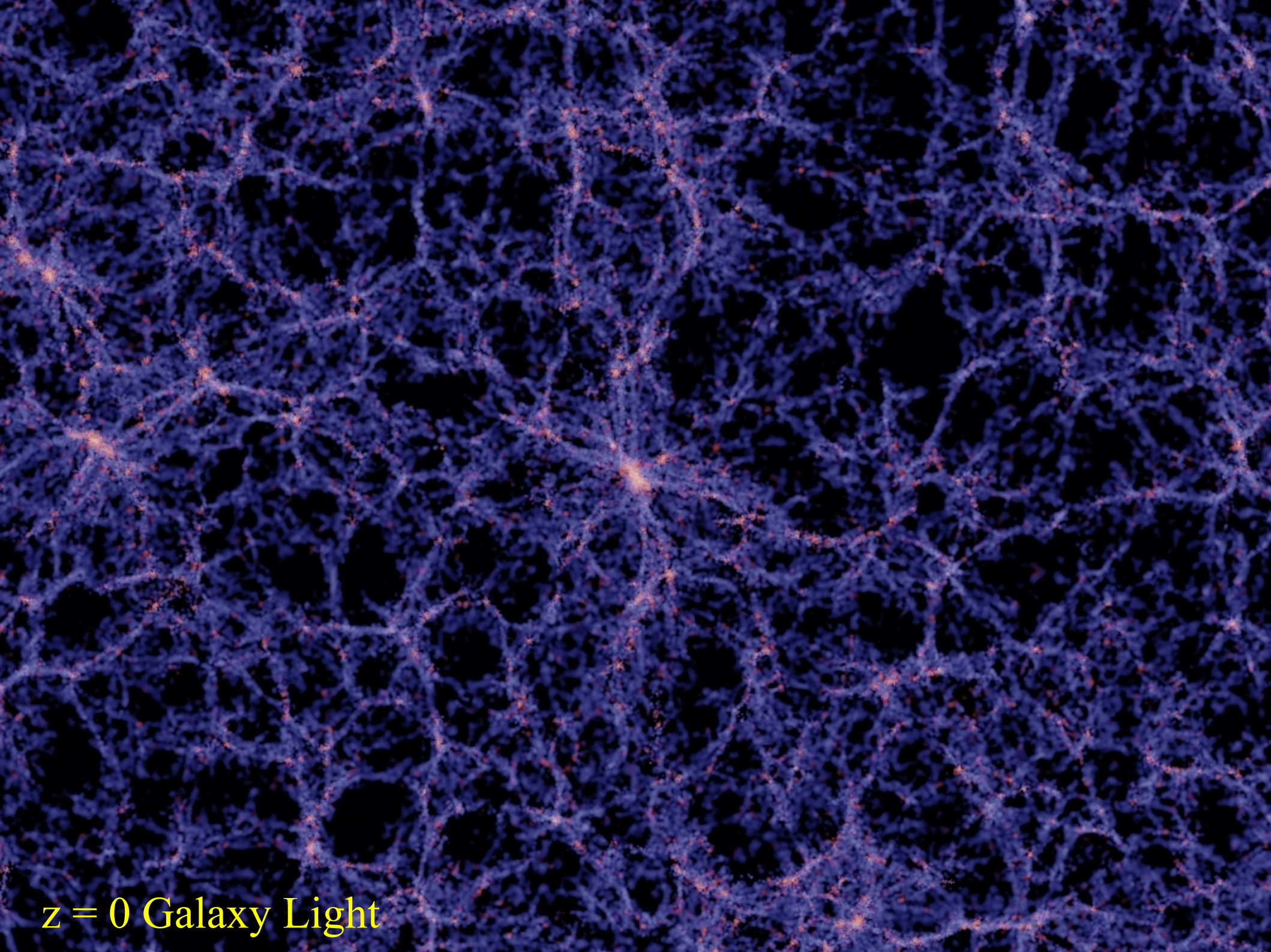
Lagrangian DM density at the present day

