Merger rate from the close pair counts

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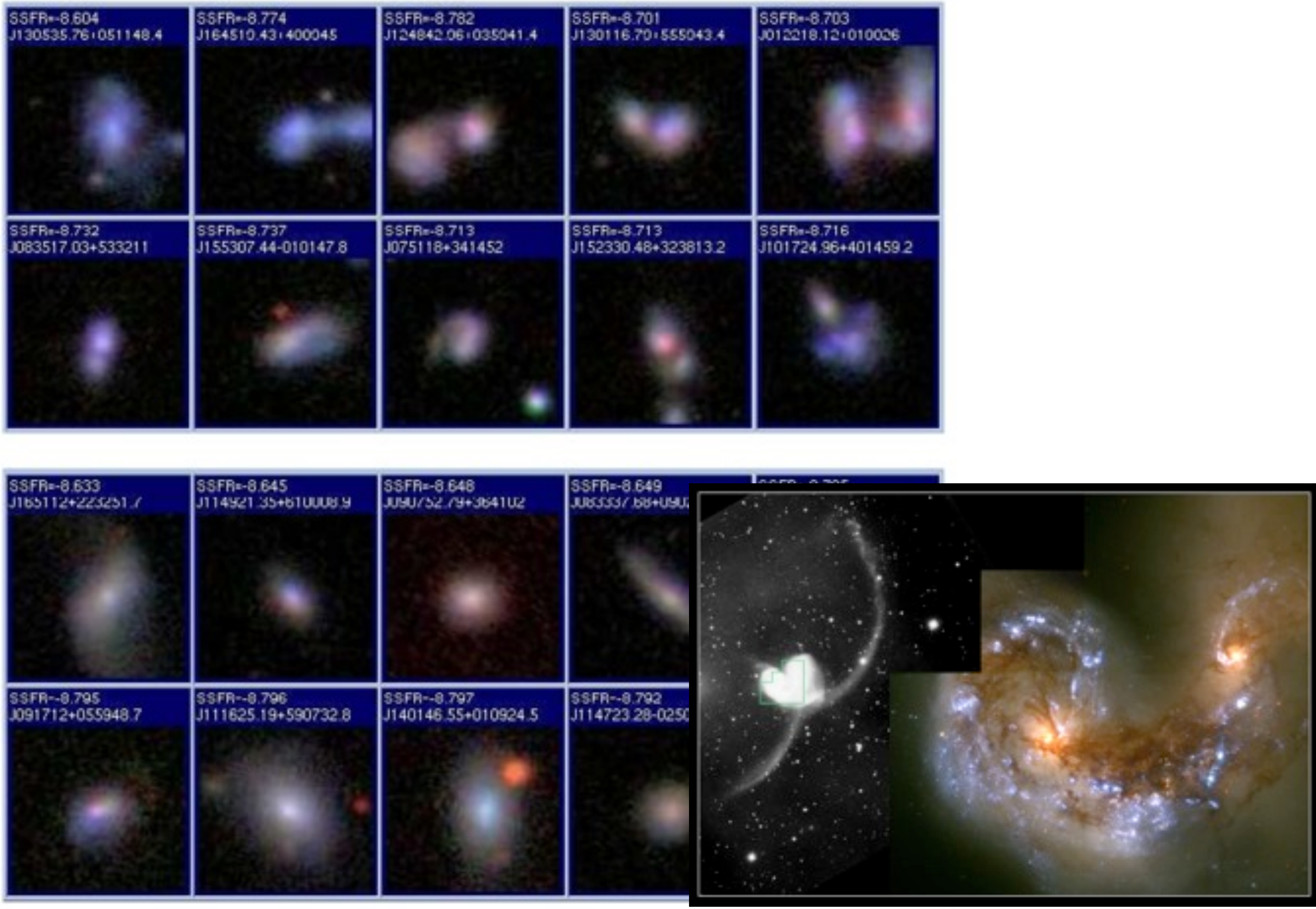
Merging of galaxies



Merger of galaxies

- Observations: mergers are common and are important for understanding
  - Starbursts;
  - formation and evolution of elliptical galaxies, such as size evolution and mass growth;
  - maybe AGNs;
  - etc

How many mergers?

- Observations: galaxy image perturbed (substructures, irregular shape, etc) or the count of close pairs can be determined;
- Important: the timescale
  - of the substructure survival
  - of the merger of the satellite to the host

Theories

- Time scale can be only from theories. For the merger time:
  - Mechanism: the dynamical friction (Chandrasekhar);
  - Difficulties for analytical modeling
    - DM mass loss of the satellite;
    - dynamically evolution of the host halo;
    - motion of the central galaxy

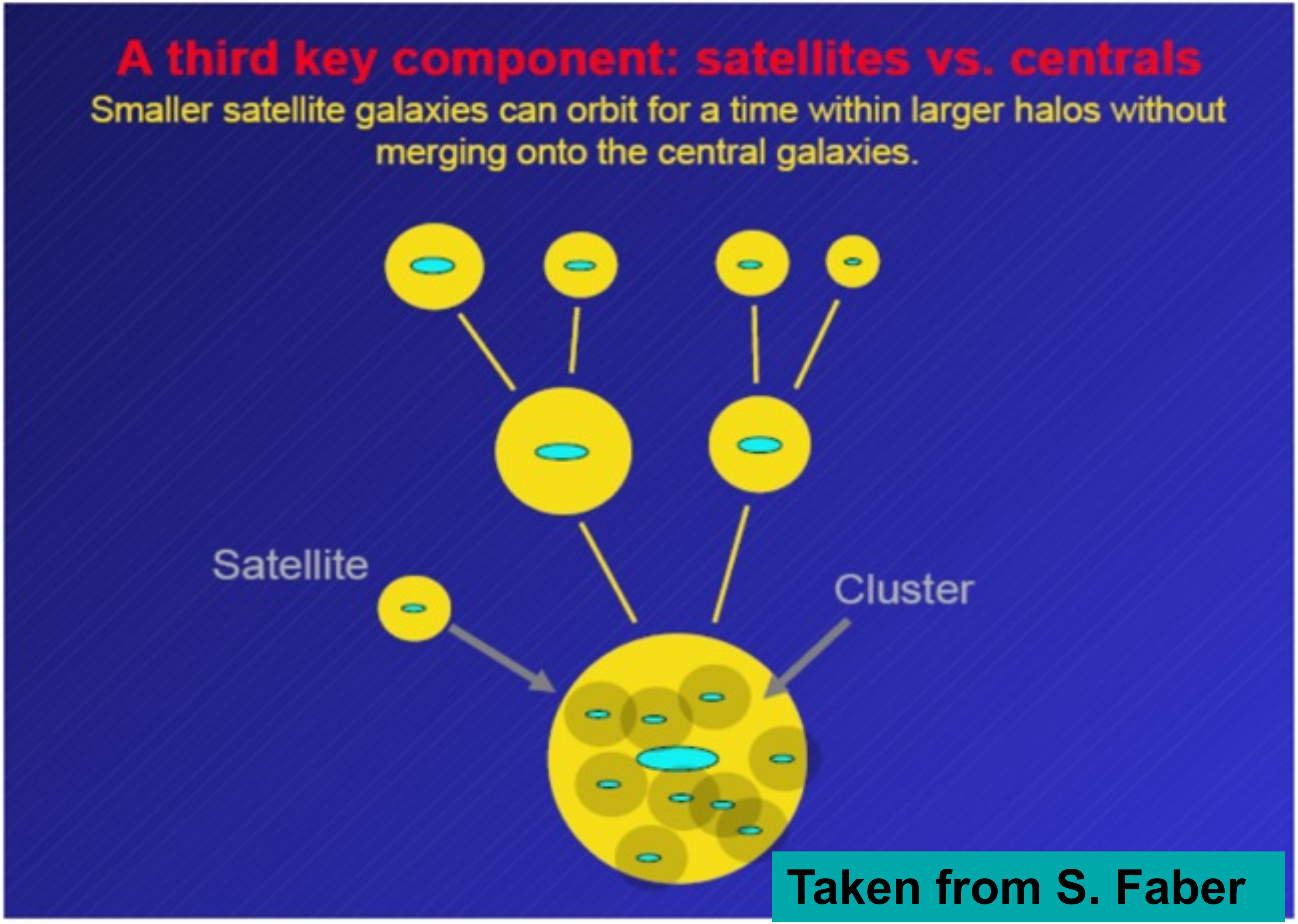
- We employed a parallel version of the SPH code GADGET 2(Springel 2005). The box is $100h^{-1}Mpc$ on a side, with 512^3 dark matter particles and 512^3 gas particles. Gravity is softened with a spline, roughly equivalent to a Plummer force softening of $4.9h^{-1}$ comoving kpc. There are totally 177 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

