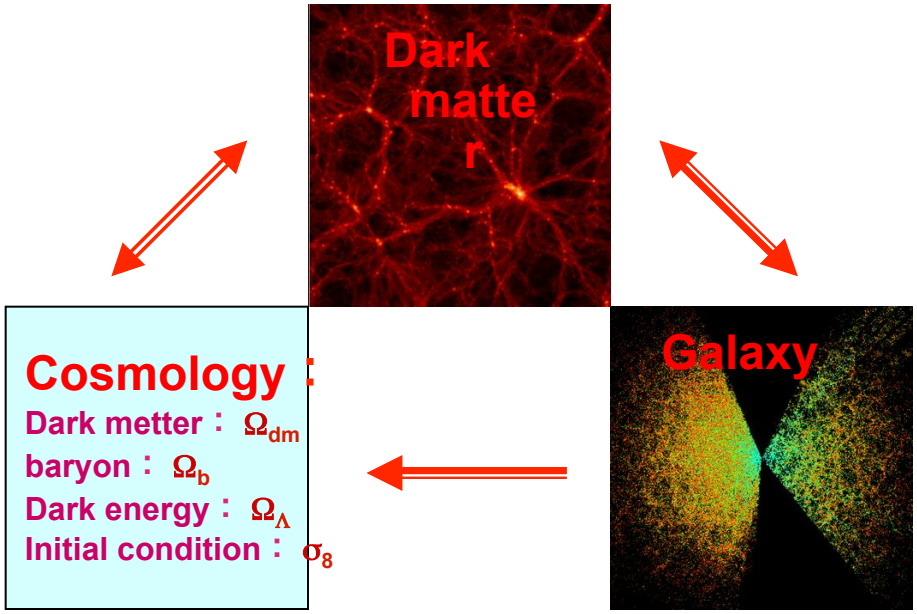
Galaxy-dark matter halo connections and the assembly of galaxies: II

