Numerical simulations of cosmic structures

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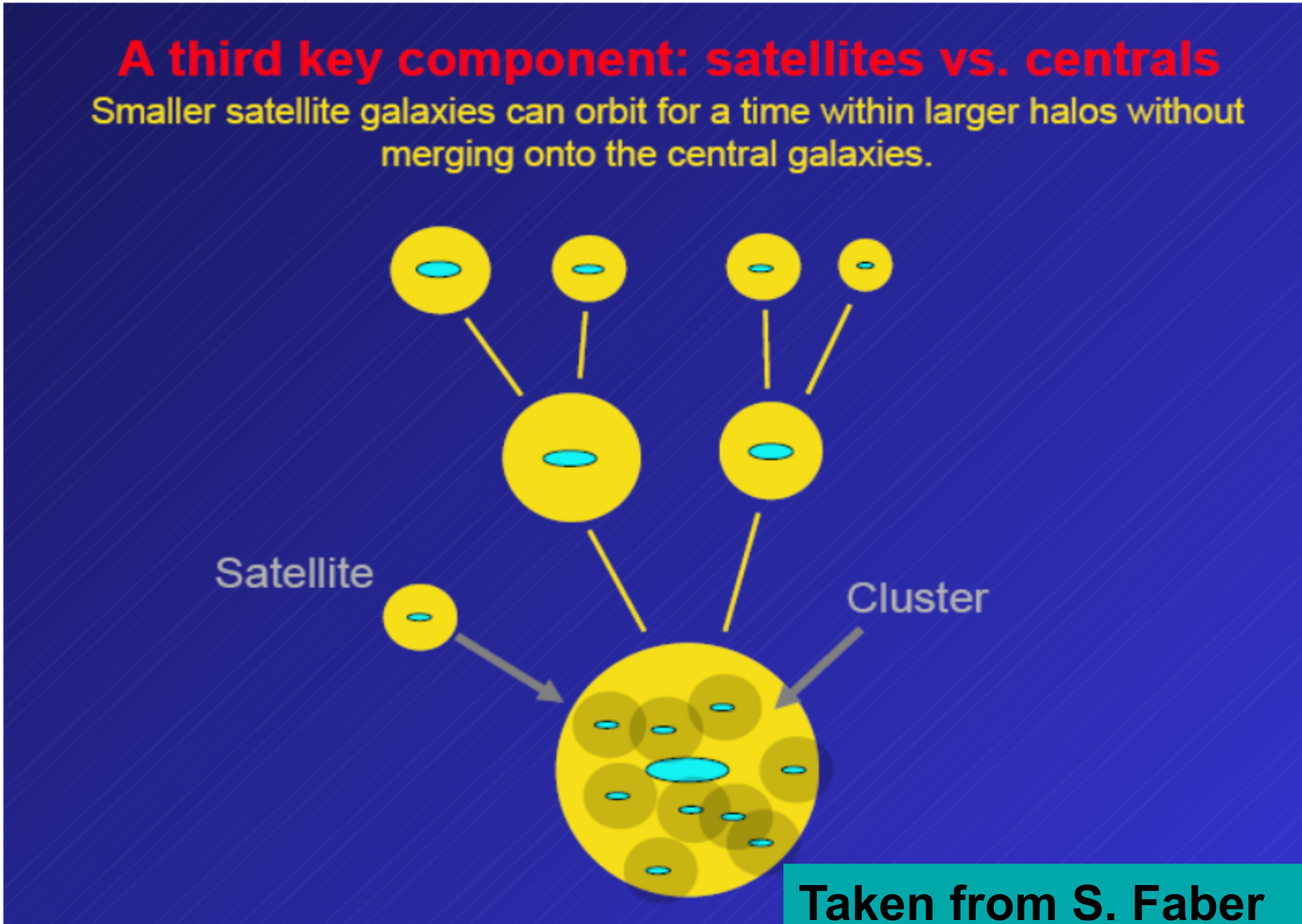
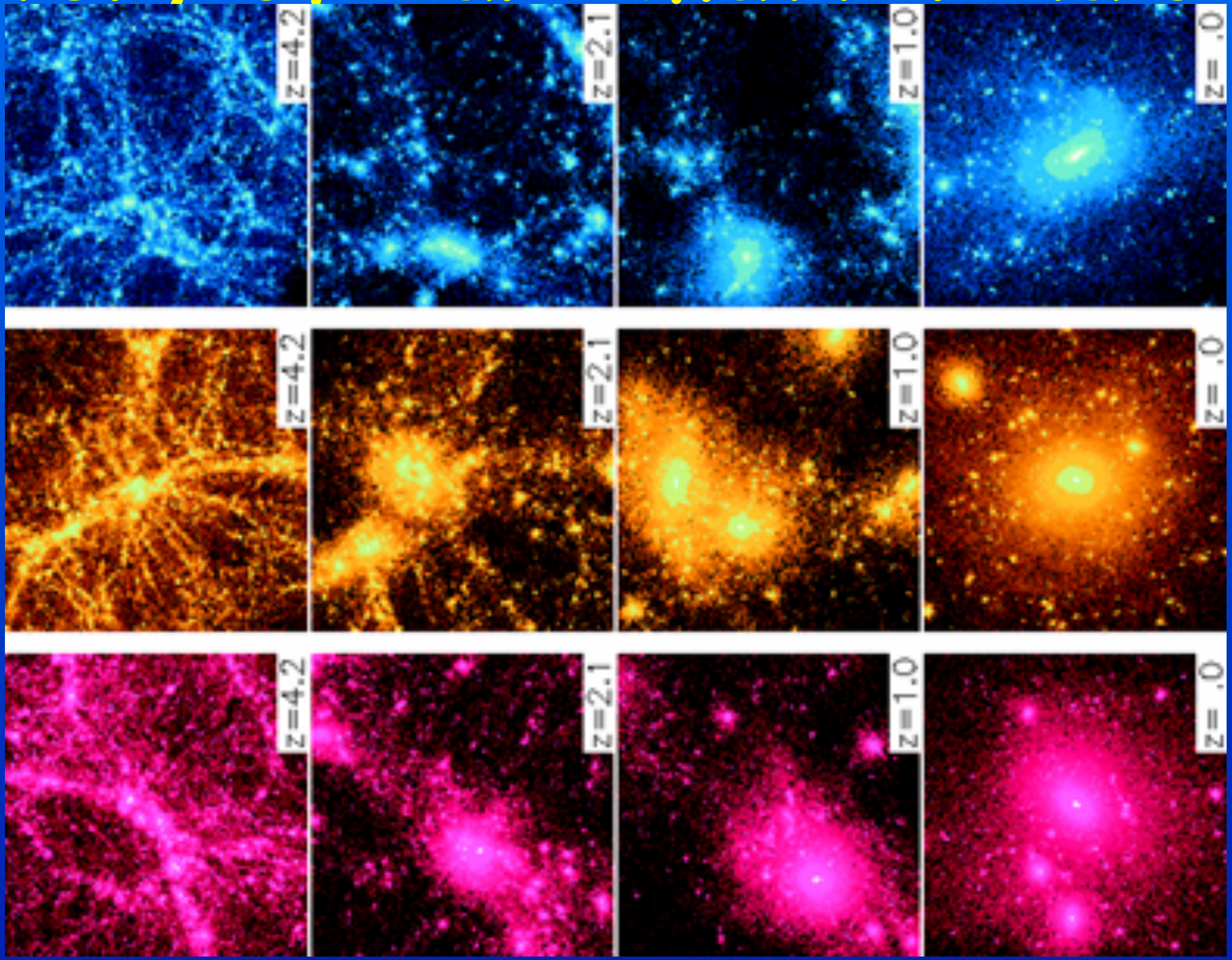
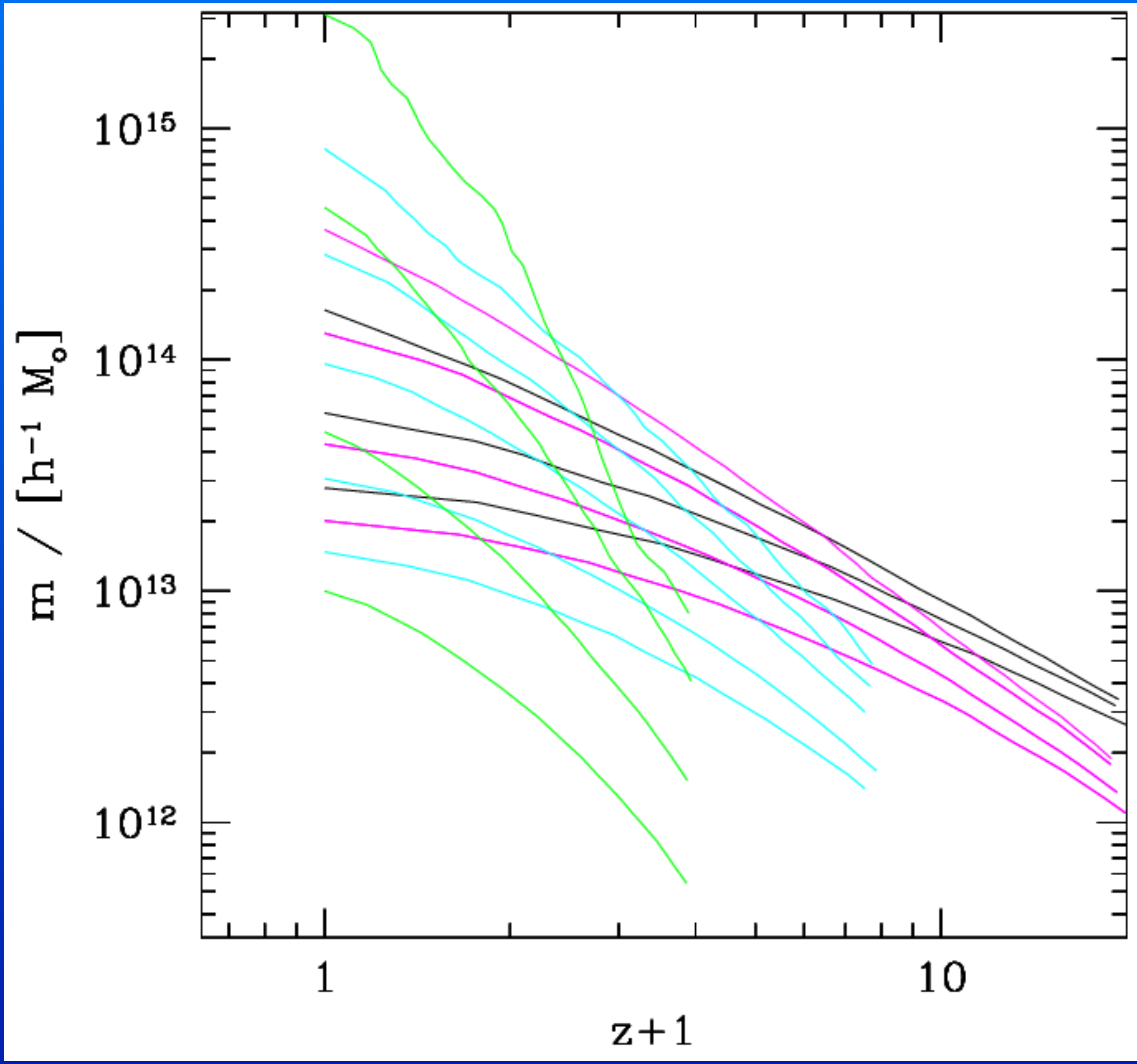
Theoretical framework for understanding evolution of galaxies and dark matter halos



