Universal mass accretion history and concentration evolution of Dark Matter Halos

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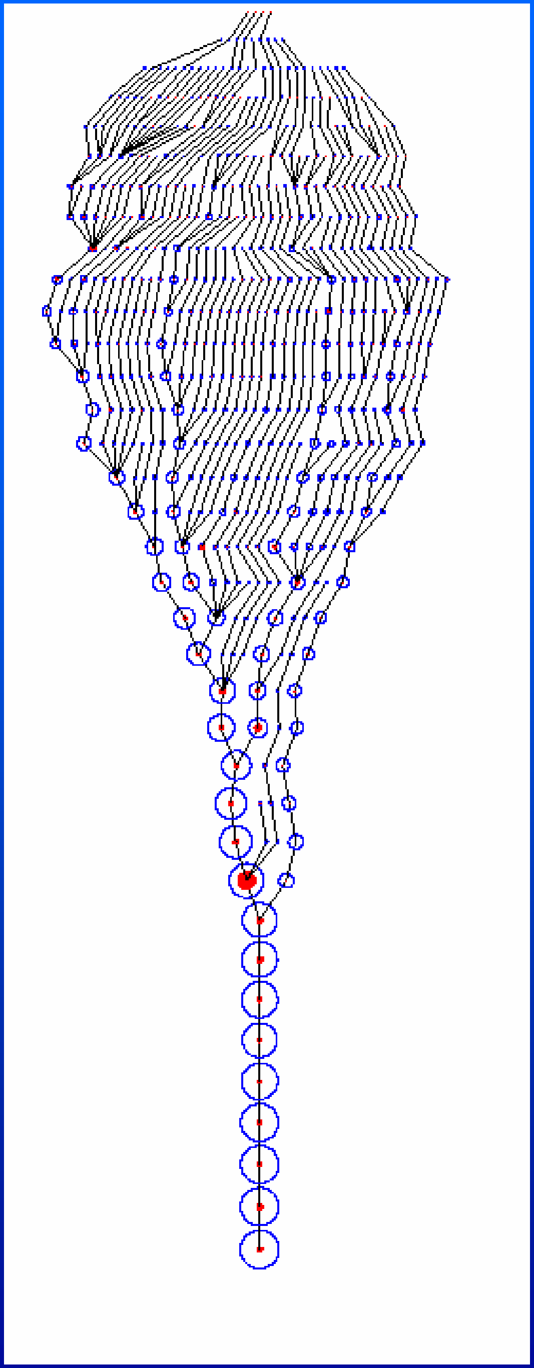
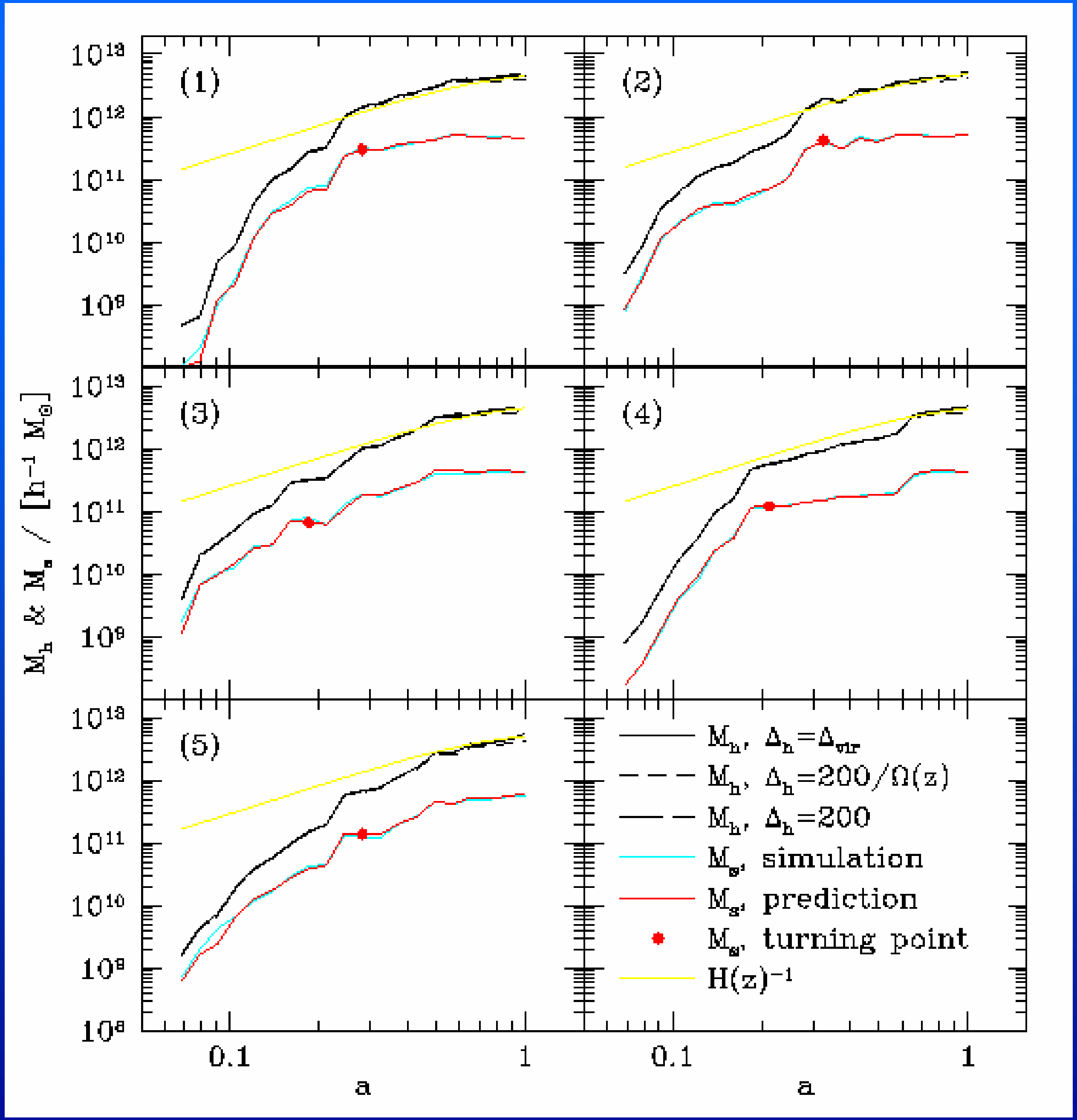


- Dark matter halo merger tree

Evolution of mass



Part I
The universal mass accretion history of dark matter haloes

- Growth of dark matter haloes in hierachical structure formation framework

Large scale structures form through gravitational magnification of initial density fluctuation. Matter falls clumped into haloes and haloes get more and more massive through mergers and accretion;

1. At given time, the bigger a halo is, the faster it grows (due to mathematical transformation, nonlinear effects, etc.);

2. For a given mass, higher redshift means faster growth
3. Halo <u>M</u>ass <u>A</u>ccretion <u>H</u>istories depend on power spectrum of initial density ;