Xiaohu Yang

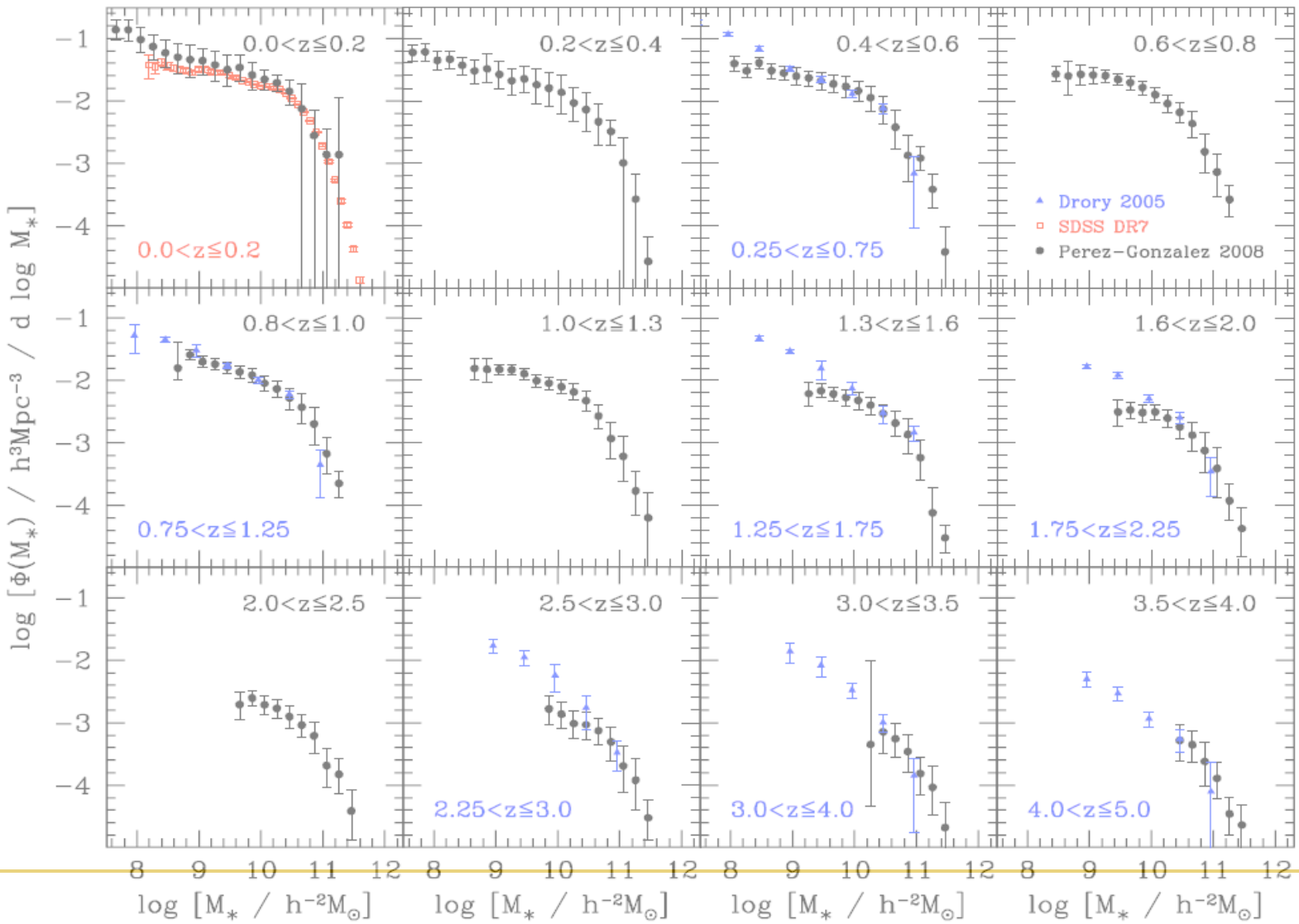
Shanghai Astronomical Observatory

Santa Fe 2012/07/02



Local universe: With the reiable link between galaxies and dark matter halos being established using HOD/CLF, it has been used for various purposes: understanding/constraining the galaxy formation processes, the large scale structure of Universe, the cosmological