Selected Stories

A. Klypin, S.Trujillo-Gomez (NMSU)
J.Primack (UCSC), F. Prada (Granada)

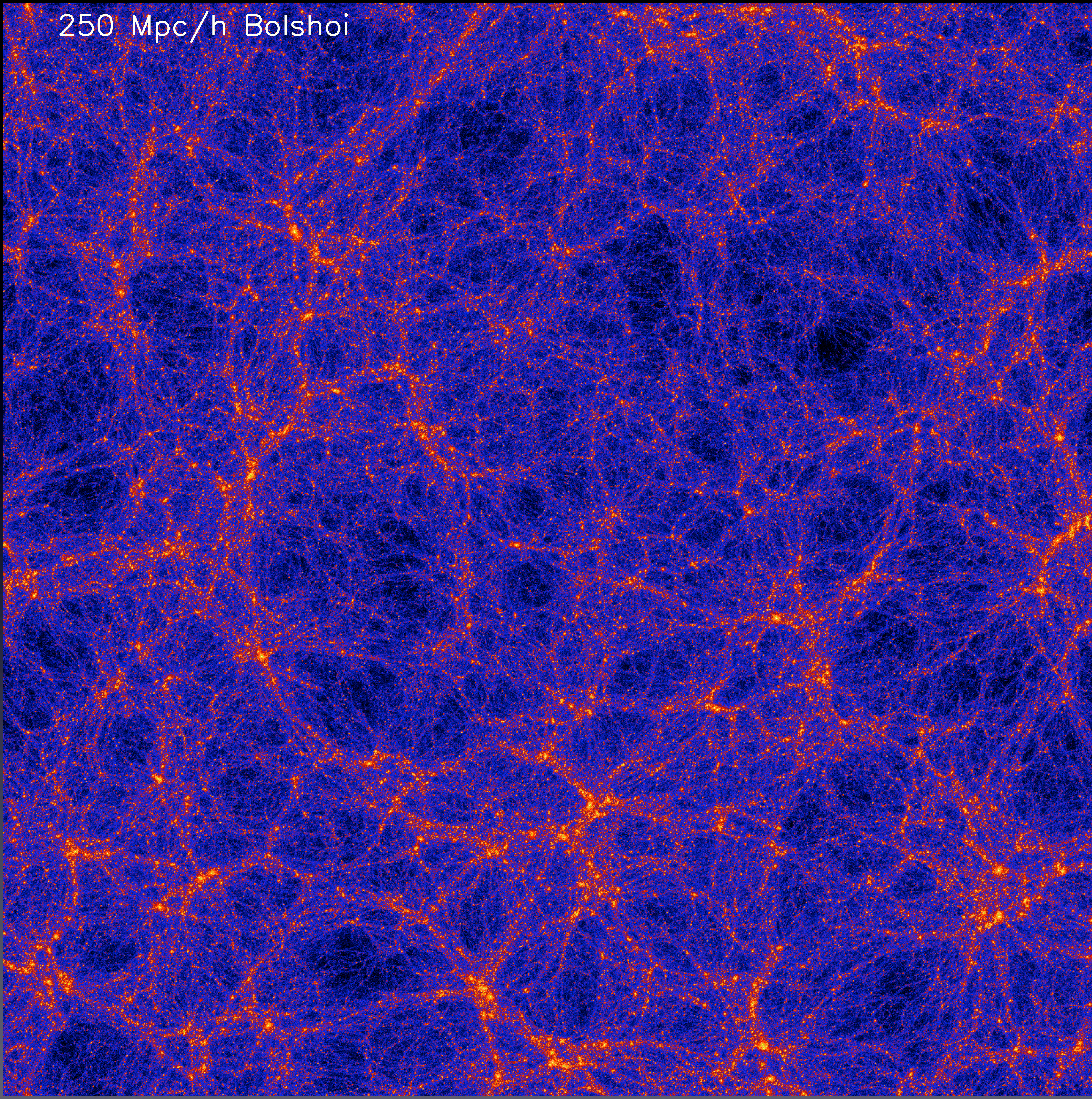
Chapter I: *Halo concentration, in which we discover three stages of halo formation*

The Bolshoi simulation ART code

250Mpc/h Box
LCDM
s8 = 0.82
h = 0.70
8G particles
1kpc/h force resolution
1e8 Msun/h mass res

dynamical range 262,000
time-steps = 400,000

NASA AMES
supercomputing center
Pleiades computer
13824 cores
12TB RAM
75TB disk storage
6M cpu hrs
18 days wall-clock time



Halo Concentration: $C = R_{vir}/R_s$ *Why it is important*

Halo Concentration: $C = R_{vir}/R_s$ Why it is important

Basic property of DM halos: you need it if you do anything with DM halos.

Halo Concentration: $C = R_{vir}/R_s$ Why it is important

Basic property of DM halos: you need it if you do anything with DM halos.

Tells us how halos formed.

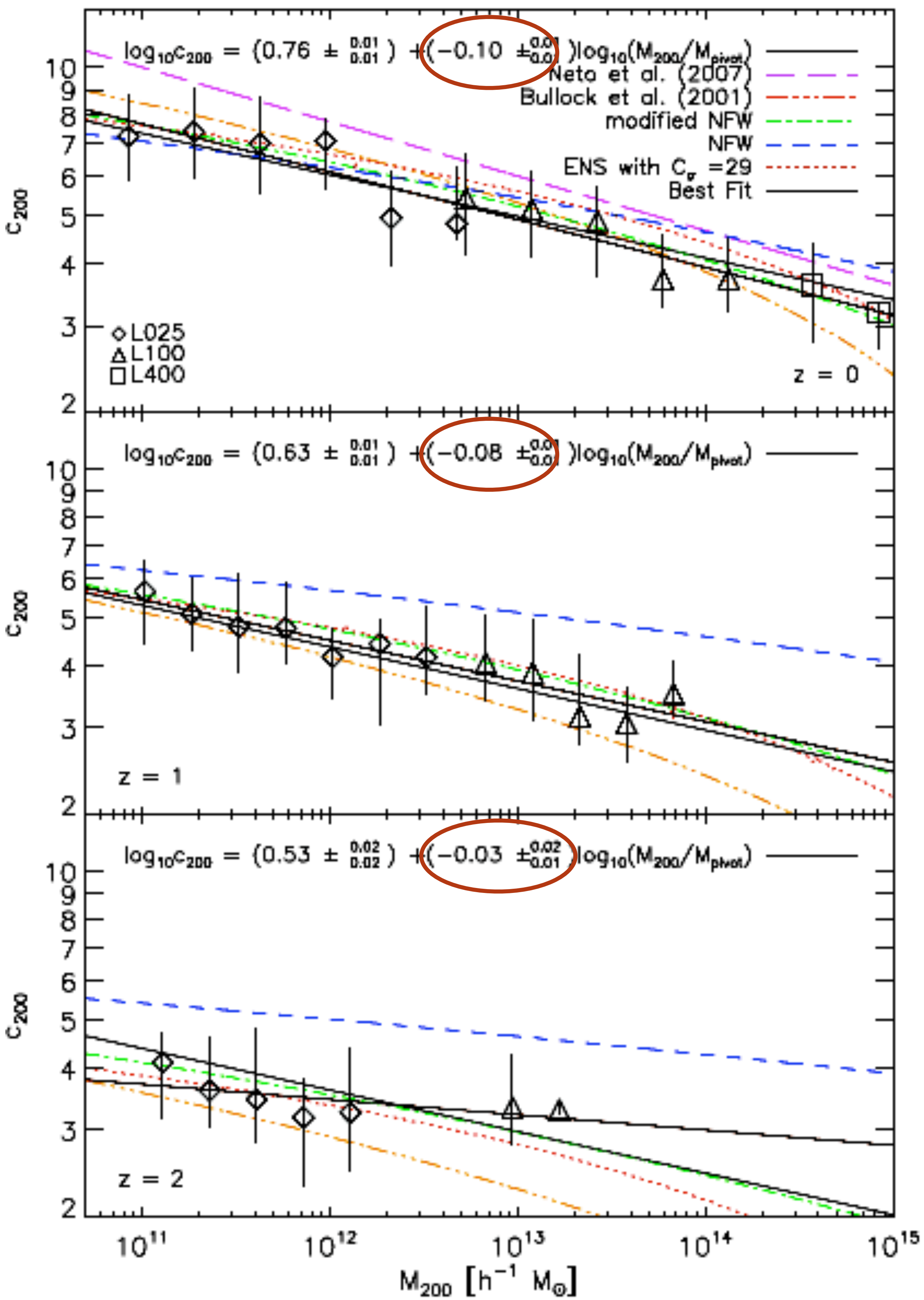
Halo Concentration: $C = R_{vir}/R_s$ Why it is important

Basic property of DM halos: you need it if you do anything with DM halos.

Tells us how halos formed.