Theoretical framework for understanding evolution of galaxies and dark matter halos



Taking into account the dependence on the orbital circularity, Lacey & Cole (1993) derived the following expression for the merger timescale of a satellite galaxy orbiting around a massive halo of circular velocity V_c,

$$T_{\rm Chandra} = 0.5 \frac{f(\epsilon) V_c r_c^2}{C G m_{\rm sat} \ln \Lambda} \quad (1)$$

where ϵ is the circularity parameter of the satellite's orbit and r_c is the radius of a circular orbit with the same energy as the satellite's orbit. $f(\epsilon)$ describes the dependence of $T_{\rm Chandra}$ on the orbital circularity, and is approximated by $f(\epsilon) \sim \epsilon^{0.78}$ for $\epsilon > 0.02$ (Lacey & Cole 1993). C is a constant, approximately equal to 0.43, and $m_{\rm sat}$ is the satellite mass. $\ln \Lambda$ is the Coulomb logarithm, and is expected to be valid for the case

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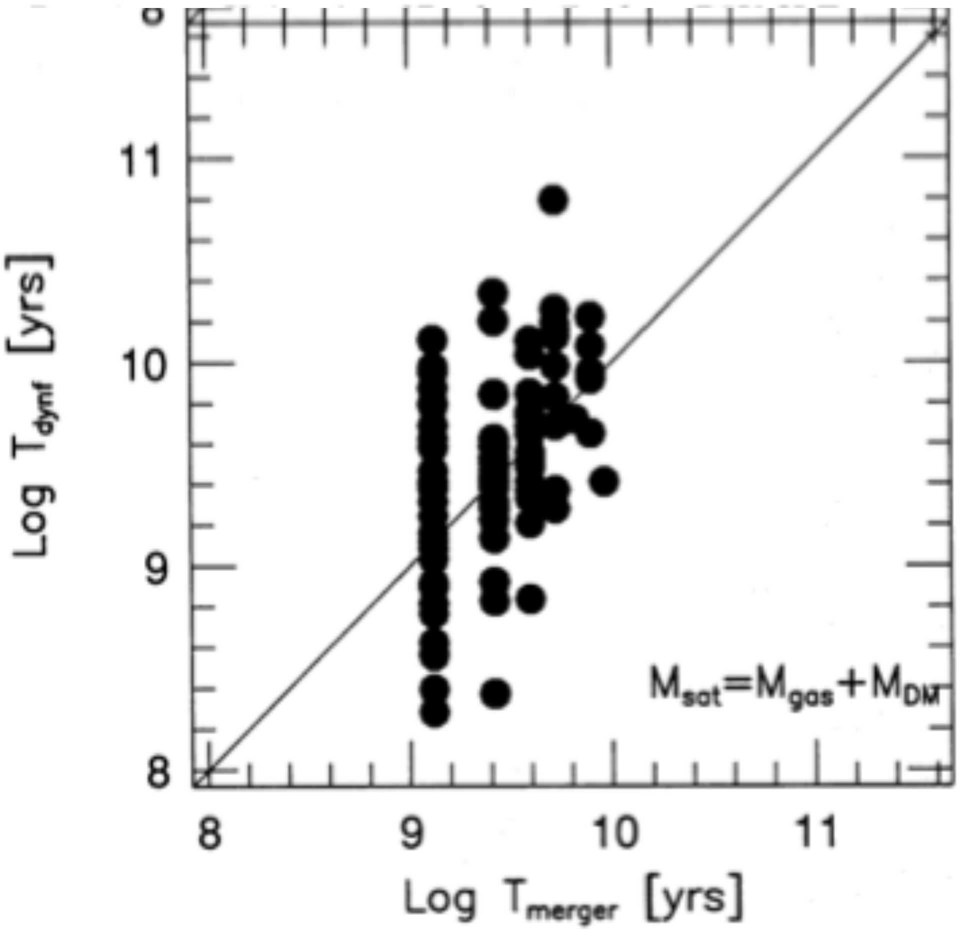
The assembly of galaxies in a hierarchically clustering universe

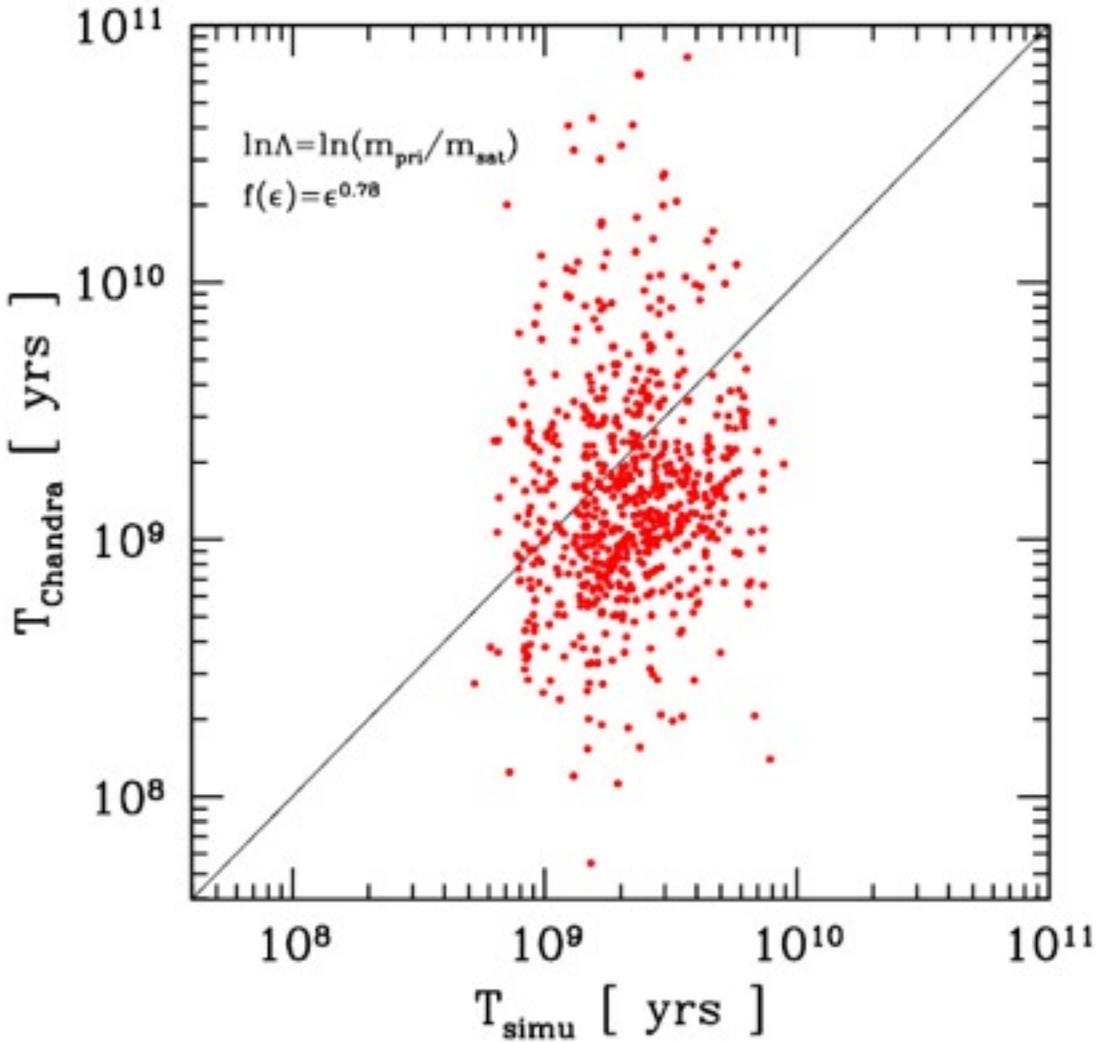
Julio F. Navarro,[1★] Carlos S. Frenk[1] and Simon D. M. White[2†]



$$\Lambda \equiv \frac{d_{\rm max} {V_{\rm typ}}^2}{G(m_{\rm sat}+m_{\rm dm})} = \frac{m_{\rm pri}}{m_{\rm sat}} \ ,$$