parameters, etc. *Jing et al. 1998;Berlind & Weinberg 2002; Yang et al. 2003;2004;2012;van den Bosch et al. 2003a; 2003b; 2007; 2012; Vale & Ostriker 2004; Cooray 2006; Zehavi et al. 2005; Zheng et al. 2005; 2007*

Stellar mass functions at high redshift



Significant cosmic variance in 2PCFs

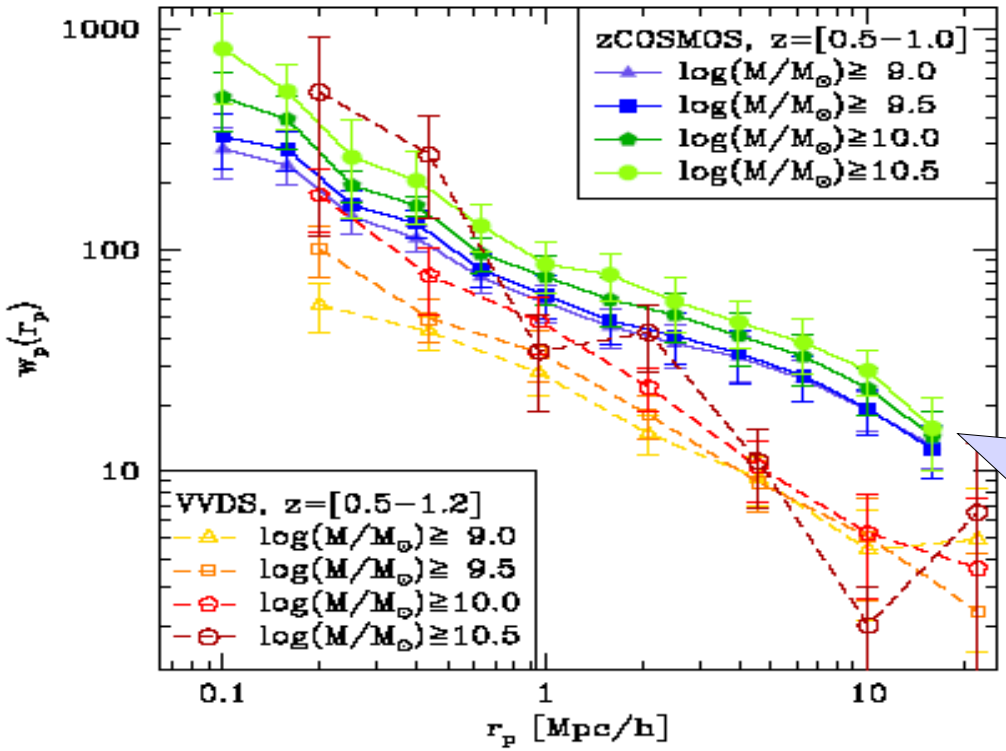
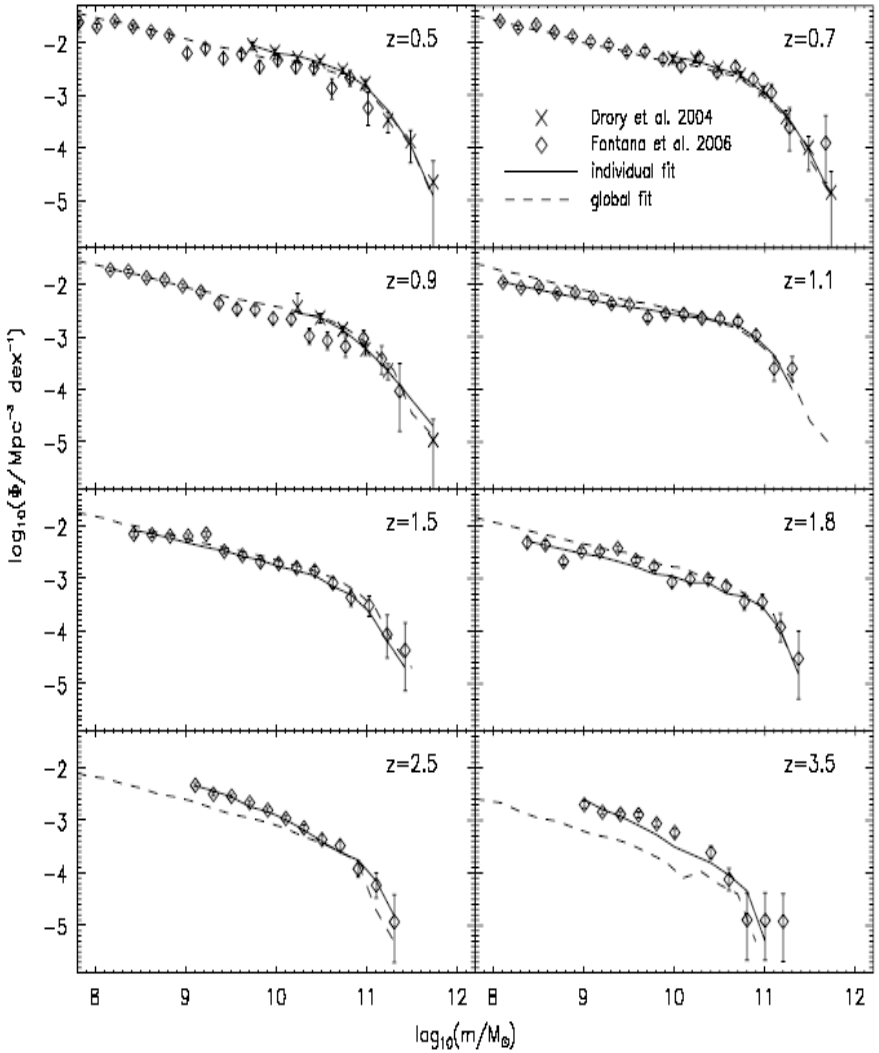