fluctuation — since structure forms form initial density fluctuation

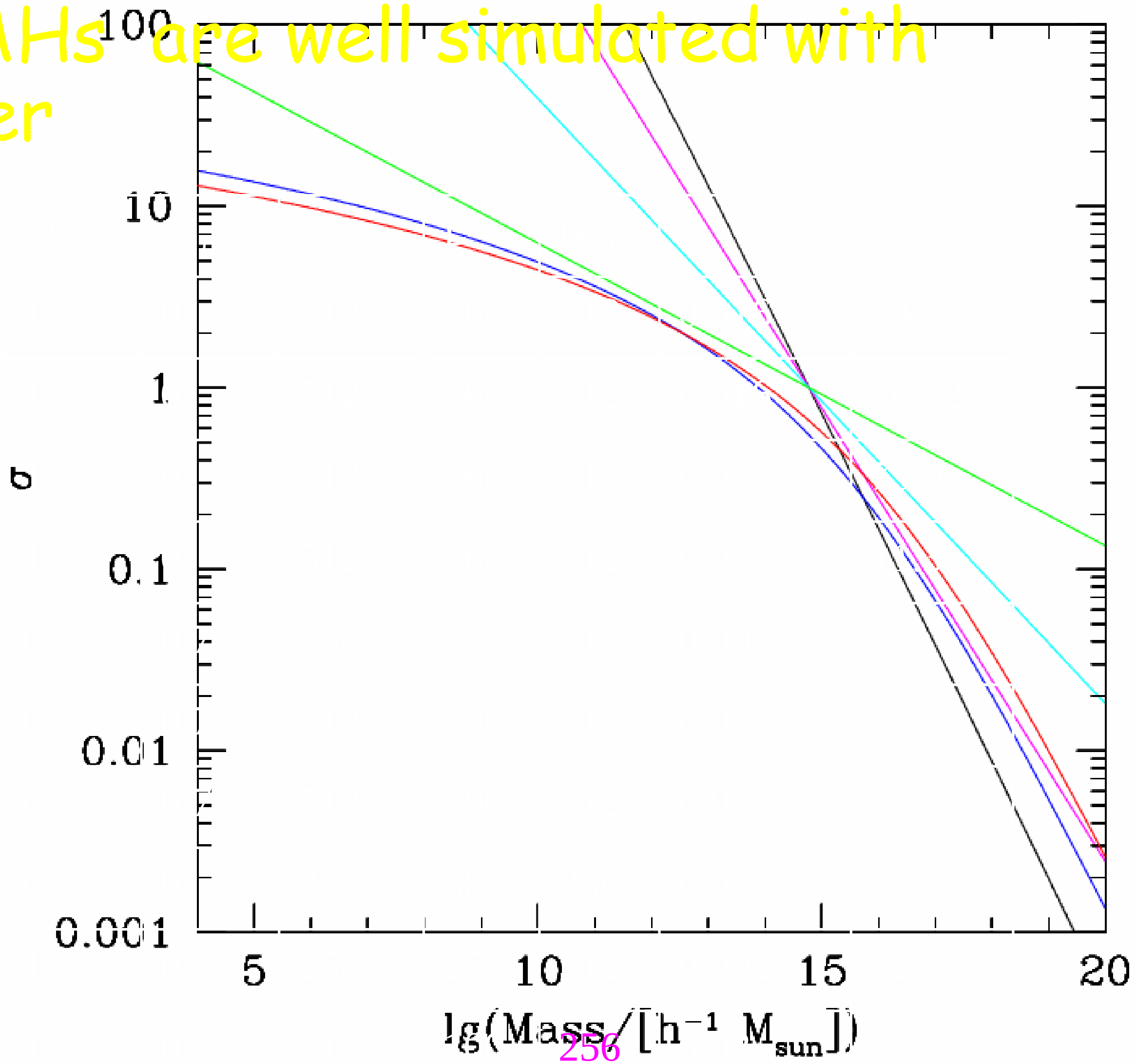
4. Halo MAHs depend on cosmology — since cosmology determines the expansion behavior of the background universe.

How to describe halo MAHs quantitatively? Can we disentangle effects of mass, time, power spectrum and cosmology?

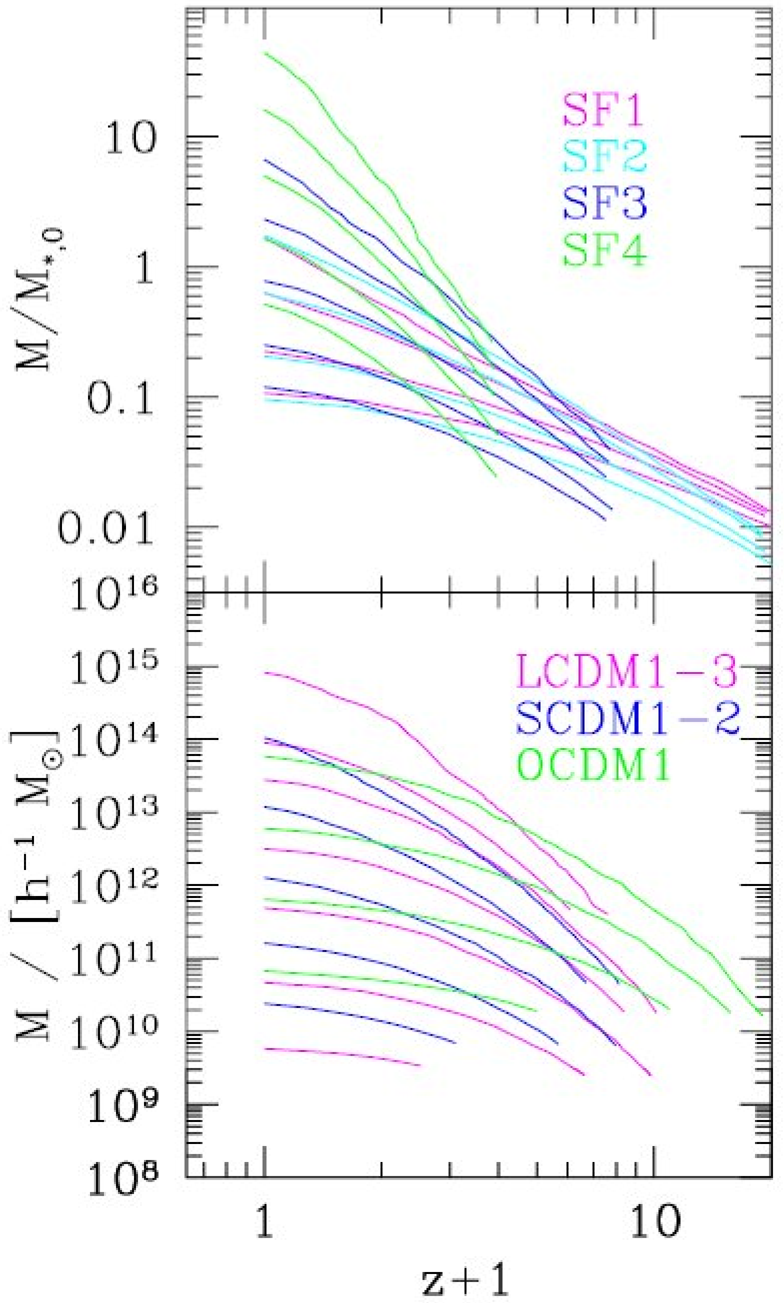
N-body cosmological simulation

- Assumption: MAHs are well simulated with pure dark matter

model	n_i	Γ	σ_8
SF1	1	K cut	1
SF2	0		1
SF3	-1		1
SF4	-2		1
LCDM1	1	0.2	0.9
LCDM2	1	0.2	0.9
LCDM3	1	0.2	0.9
OCDM1	1	0.2	1.0
SCDM1	1	0.5	0.55
SCDM2	1	0.5	0.55



Simulated Mass Accretion Histories



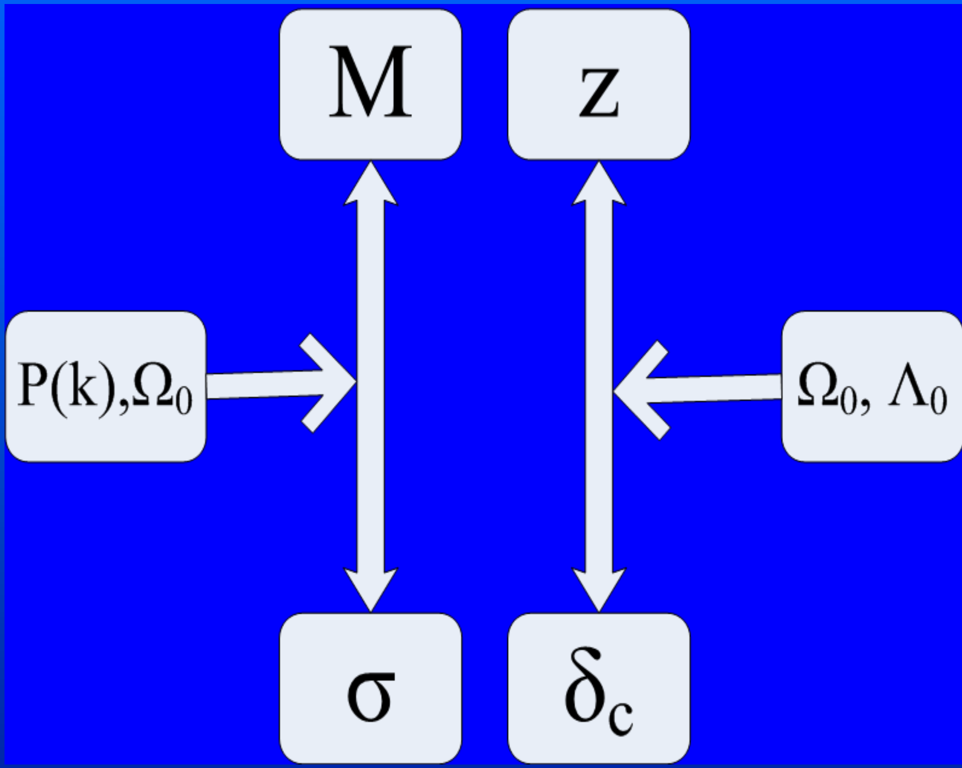
Choosing quantities for modeling

- Given cosmology and power spectrum, after extrapolating linearly to z=0, the linear mass variance of a given volume σ is determined by M, and