Using ln(m_h/m_sub) for Coulomb logarithm (c.f. Navarro et al. (1995)

Predicted friction timescale

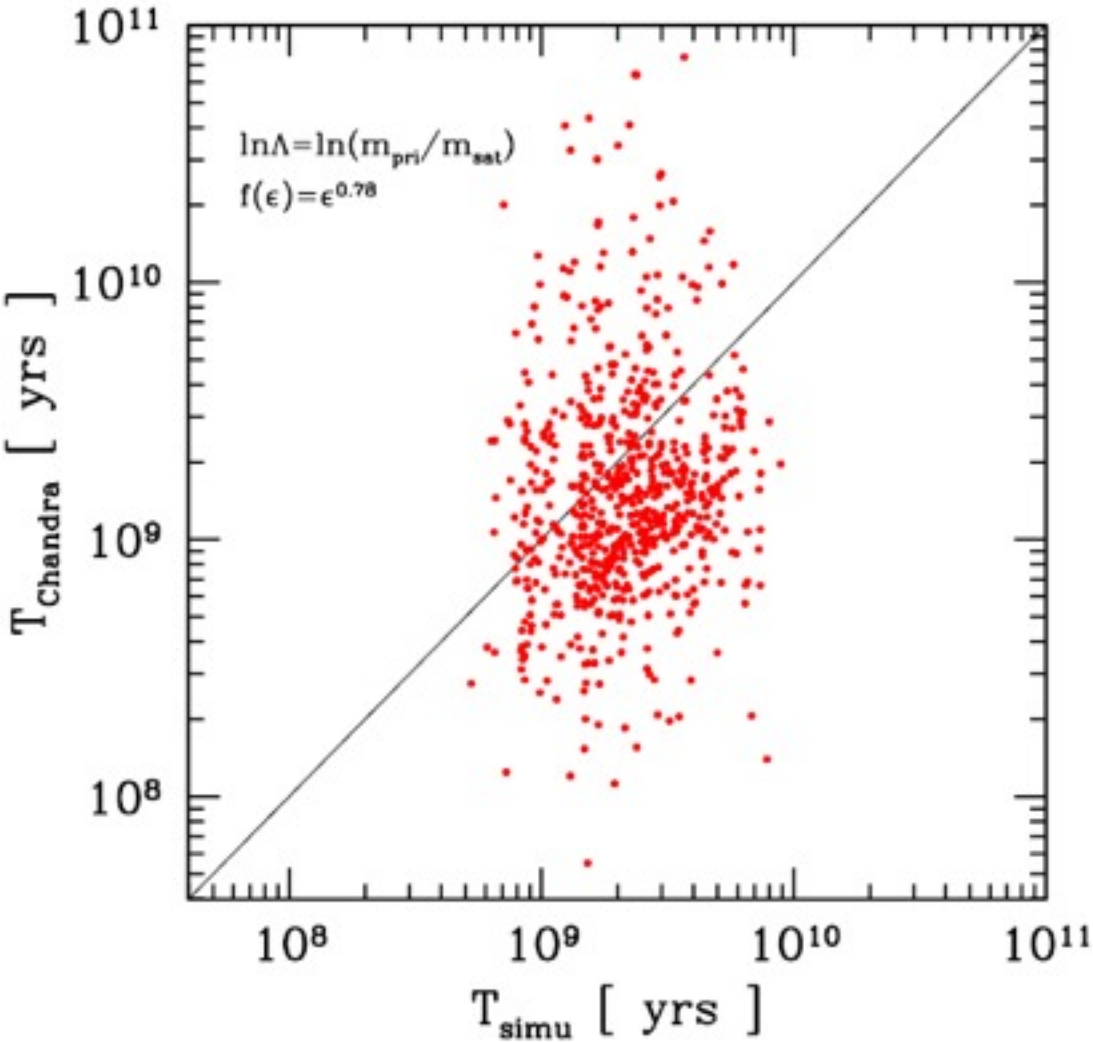


Measured merger timescale

Jiang et al. 2008

Using ln(m_h/m_sub) for Coulomb logarithm (c.f. Navarro et al. (1995)

Predicted friction timescale



repeated Navarro et al. 1995

Measured merger timescale

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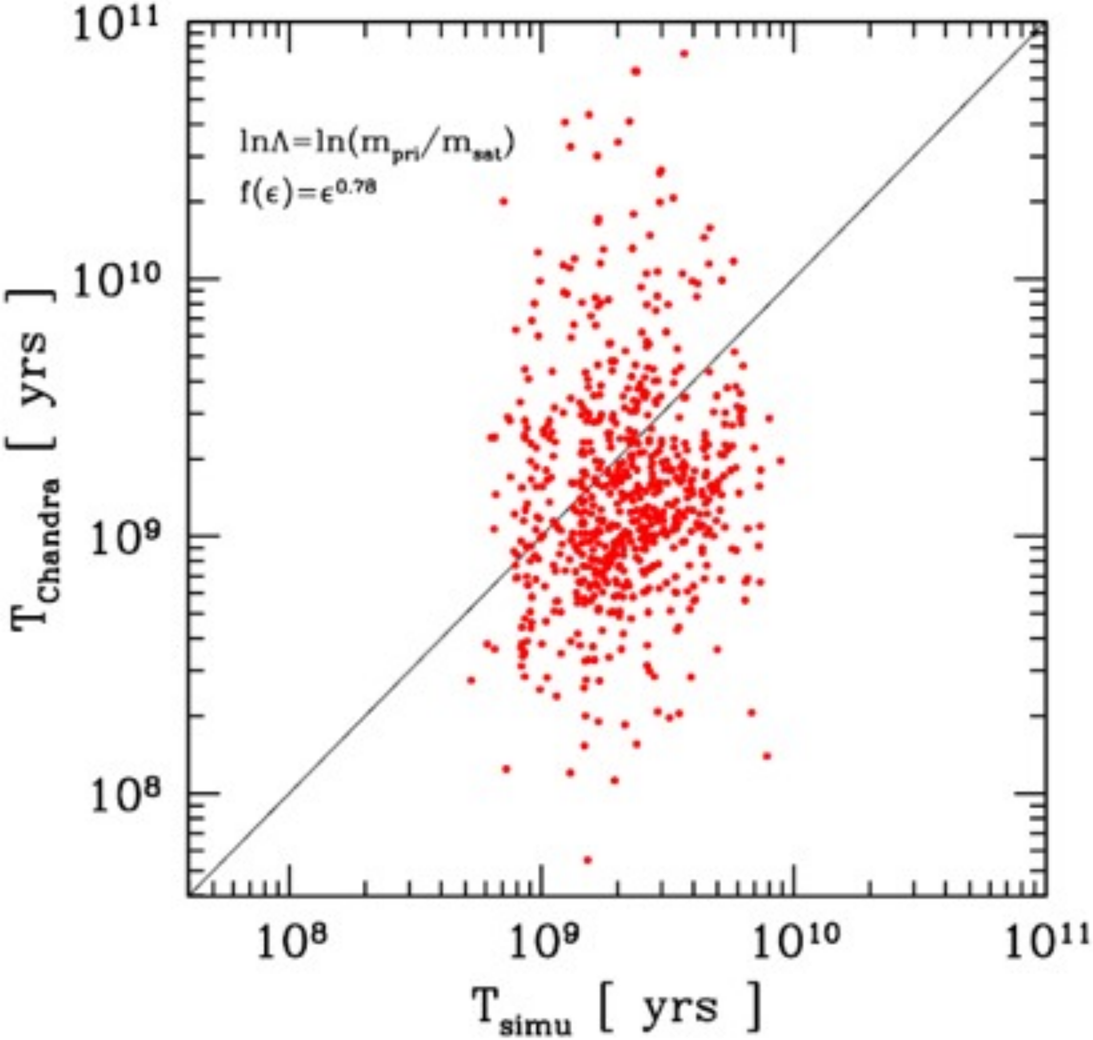
Predicted friction timescale