Fig. 18. Direct comparison of the dependence of clustering on stellar mass in the VVDS-Deep and zCOSMOS samples, over a similar redshift range. This plot evidences the significant intrinsic difference between the two surveys, with the zCOSMOS sample showing a significantly larger clustering amplitude for all stellar masses. In addition, the much flatter shape of $w_p(r_p)$ indicates the predominance of coherent structure perpendicularly to the line of sight, due to the "walls" discussed in the text.

The large cosmic variance in the current deep surveys prevent us from the accurate modeling of HOD/CLF.

Meneux et al. 2009

With SHAM4



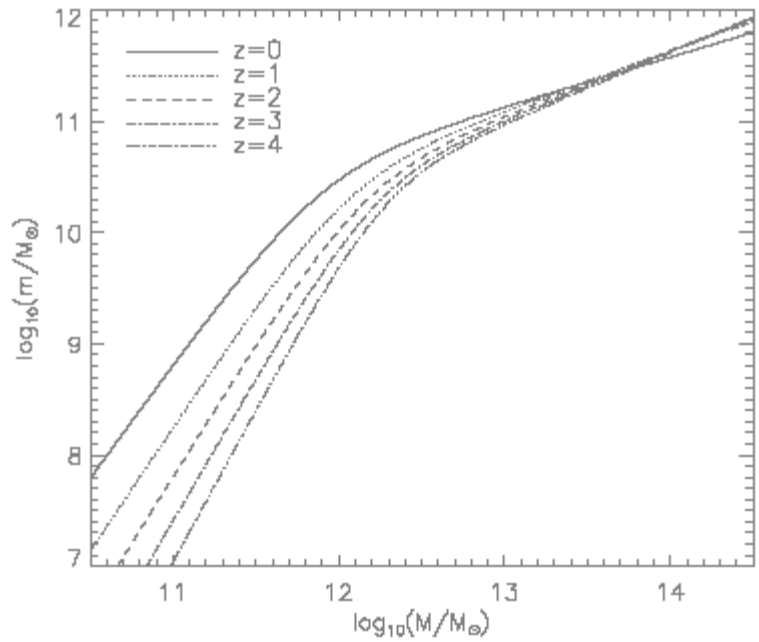


FIG. 14.— Stellar mass as a function of halo mass for different redshifts. The solid lines show different redshifts, which are indicated at the top of the panels.

Moster et al. 2010

- The growth of central galaxies can be reasonably modeled using the current high redshift SMFs. Many useful constraints related with central galaxies have been obtained, especially with the help of N-body simulations.

- There is no reliable constraints on satellite population at high redshift at all.