Need high-quality data

Halo Concentration: $C = R_{vir}/R_s$ Brief review

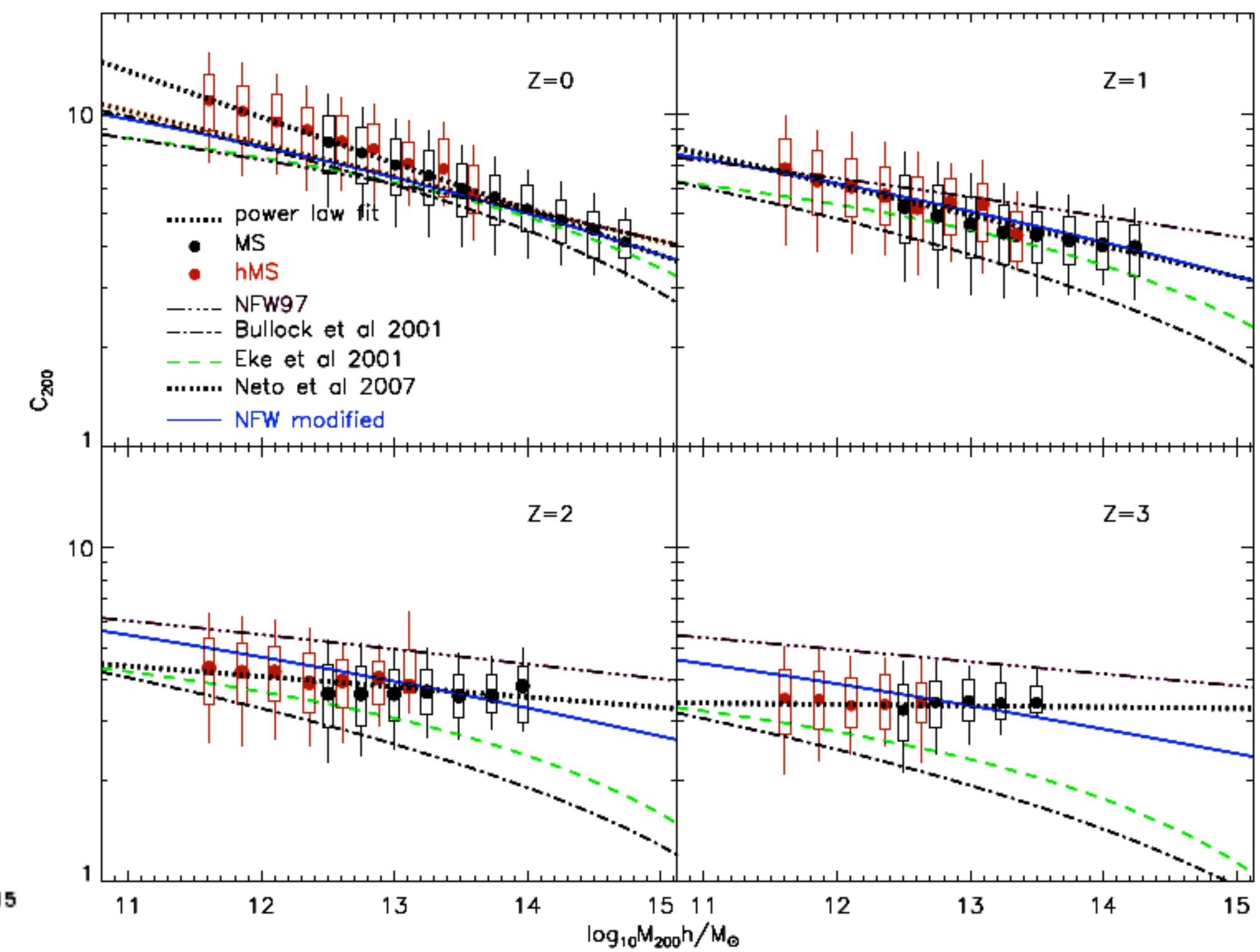


Duffy et al 2007

At z=0 C(M) is almost a power law

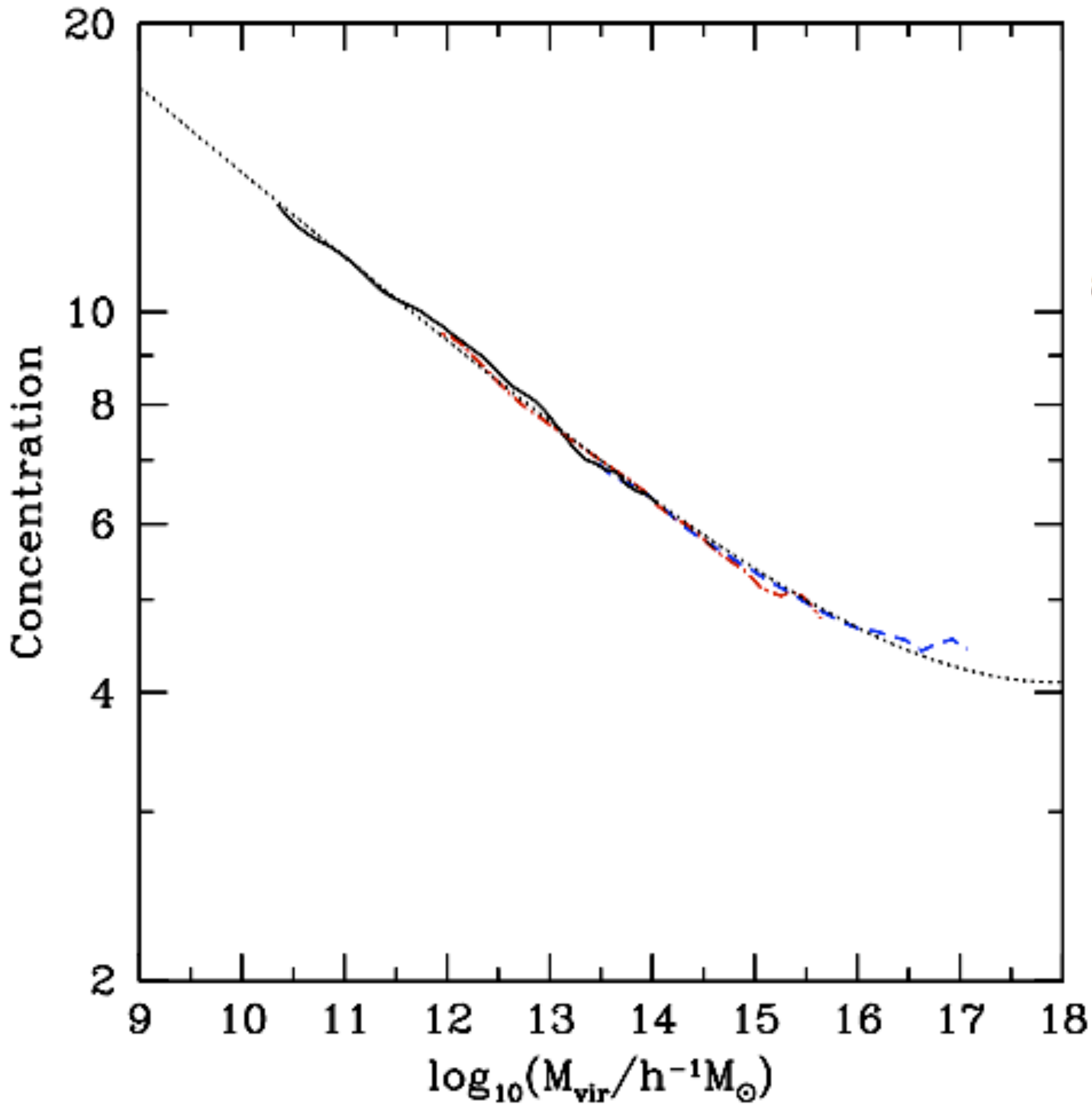
Slope gets shallower at high z

Gao et al 2008



Halo Concentration: $C = R_{vir}/R_s$

Klypin et al 2010



$$c(M_{\rm vir}) = 9.35 \left(\frac{M_{\rm vir}}{10^{12} h^{-1} M_\odot} \right)^{-0.09}$$

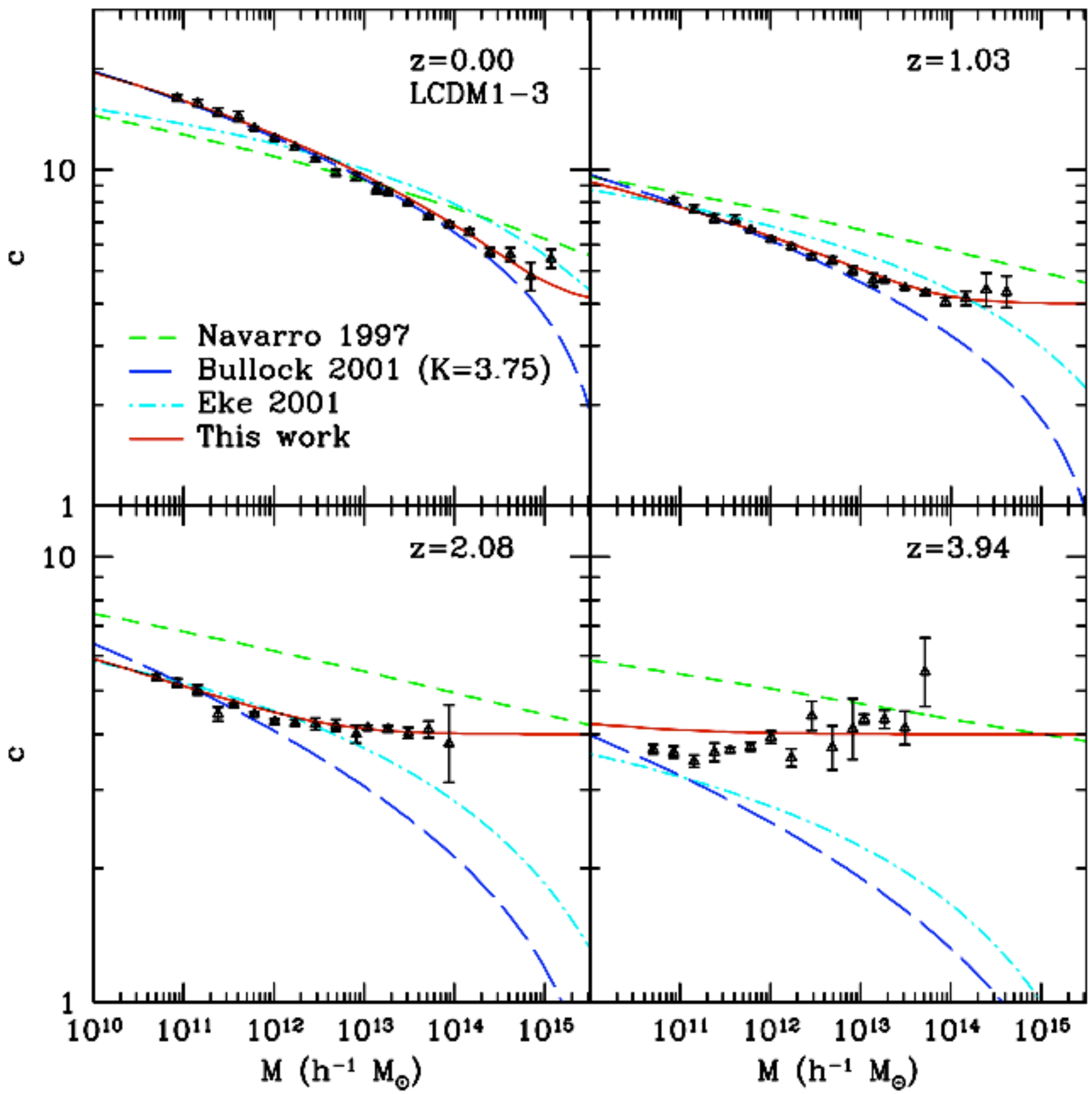
and for subhalos:

$$c(M_{\rm sub}) = 12 \left(\frac{M_{\rm sub}}{10^{12} h^{-1} M_\odot} \right)^{-0.12} .$$

Concentration at z=0
for σ_8=0.82

Halo Concentration: flattening at high redshifts

First noticed by Wechsler et al 2003: $C_{vir,min}$ =4.1
Also: Zhao etal 2003, Zhao et al 2009

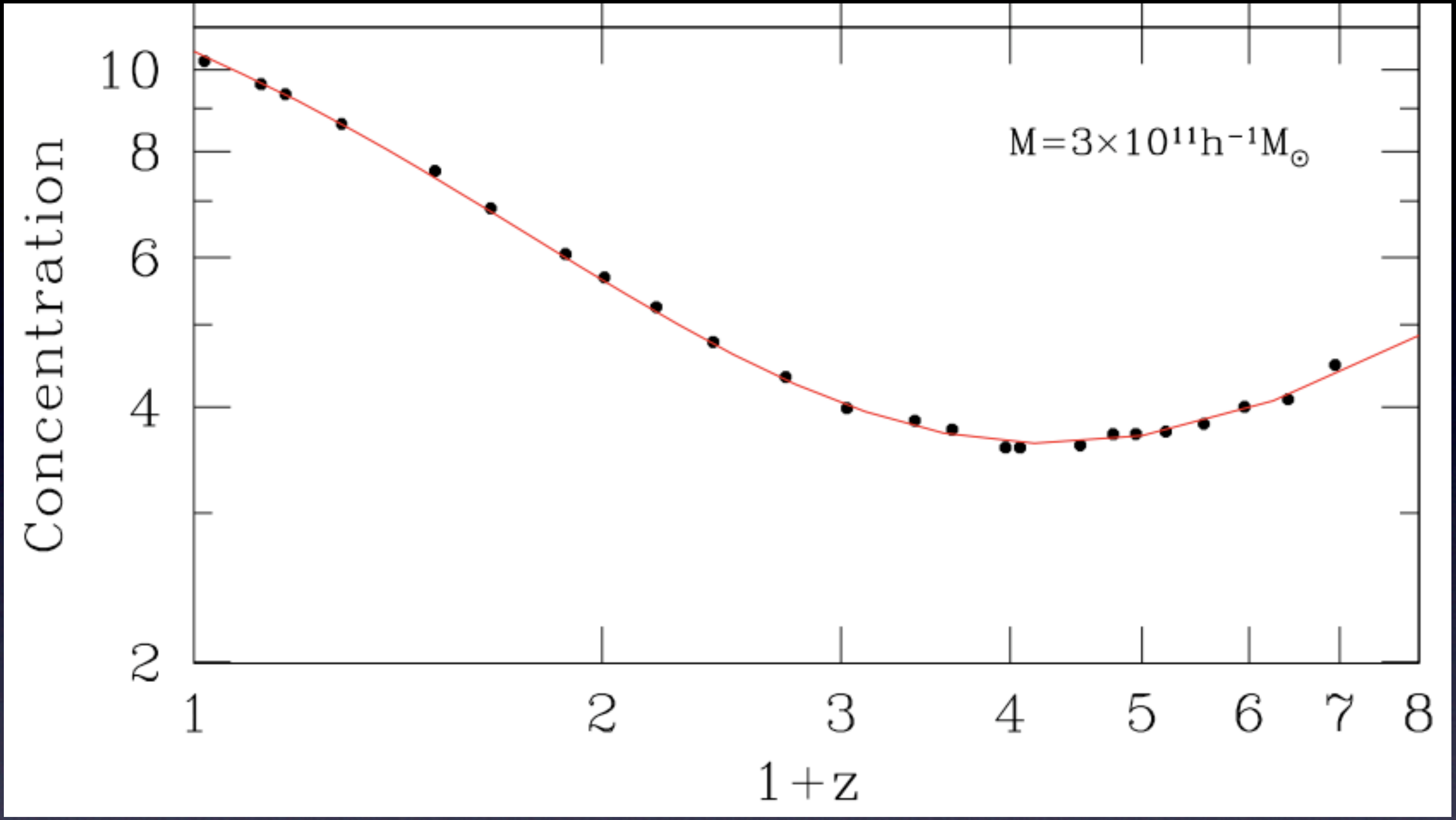


Flattening in C(M) separates two regimes:

- fast growth of mass with nearly constant concentration
- slow growth accretion, increasing concentration

Halo Concentration: evolution with redshift

After initial decline the concentration flattens and then starts to increase again



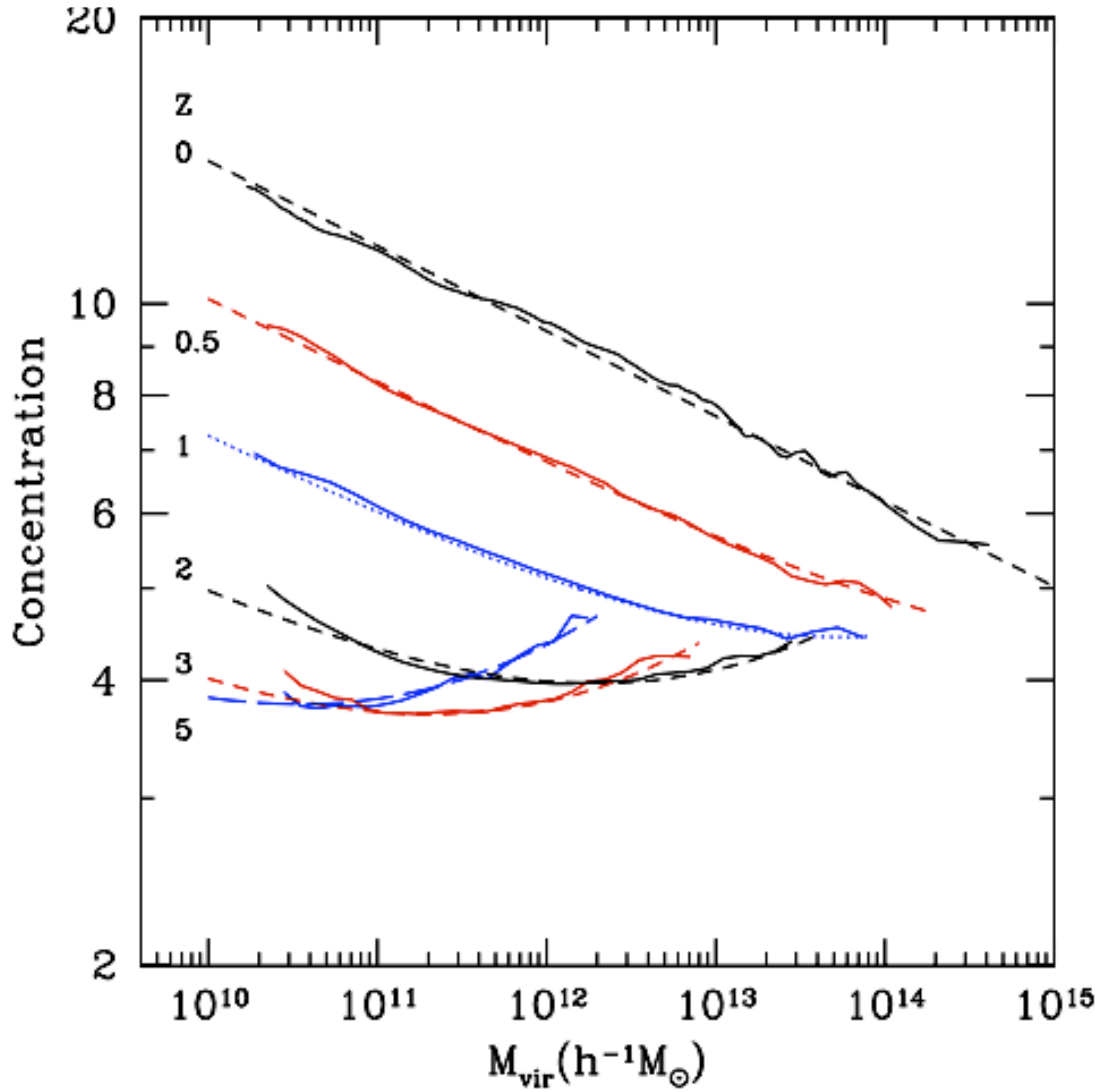
$$c(M_{\rm vir}, z) = c_0(M_{\rm vir}) \left[\delta^{3/2}(z) + \kappa(\delta^{-1}(z) - 1)\right], \quad (14)$$