$$\sigma(M) \equiv \sigma'(M,z)/D(z)$$

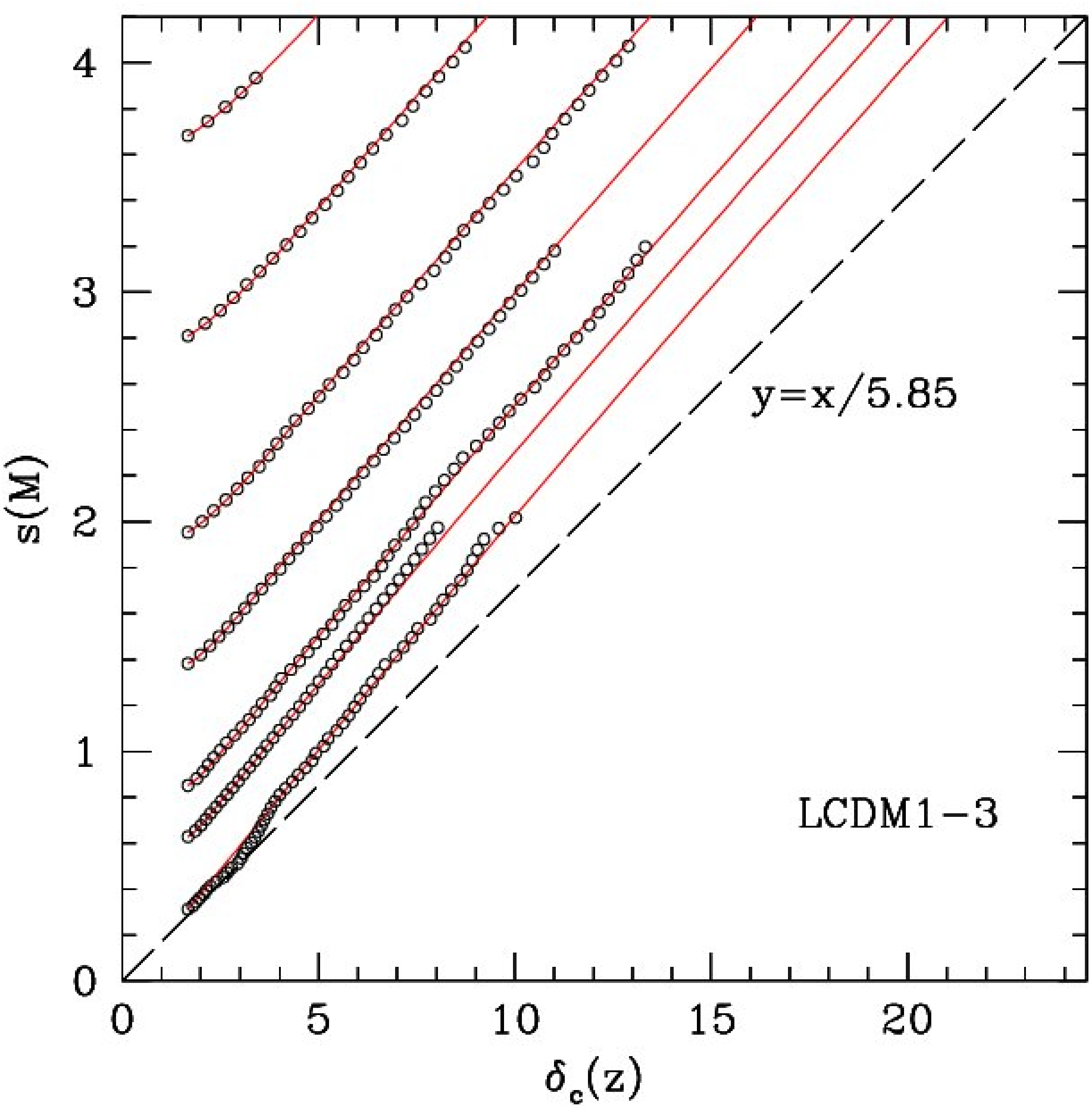
  linear critical collapse overdensity δ_c by z.

$$\delta_c(z) \equiv \delta_c(\Omega_m(z),\Omega_\Lambda(z))/D(z)$$



$$w(z, M) \equiv \delta_c(z)/s(M)\,,$$

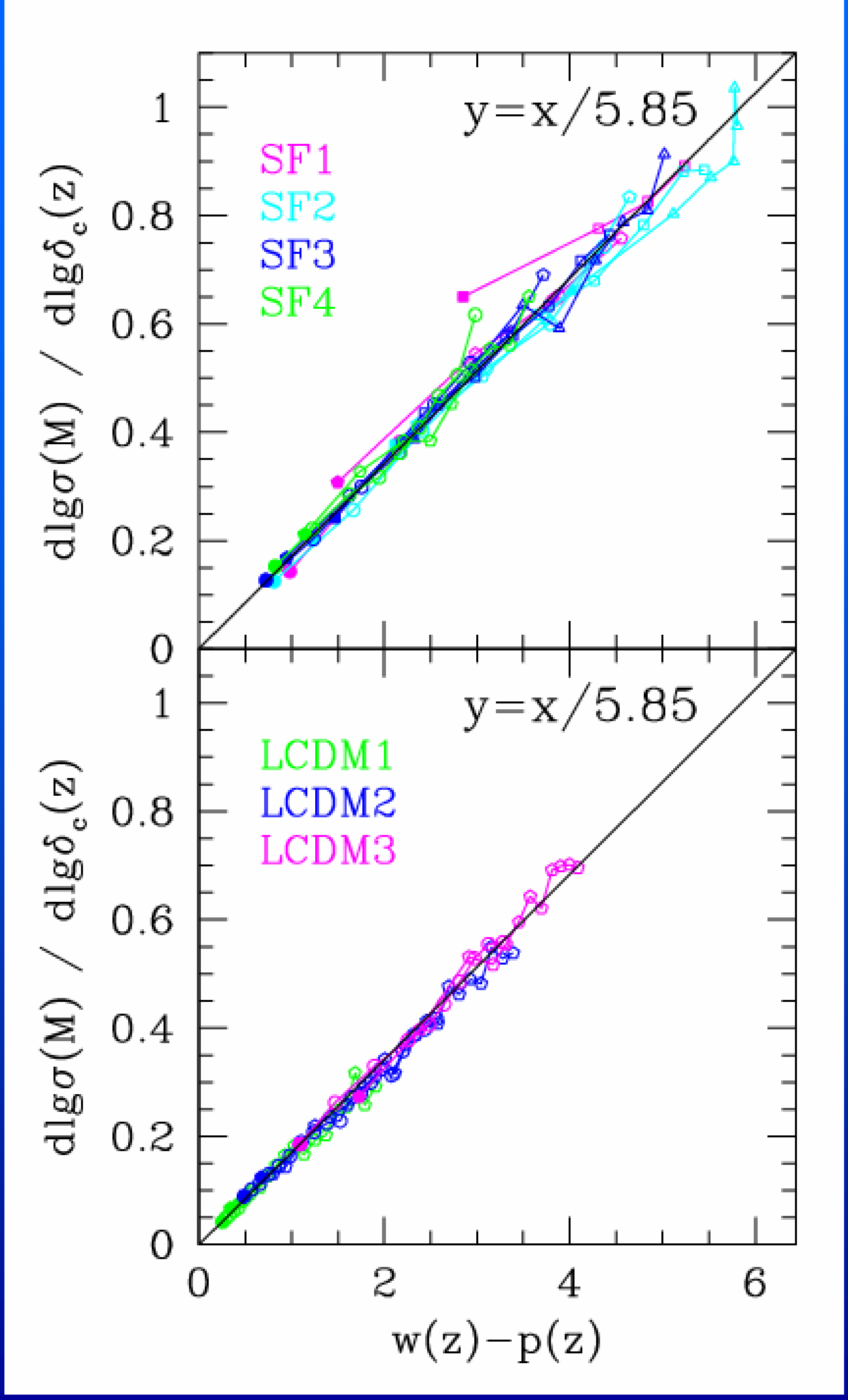
$$s(M) \equiv \sigma(M) \times 10^{\mathrm{dlg}\sigma/\mathrm{dlg}m|_M}\,.$$