Taken from S. Faber

The universal mass accretion history of dark matter haloes





10^{15}
10^{14}
10^{13}
10^{12}
m / [h^{-1} M$_{\odot}$]
1
10
z+1

Choosing proper variables for modeling

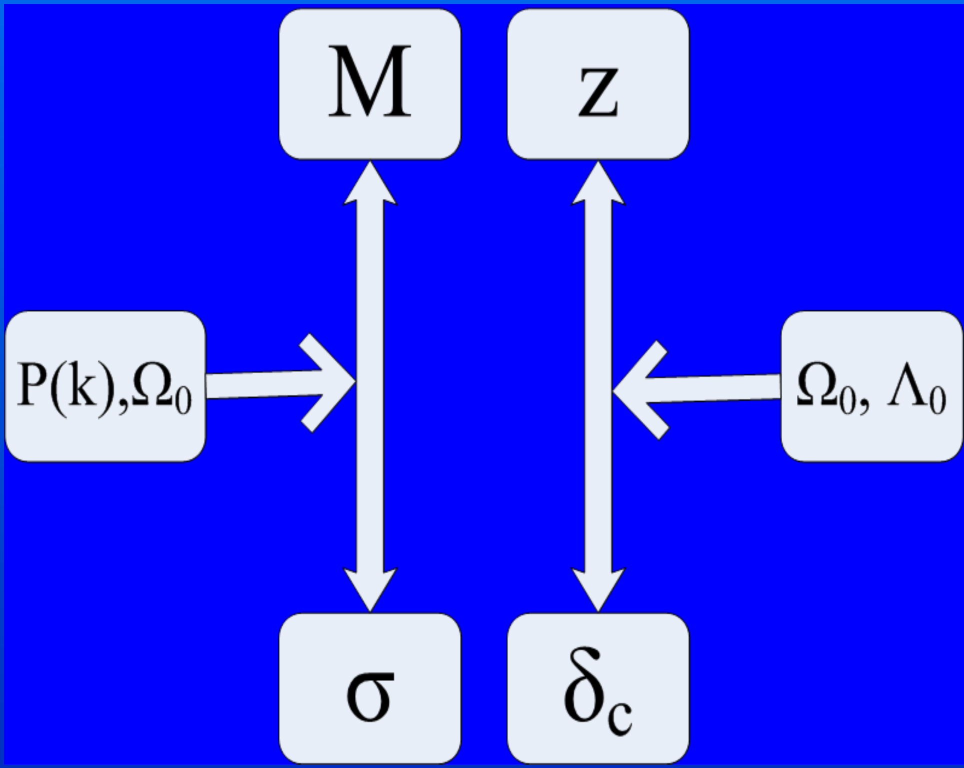
- Given cosmology and power spectrum, after extrapolated linearly to z=0,