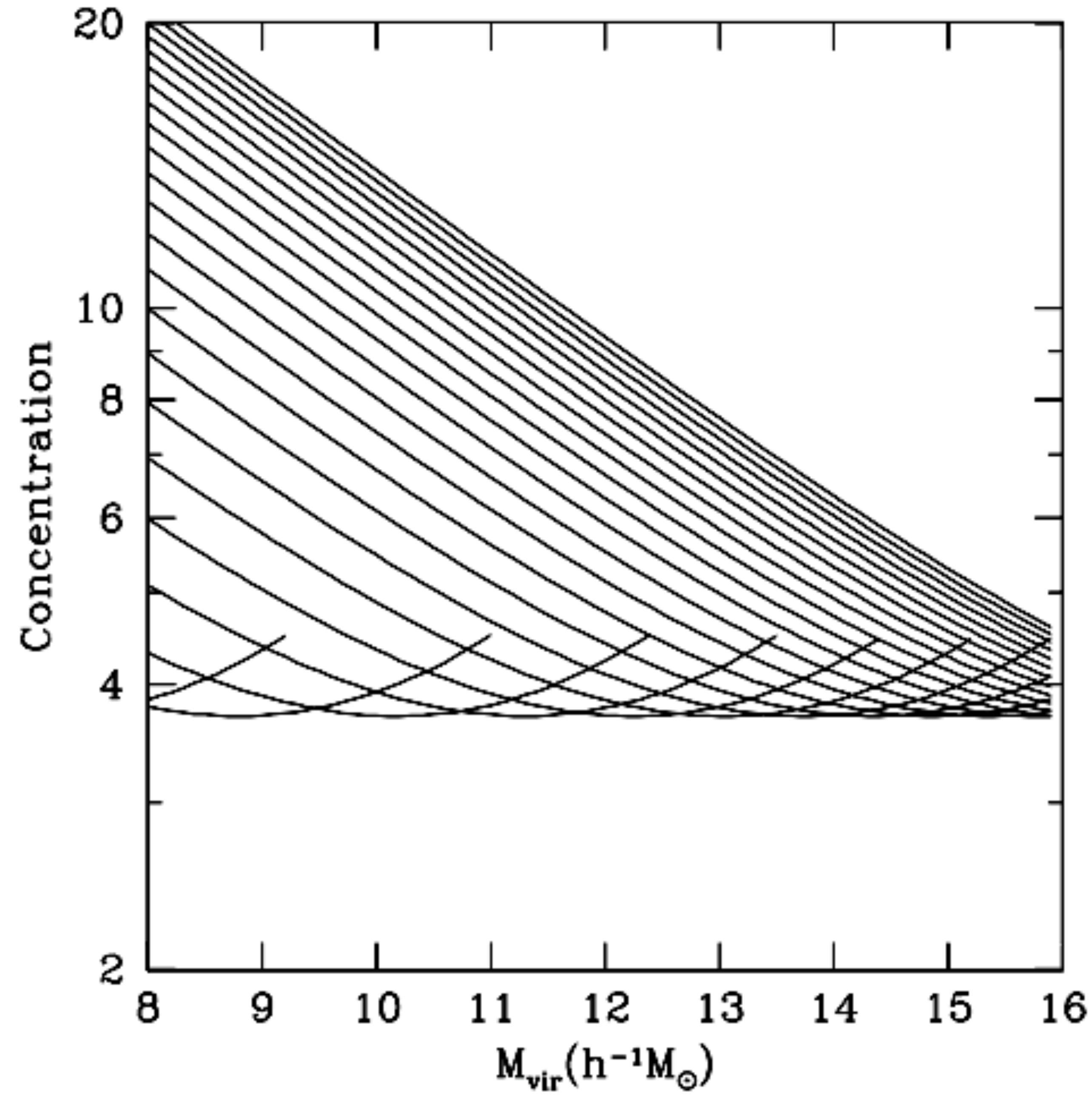
here $\delta(z)$ is the linear growth factor of fluctuations normalized to be $\delta(0) = 1$ and κ is a free parameter

Klypin et al 2010

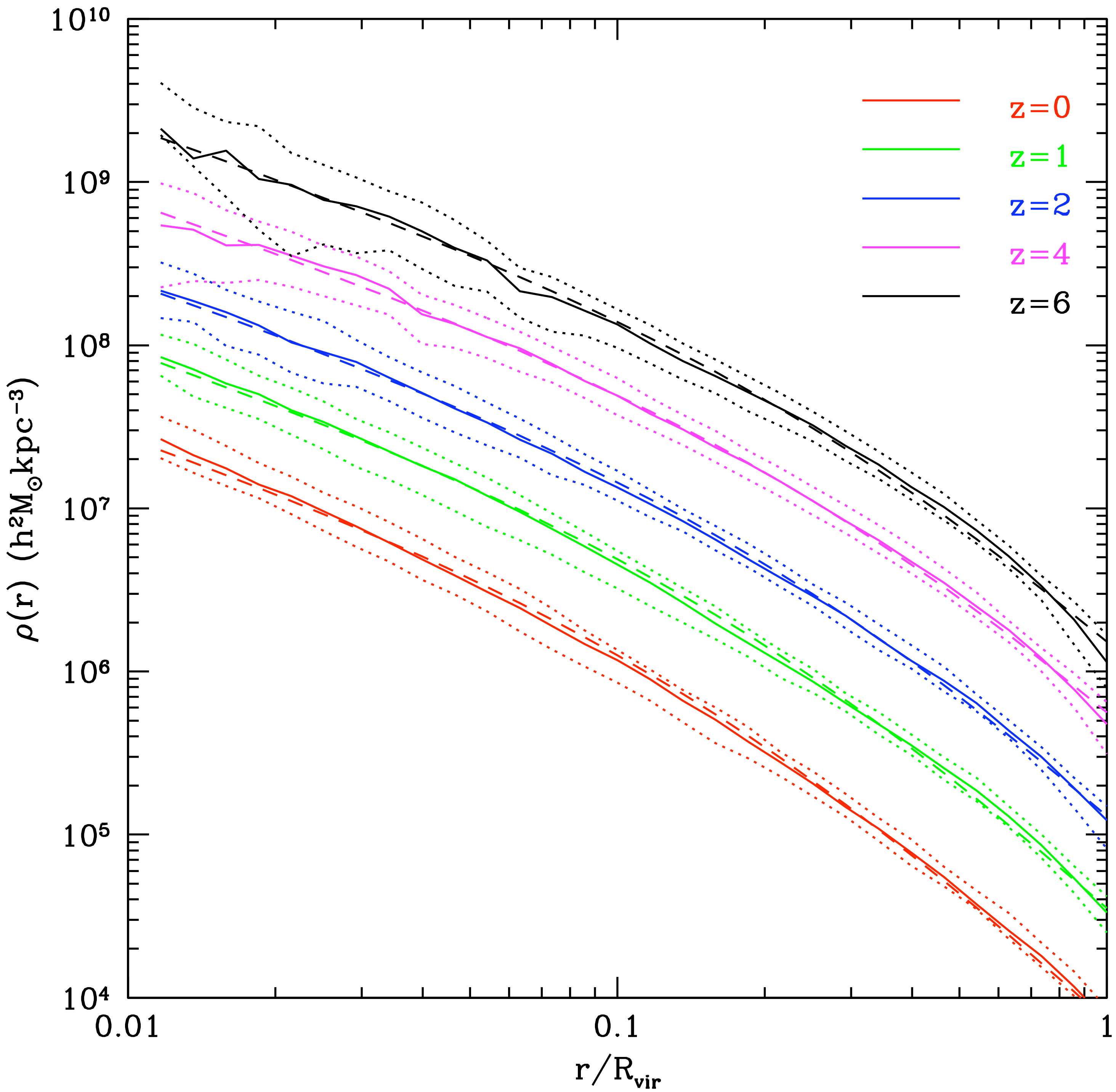
$$c(M_{\rm vir}, z) = 9.2\delta^{1.3}(z)\left(\frac{M_{\rm vir}}{10^{12}h^{-1}M_\odot}\right)^{-0.09}$$
$$\times\left[1 + 0.013\left(\frac{M_{\rm vir}}{10^{12}h^{-1}M_\odot}\delta(z)^{-\frac{1.3}{0.09}}\right)^{0.25}\right]$$

Halo Concentration: medians depend only on the amplitude of perturbations and mass: no explicit dependance on accretion history





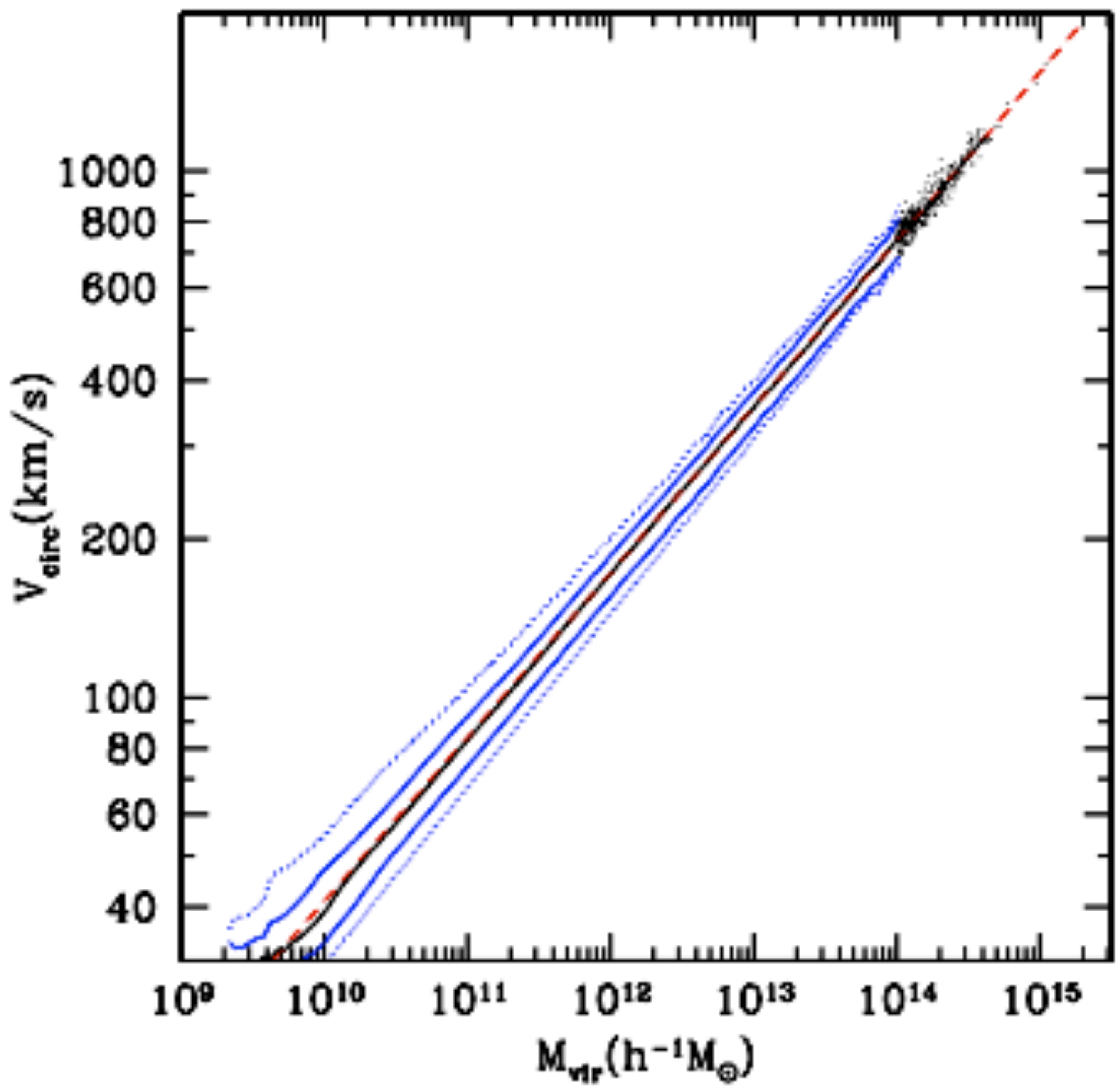
Structure of halos in the upturn: Density Profiles: 3-4 sigma peaks