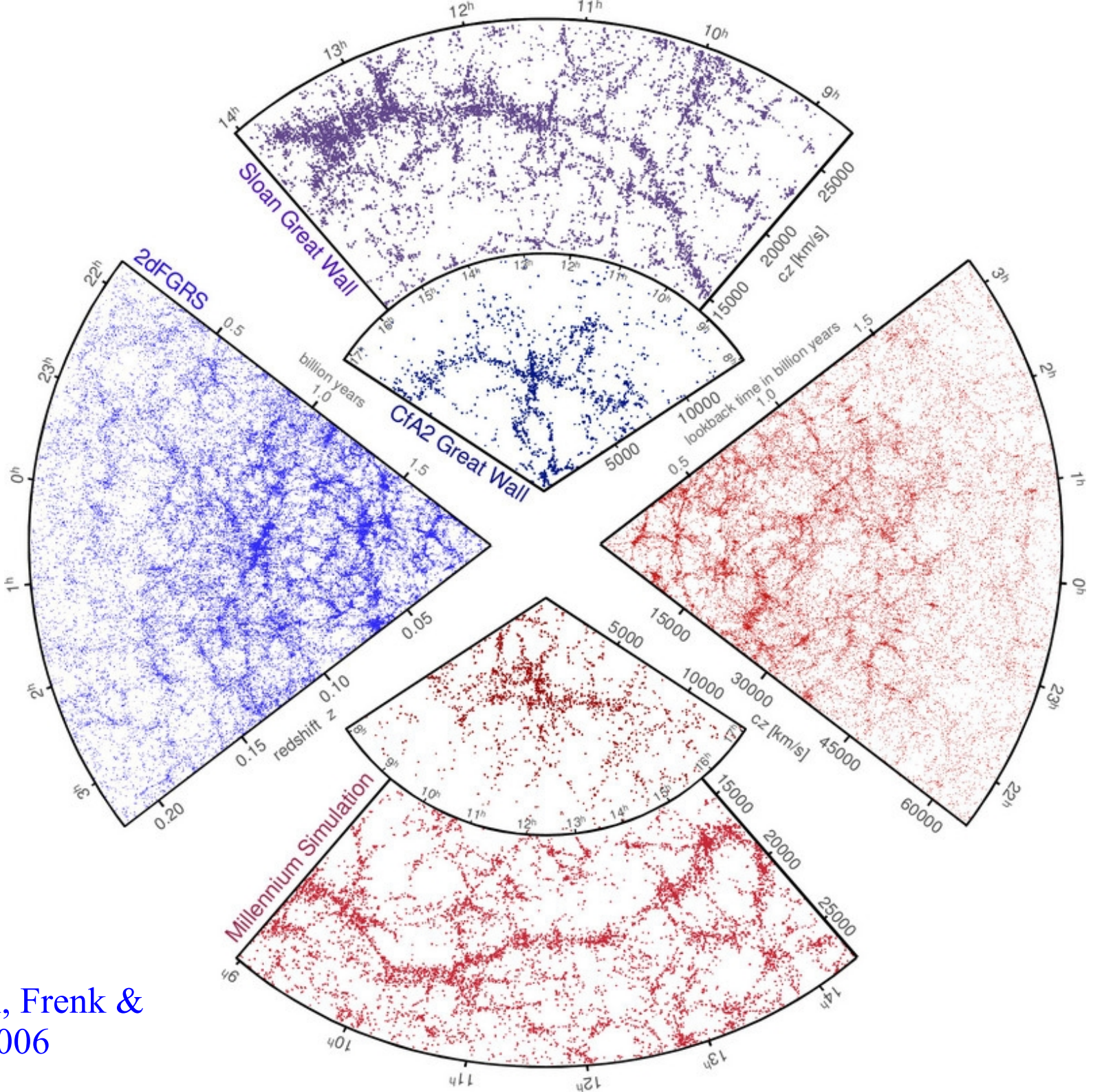
Gao et al 2006



- Lagrangian smoothing gives density today on given *mass* scale
- Distribution function is flat over at least 6 orders of magnitude
- It is very far from lognormal
- The linear-nonlinear transition is *not* very obvious