Measured merger timescale

repeated Navarro et al. 1995

But our conclusion is different from theirs

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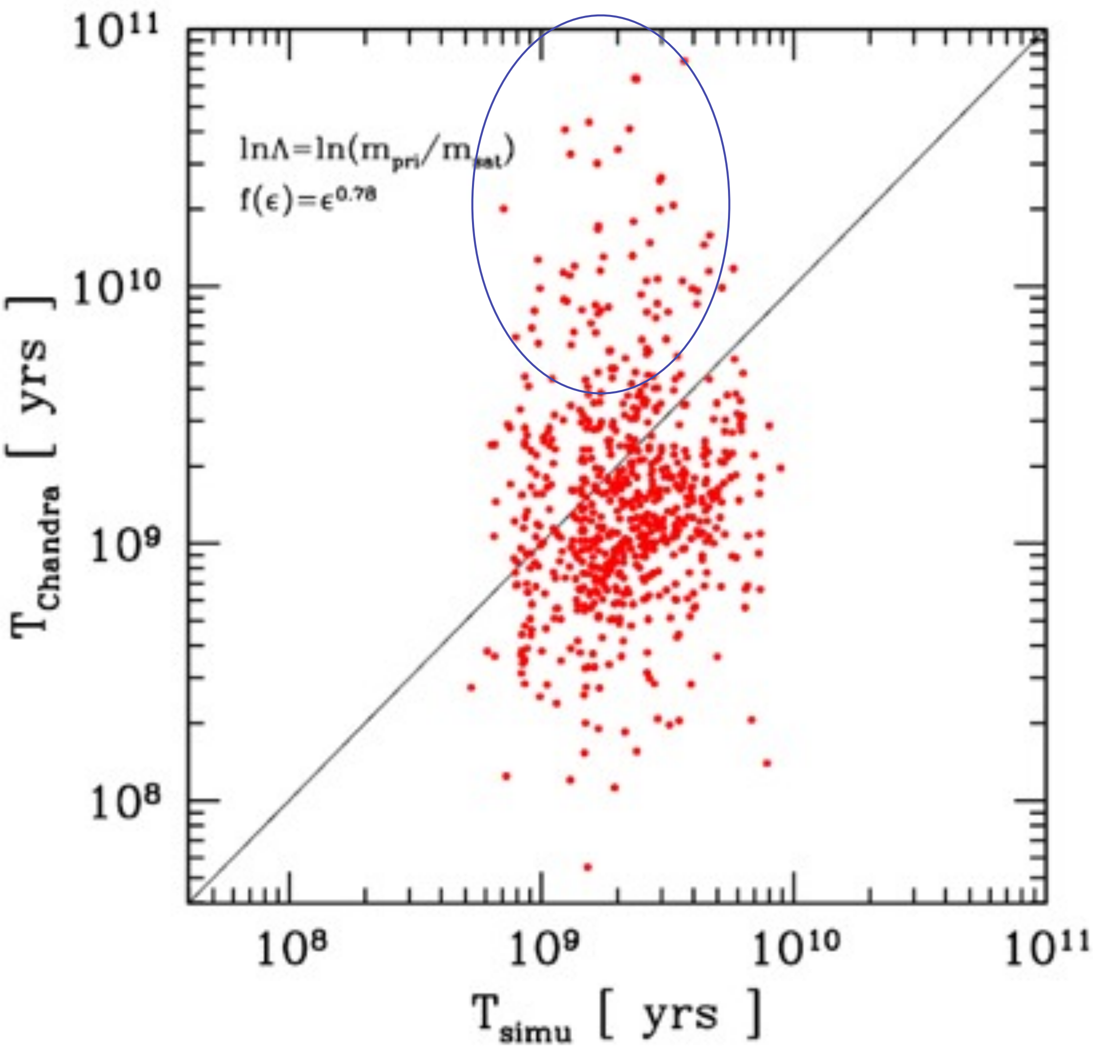

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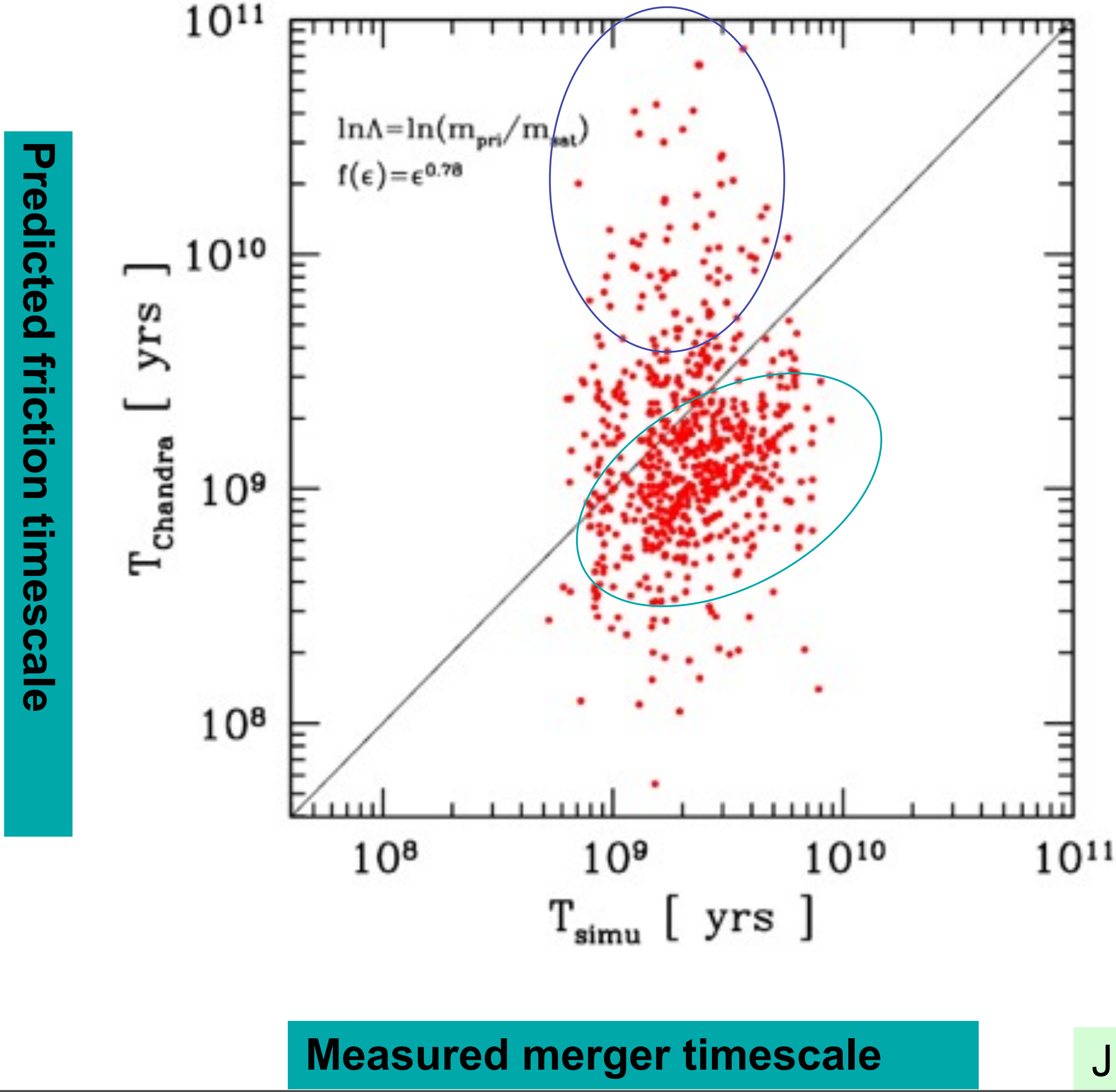