Density Profiles of rare peaks: thery look normal though many of them are mergers and fast accretors

z=0: M=2e14 (s=0.7866074); c=5.42
z=1: M=5e13 (s=0.6688836); c=4.30
z=2: M=2e13 (s=0.5335957); c=3.48
z=4: M=2e12 (s=0.4940273); c=2.79
z=6: M=5e11 (s=0.4215051); c=2.90

Courtesy of A.Cuesta



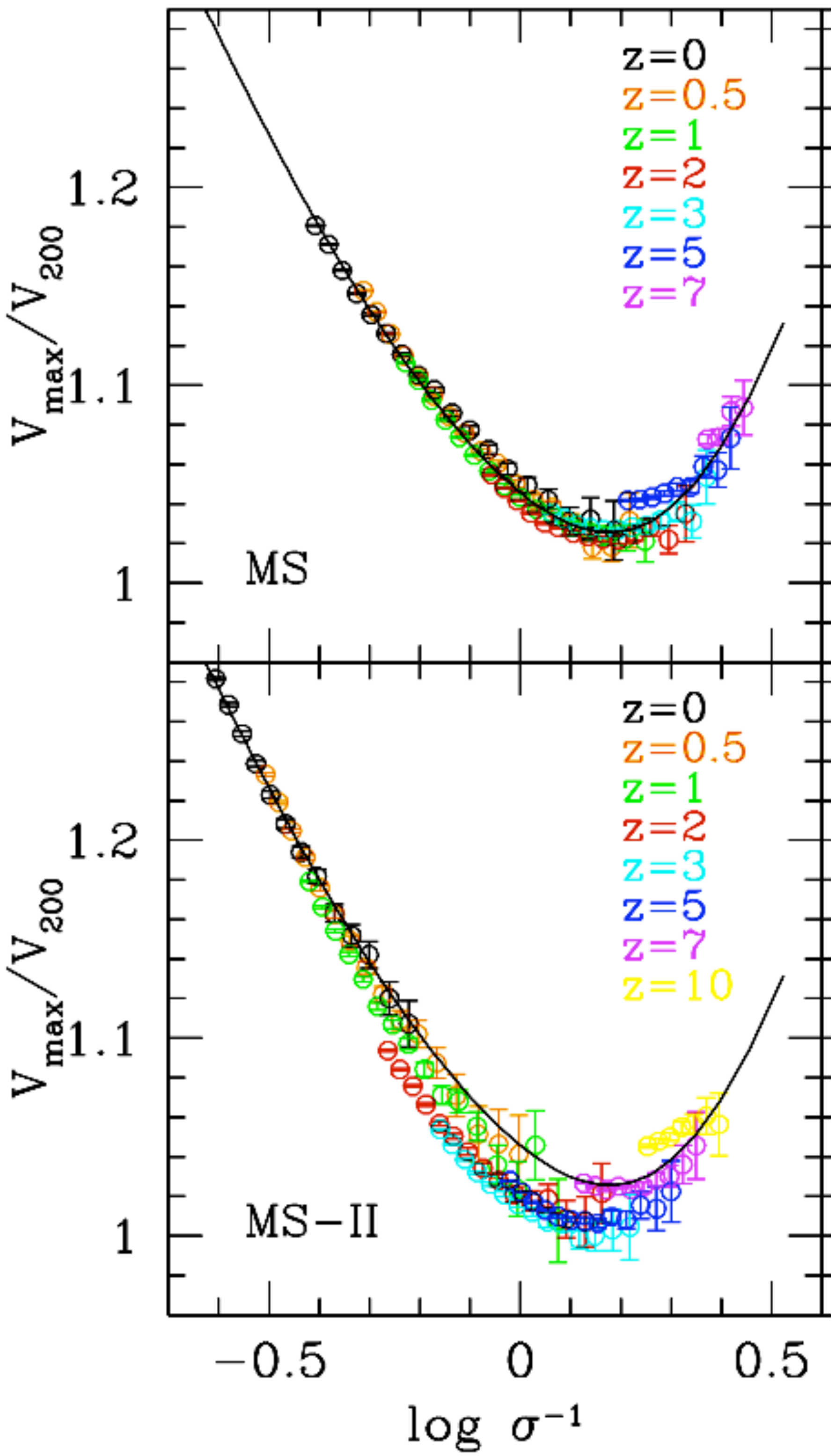
V_{max} - M_{vir}

V_{max}/V_{200}

Mass inside R_s as function of R_s

Halo Concentration: evolution with time

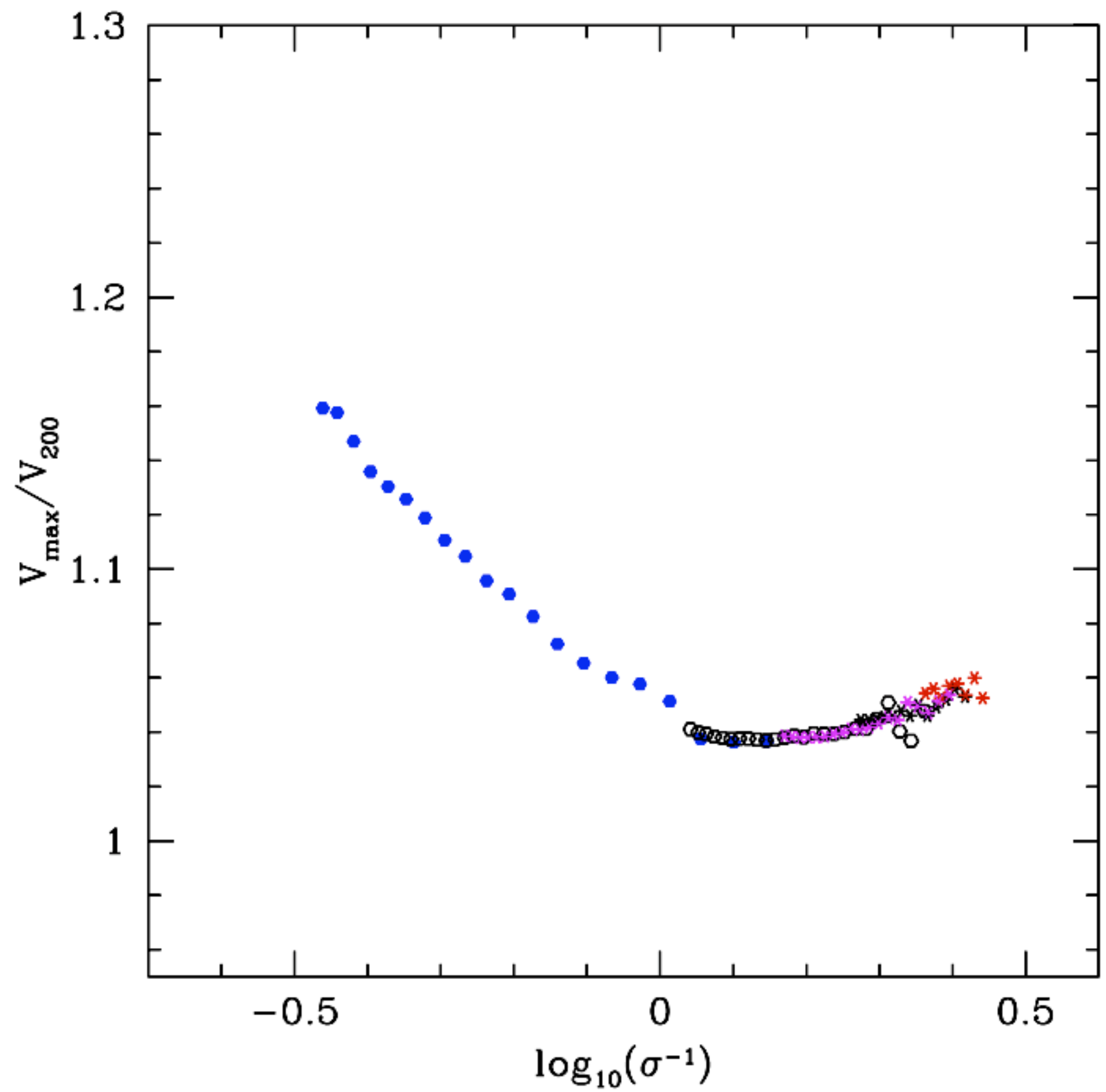
Gadget: Millennium runs



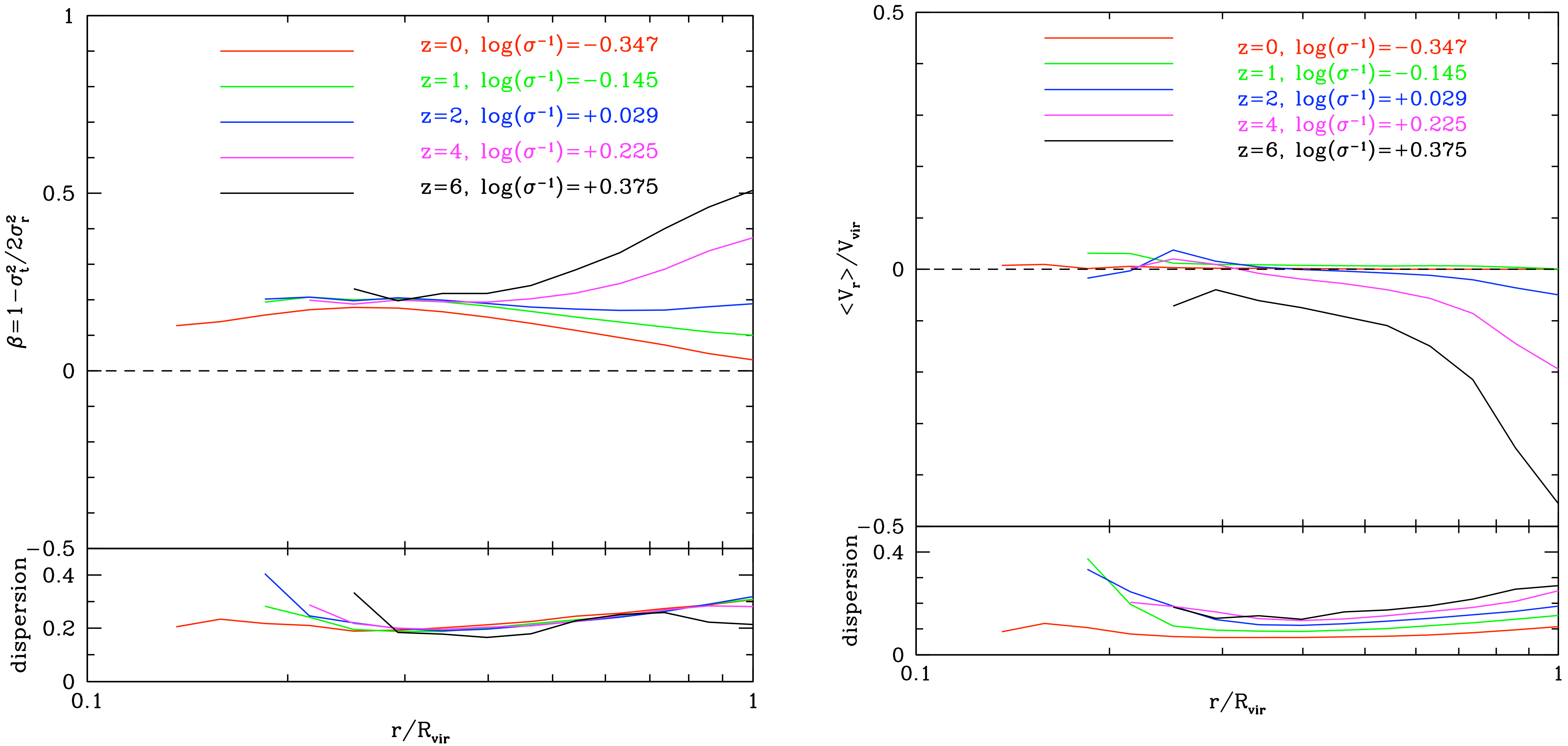
Upturn is in all the simulations. Average concentration depends only on mass.