125 Mpc/h
z = 0 Dark Matter

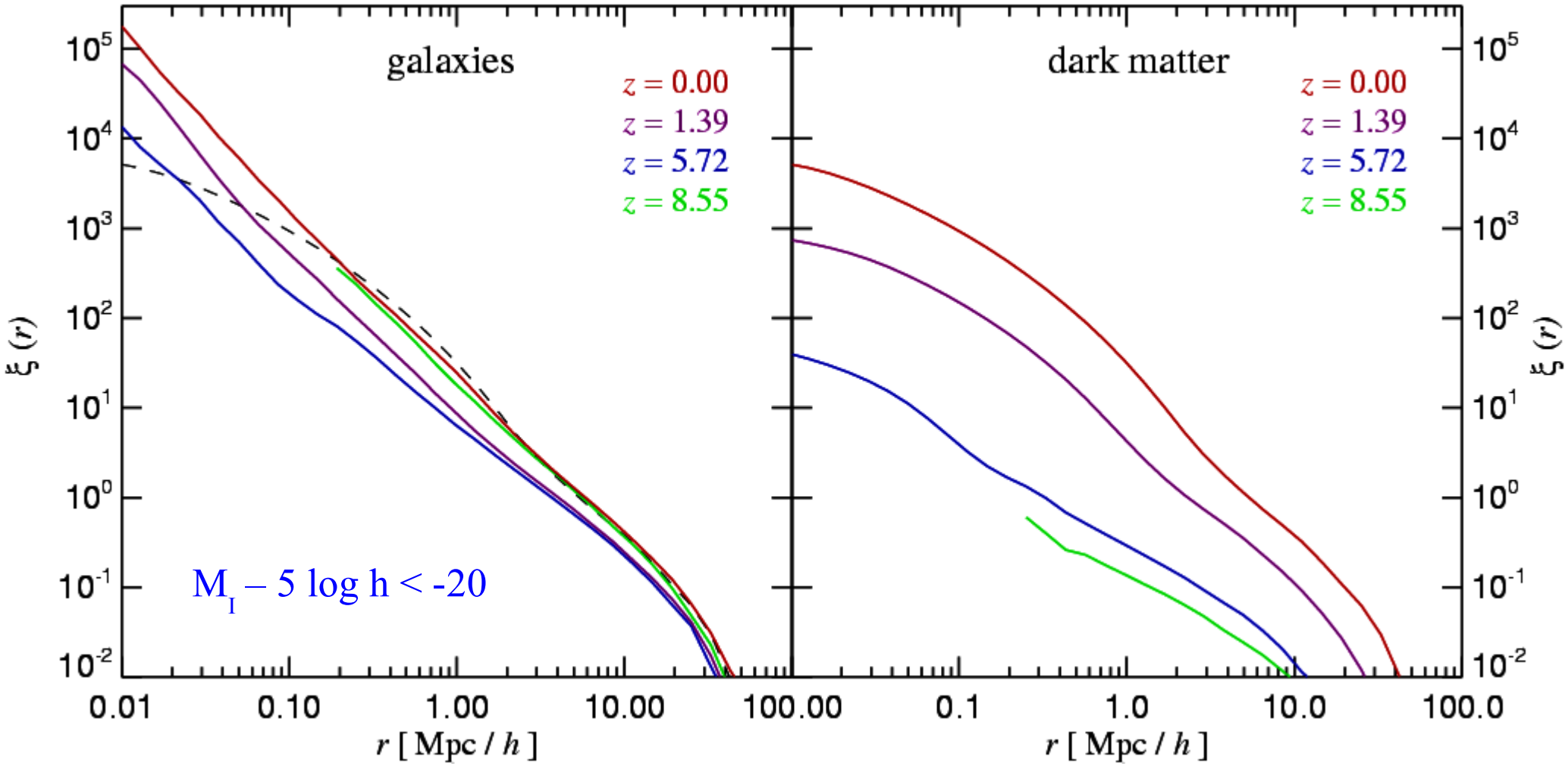

z = 0 Galaxy Light