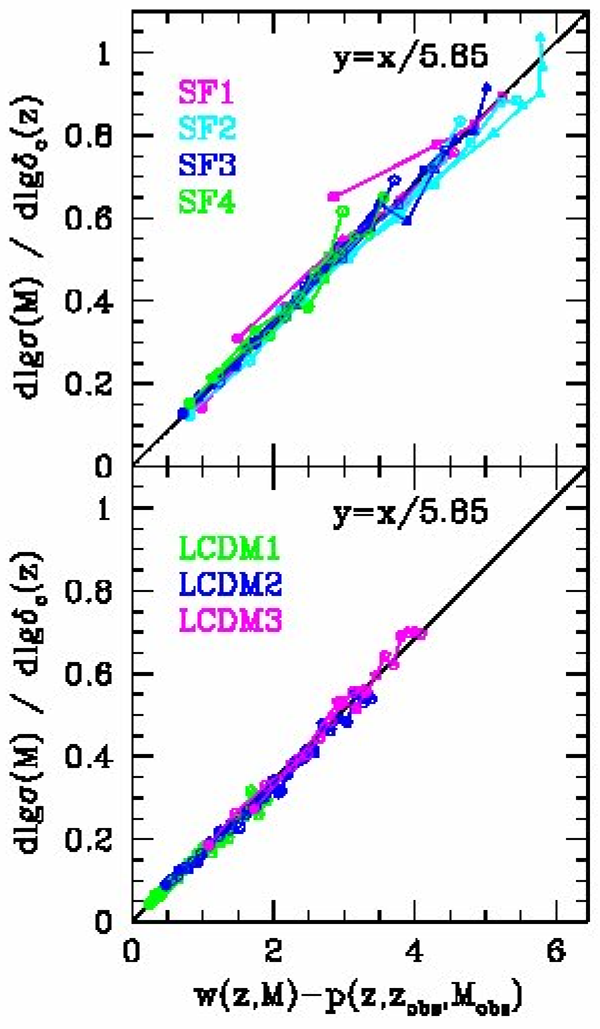


y=x/5.85
LCDM1−3
s(M)
δc(z)
0
1
2
3
4
0
5
10
15
20

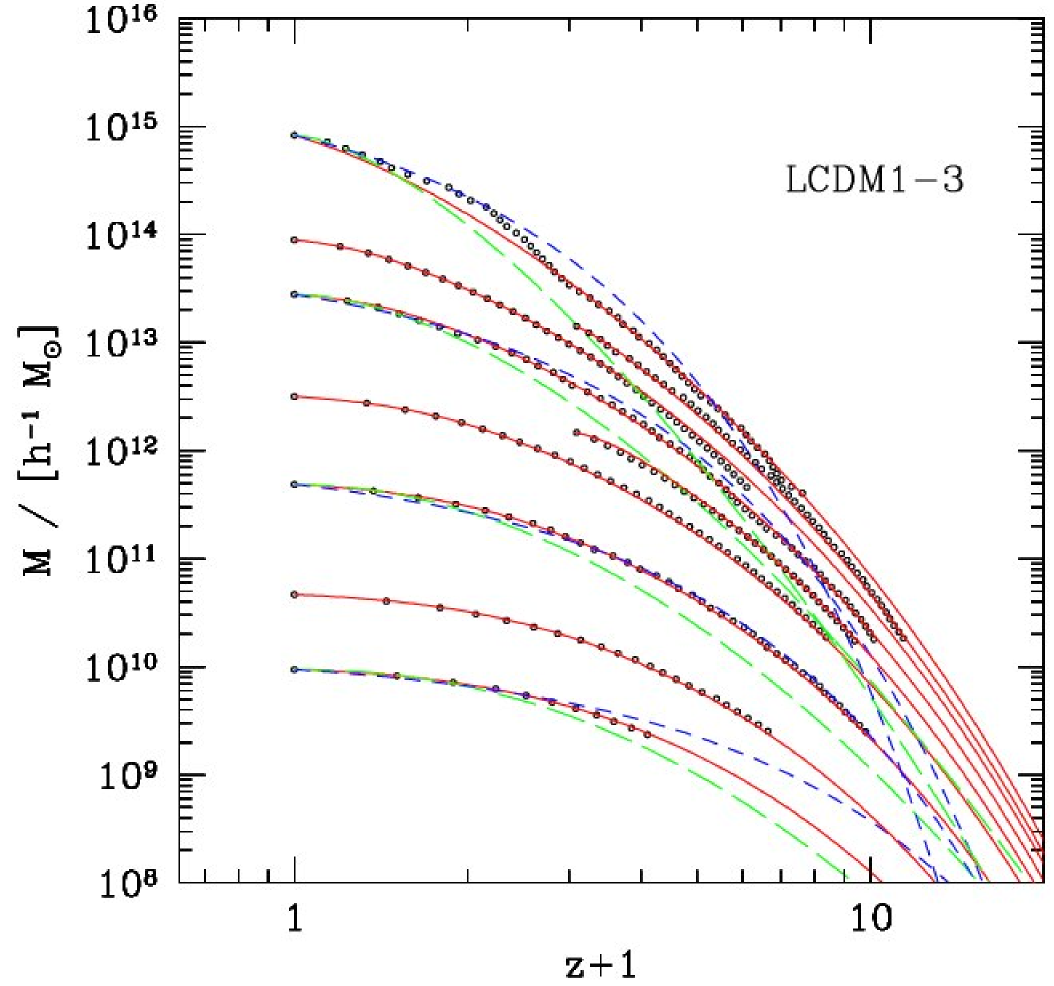
Universal differential relation

w-p determines growth rate of halo of mass M

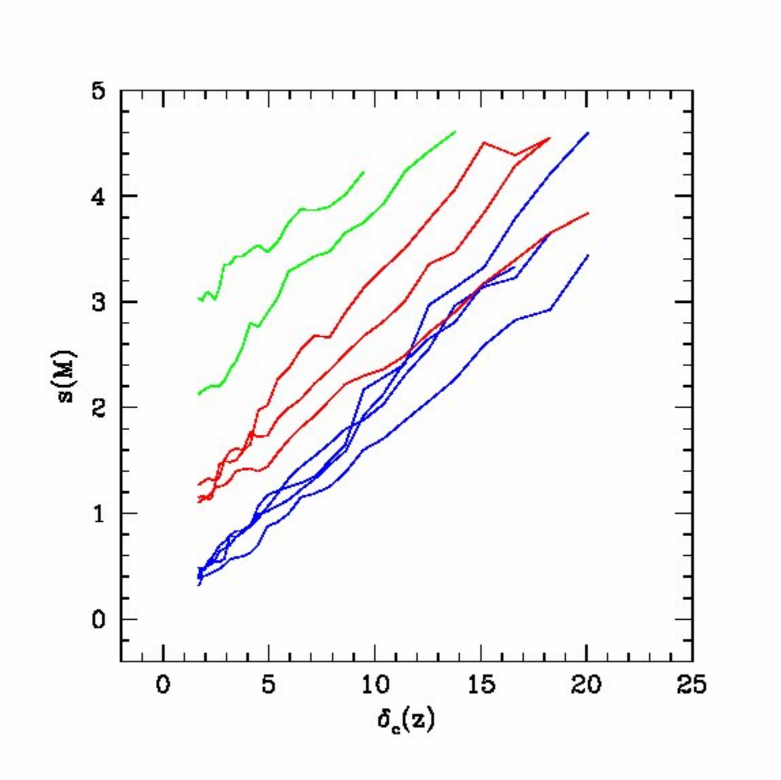




y=x/5.85
SF1
SF2
SF3
SF4
LCDM1
LCDM2
LCDM3
dlgσ(M) / dlgδc(z)
w(z,M)−p(z,zobs,Mobs)