σ(M) = amplitude of fluctuations at given mass

ART: Bolshoi (250Mpch), MultiDark (1000Mpc, 8G particles)



3 stages of halo formation



Halos with Mvir = 5x10^{11} Msun at different redshifts:
at z=6: large infall velocities even inside virial radius and very radial orbits

Halo Concentration: 3 stages

(a) The main driving force of halo evolution is NOT the major mergers: they happen when they should happen
(b) The main effect is the halo mass relative to the typical mass at given redshift: M/M_*

- Very rare peaks: radial infall results in a high concentration. Another way looking at it: it builds dense center of halos
- Fast accretion with less radial velocities. At the end of the stage we have the core build. Gives low concentration.
- Slow accretion builds outer regions of halos. Velocity anisotropy declines

Halo Concentration: different perspectives

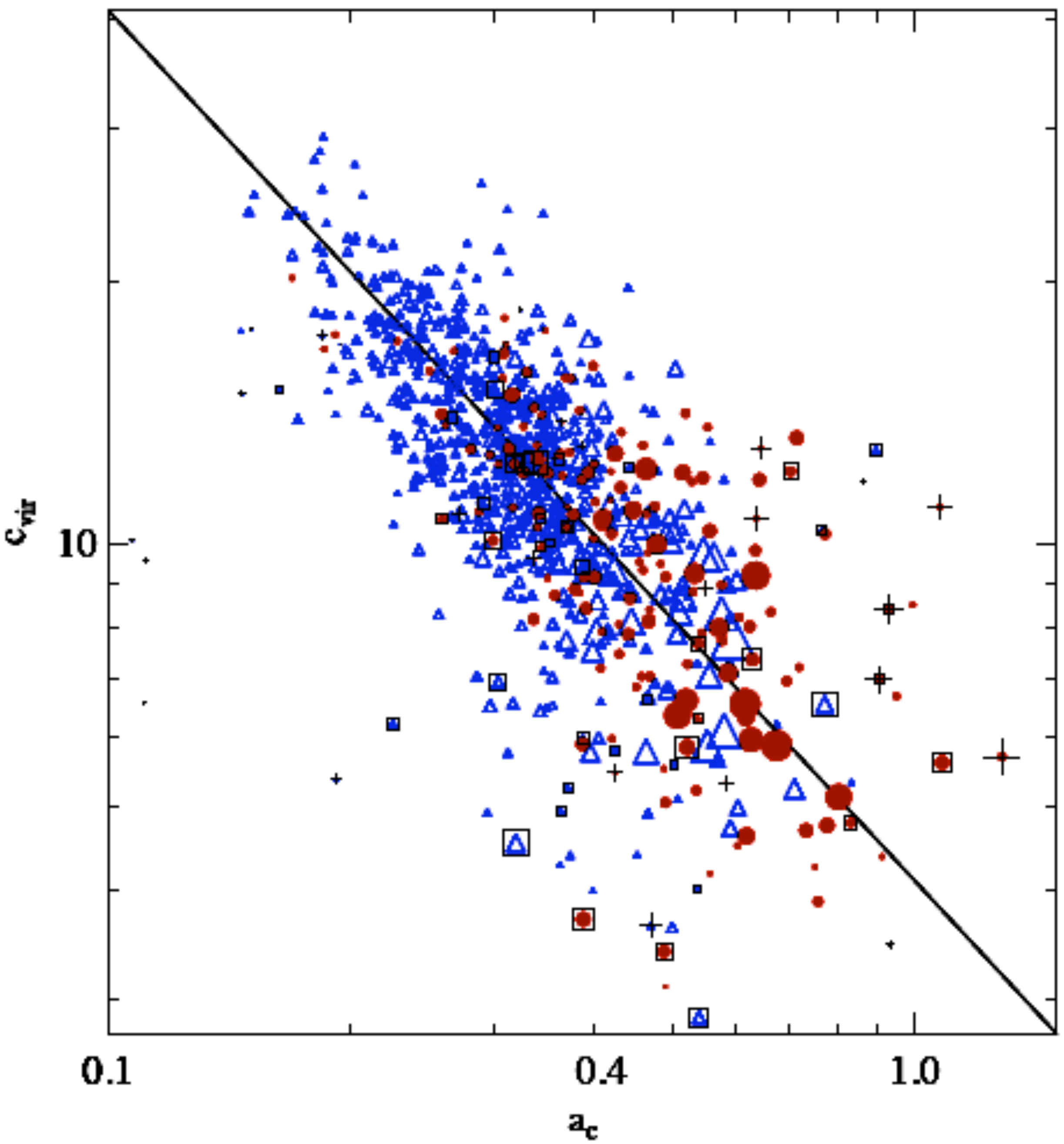


Figure 6 shows the relation between concentration and a_c for halos at $z = 0$. The concentration of a halo is strongly correlated with its characteristic formation time, and a good fit is obtained with the inverse relation:

$$c_{vir} = c_1/a_c, \quad (6)$$

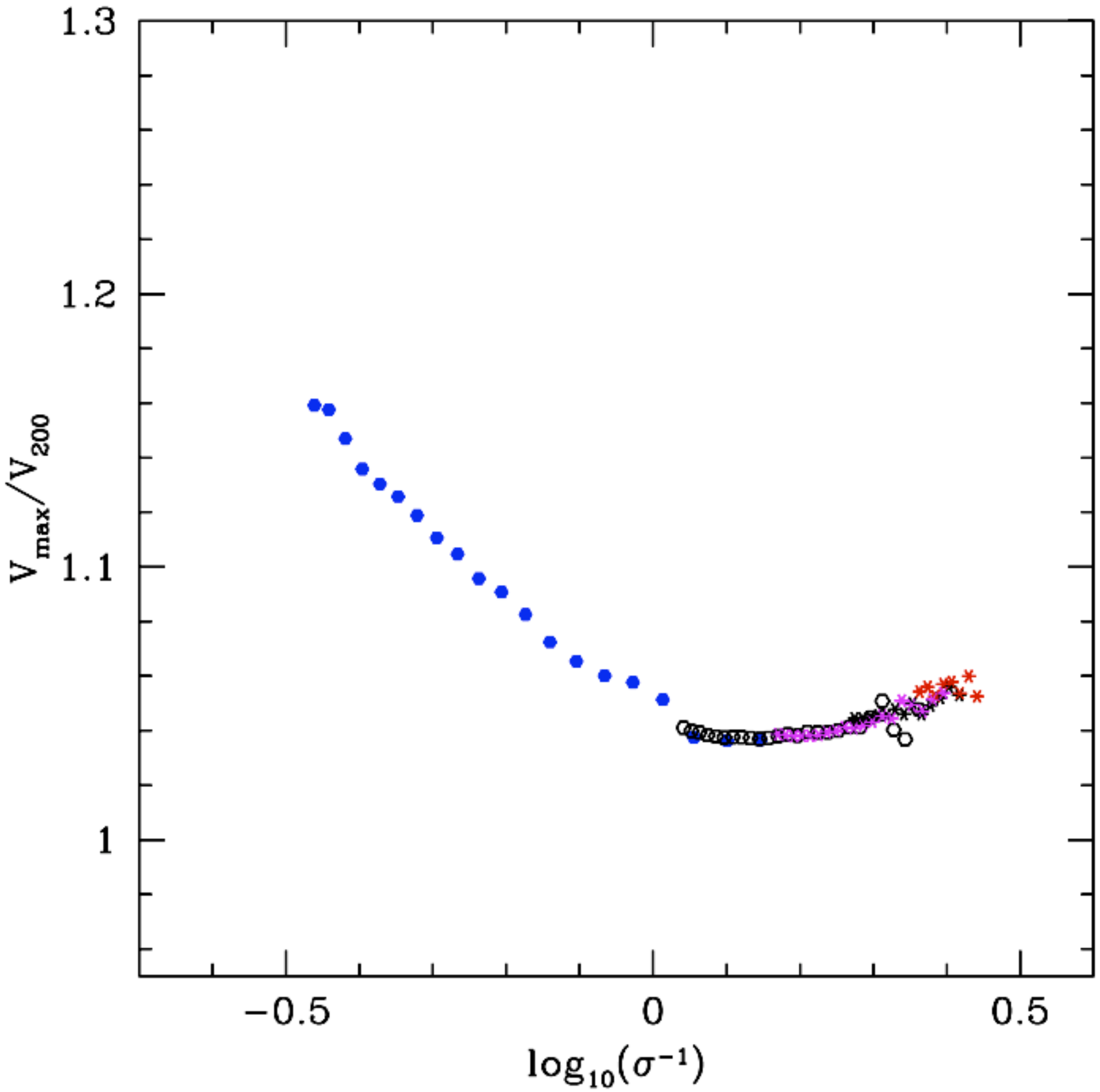
where $c_1 = 4.1$ is the typical concentration of halos form-

Wechsler et al 2002
Time of accretion a_c for halos more massive than 10^{12}Msun at z=0