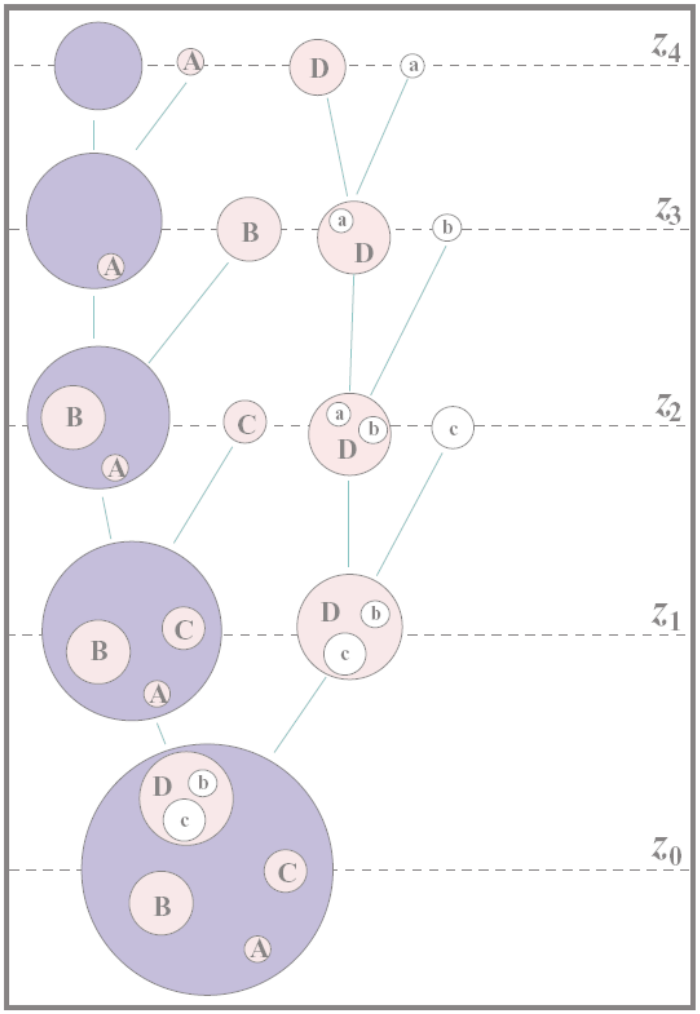
- Thus we do not know how much did satellite galaxies contribute to the growth of the central galaxies. And what fraction of central growth is by the star formation itself.

- We do not know how the satellite galaxies are evolved.

- Moreover, by definition, the SHAM is not selfconsistent!
- By construction, there is no orphan satellite galaxies!
- Thus the satellite-subhalo connection therein is nonsense!

- Any better solutions?