  linear mass variance of given volume σ is determined by M, and

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

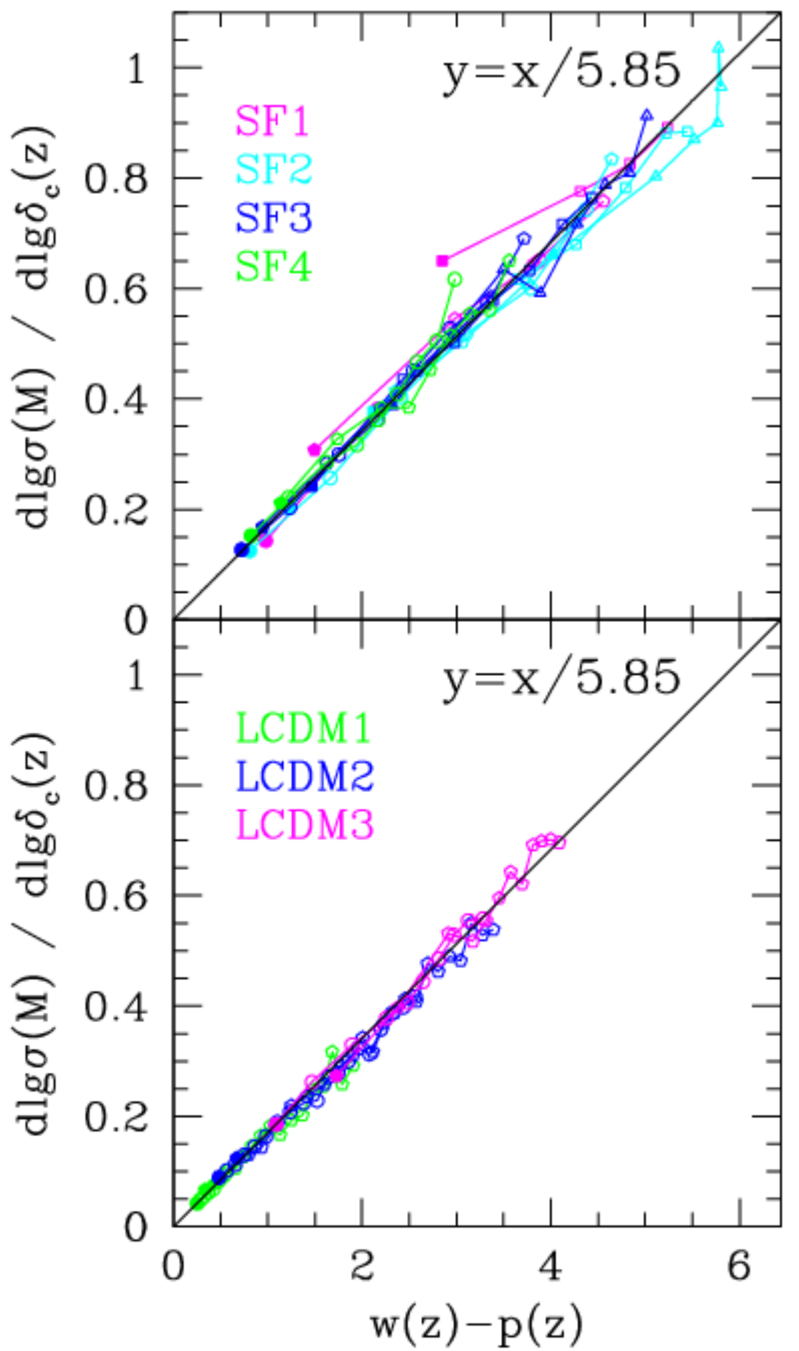
  linear critical collapse overdensity δ_c by z.

$$\delta_c(z) \equiv \delta_c^{'}(\Omega_m(z), \Omega_\Lambda(z)) / D(z)$$



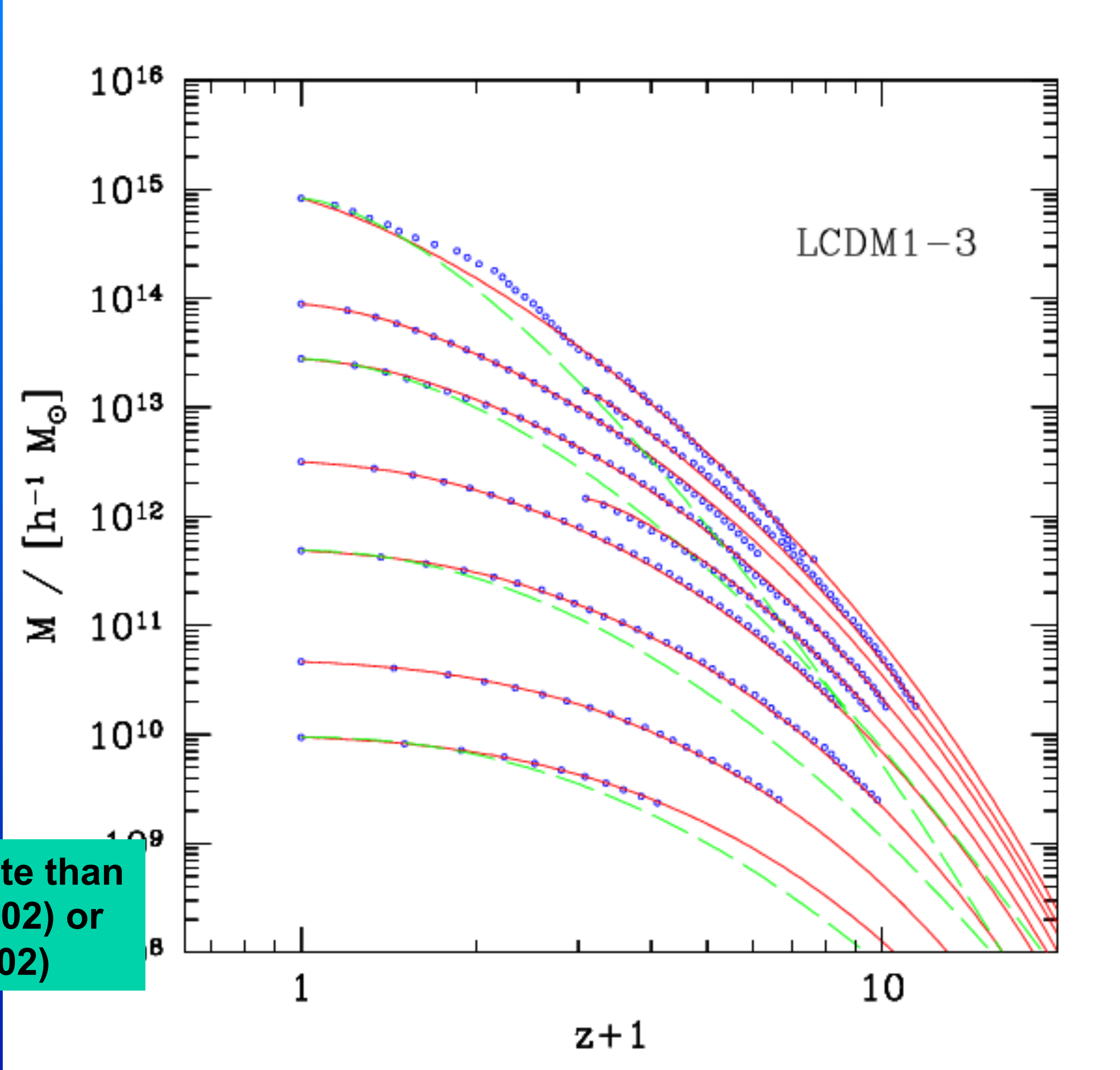
Universal differential relation

w-p determines growth rate of halo of mass M



D.H. Zhao, et al. ApJ (2009)