Springel, Frenk & White 2006

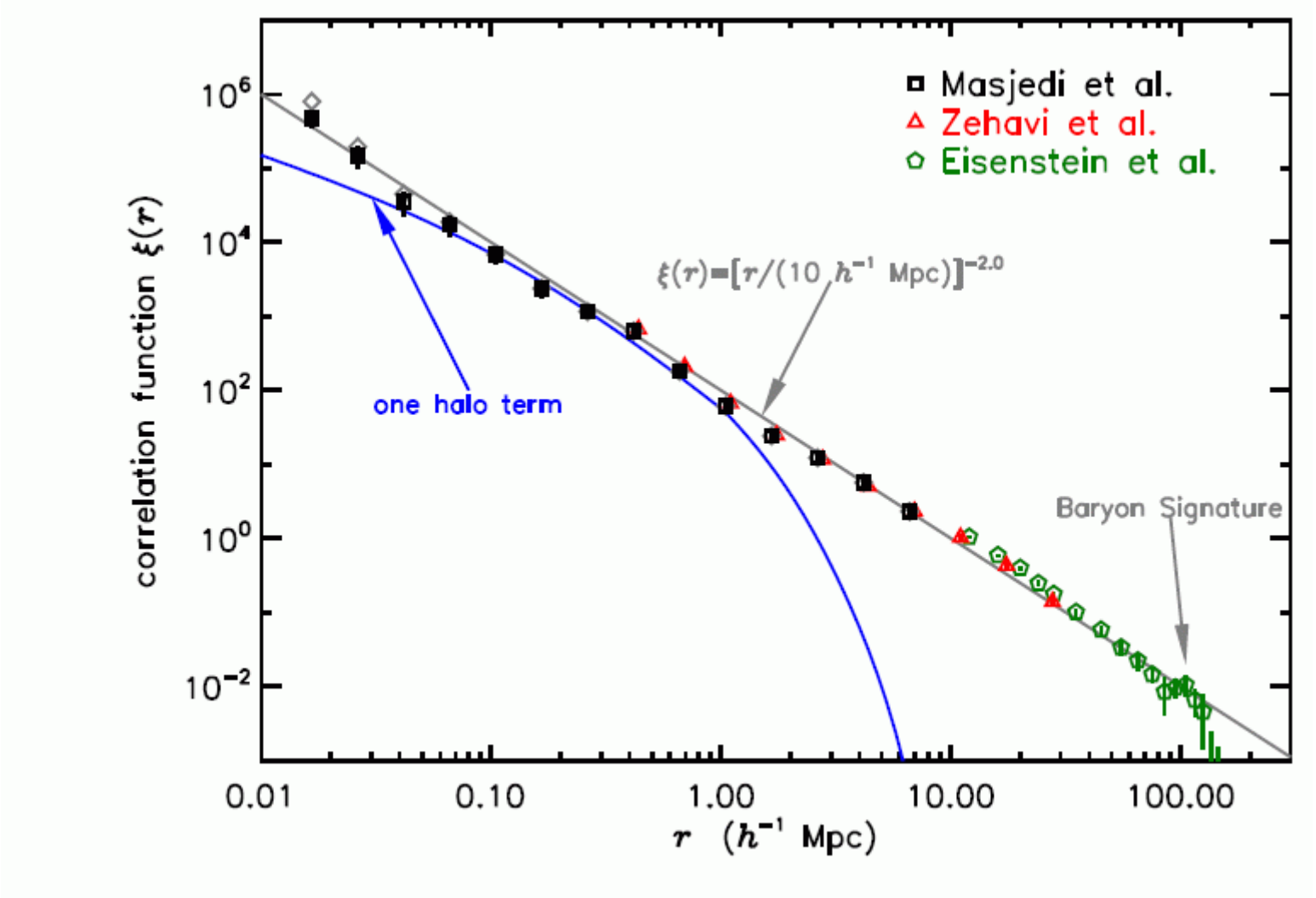
Evolution of mass and galaxy correlations