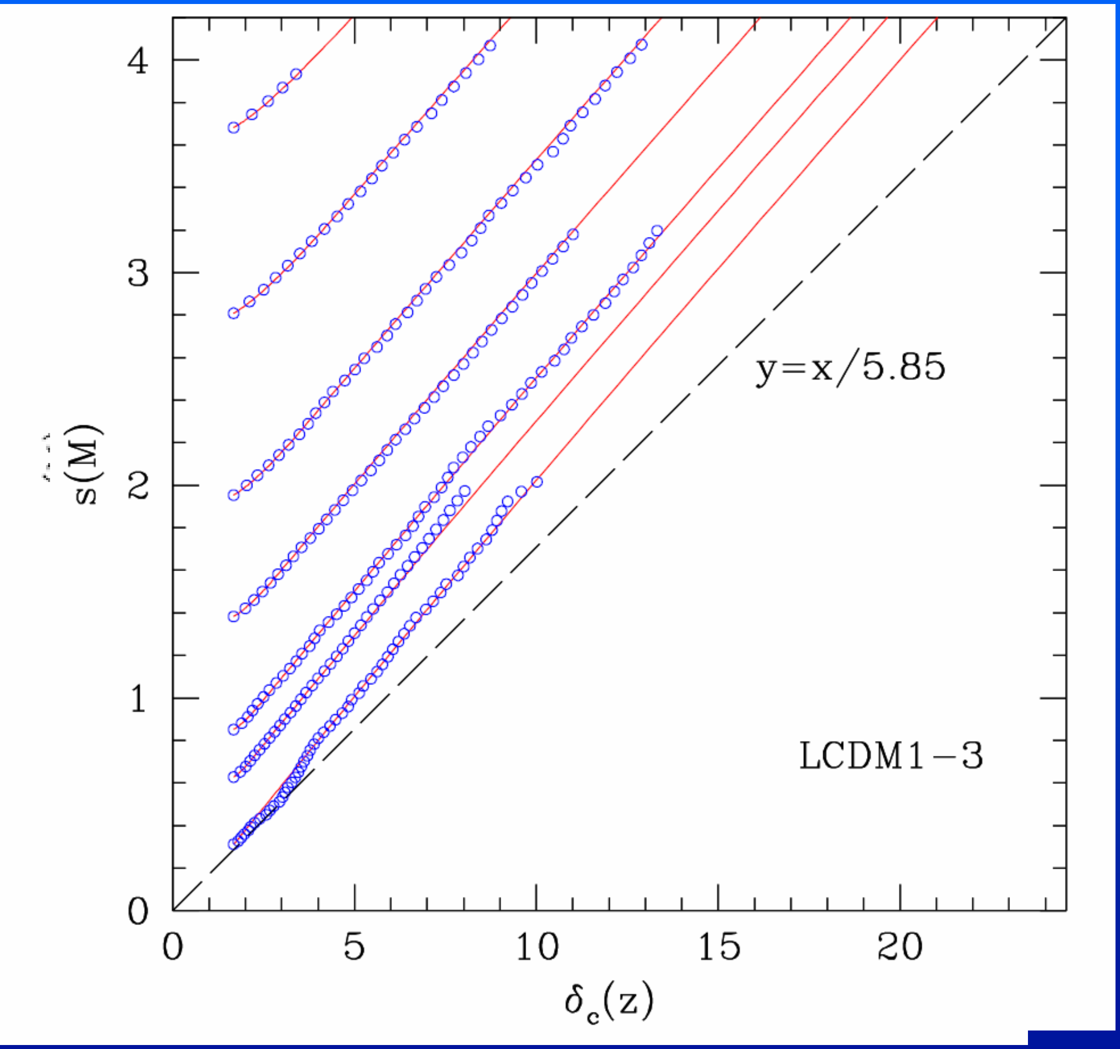


LCDM1−3
M / [h⁻¹ M⊙]
10¹⁶
10¹⁵
10¹⁴
10¹³
10¹²
10¹¹
10¹⁰
10⁹
10⁸
1
10
z+1

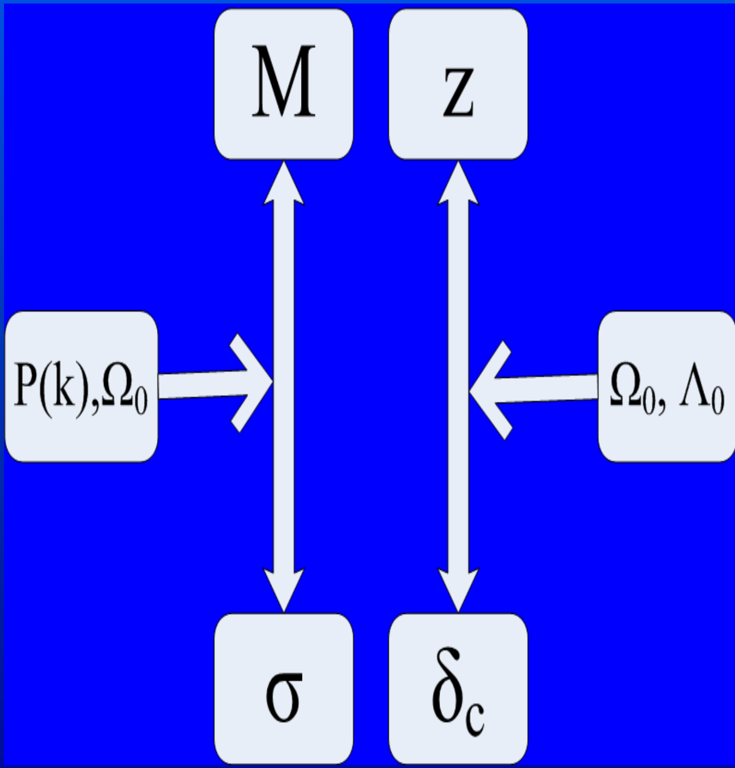


Indidual MAHs
Model LCDM1-3

Model prediction



- First go step by step in [σ , δ_c] space, then convert the history to [M, z] space



Other model predictions

- Application 2: accretion rate
- Application 3: a new characteristic mass scale

$$w(z, M) \equiv \delta_c(z)/s(M) = 5.85 \qquad M/M_* = 1.415, 3.422, 20.02, \text{ and } 4008.07,$$

- Application 4: halo formation time distribution (half mass redshift)
- Application 5: halo survival time (time when merging with a more massive halo) distribution (mass function needed)
- Application 6: modeling the dependence of MAHs on environment (???)
- Application 7: Predicting the evolution of the halo density profile