- LCDM

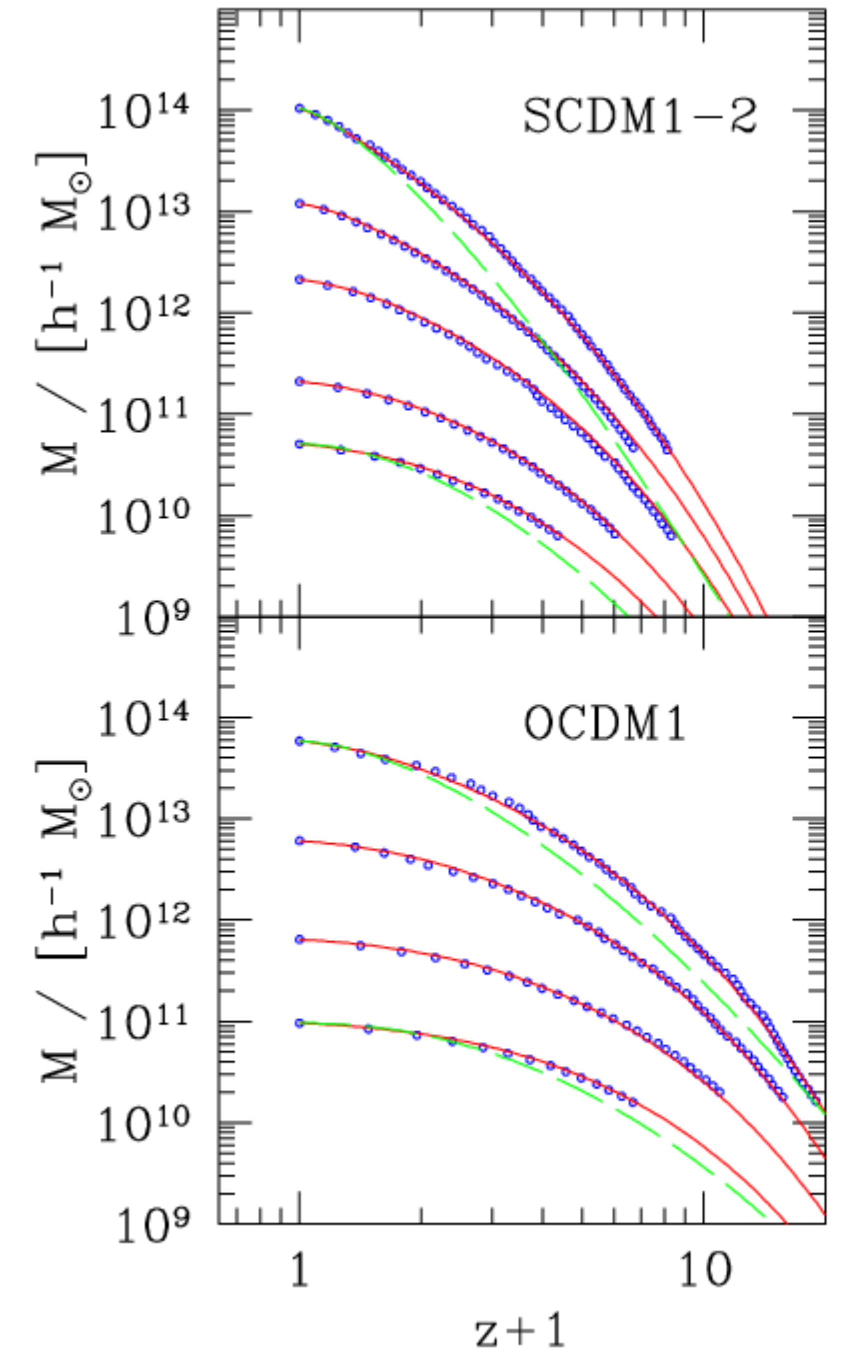


Much more accurate than van den Bocsh (2002) or Wecshler et al. (2002)