Halo Concentration: different perspectives

Zhao et al 2009, Klypin et al 2010, Prada etal 2010

***Evolution of halo concentration is mostly defined by M/M**

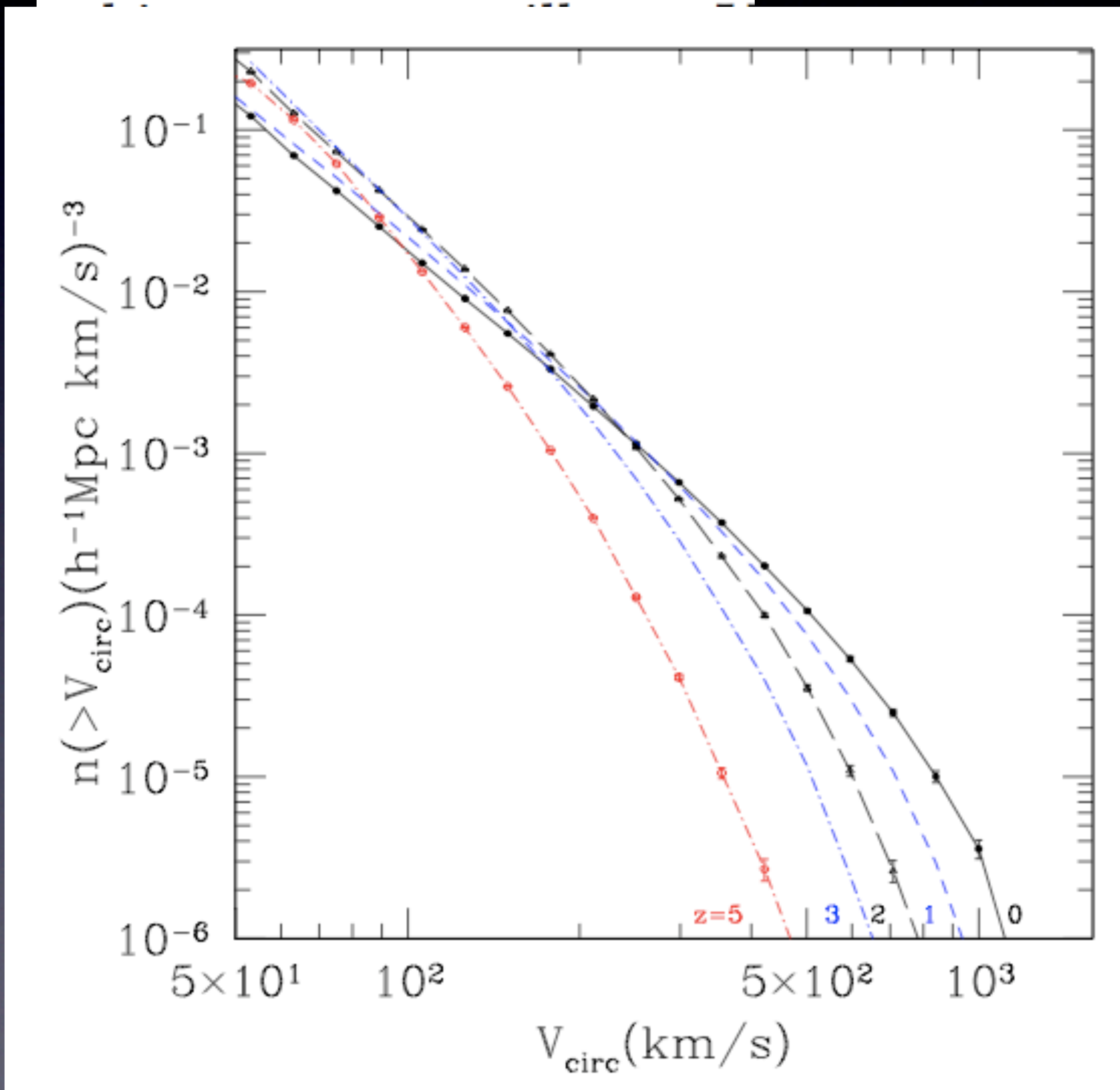


Chapter II: *Satellites*

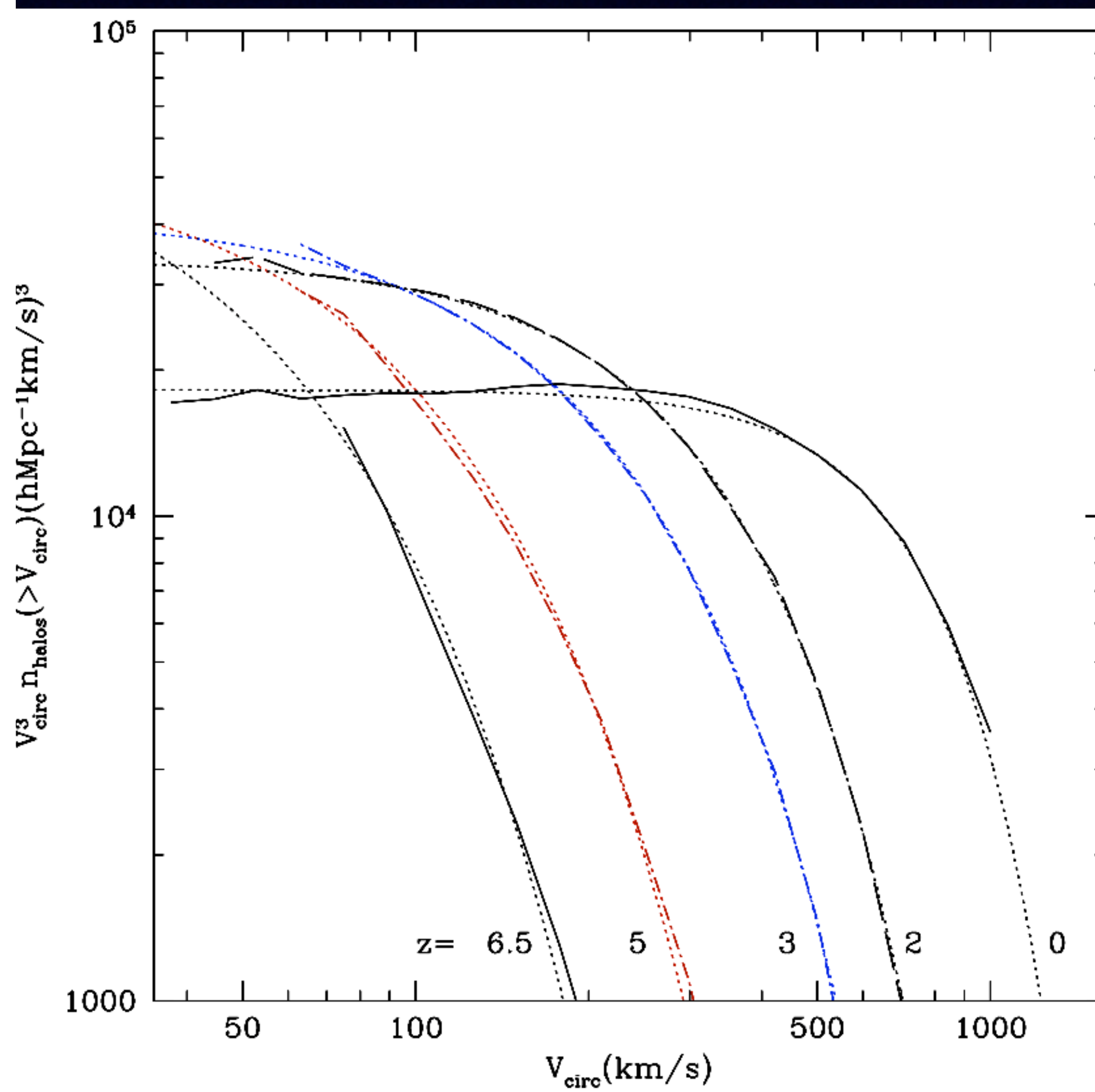
how and where they live

$$V_{\rm circ} = \sqrt{\frac{GM(<r)}{r}}\Bigg|_{\rm max}.$$

Main property of halos is circular velocity

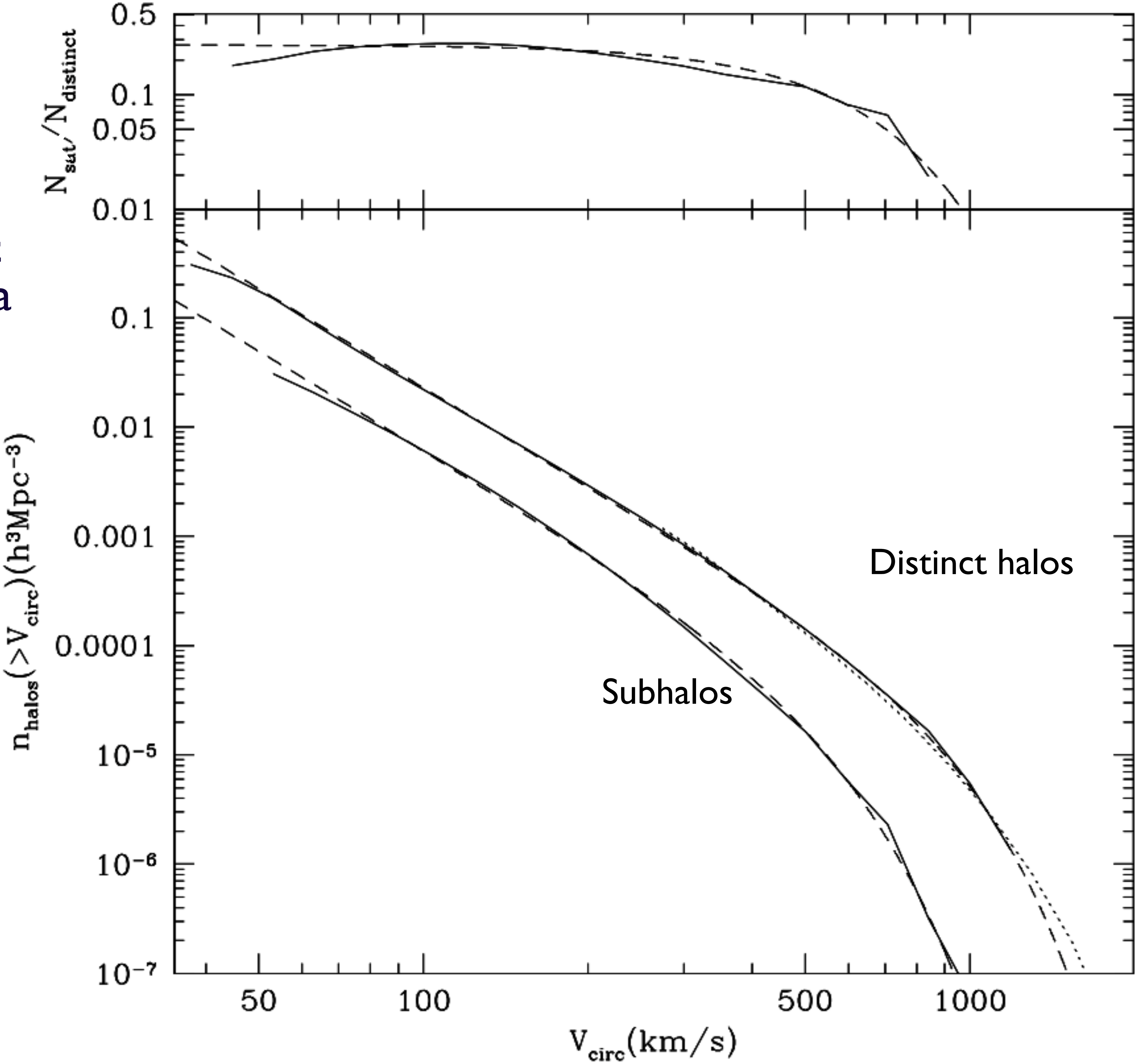


Accurate predictions for Velocity function of distinct halos

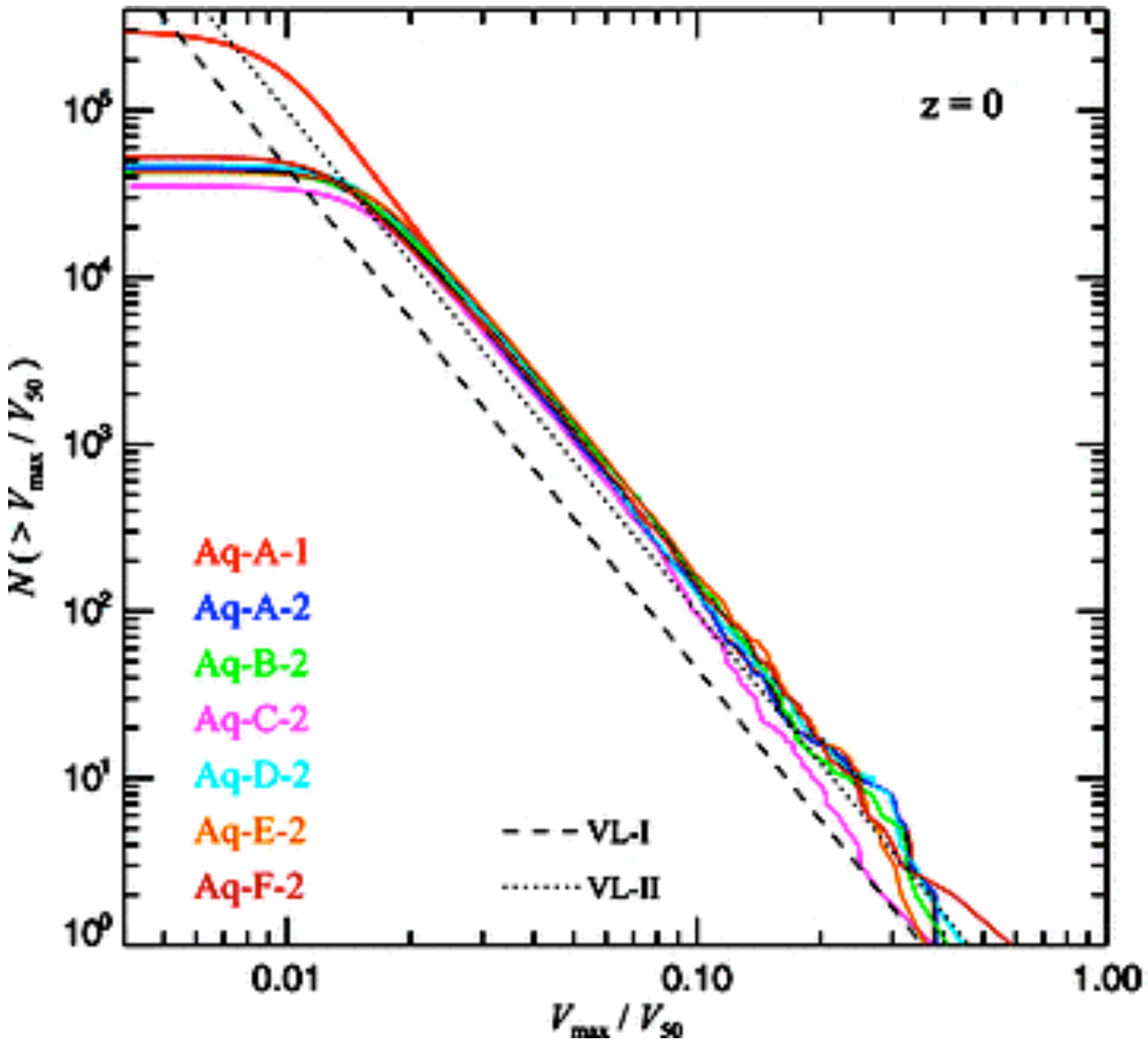


Velocity Functions

From Magellanic Clouds to Coma Cluster



250Mpc/h
8G particles
1kpc resolution



Aquarius simulation. Springel et al 2008. WMAP-1

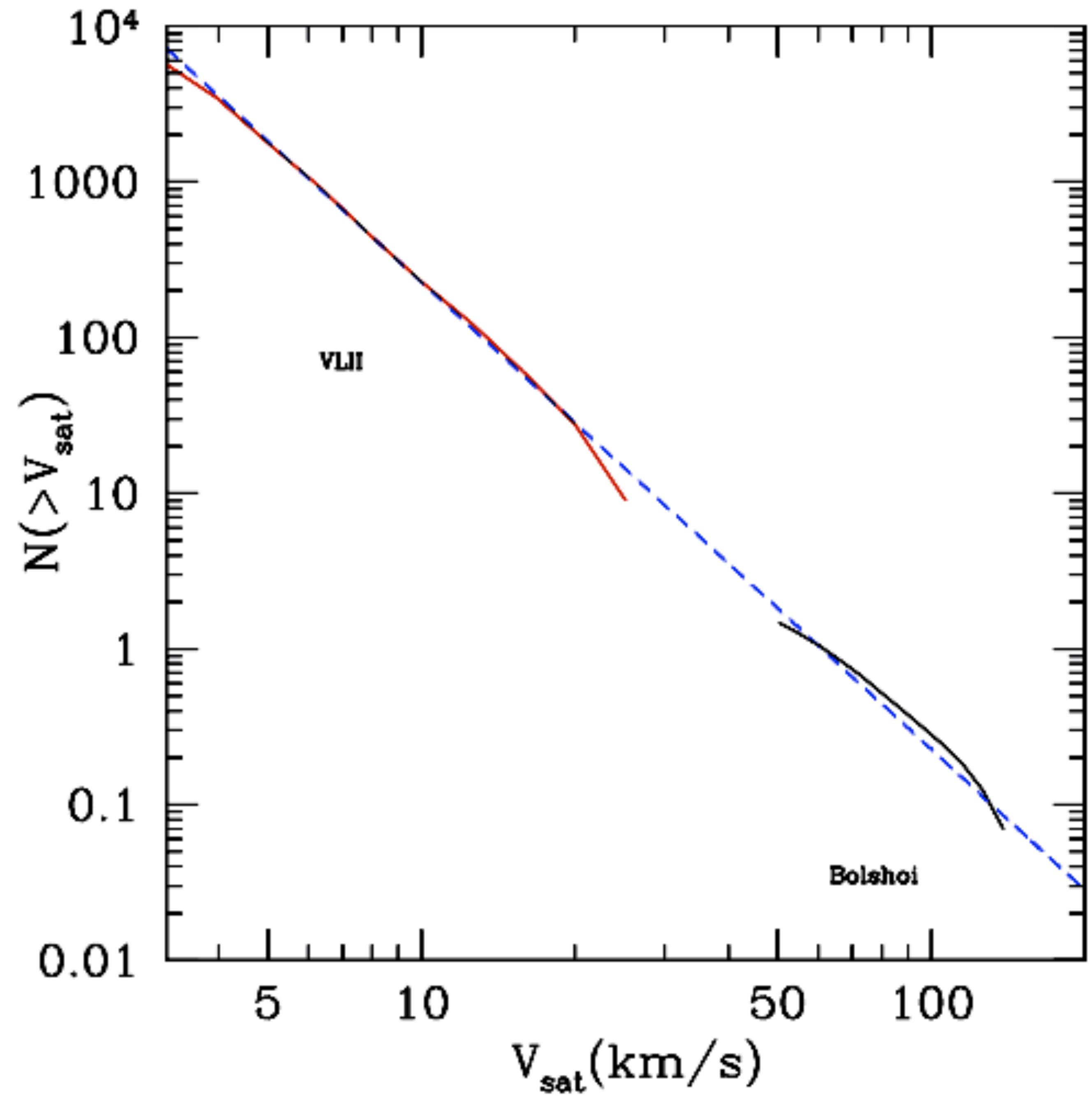
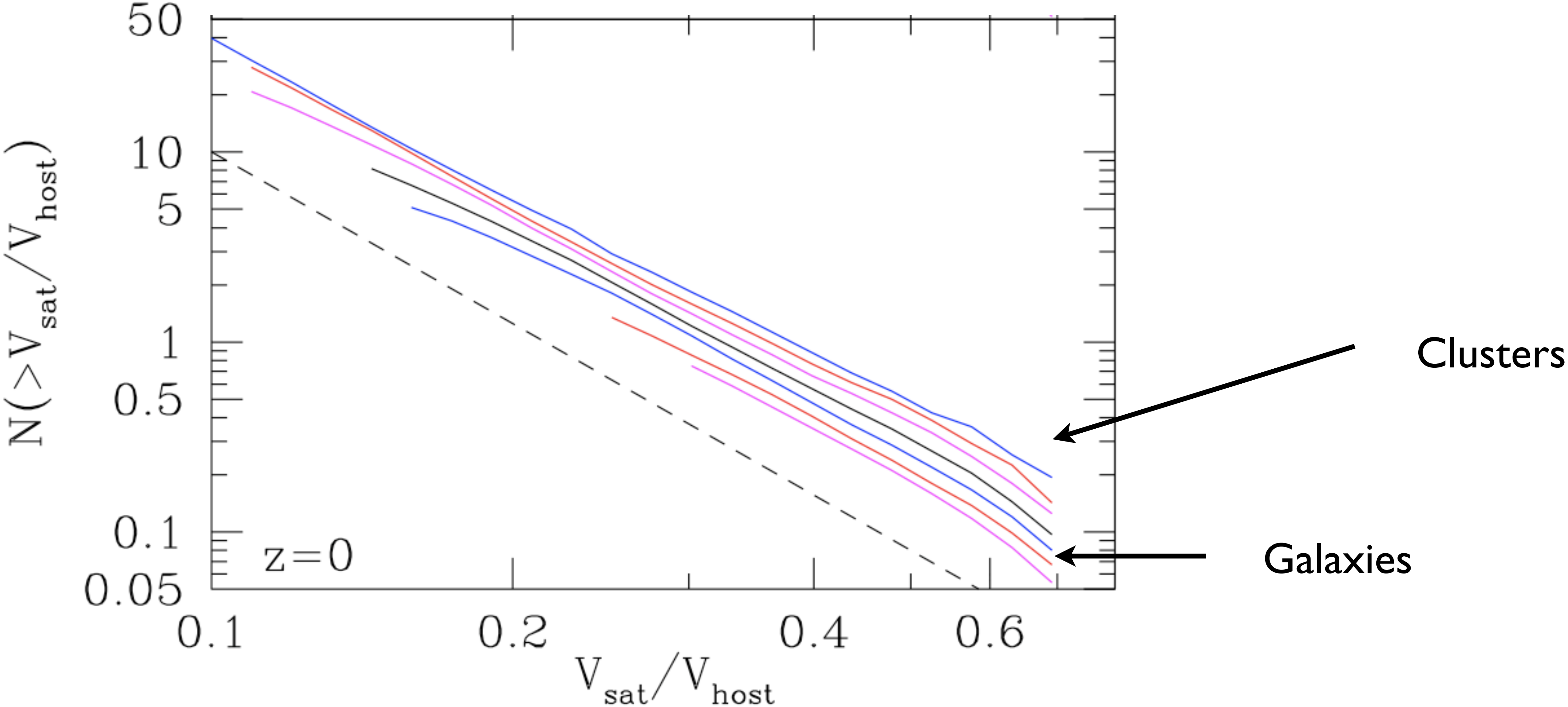