Springel, Frenk & White 2006



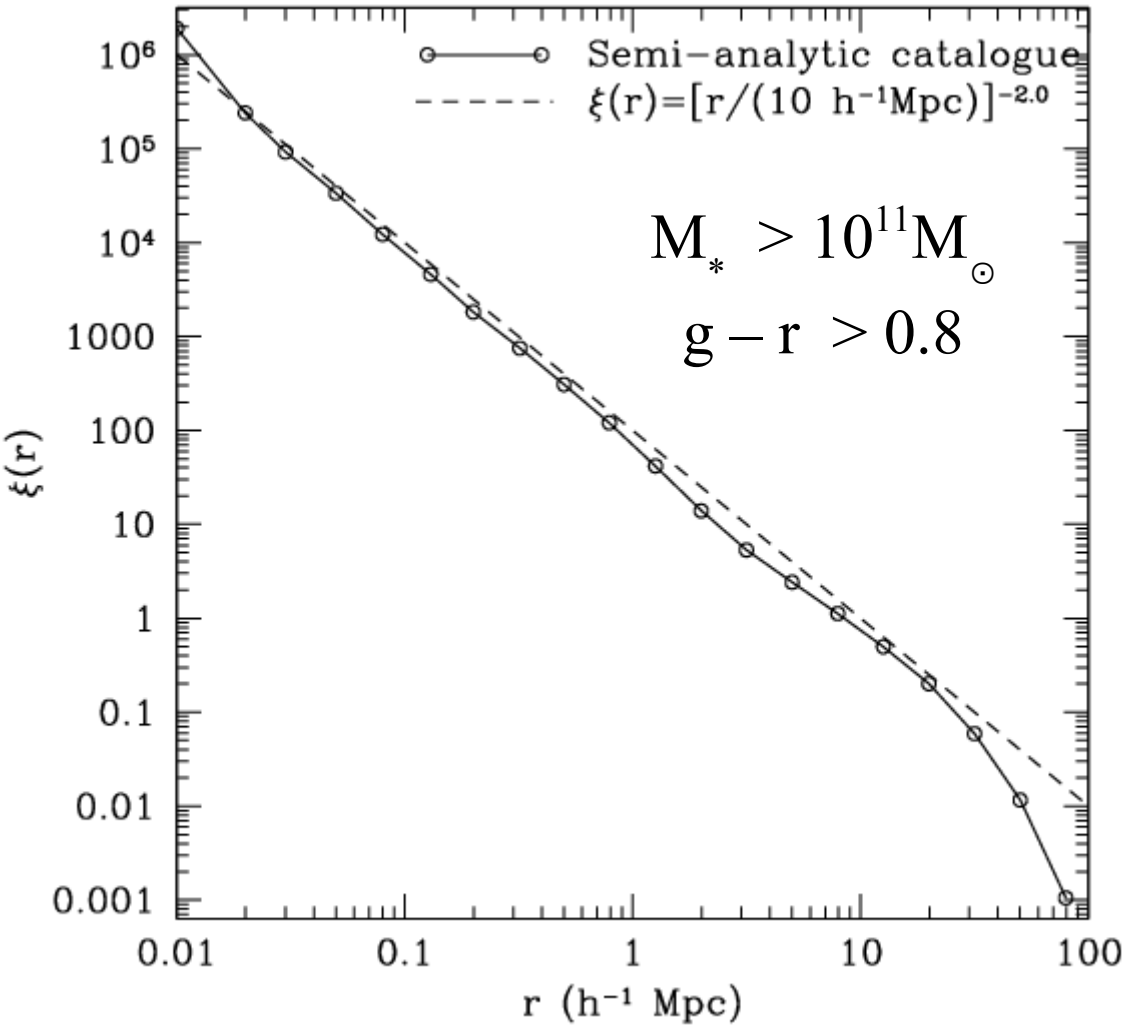
Precise estimates of autocorrelation functions Luminous red galaxies in the SDSS

Masjedi et al 2005



Precise estimates of autocorrelation functions Luminous red galaxies in the M.S.