Establish an accurate subhalo accretion model

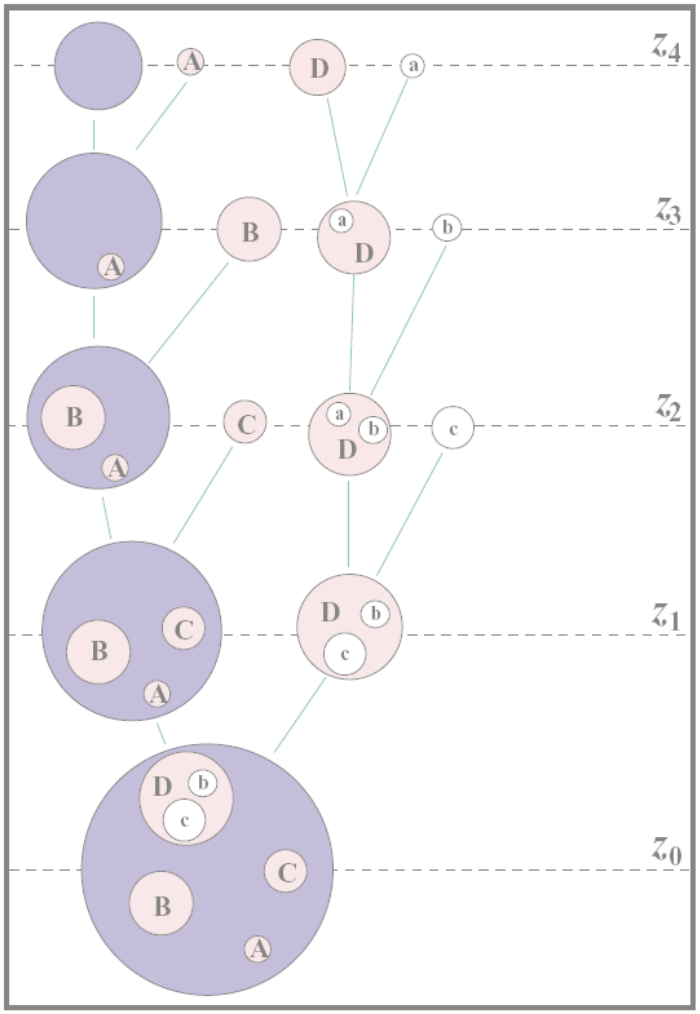


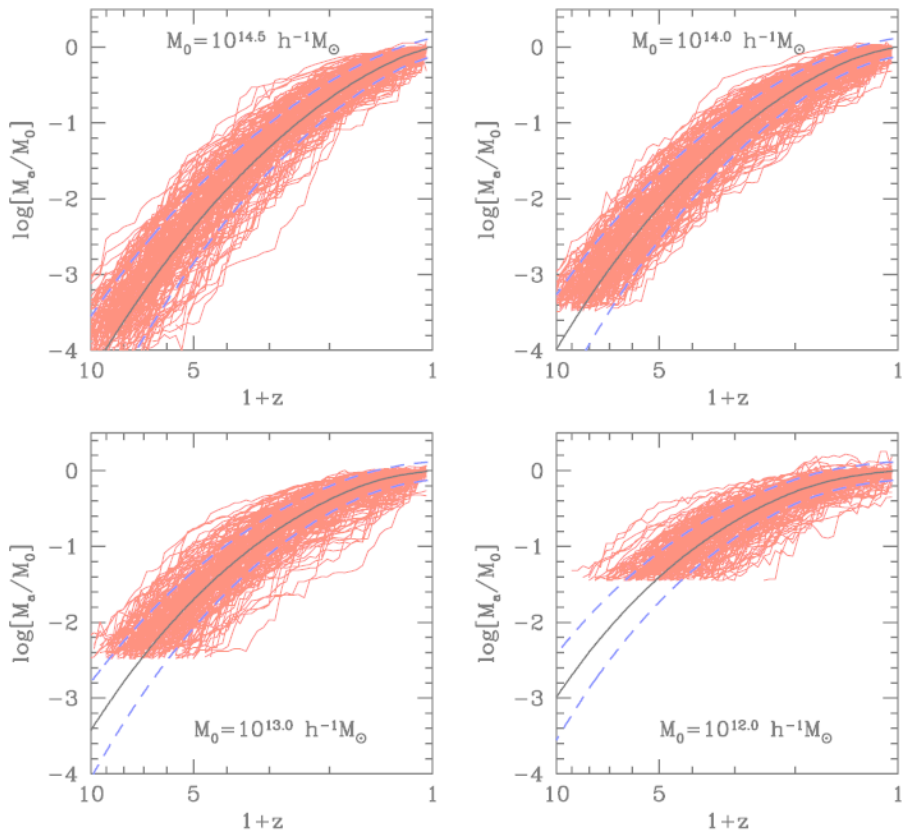
$$f(M_1|M_2)\,d\ln M_1 = \sqrt{\frac{2}{\pi}}\,\frac{\sigma_1^2(\delta_1-\delta_2)}{[\sigma_1^2-\sigma_2^2]^{3/2}}\times \exp\left[-\frac{1}{2}\frac{(\delta_1-\delta_2)^2}{(\sigma_1^2-\sigma_2^2)}\right]\left|\frac{d\ln\sigma}{d\ln M_1}\right|\,d\ln M_1,$$

This model does not give accurate prediction of the mass and redshift distribution of subhalos been accreted according the N-body simulations.

Modifications: e.g. Cole et al. 2008; Parkinson et al. 2008; Fakouri et al. 2010

The mass growth of main branch of the halos





Zhao et al. 2009

The conditional mass distribution of subhalos

$$F(S_a, \delta_a | S_0, \delta_0; M_a)\ \mathrm{d}\ln\delta_a = \frac{1}{\sqrt{2\pi}} \frac{\delta_a - \delta_M}{(S_a - S_M)^{3/2}} \exp\left[-\frac{(\delta_a - \delta_M)^2}{2(S_a - S_M)}\right], \quad (14)$$