Part II
The density profile evolution of dark matter haloes

Halo Structure

$$\rho(r) = \frac{4\rho_s}{(r/R_s)(1+r/R_s)^2},$$

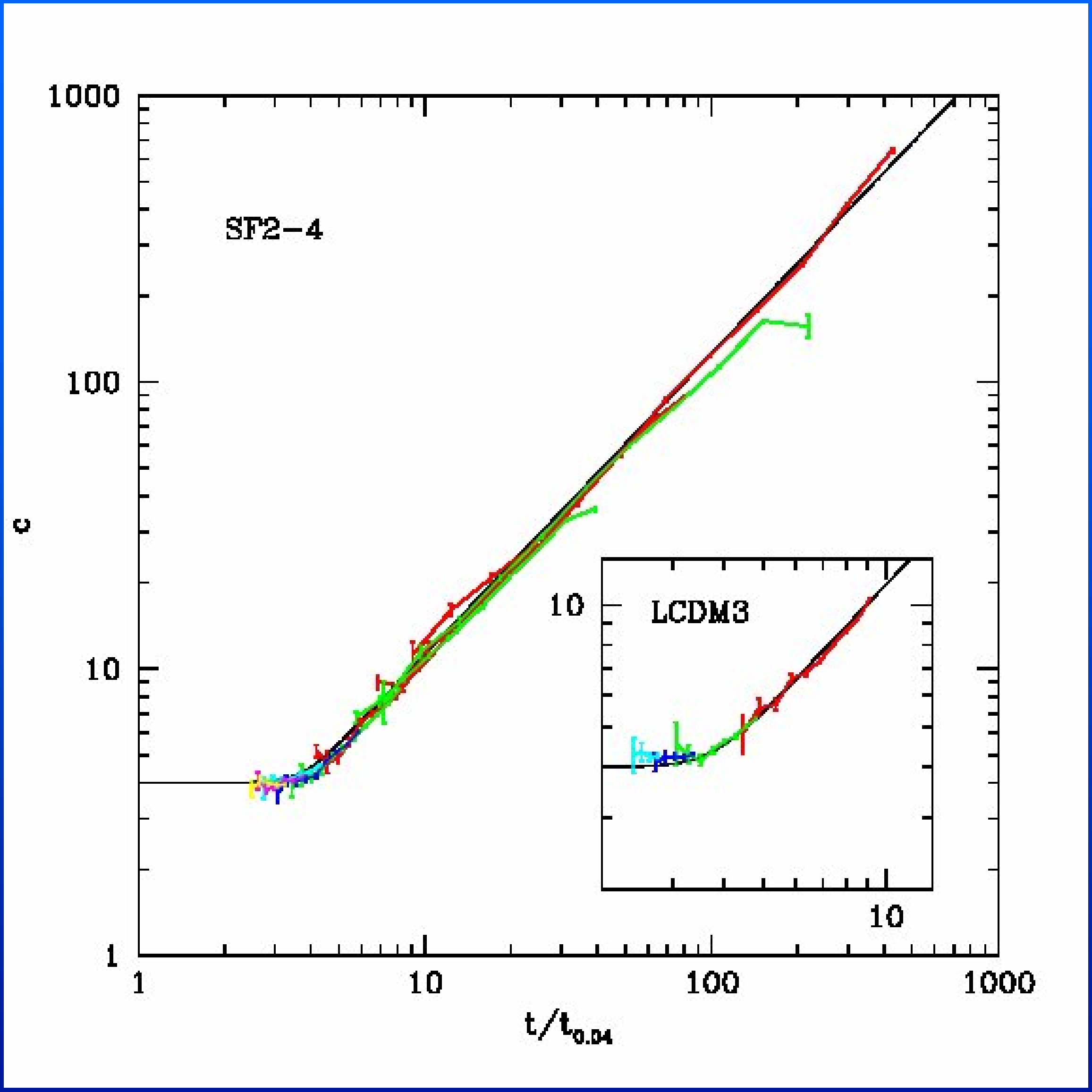
Concentration of Halo

$$c \equiv R_h/R_s$$

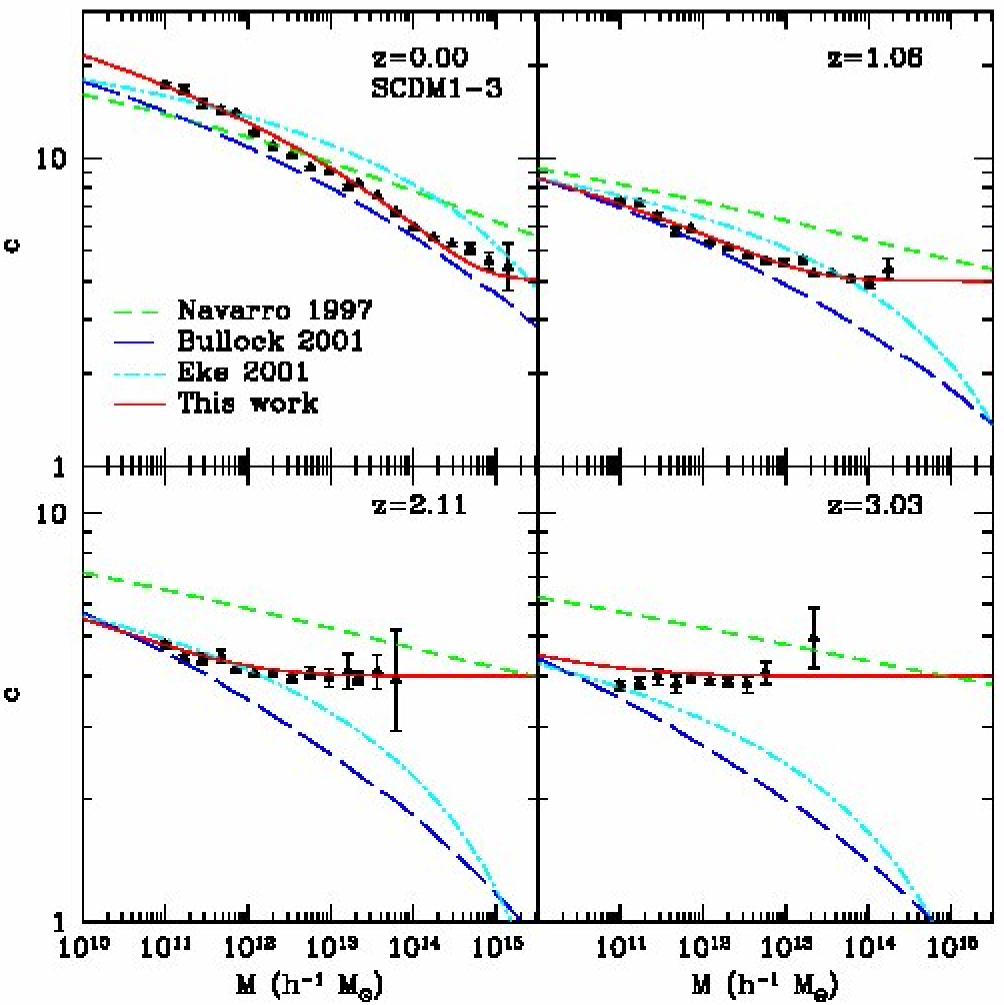
Another universal correlation

- t: universe age of final halo
- $t_{0.04}$: universe age when main progenitor mass is 4% of final halo mass

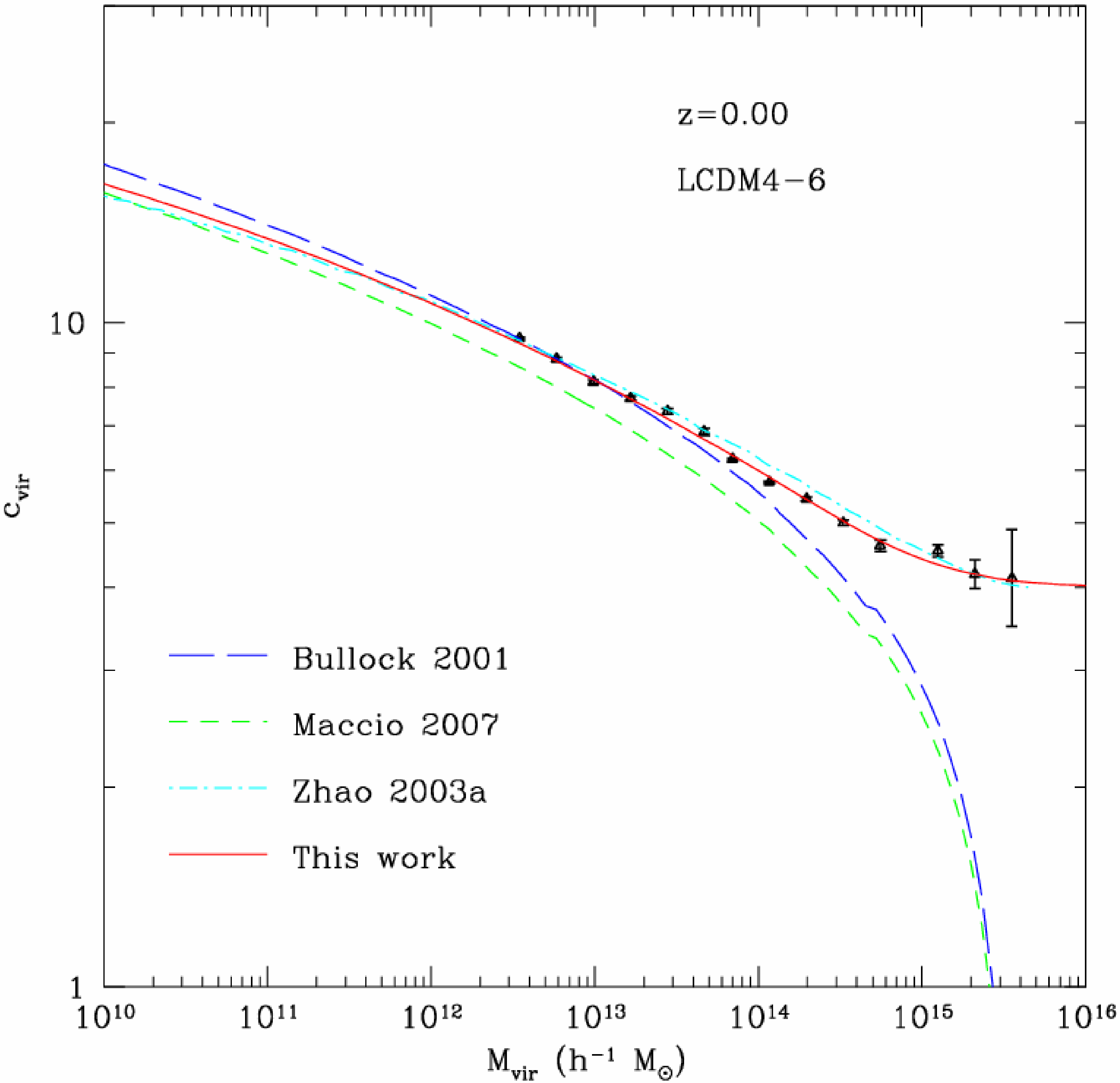
$$c = \left[4^8 + (t/t_{0.04})^{8.4}\right]^{1/8} = 4 \times \left[1 + (t/3.75t_{0.04})^{8.4}\right]^{1/8} .$$