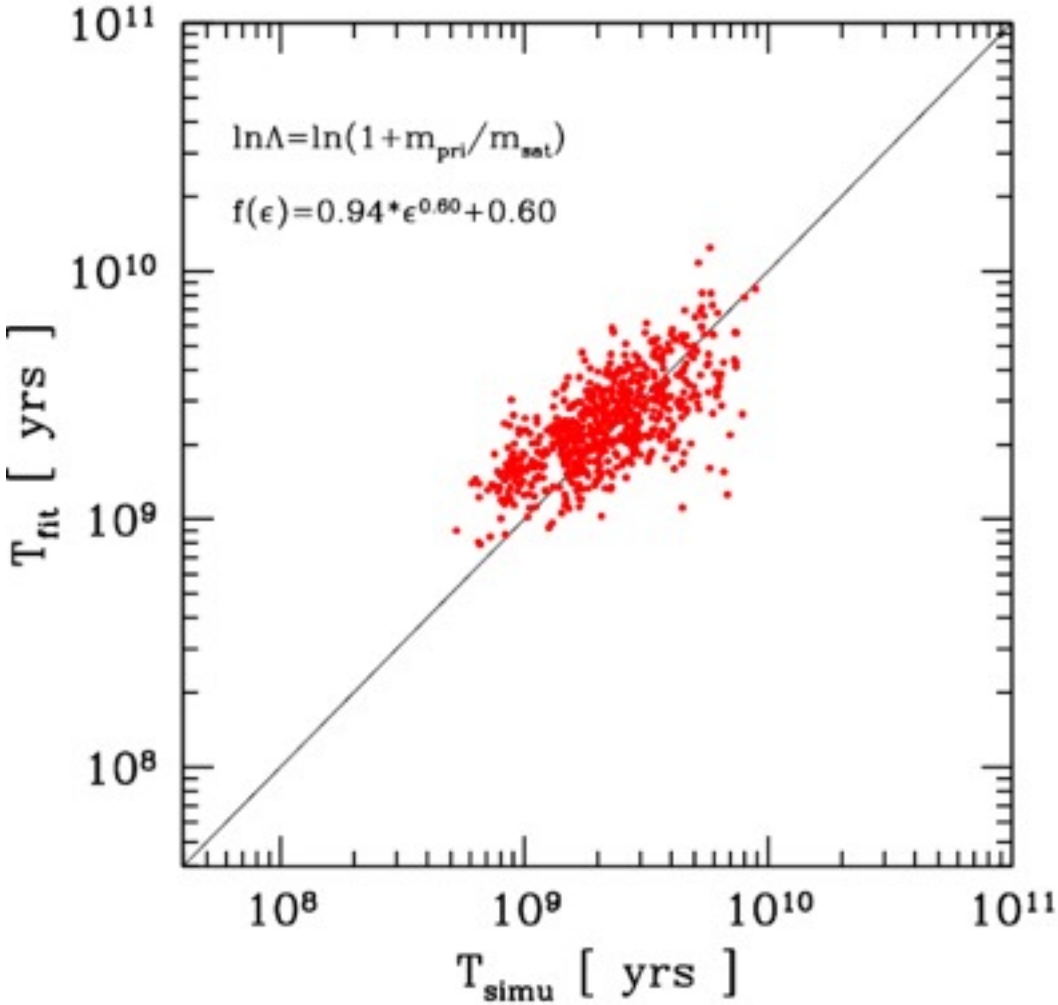
repeated Navarro et al. 1995

But our conclusion is different from theirs

Jiang et al. 2008

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

Fitting formula



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

The Lives of High Redshift Mergers

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2 May 2012

ABSTRACT
We present a comparative study of recent works on merger-timescales with dynamical friction and find a strong contrast between idealized/isolated mergers (Boylan-Kolchin et al. 2008) and mergers from a cosmological volume (Jiang et al. 2008). Our study measures the duration of mergers in a cosmological N-body simulation of dark matter, with emphasis on higher redshifts ($z \leqslant 10$) and a lower mass range. In our analysis we consider and compare two merger definitions; tidal disruption and coalescence. We find that the merger-time formula proposed by Jiang et al. (2008) describes our results well and conclude that cosmologically motivated merger-time formulae provide a more versatile and statistically robust approximation for practical applications such as semi-analytic/hybrid models.

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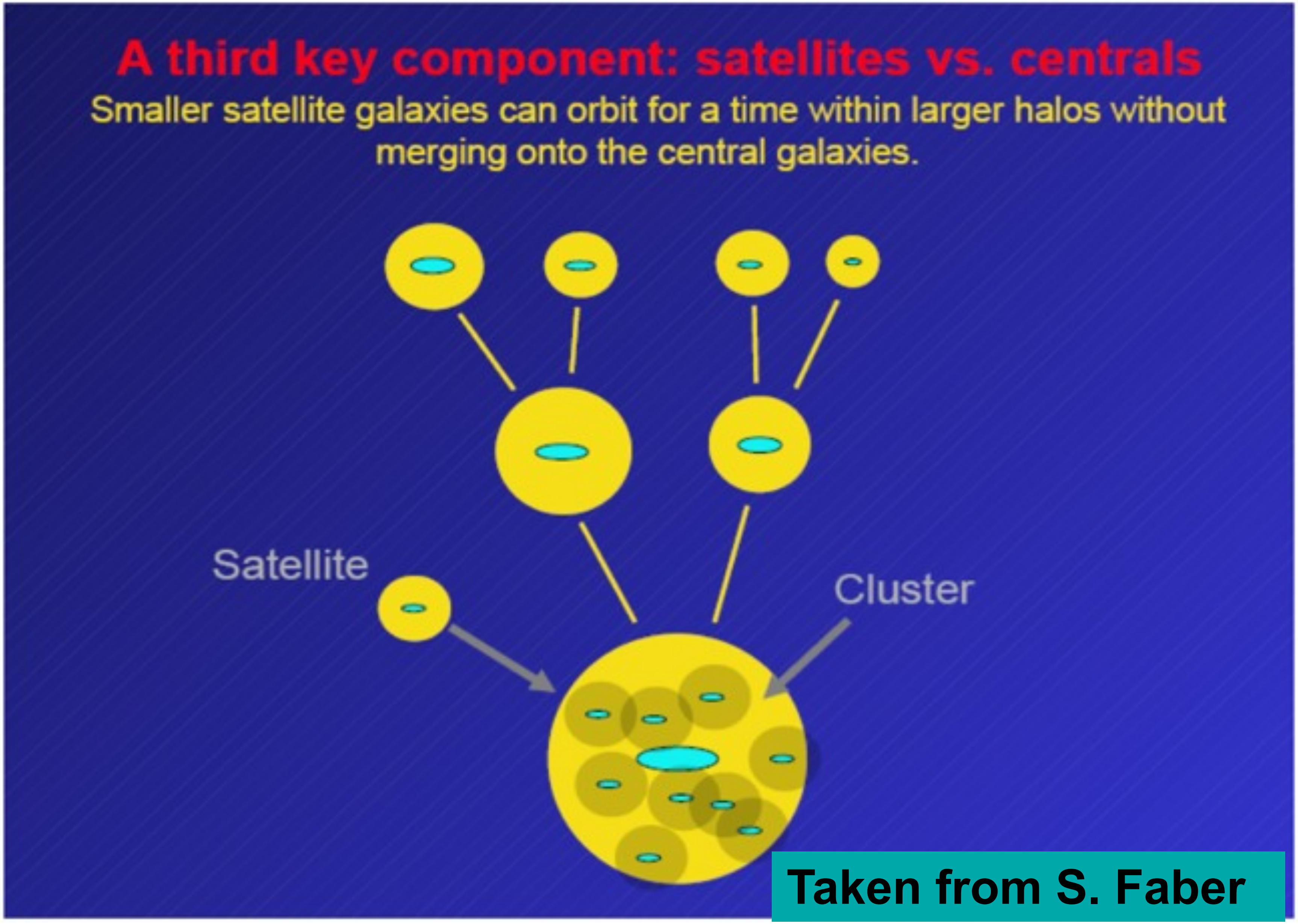
The second merger timescale