- SCDM

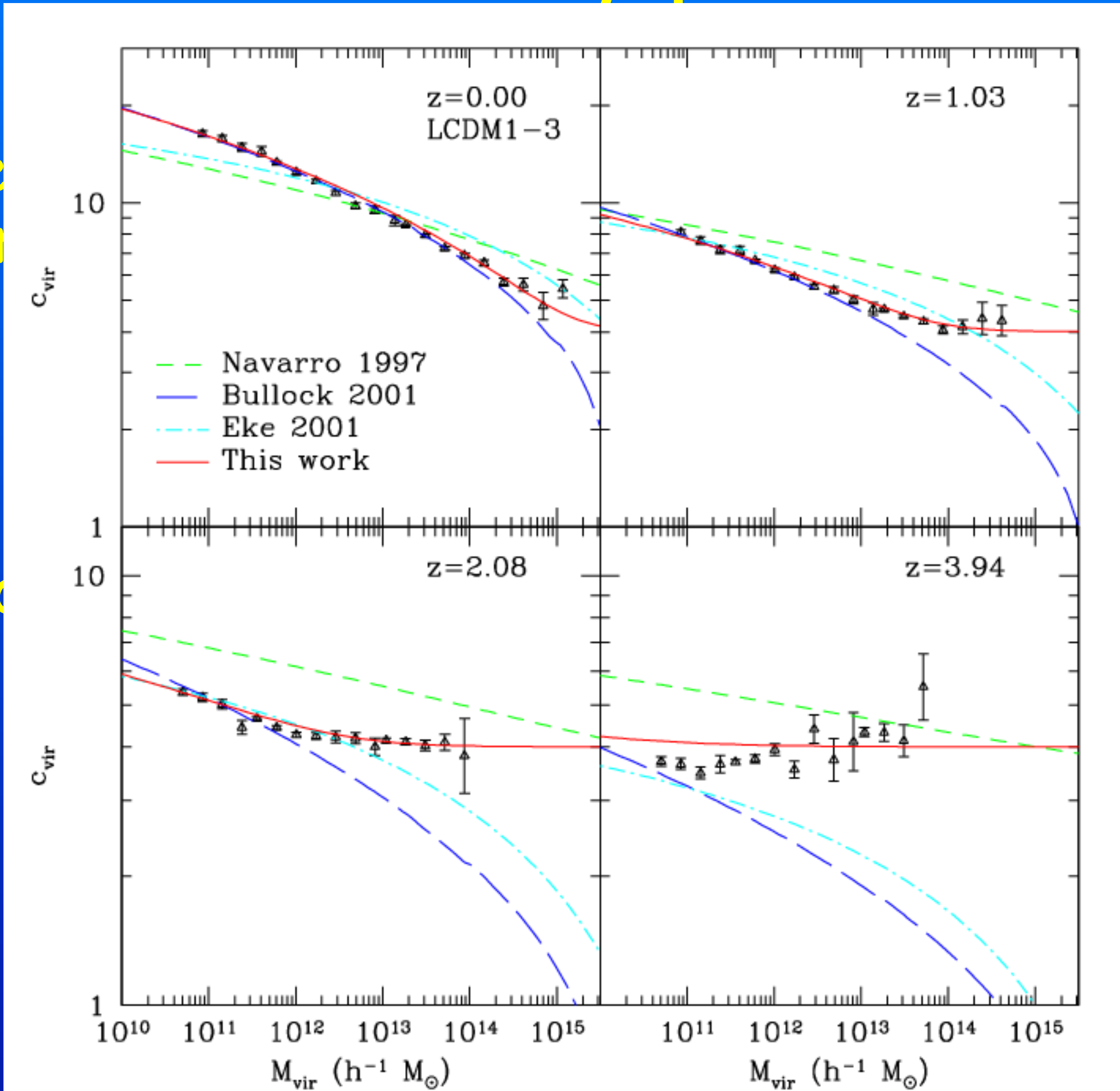
&

OCDM

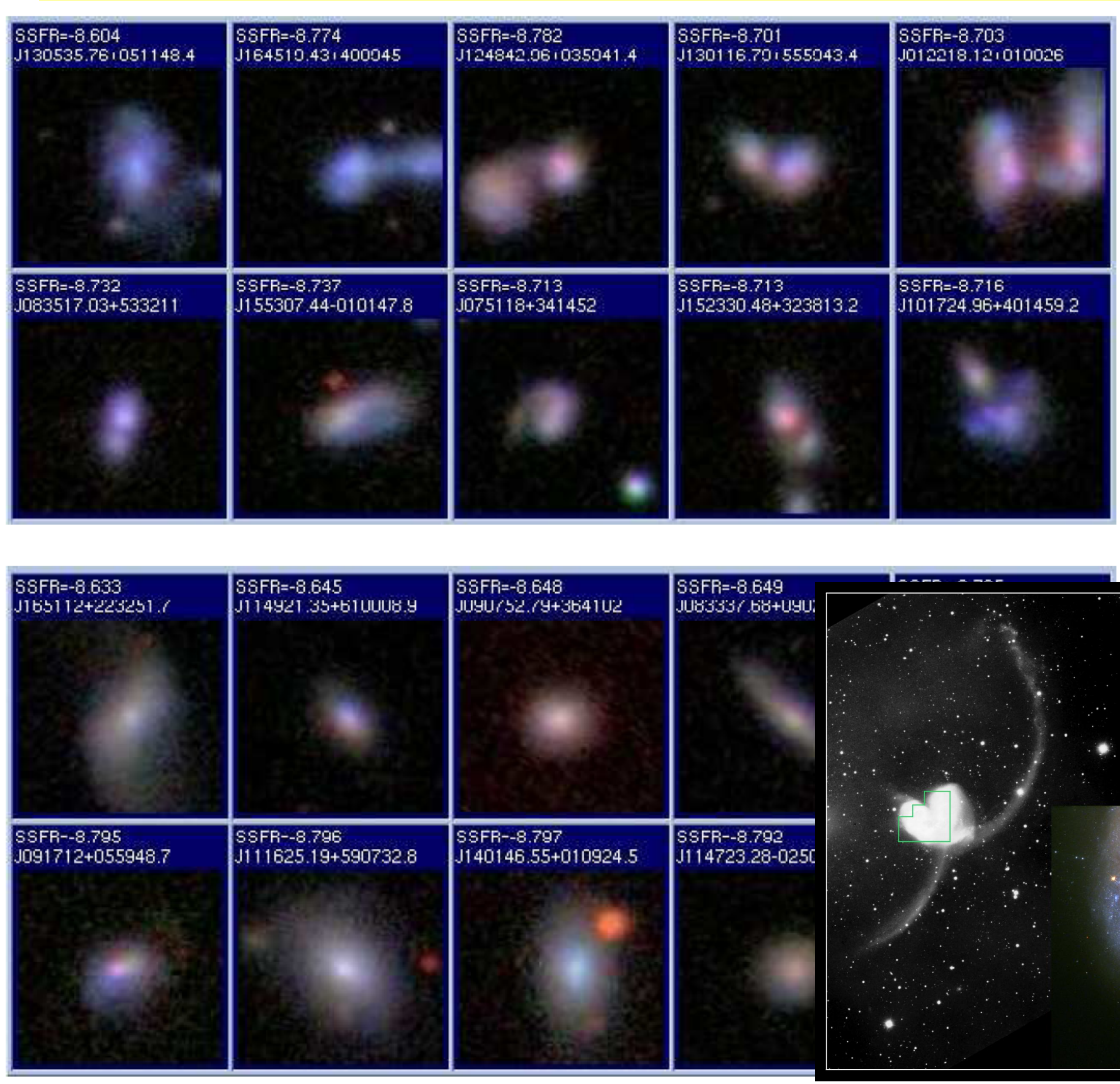


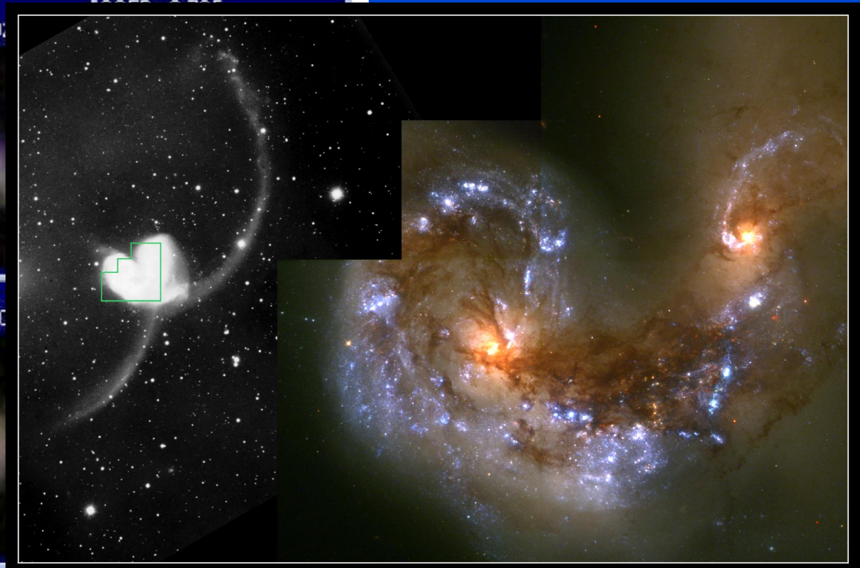
Evolution of halo density profile

- Combined with MAHs model we presented in par I, c-t correlation can be used to predict the evolution of halo density profile
  - LCDM1-3