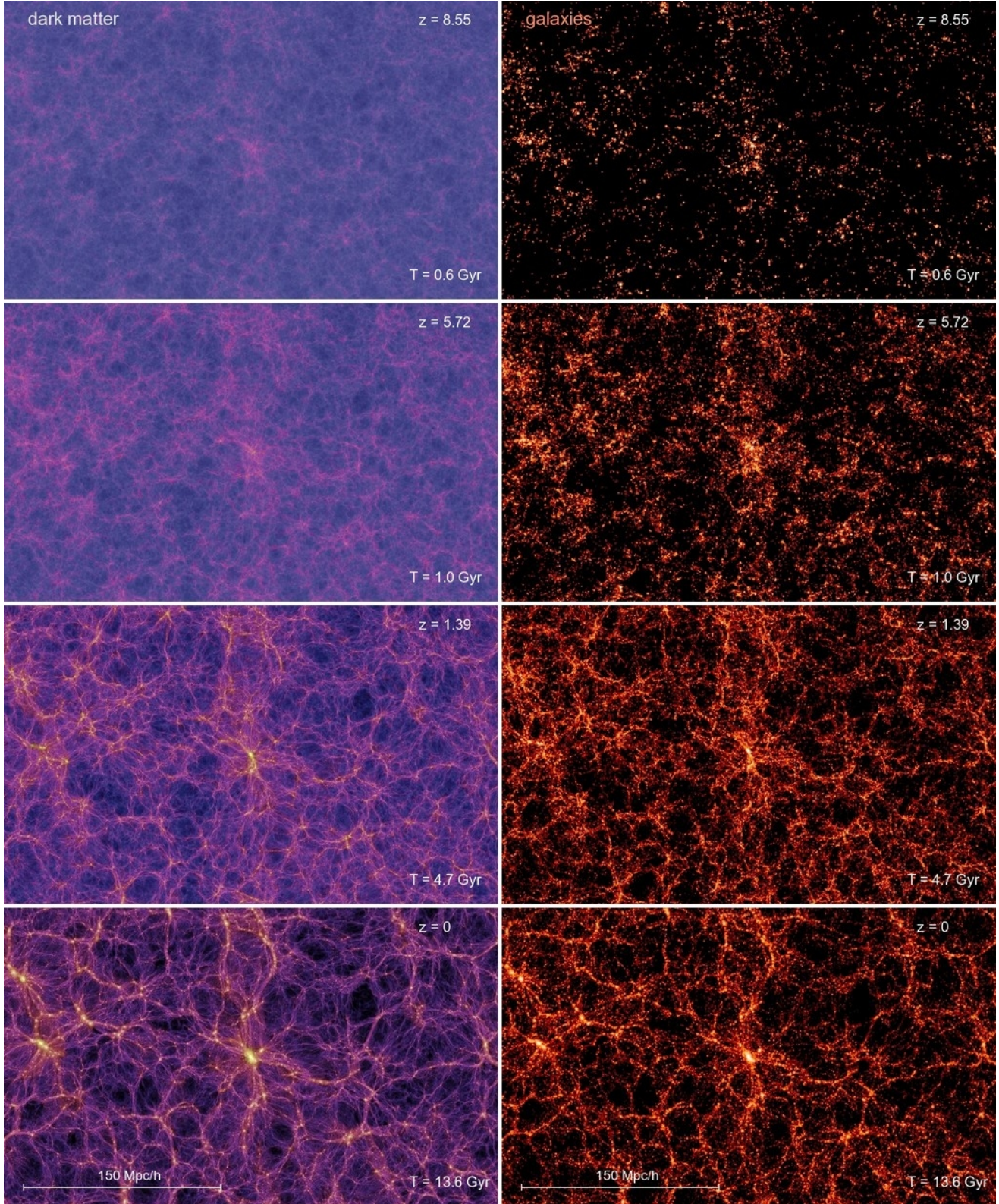
From public Millennium Simulation data archive



- Matching the observed correlations on scales below ~ 200kpc requires a radial distribution of satellites differing