- 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



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,

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

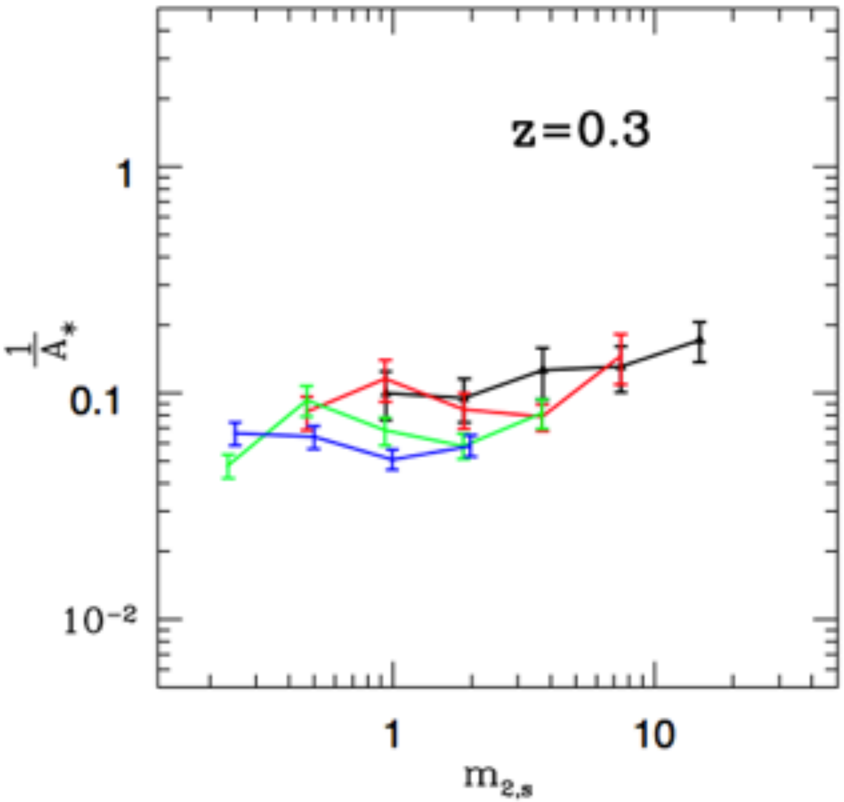
The volume merger rate can be written as

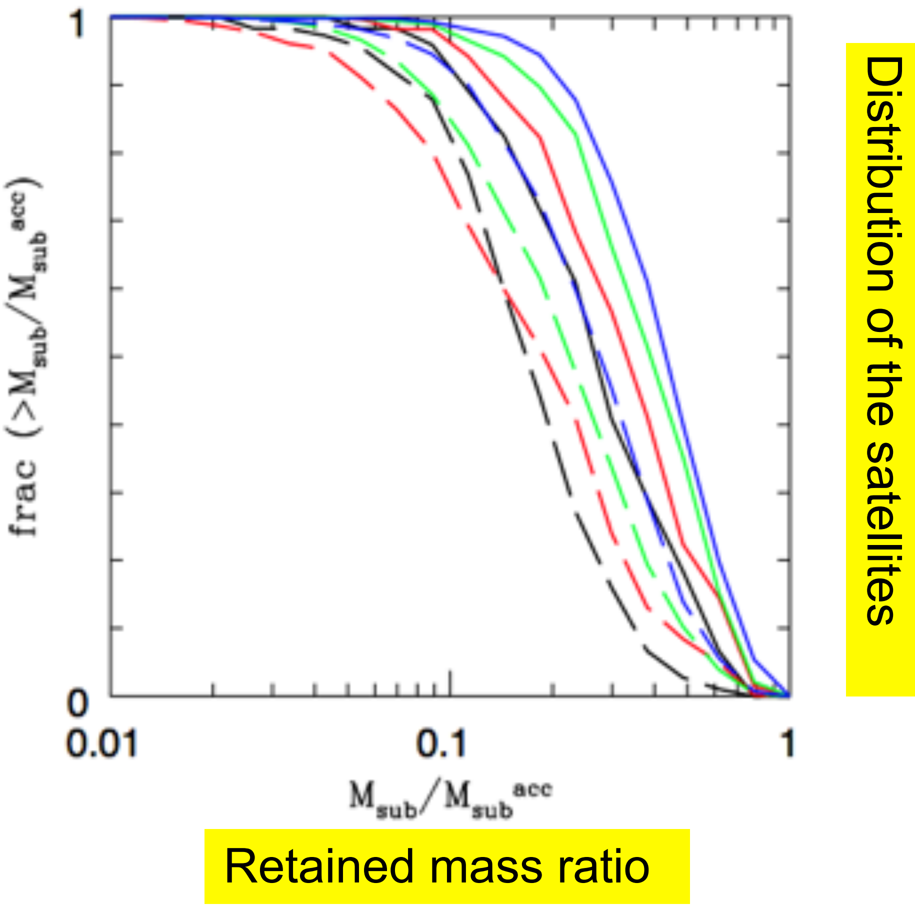
$$\Phi = C_{\rm mg}n_1n_{\rm p}(<r_{\rm p})/T_{\rm mg},$$

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

$$\Phi = A_* \frac{G^{1/2}m_2{r_{1,\rm v}}^{1/2}n_1n_{\rm p}(<r_{\rm p})}{{m_{1,\rm v}}^{1/2}{r_{\rm p}}^2}.$$

Stellar mass used for m_2





1) r_p=77 kpc/h (physical)
2) central stellar masses of 30.0 (black), 15.0 (red), 7.5 (green) and 4.0 (blue), respectively, in unit of $10^{10}\ h^{-1}M_\odot$
3) The DM retained by satellites is much larger than the stellar mass (at 77 kpc/h or 10-65 kpc/h dashed)