where δ_M corresponds to the redshift at which the main branch has the mass

$$M_{\rm mx} = \mathrm{Min}(\mathcal{M}_a + m_{\rm mx}, M_0), \quad (15)$$

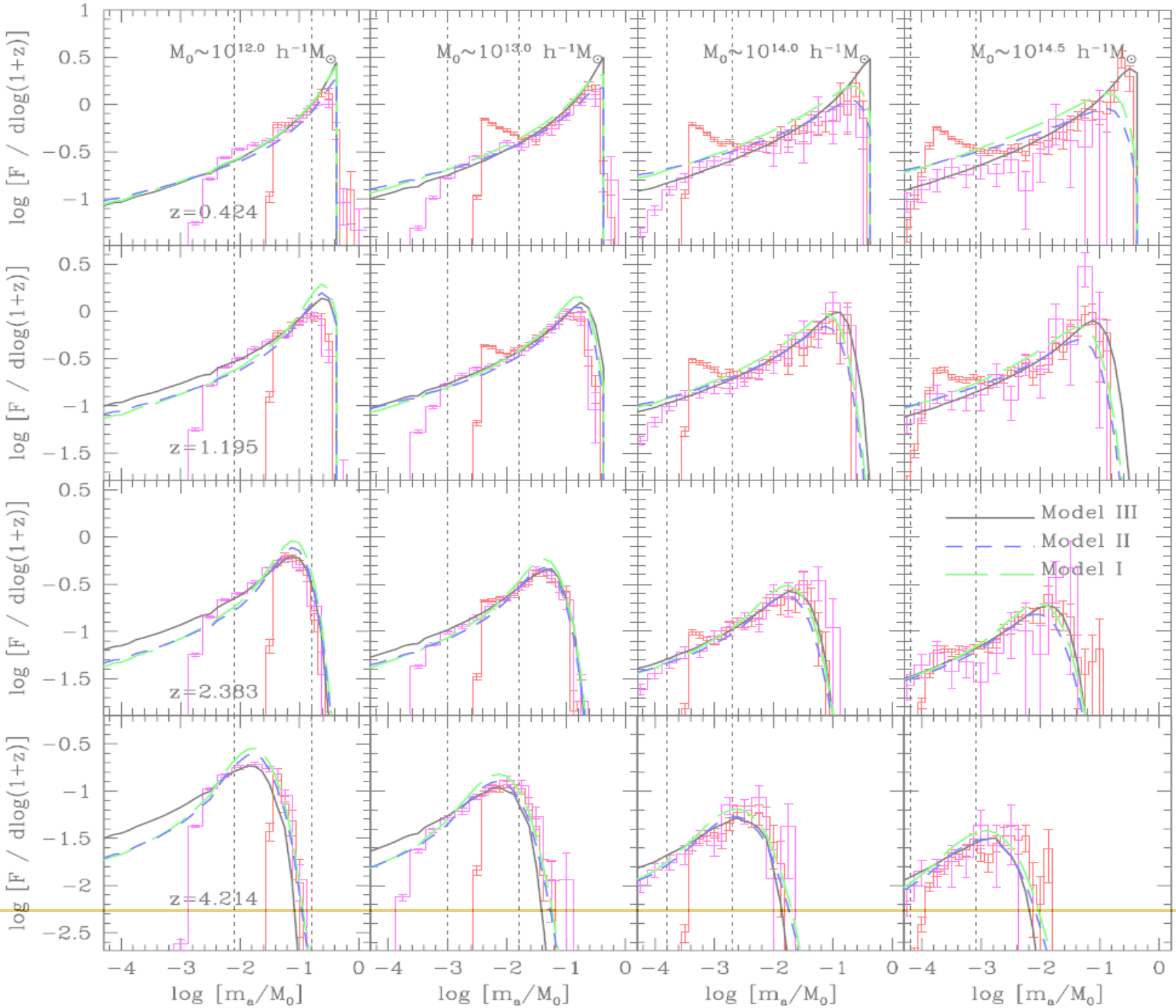
where $\mathcal{M}_a$ is the median main-branch mass and

$$S_M \equiv \sigma_M^2 = \sigma^2(M_{\rm mx}). \quad (16)$$

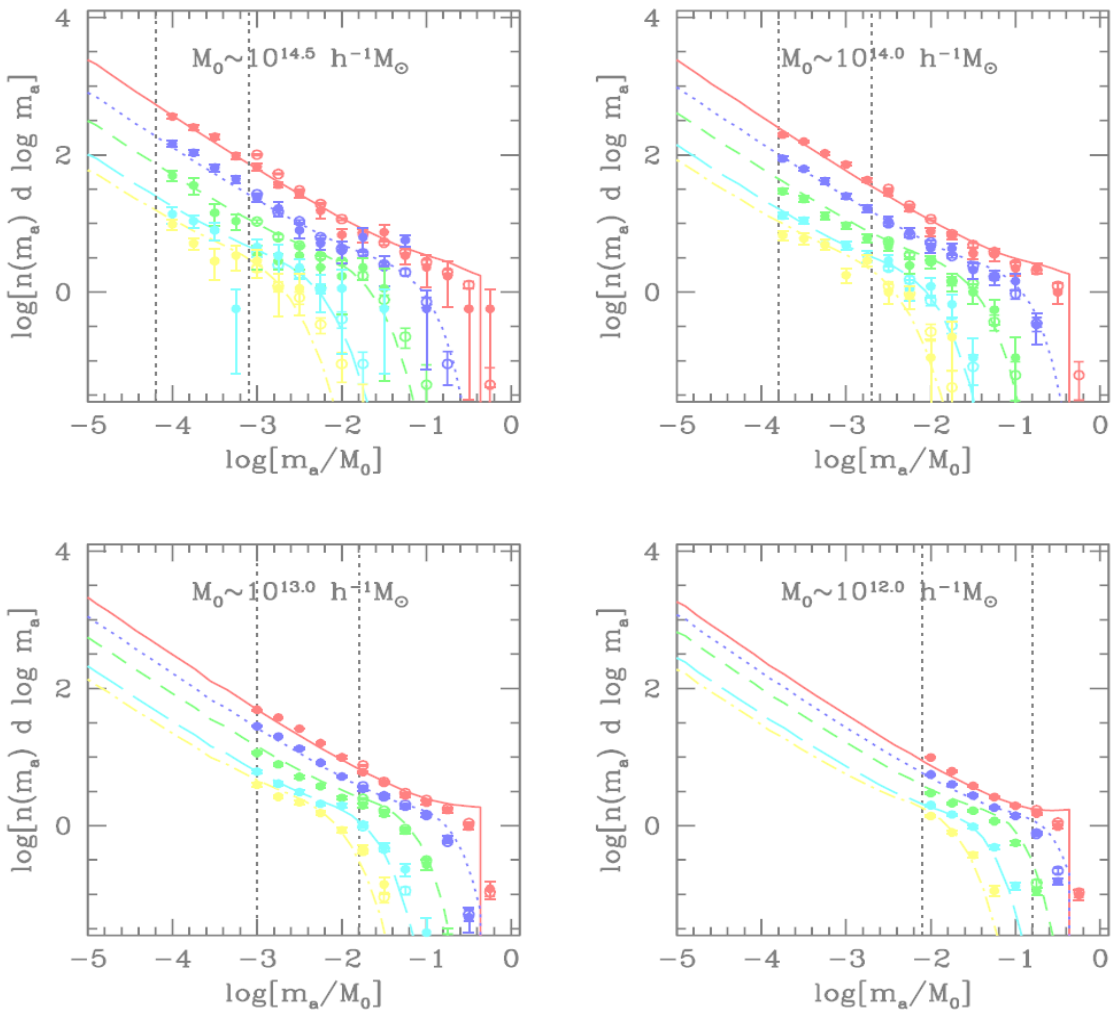
(1) Use Zhao's main branch accretion model + the log normal scatter