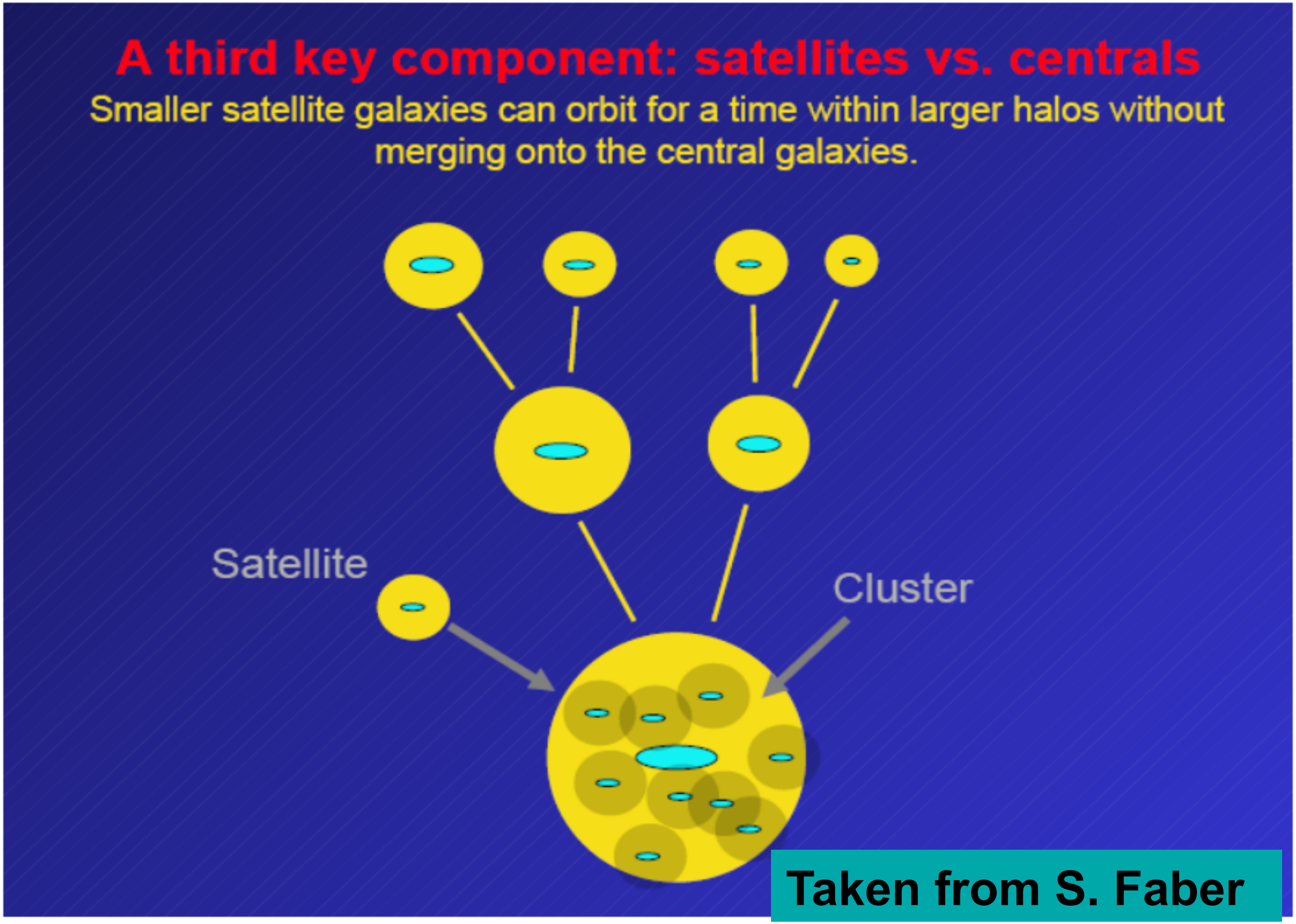


Merging of galaxies





Theoretical framework for understanding evolution of galaxies and dark matter halos



- We employed a parallel version of the SPH code GADGET 2(Springel 2005). The box is $100h^{-1}Mpc$ on a side, with 512^3 dark matter particles and 512^3 gas particles. Gravity is softened with a spline, roughly equivalent to a Plummer force softening of $4.9h^{-1}$ comoving kpc. There are totally 177 snapshots from z=19, among which 28 are before z=3.5, and 149 are at $z \leq 3.5$.

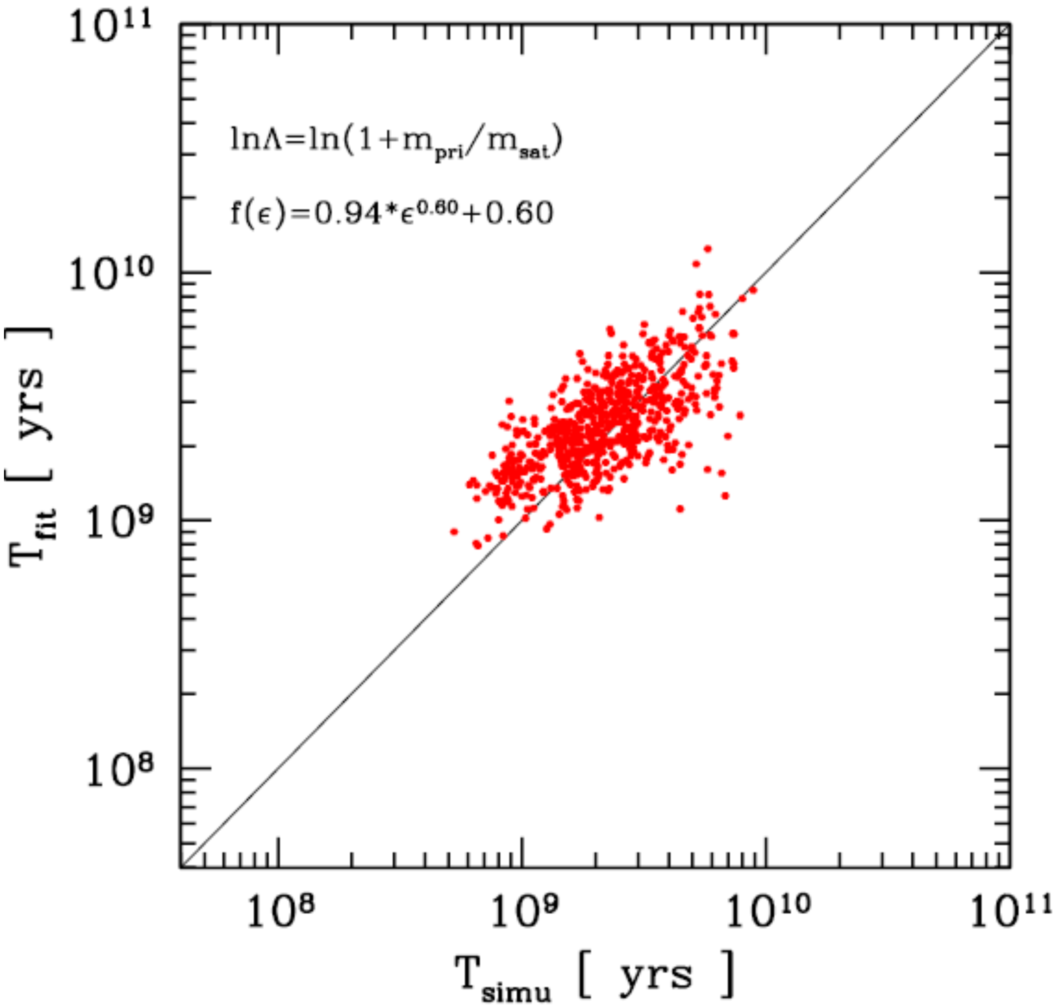
present time $z = 0$ with an equal logarithmic scale factor interval $\Delta \ln a = 0.01$ between two consecutive outputs. The large number of the outputs enables us to accurately sample orbits of satellites within massive haloes, with about 8 outputs for one dynamical crossing time. Both the good force resolution and the dense sampling of snapshots are crucial for the current study.

Two types of merger timescales in literature

- The time duration for a satellite falling into the central galaxy from the first crossing of the virial radius of host DM halo; important of theoretical modeling, such as in SAMs;
- The time duration for a close pair of galaxies at a fixed separation (small) to merge; important for observations

Fitting formula

$$T_{\rm fit} = \frac{0.90\epsilon^{0.47} + 0.60}{2C} \frac{m_{\rm pri}}{m_{\rm sat}} \frac{1}{\ln[1 + (\frac{m_{\rm pri}}{m_{\rm sat}})]} \frac{\sqrt{r_{\rm vir} r_c}}{V_c}, \quad (8)$$



Merger timescale for all mergers

Corrections:

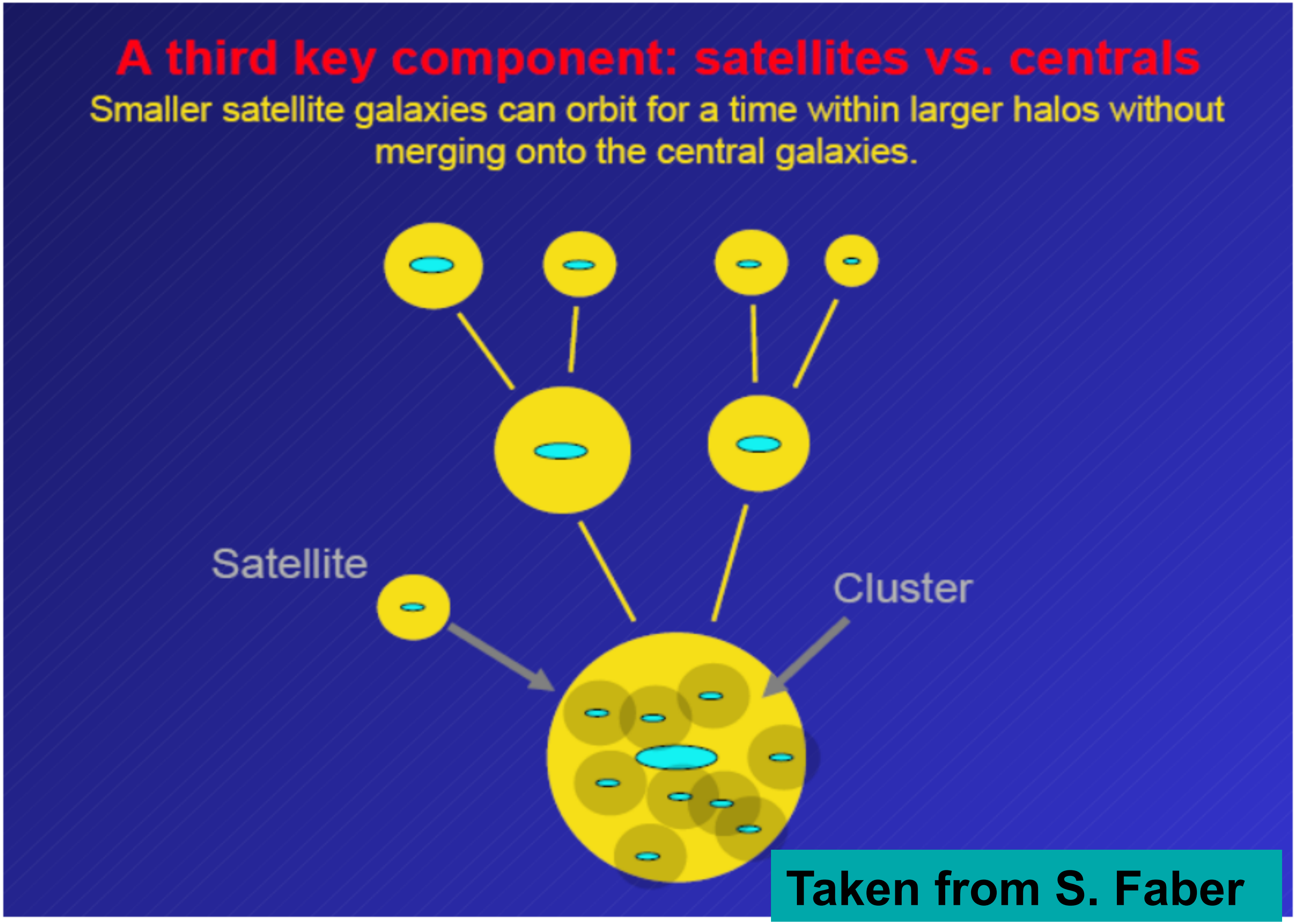
1) Mass loss: a factor of 2 longer
2) Motion of the central galaxies and dynamical evolution: weak dependence on ε (orbital circularity)
3) Dependence on the DM mass of the primary and satellite: the Coulomb logarithm
4) Scatter: 40% reflecting hierarchical formation and diversity of host halos

Jiang et al. 2008

The second merger timescale

- A merger time for close pairs of certain mass (luminosity) and separation, related to measure the merger rate from the counts of close pairs in observations
- (Jiang, YPJ, Han, 2013, astroph/ 1307.3322)

Theoretical framework for understanding evolution of galaxies and dark matter halos



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Some scaling considerations

$$T_{\rm fit} = \frac{0.90\epsilon^{0.47} + 0.60}{2C} \frac{m_{\rm pri}}{m_{\rm sat}} \frac{1}{\ln[1 + (\frac{m_{\rm pri}}{m_{\rm sat}})]} \frac{\sqrt{r_{\rm vir} r_c}}{V_{\rm c}}, \quad (8)$$

Considering $v_{\rm c} \approx \sqrt{\frac{Gm_{1,\rm v}}{r_{1,\rm v}}}$ in the primary halo,

$$T_{\rm mg} \propto \frac{{m_{1,\rm v}}^{1/2} {r_{\rm p}}^2}{G^{1/2} m_2 \ln \Lambda {r_{1,\rm v}}^{1/2}}.$$

The volume merger rate can be written as

$$\Phi = C_{\rm mg} n_1 n_{\rm p}(< r_{\rm p})/T_{\rm mg},$$

Replacing $T_{\rm mg}$ in equation (1) with equation (2), obtain

$$\Phi = A_* \frac{G^{1/2} m_2 {r_{1,\rm v}}^{1/2} n_1 n_{\rm p}(< r_{\rm p})}{{m_{1,\rm v}}^{1/2} {r_{\rm p}}^2}.$$