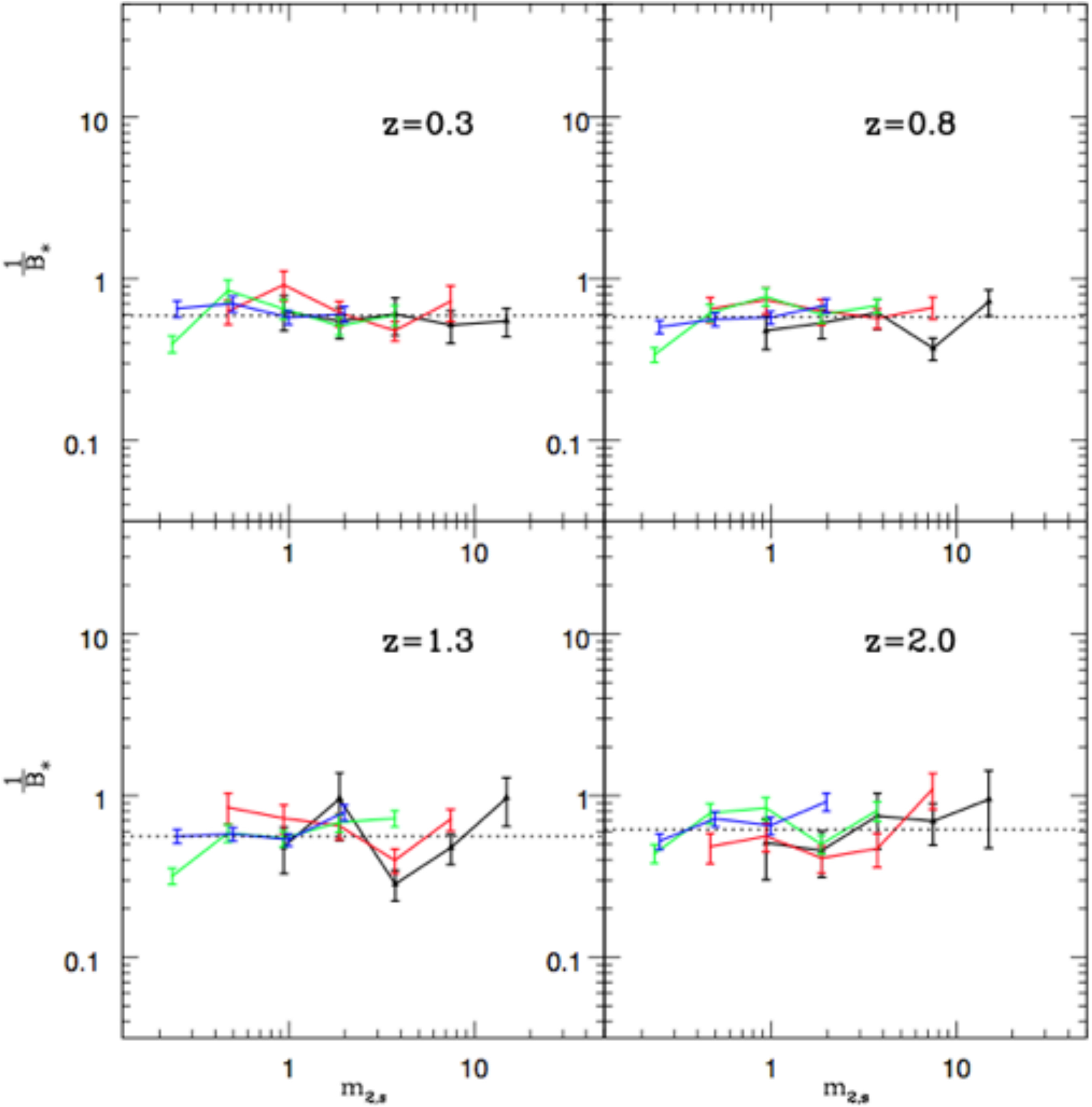
More scaling considerations

- 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

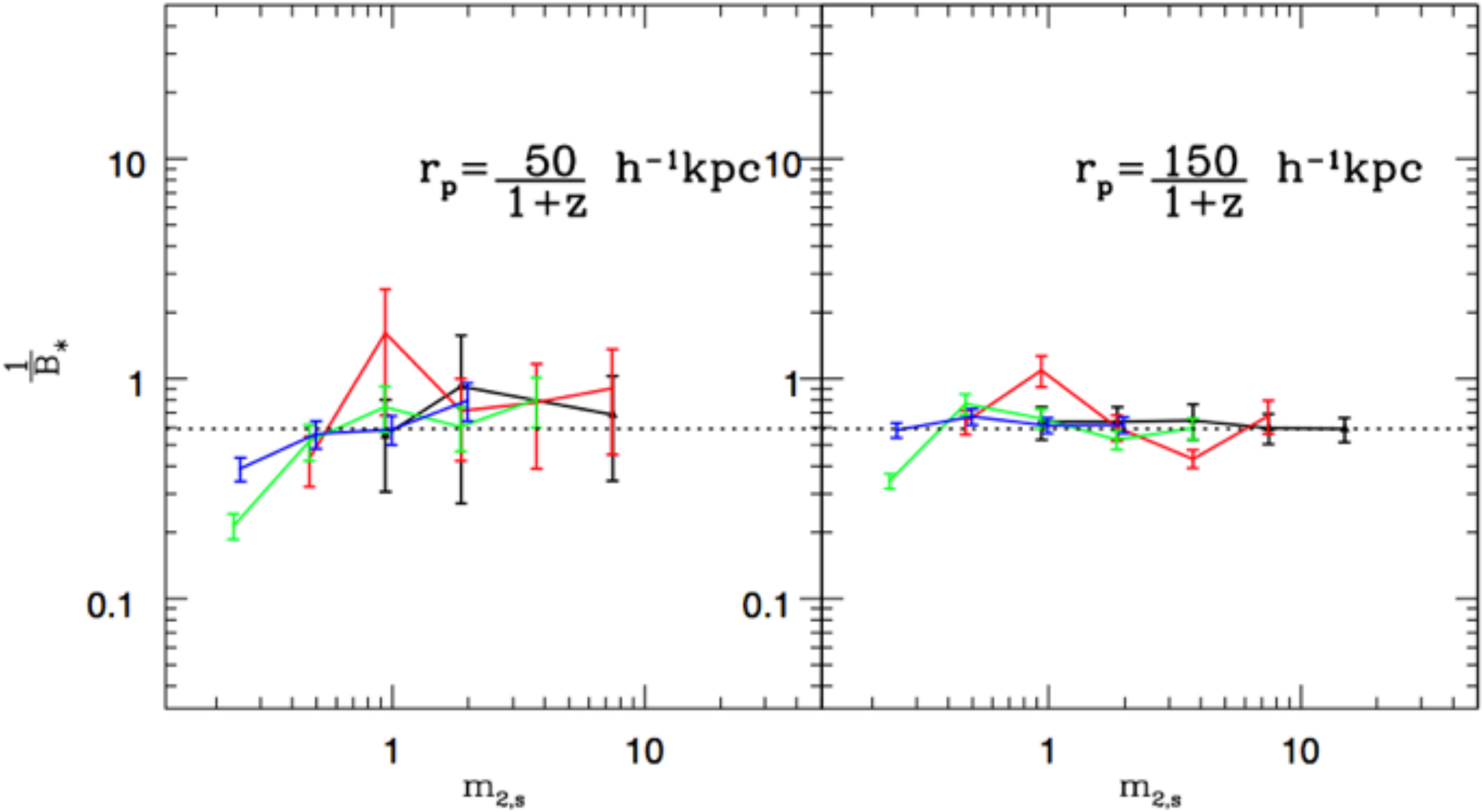
$$T_\mathrm{mg} \propto \frac{m_{1,\mathrm{v}}}{m_{2,\mathrm{v}}} [m_{1,\mathrm{v}} G H_0 E(z)]^{-1/3} r_\mathrm{p}$$

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

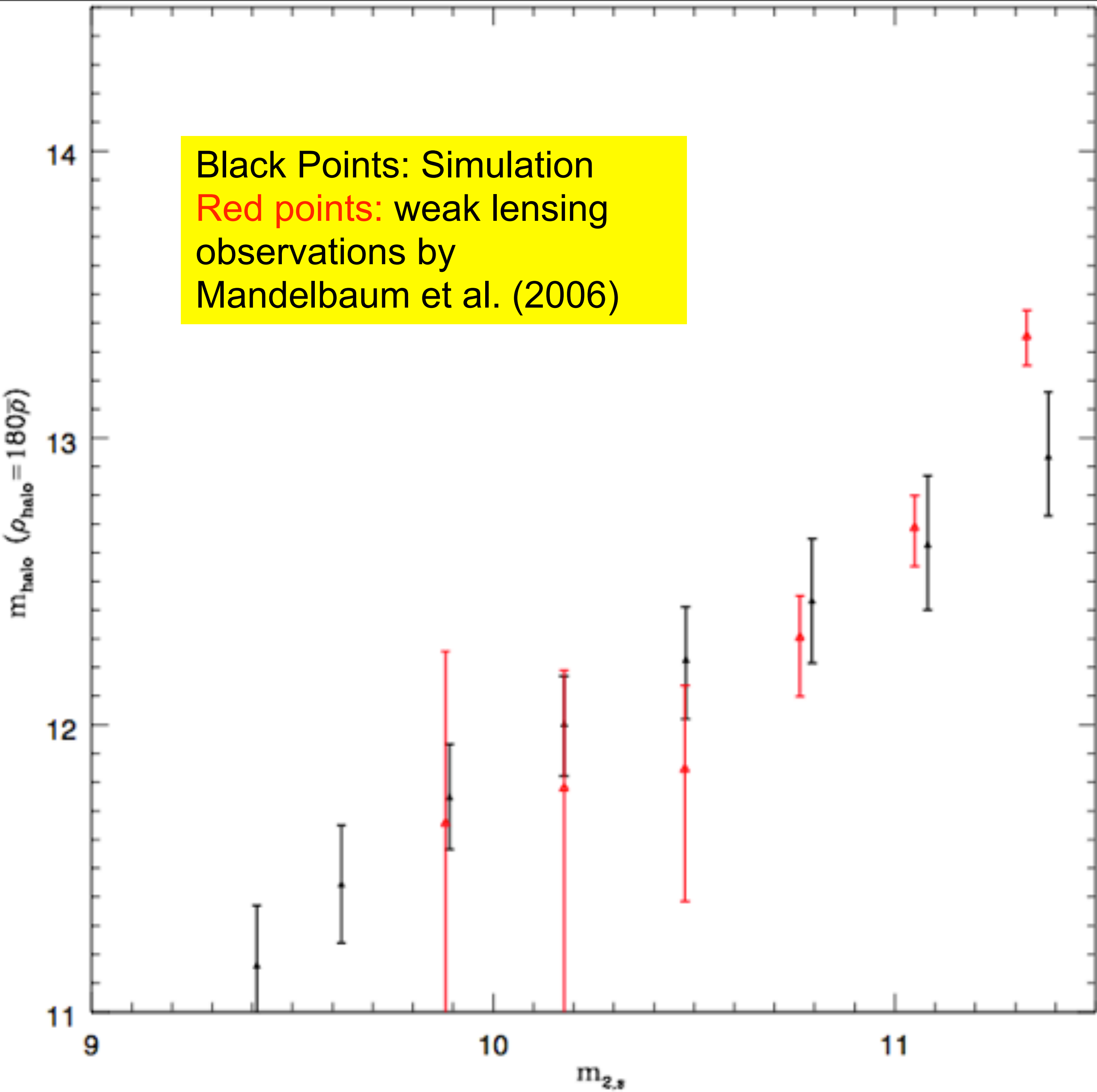
$E(z) = \Omega_\Lambda + \Omega_m (1+z)^3$: dimensionless Hubble parameter (i.e. $H(z)$ in unit of H_0)