  (i) from the mass distr'n

  (ii) from the simulated subhalo distribution

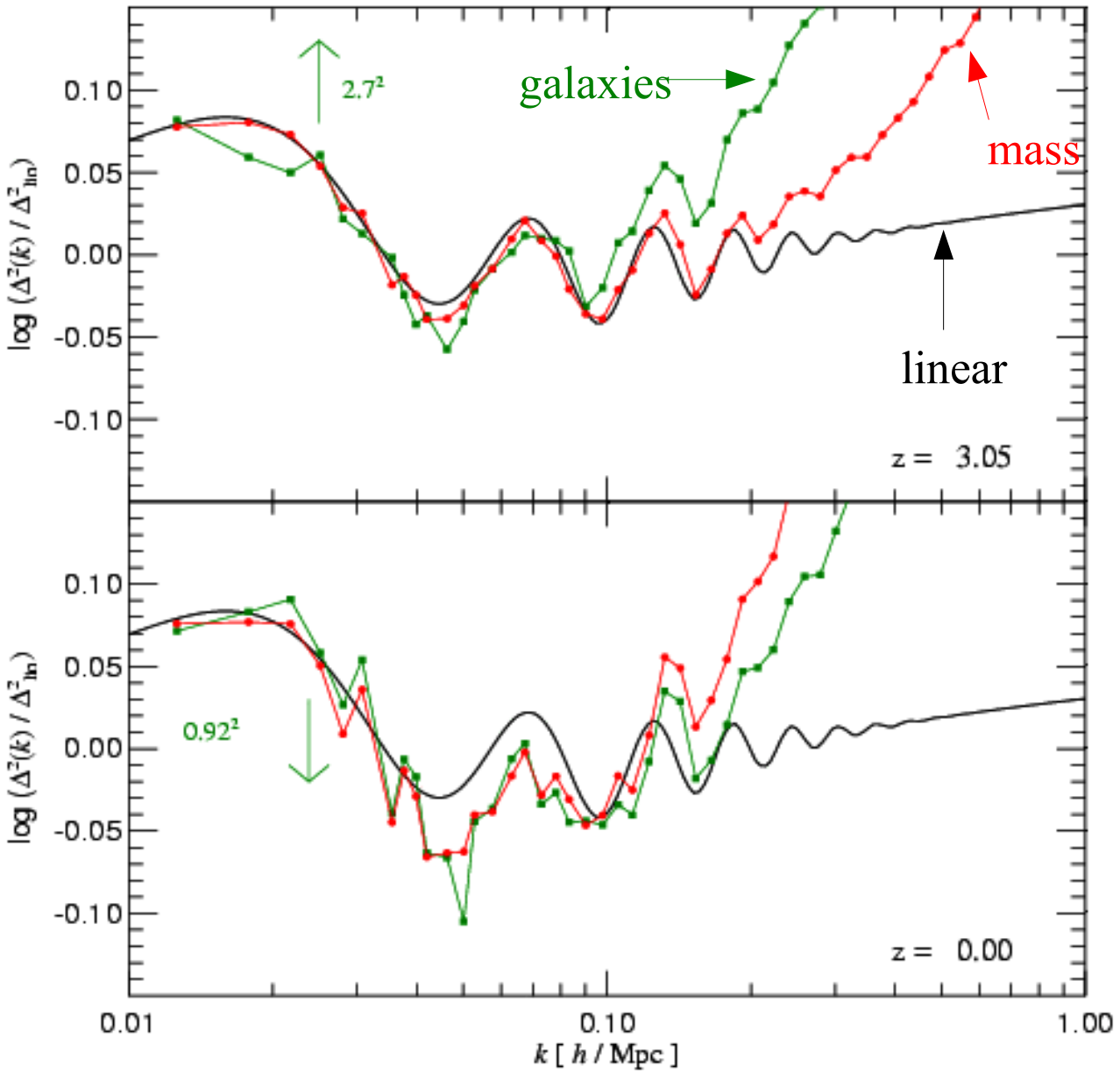


Large-scale structure at high redshift

Springel, Frenk & White 2006

Large-scale structure in the galaxy distribution evolves very little with redshift