Fig. 18.— Comparison of satellite velocity functions in Via Lactea II and Bolshoi simulations for halos with V_{circ} = 200 kms/s and $M_{vir} \approx 1.3 \times 10^{12} h^{-1} M_{\odot}$. The dashed line is a power law with the slope −3, which provides excellent fit to

$$n(> V) = AV^{-3}$$

Bolshoi and ViaLactea II. Klypin et al 2010. WMAP-7

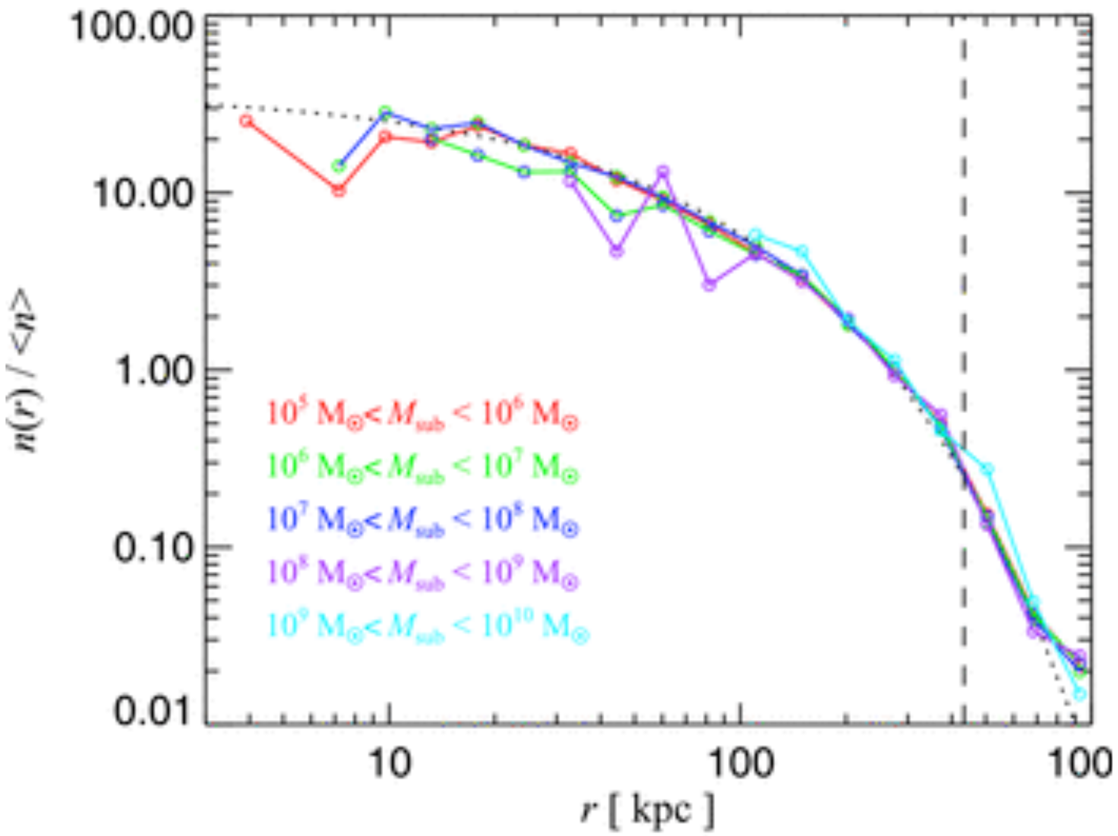
$$N(>x) = 1.7 \times 10^{-3} V_{\rm host}^{1/2} x^{-3},$$
$$x \equiv V_{\rm sub}/V_{\rm host},\ x < 0.7,$$



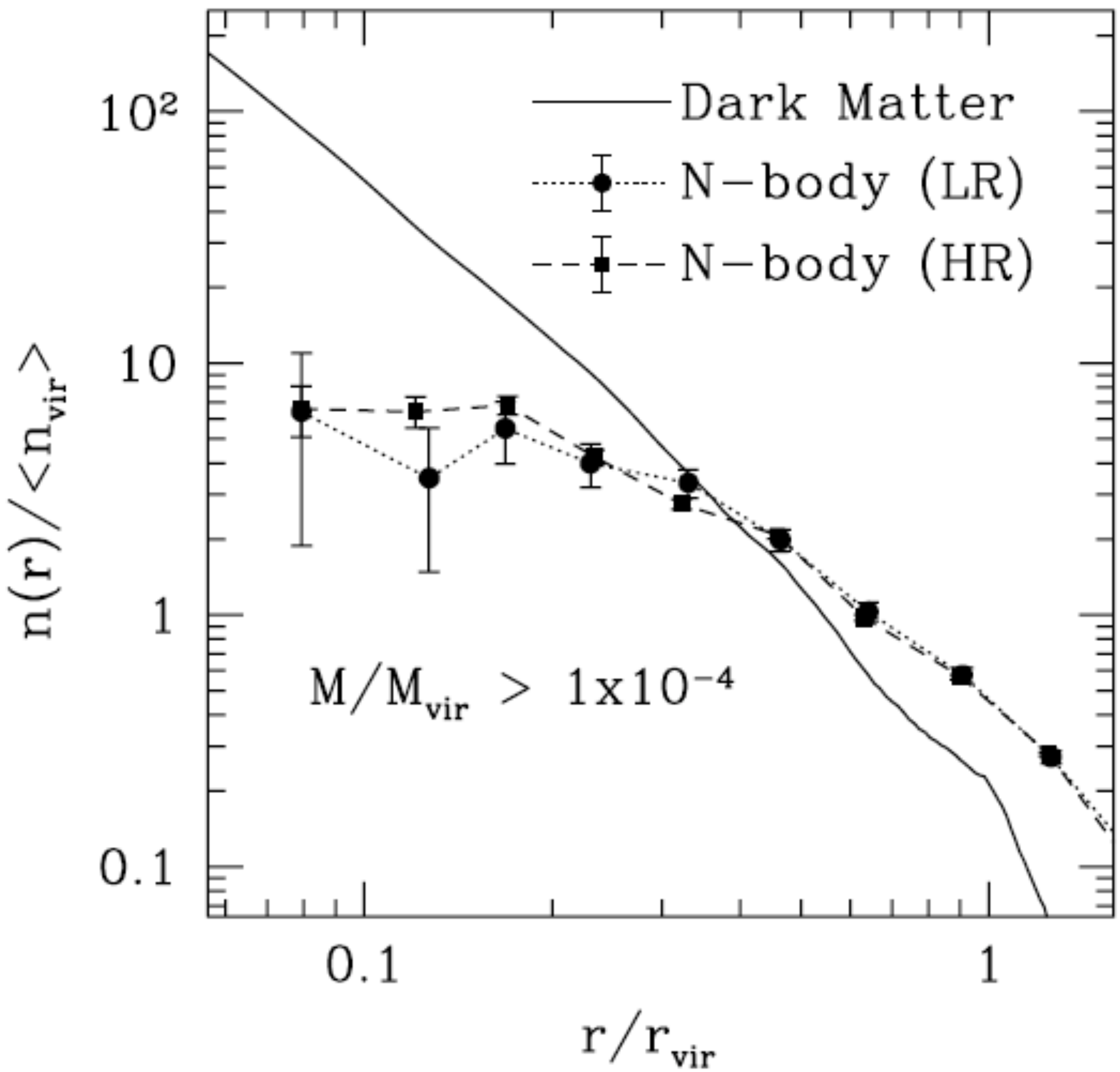
Number of satellites increases with the mass of parent halo

Gao etal 2004, Klypin et al 2010. WMAP-7

Number-density of satellites



Aquarius simulation. Springel et al 2008.
WMAP-1
Subhalos are selected by mass. This gives an impression of a very large core



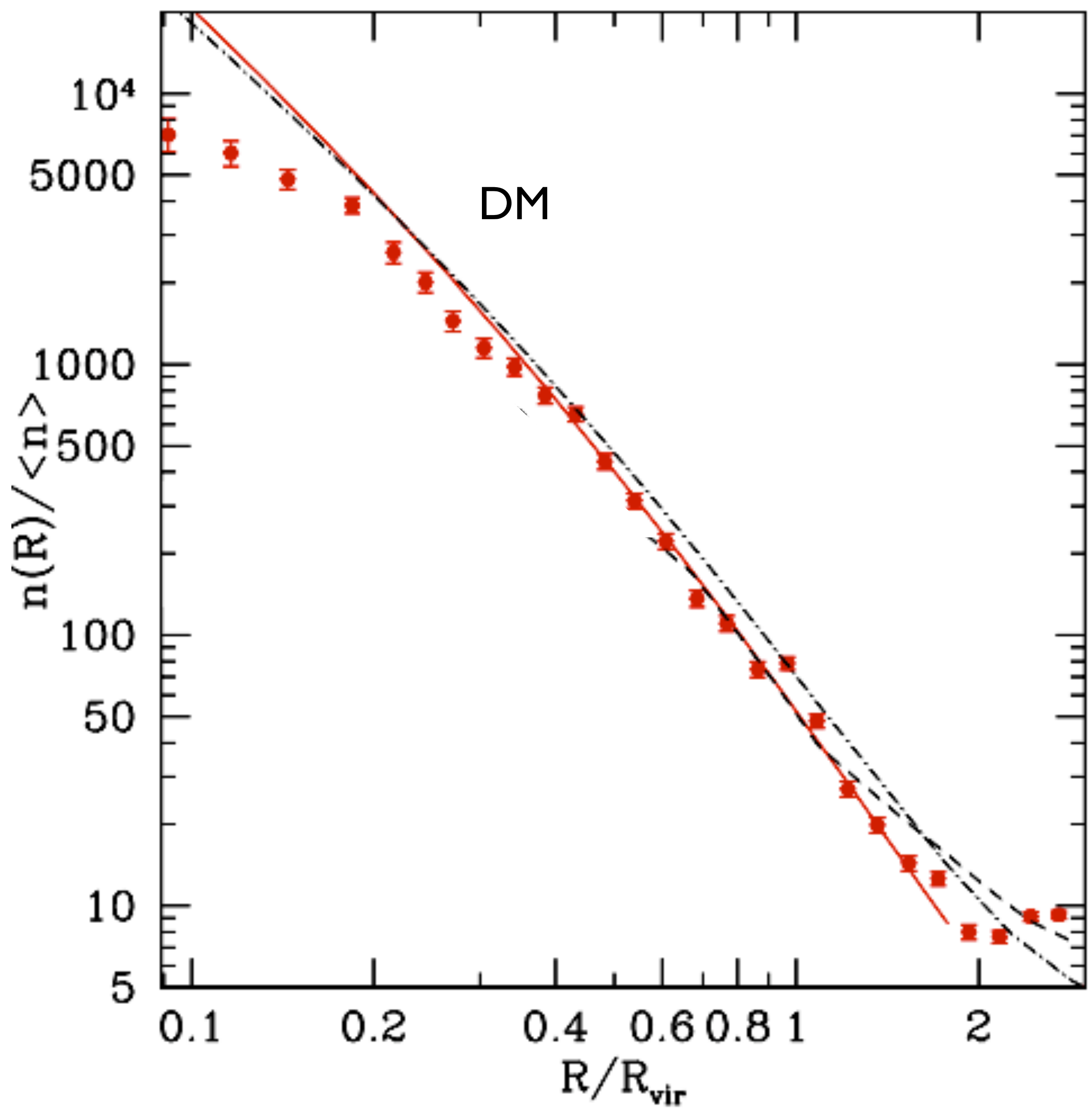
Nagai & Kravtsov 2005

Symbols are satellites in Via Lactea II simulation (1G particle, one halo with Vcirc =200km/s) normalized using Bolshoi