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


Black Points: Simulation
Red points: weak lensing observations by Mandelbaum et al. (2006)
14
13
12
11
9
10
11
m_{halo} ($\rho_{halo} = 180\bar{\rho}$)
$m_{2,s}$

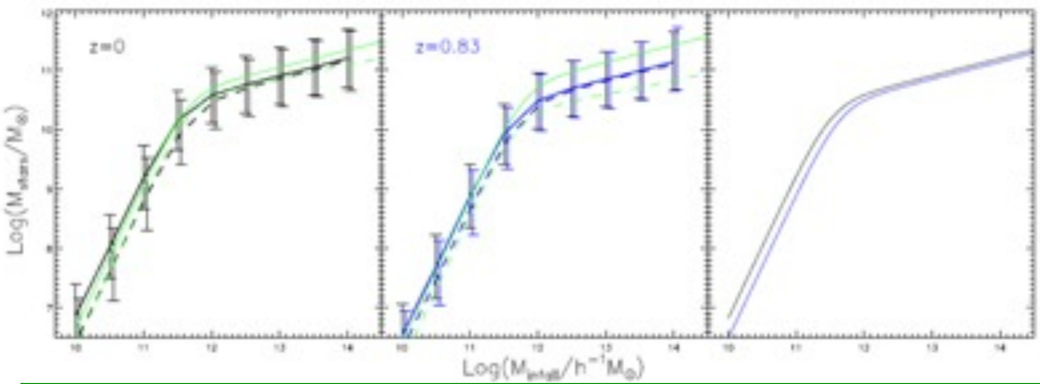
Applications to observations

- 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: $\Phi = N_p(< r_p)/T_{mg}$;
- Me

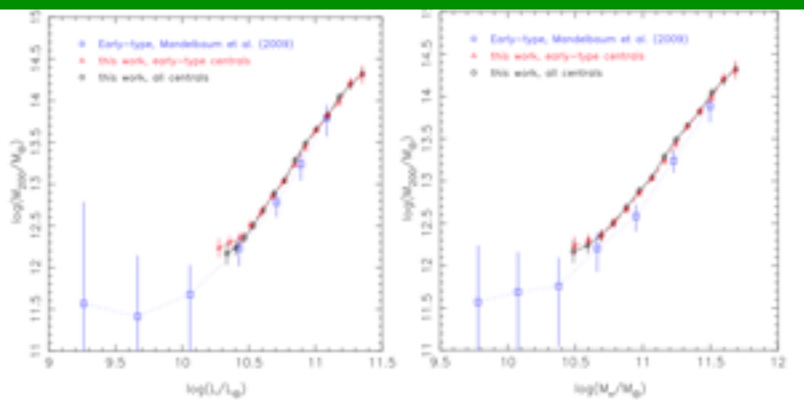
$$T_{\rm mg}(< {r_{\rm p}}^{\rm proj}) = \frac{10^{-0.23}}{0.66}\frac{m_{1,\rm v}}{m_{2,\rm v}}[m_{1,\rm v} G H_0 E(z)]^{-1/3} r_{\rm p}$$

g

To be applied to observations: find out the stellar mass(luminosity)-halo mass relation, compute T_{mg}, and then the volume merger rate



HOD modeling from clustering and MF (Wang & YPJ 2010; cf. Yang et al 2003; Zheng et al 2005; Wang and Kauffmann 2006; Moster et al. 2011 etc)

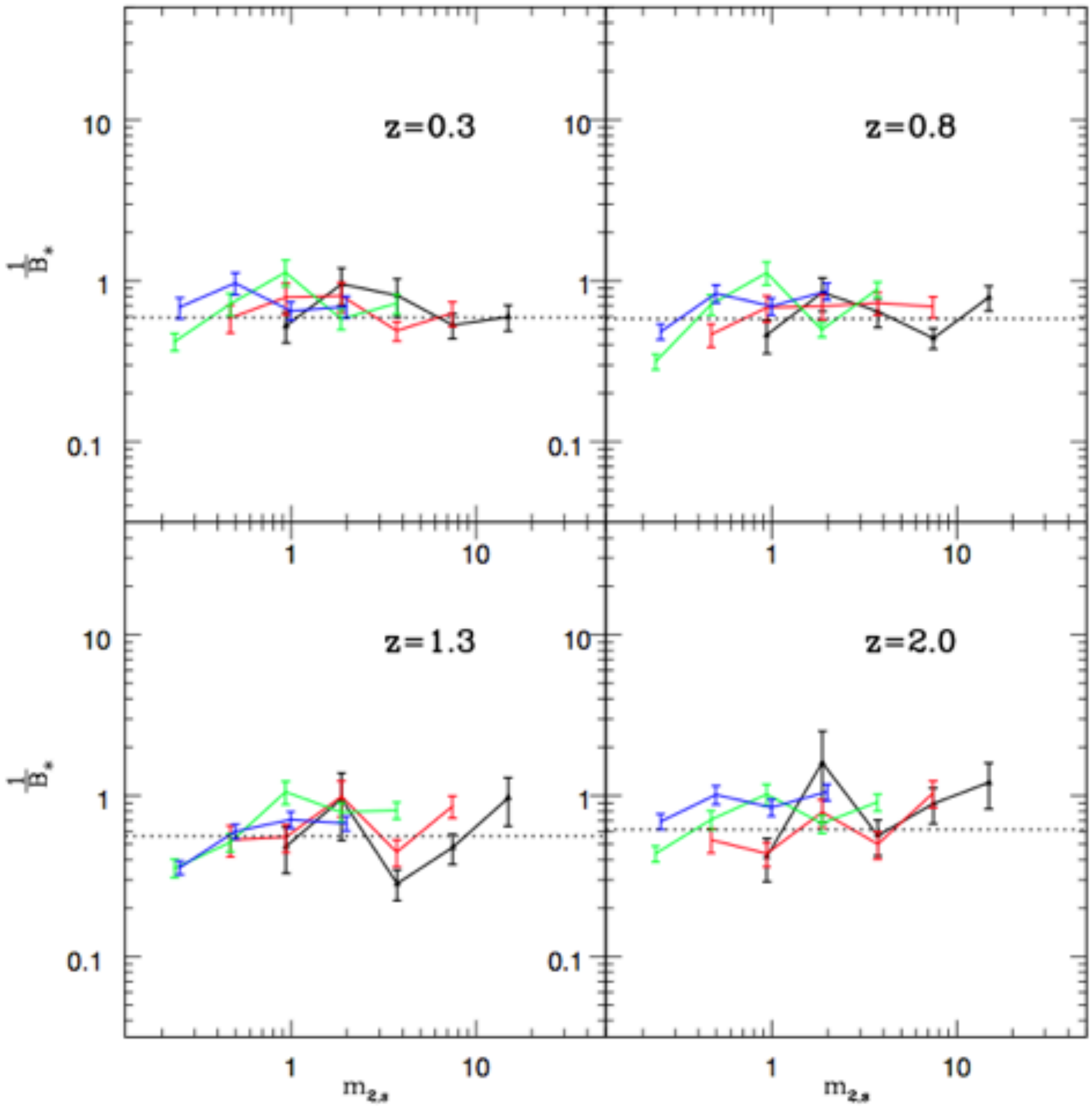


Direct measurement from weak lensing (Mandelbaum et al. 2006) and satellite dynamics (Li, et al 2012)

Many ways:
1)HOD, CLF etc
2)Weak lensing
3)Satellite dynamics
4)Hydrodynamcs simulations etc
5)……

Conclusions and discussion

- We have considered the subhalo DM mass of satellites and the scaling relations on z and r_p;
- We have, for the first time, worked out a accurate merger timescale that accounts for the dependences on the masses, redshift, and separation; our results extends to minor mergers (1:30 in M_s)
- The mass dependence is important since M_h-Ms could be steep [e.g Kitzbichler & White (2008) for major mergers (1:1-1:4) but valid for 1:4 mergers only];



When a different method to define a "galaxy" (b=0.0125), with the stellar mass much smaller than the fiducial case(b=0.025)