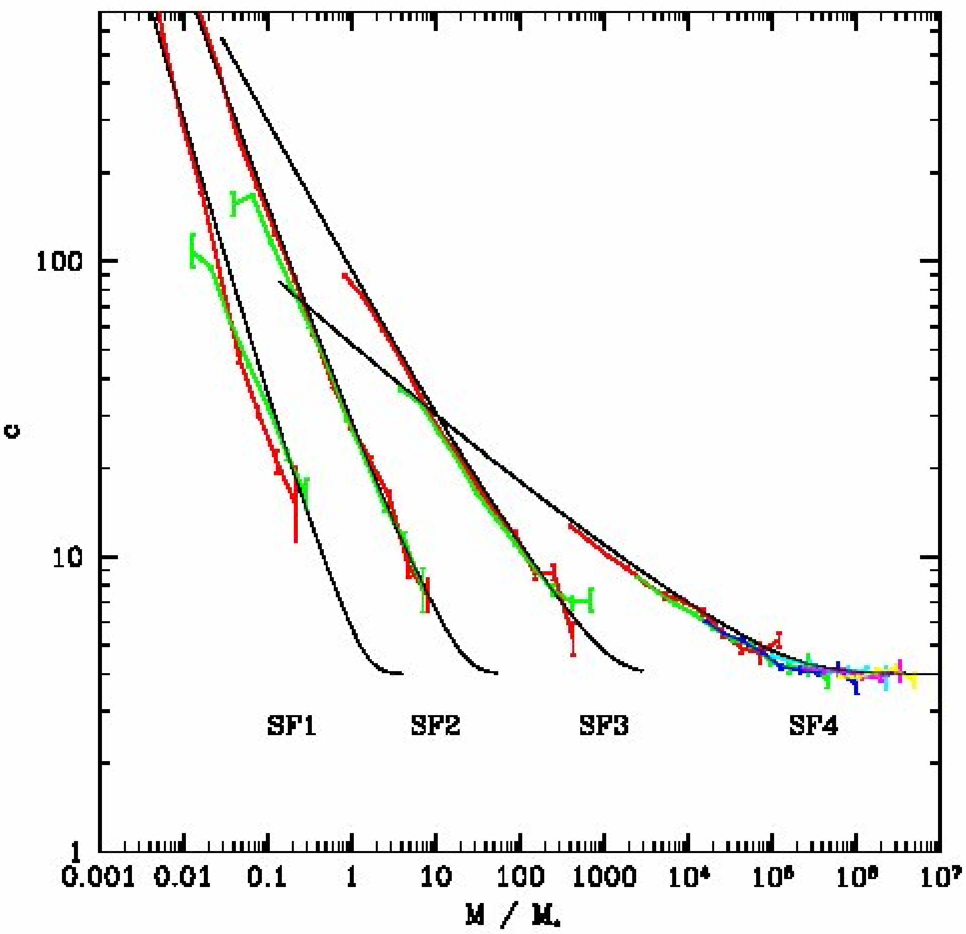
SF2-4
LCDM3
c
t/t_{0.04}
1
10
100
1000



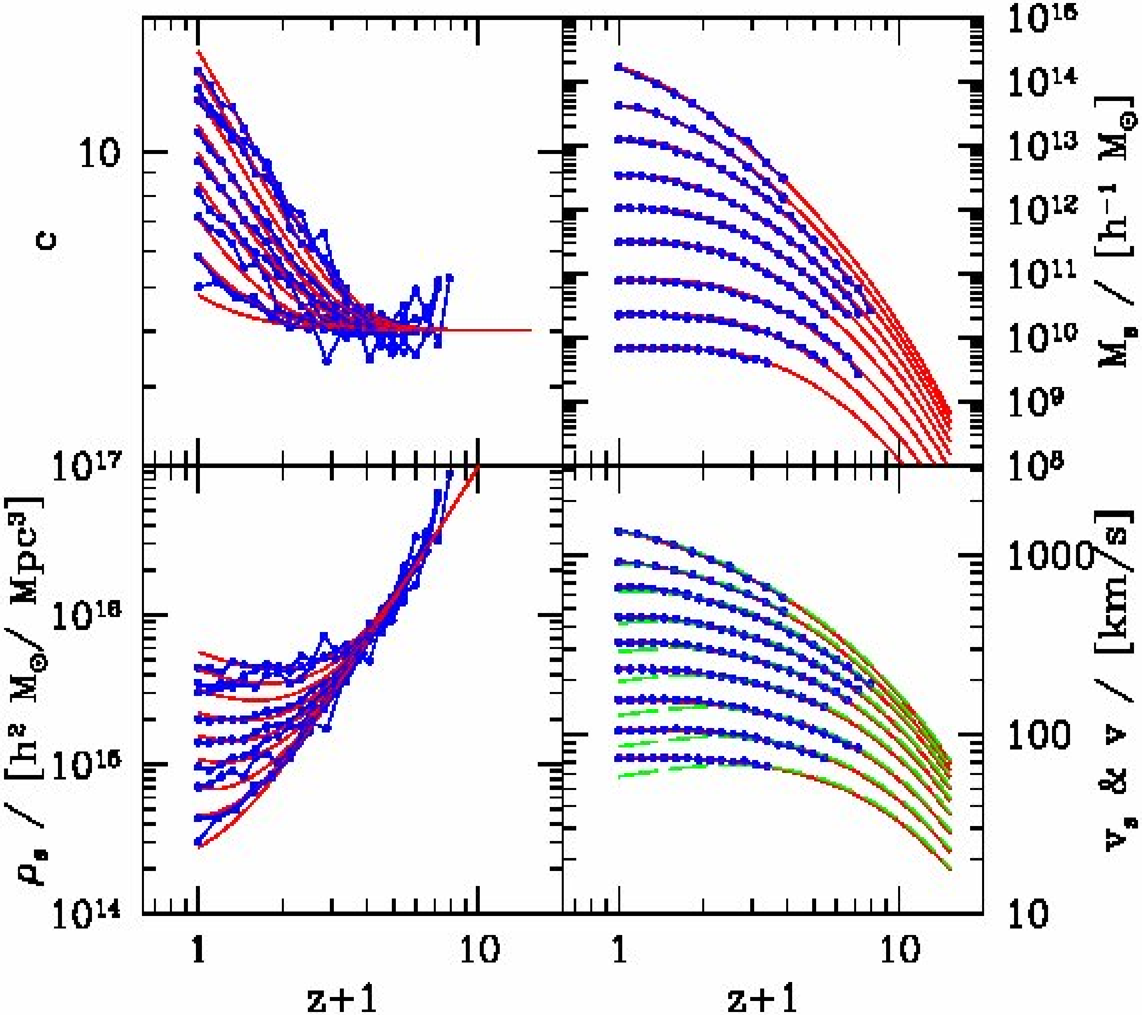
z=0.00
SCDM1-3
z=1.06
z=2.11
z=3.03
Navarro 1997
Bullock 2001
Eke 2001
This work
c
c
10
1
10
1
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
M (h^{-1} $M_{\odot}$)
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
M (h^{-1} $M_{\odot}$)



z=0.00
LCDM4-6
Bullock 2001
Maccio 2007
Zhao 2003a
This work
10
1
c_{vir}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
M_{vir} (h^{-1} $M_\odot$)