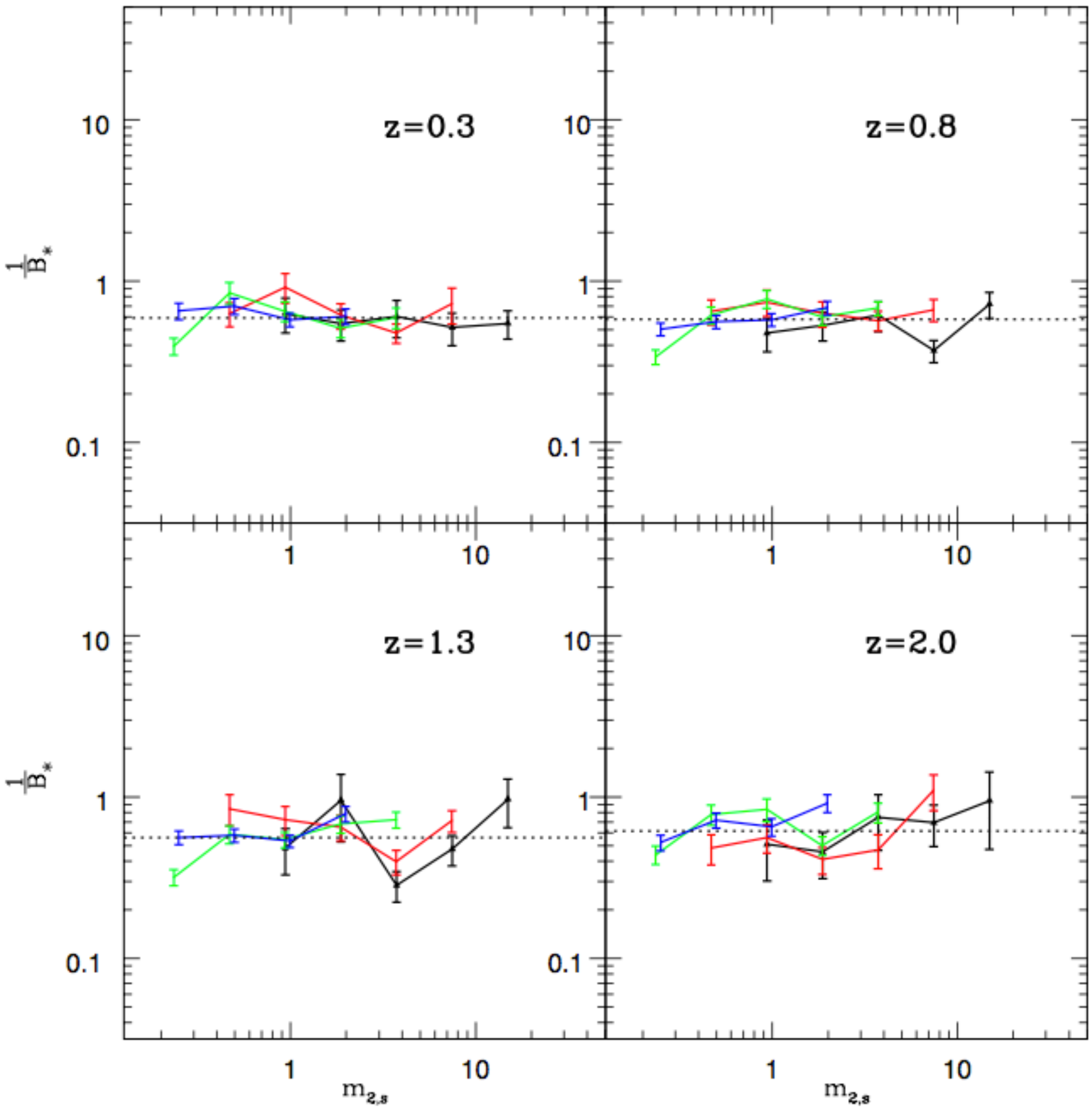
More scaling considerations

- The retained mass of the satellite: $m_{2,\mathrm{v}} \frac{r_\mathrm{p}}{r_{1,\mathrm{v}}}$.
  - Correct when DM halo is an isothermal sphere of; but good for real DM halos
- With the definition of halos (200 critical density) and cosmological parameter relations, we have

$$T_\mathrm{mg} \propto \frac{m_{1,\mathrm{v}}}{m_{2,\mathrm{v}}} [m_{1,\mathrm{v}} G H_0 E(z)]^{-1/3} r_\mathrm{p}$$

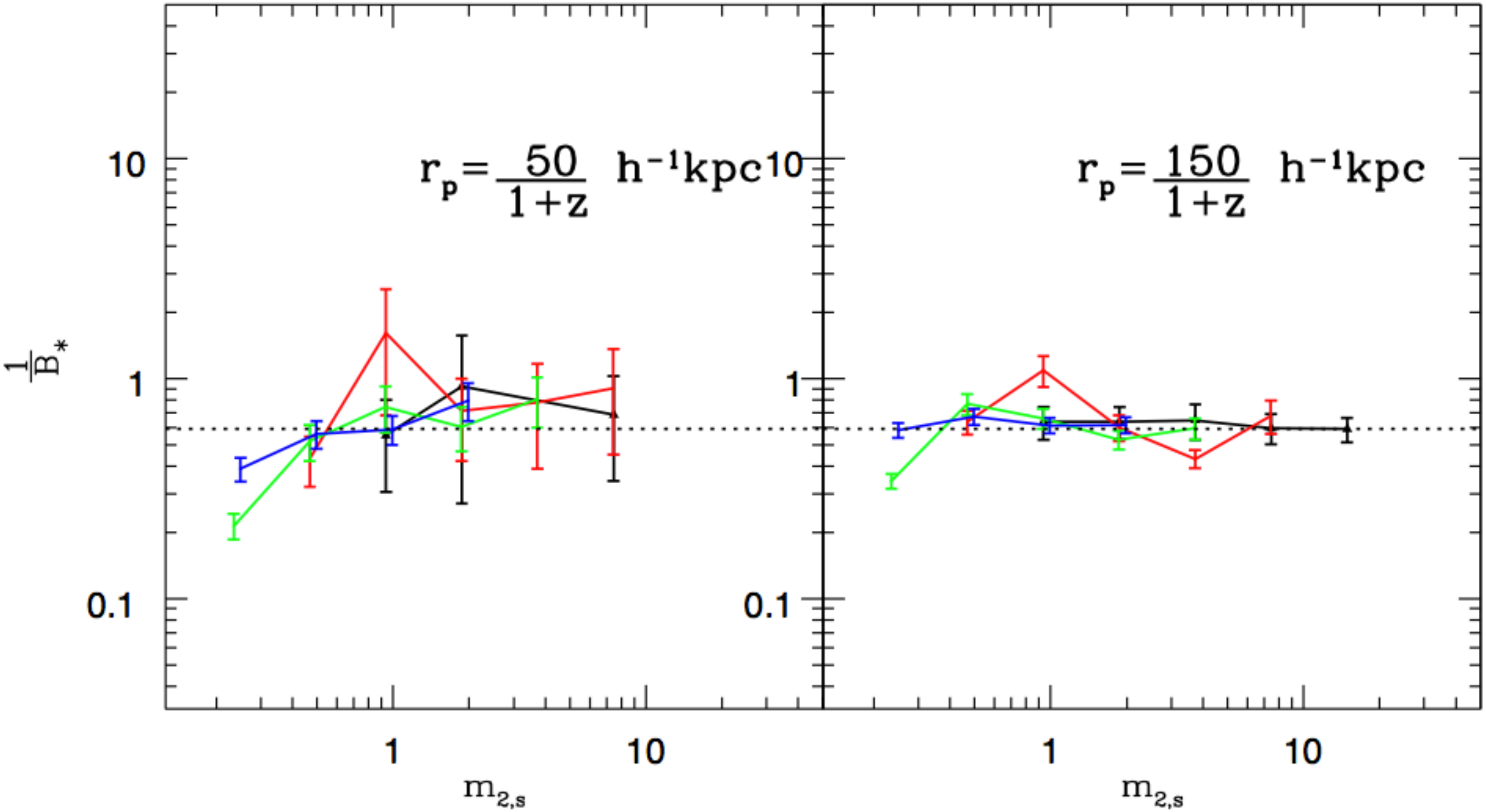
$$\Phi = B_* \frac{m_{2,\mathrm{v}} n_1 n_\mathrm{p}(< r_\mathrm{p}) [m_{1,\mathrm{v}} G H_0 E(z)]^{1/3}}{m_{1,\mathrm{v}} r_\mathrm{p}}.$$

$E(z) = \Omega_\Lambda + \Omega_m(1+z)^3$: dimensionless Hubble parameter (i.e. $H(z)$ in unit of H_0)



When the retained mass is considered for the satellites:

1) For different masses of central and satellites
2) For different redshifts



for the different separations

Applications to observations

- Measure the pair count per unit volume of stellar masses $m_{1,s}$ and $m_{2,s}$ (or luminosities) $N_p(< r_p) = n_1 n_p(< r_p)$
  - n_1 is the density of galaxy 1 and n_p is the number count within projected r_p (corrected for the background) of galaxies 2 around galaxy 1
- Volume merger rate: $\Phi = N_p(< r_p)/T_{mg}$;
- Merger rate of G 1 and G 2: $n_p(< r_p)/T_{mg}$

$$T_{\rm mg}(< r_{\rm p}{}^{\rm proj}) = \frac{10^{-0.23}}{0.66} \frac{m_{1,\rm v}}{m_{2,\rm v}} [m_{1,\rm v} G H_0 E(z)]^{-1/3} r_{\rm p}$$