It is as strong at z=8.5 as at z=0



Baryon wiggles in the *galaxy* distribution

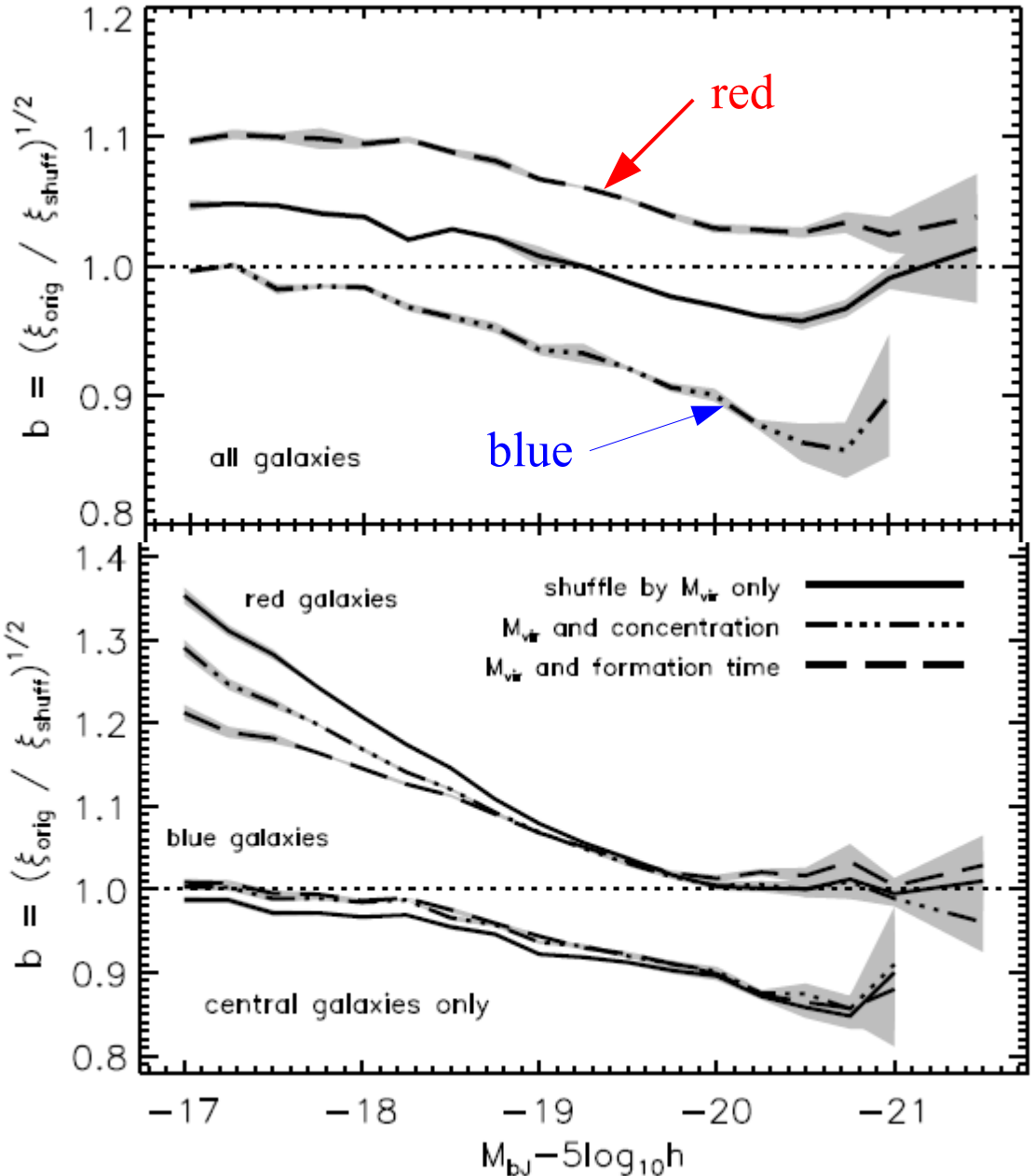
Springel et al 2005

Power spectra from the Millennium run divided by a baryon-free ΛCDM spectrum

Galaxy samples are matched to plausible large observational surveys at given z

Assembly bias in simulated galaxy catalogues

Croton, Gao & White 2006



- Take a *simulation* of galaxy formation (Croton et al 2006)
- Calculate galaxy correlations for absolute magnitude limited galaxy samples
- Shuffle galaxy populations among halos of *identical* mass
- Calculate galaxy correlations for the same galaxy samples
- Compare relative bias on large scales as function of mag. limit

GERMAN ASTROPHYSICAL VIRTUAL OBSERVATORY

Exploring the milli-Millennium simulation with a relational database


```
select D.I_HALO,
       D.SNAPNUM,
       D.N_P as D_NP,
       P1.N_P as P1_NP,
       P2.N_P as P2_NP
  from HALO P1,
       HALO P2,
       HALO D
 where P1.SNAPNUM=P2.SNAPNUM
   and P1.I_HALO < P2.I_HALO
   and P1.I_DESCENDANT = D.I_HALO
   and P2.I_DESCENDANT = D.I_HALO
   and P1.N_P >= .2*D.N_P
   and P2.N_P >= .2*D.N_P
   and D.N_P > 1000
```

Execute Query

Clear all

Help

Maximum number of rows to return to the query form: 10

Previous queries :

Halo 1 | Galaxy 1 — Find halos/galaxies at a given redshift (SNAPNUM) within a certain part of the simulation volume (X,Y,Z).

Halo 2 — Find the whole progenitor tree, in depth-first order, of a halo identified by its id (I_HALO)

Halo 3 — Find the progenitors at a given redshift (SNAPNUM) of all halos of mass (N_P) greater than 4000 at a later redshift (SNAPNUM). The progenitors are limited to have mass >= 100.

Halo 4 — Find all the halos of mass (N_P) >= 1000 that have just had a major merger, defined by having at least two progenitors of mass >= 0.2*descendant mass.

Halo 5 | Galaxy 5 — Find the mass/luminosity function of halos/galaxies at z=0 using logarithmic intervals.

Galaxy 6 — Find the Tully-Fisher relation, Mag_b/v/i/k vs V_vir for galaxies with bulge/total mass ratio < 0.1. Subsample by about 1% (RANDOM between 20000 and 30000).

Reformat | CSV

Plot (VOPlot) — This button wil attempt to start up VOPlot within an applet, so that the current result can be explored graphically. This clearly requires that the browser has been configured for viewing applets.
DISCLAIMER This functionality has been partially tested only. Any problems are our responsibility, not VOPlot's.
It seems that the applet does not work properly with Konqueror.

Query time (in millisec) = 15623
Number of rows retrieved from database = 12 (Maximum # = 10000)

i_halo	snapnum	d_np	p1_np	p2_np
2576	60	1079	924	222

http://www.mpa-garching.mpg.de/Millennium