Curves are n(r) DM density profile

Dash - satellites in Bolshoi

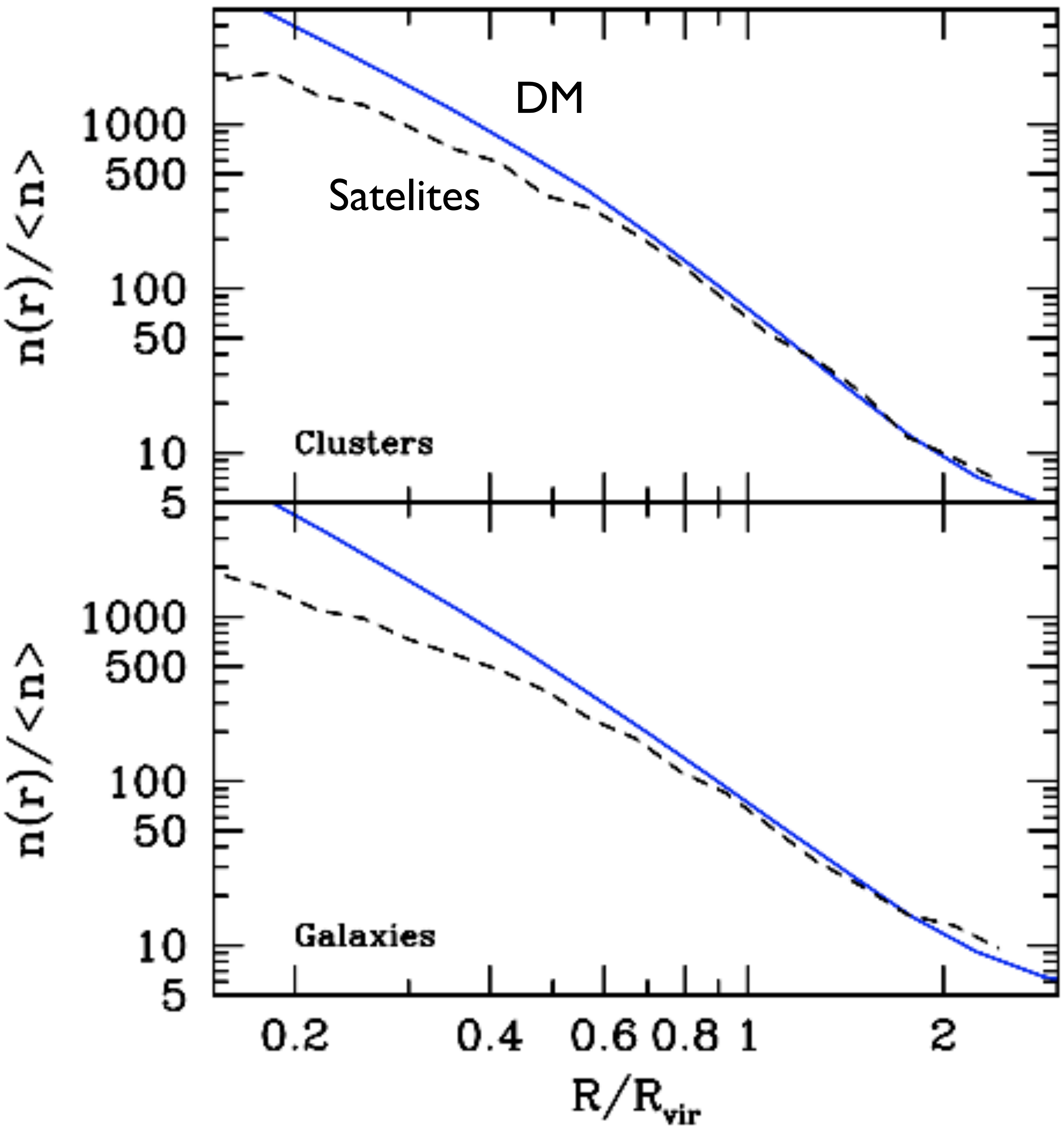
Satellites tightly follow DM at r > 0.2Rvir: they are NOT 'flatter' distributed in the outer regions of halos.



Bolshoi and ViaLactea II. Klypin et al 2010. WMAP-7

Subhalos are selected by circular velocity.

Satellites follow Dark matter for R= 0.2-2Rvir

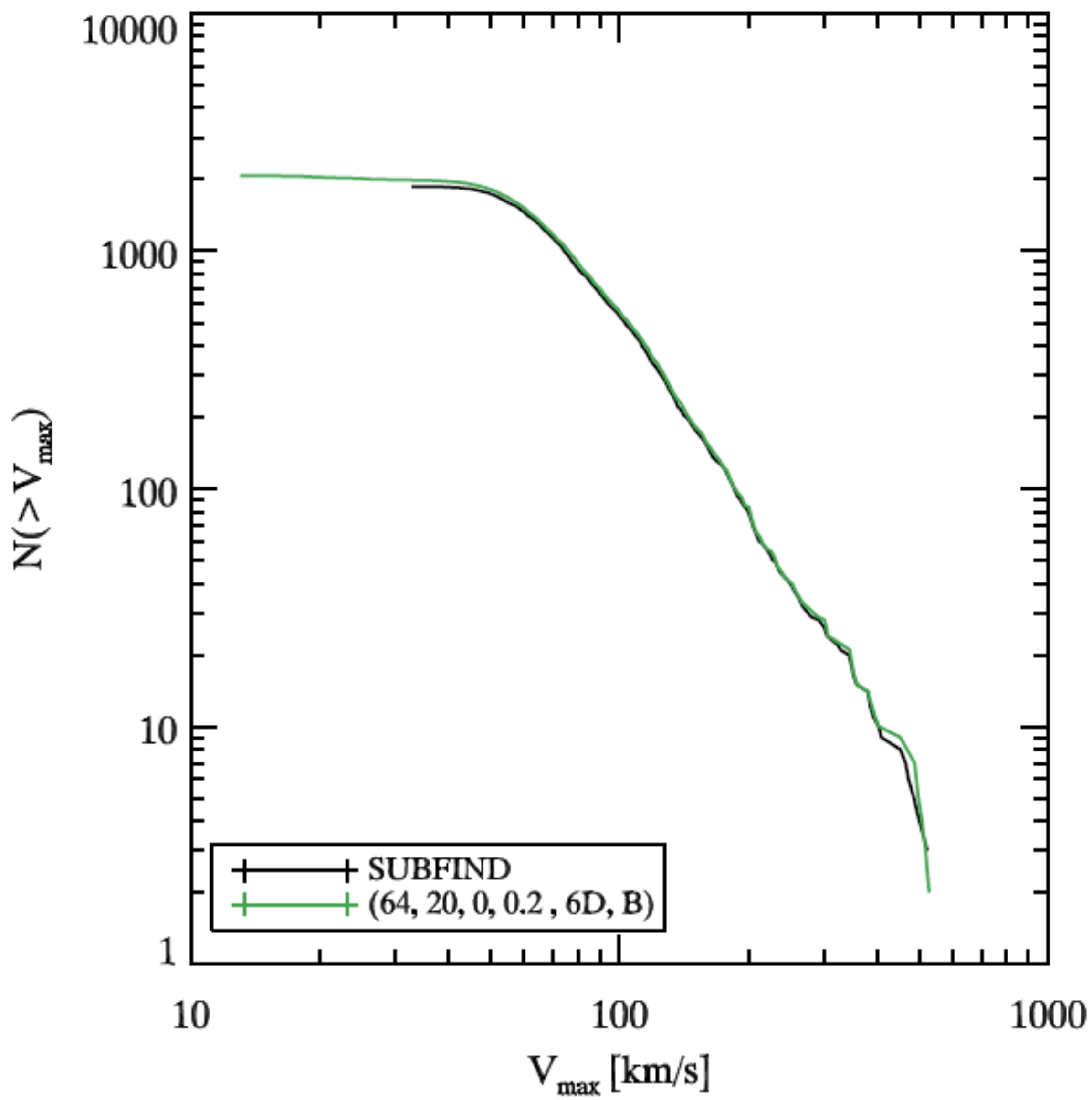


Small anti-bias in the central regions. Very little in the outer parts

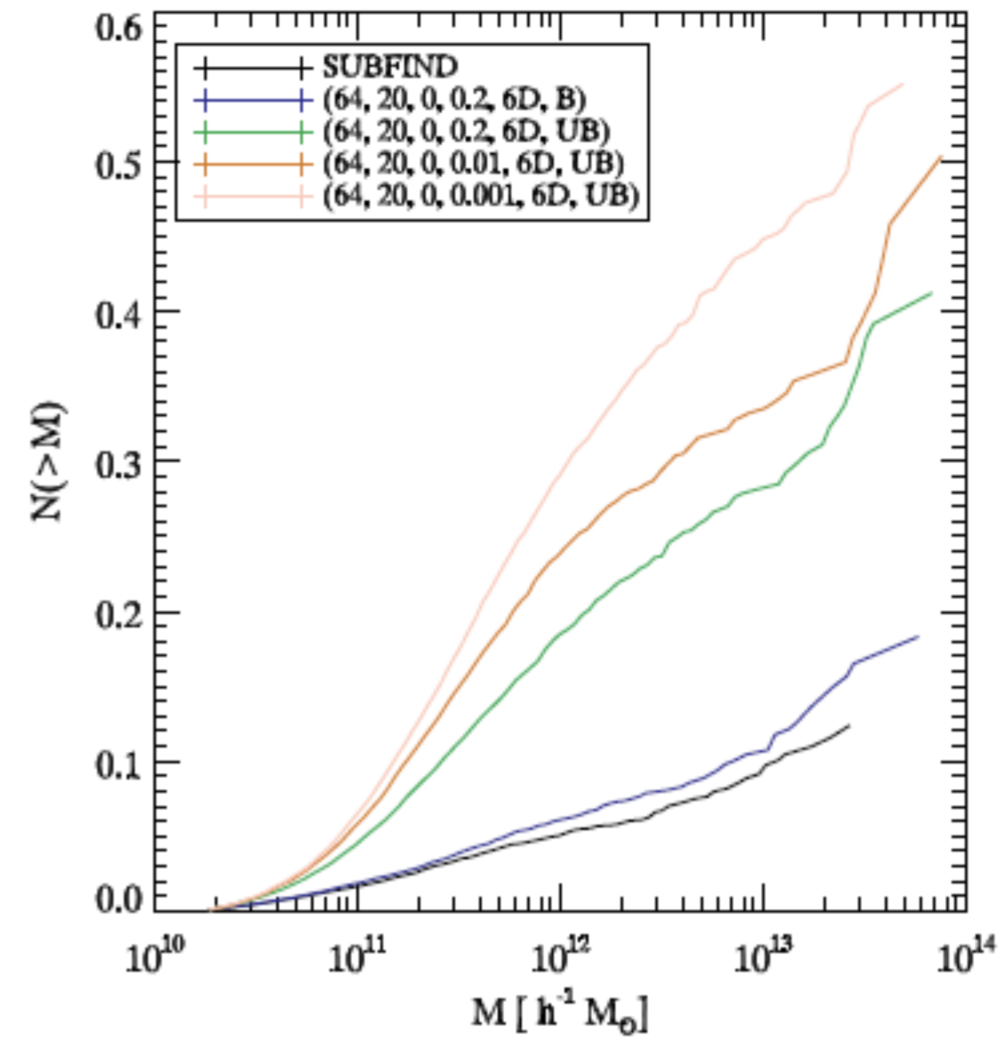
Bolshoi

How good are masses of subhalos?

6D halo finder vs Subfind
the same halos and <u>the same circular velocities</u>



6D halo finder vs Subfind
<u>masses are 2-3 times different</u>



6D

Subfind

Figure 18. Cumulative mass in substructures found by SUBFIND, bound HSF method, and HSF with different choices of the connectivity parameter α.

Maciejewski et al 2009

Chapter III: Conclusions

- Three stages for halo formation
- Mass accretion history is not the only (or even main) component which defines halo concentration: dynamics is different for different stages.
- There is no ‘core’ in the satellites profile