c
100
10
1
0.001 0.01 0.1 1 10 100 1000 10⁴ 10⁵ 10⁶ 10⁷
M / M*
SF1
SF2
SF3
SF4



Model LCDM1-3

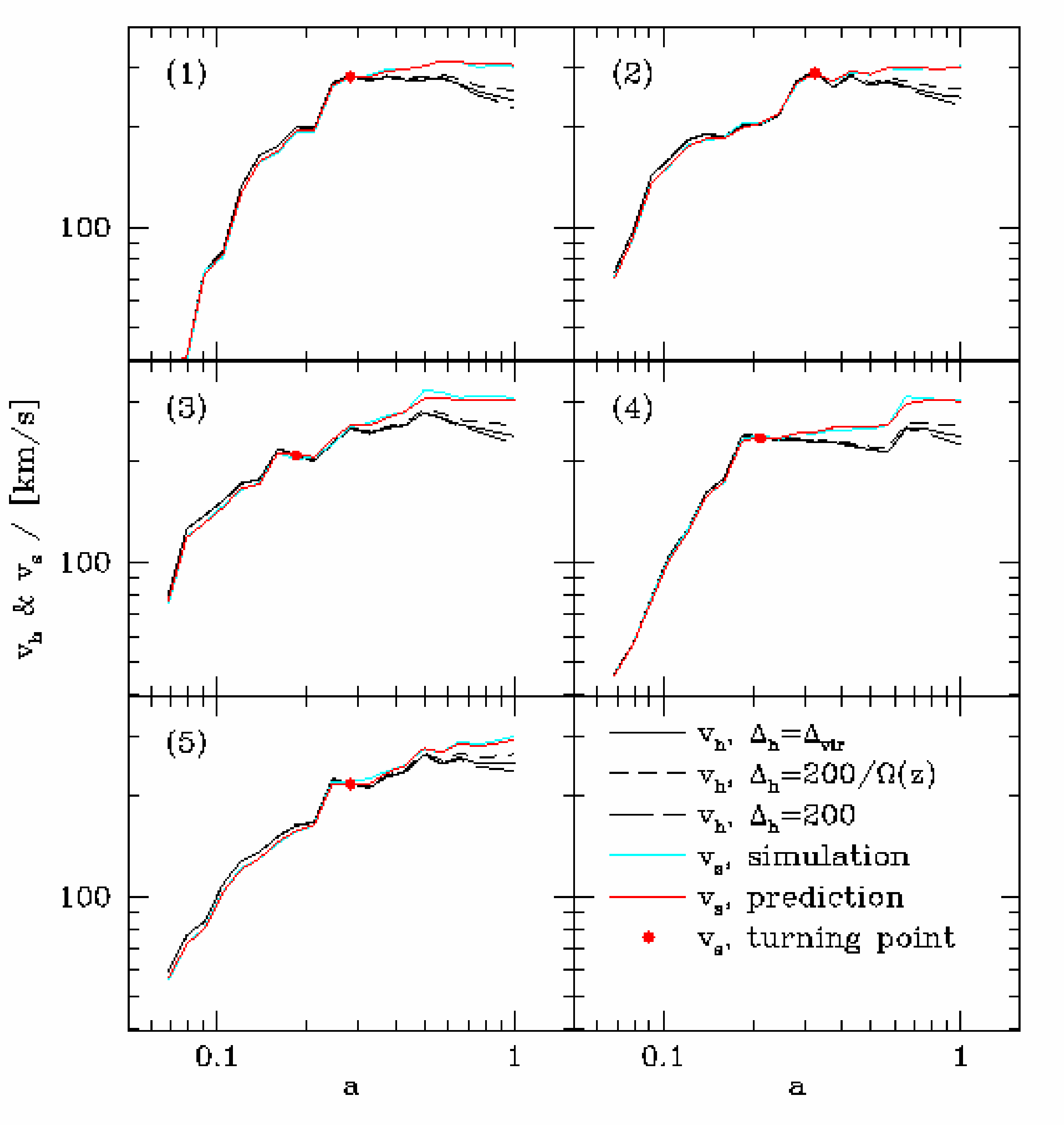
Conclusion

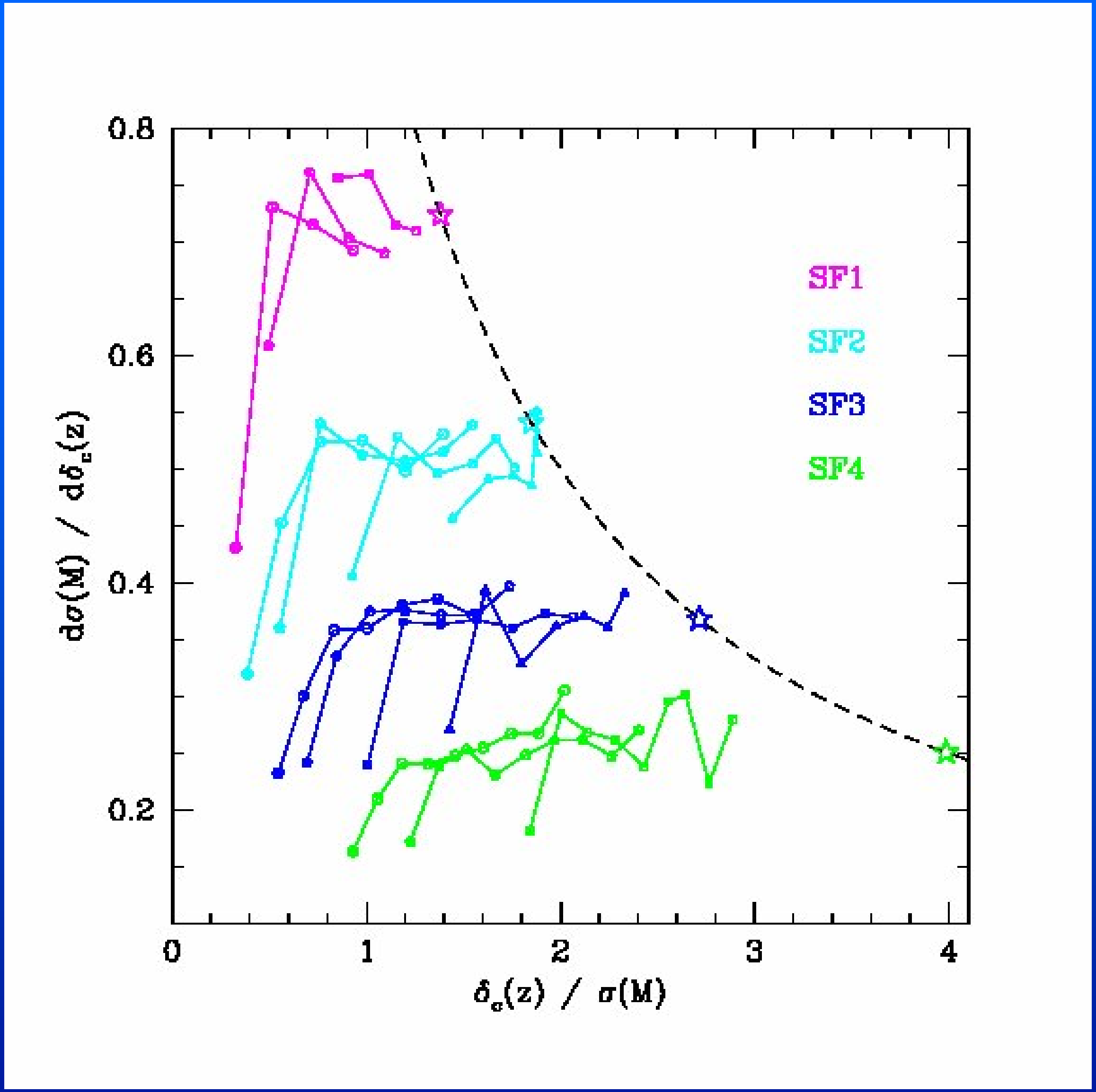
- We found a tight universal correlation between the median halo concentration c and with time when the main progenitor has gained 4% of the mass of the final halo.
- Combining this function with he MAHs model above, we can predict halo concentration as a function of M and z, c(z,M), valid for different halo mass, redshift, cosmology and power spectra .
- This model can also be used to predict the evolution of c along main branches, $c(z|M_0,z_0)$.

Website

- A calculator which allows one to interactively generate data for any given cosmological model is provided at http://www.shao.ac.cn/dhzhao
- And there a user-friendly code to make the relevant calculations is also provided

Evolution of circular velocity





Star: asymptotic value

SF1: n = +1
SF2: n = 0
SF3 n = -1
SF4 = - 2