(2) A simple modification to the PS form: replace the final halo M_0 with M_mx (about Main progenitor mass*2).

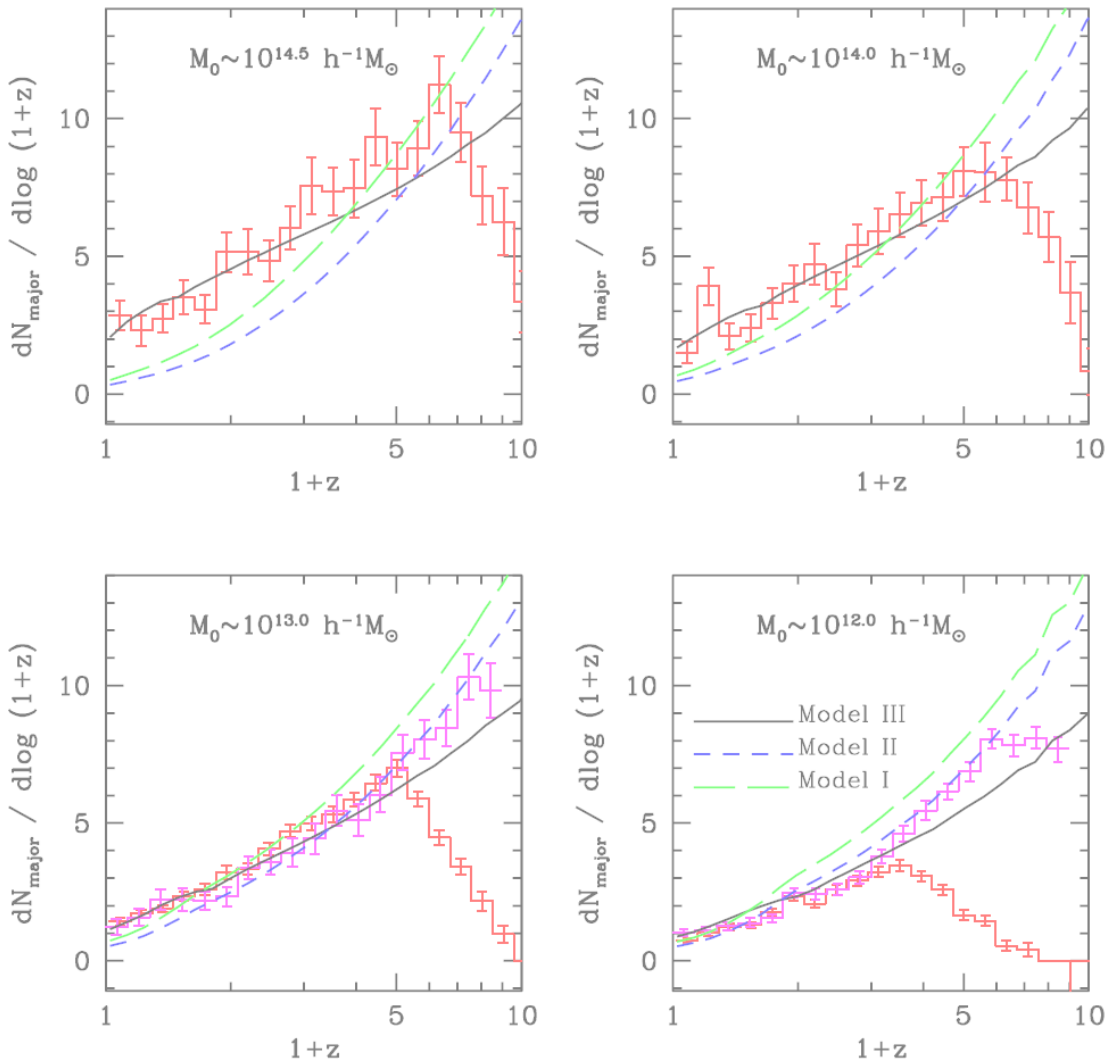
Yang et al. 2011


$M_0 \sim 10^{12.0}\ h^{-1}M_\odot$
$M_0 \sim 10^{13.0}\ h^{-1}M_\odot$
$M_0 \sim 10^{14.0}\ h^{-1}M_\odot$
$M_0 \sim 10^{14.5}\ h^{-1}M_\odot$
z=0.424
z=1.195
z=2.383
z=4.214
Model III
Model II
Model I
log [F / dlog(1+z)]
log [m_a/M_0]

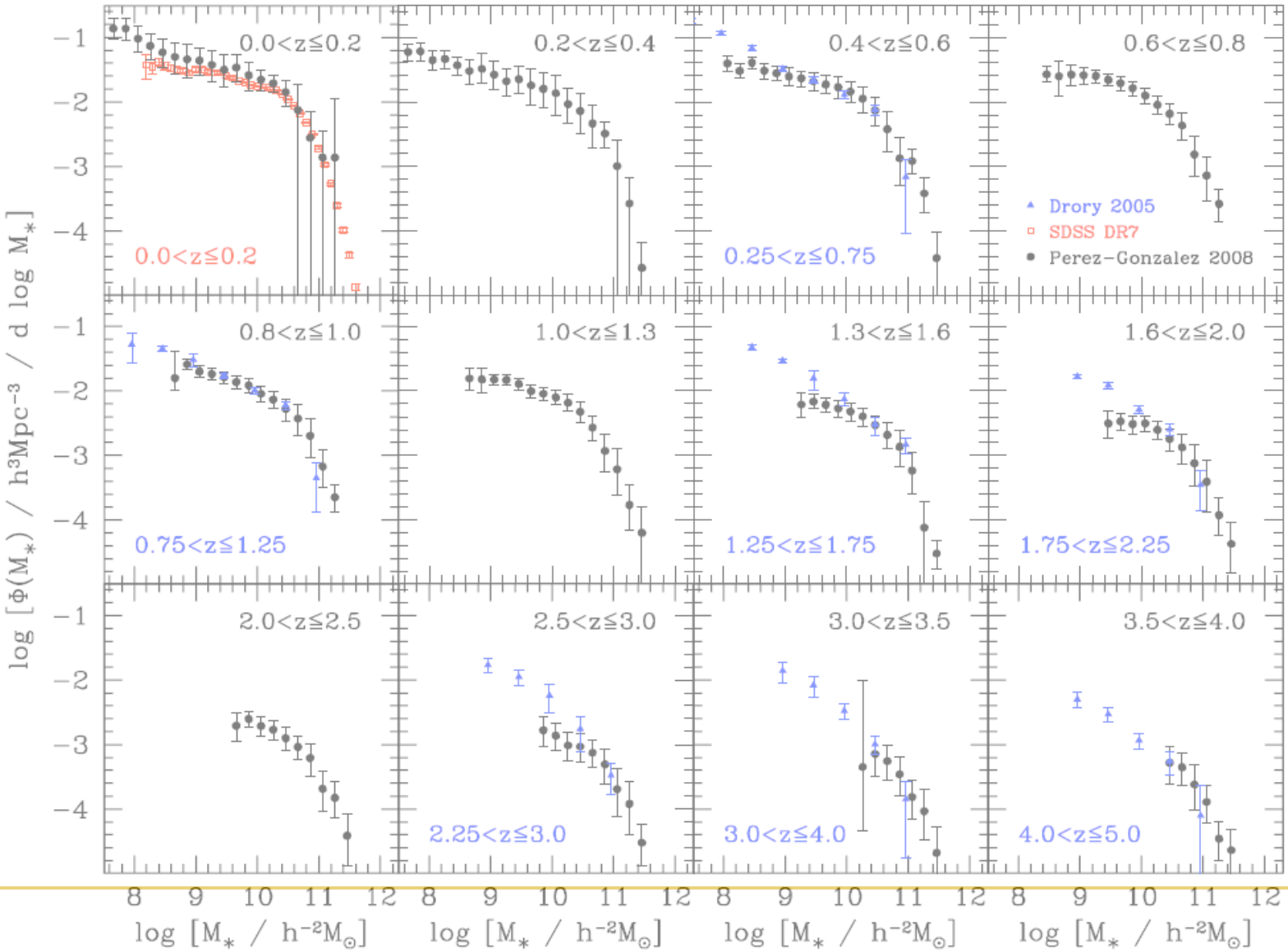
The subhalo mass functions at different redshifts



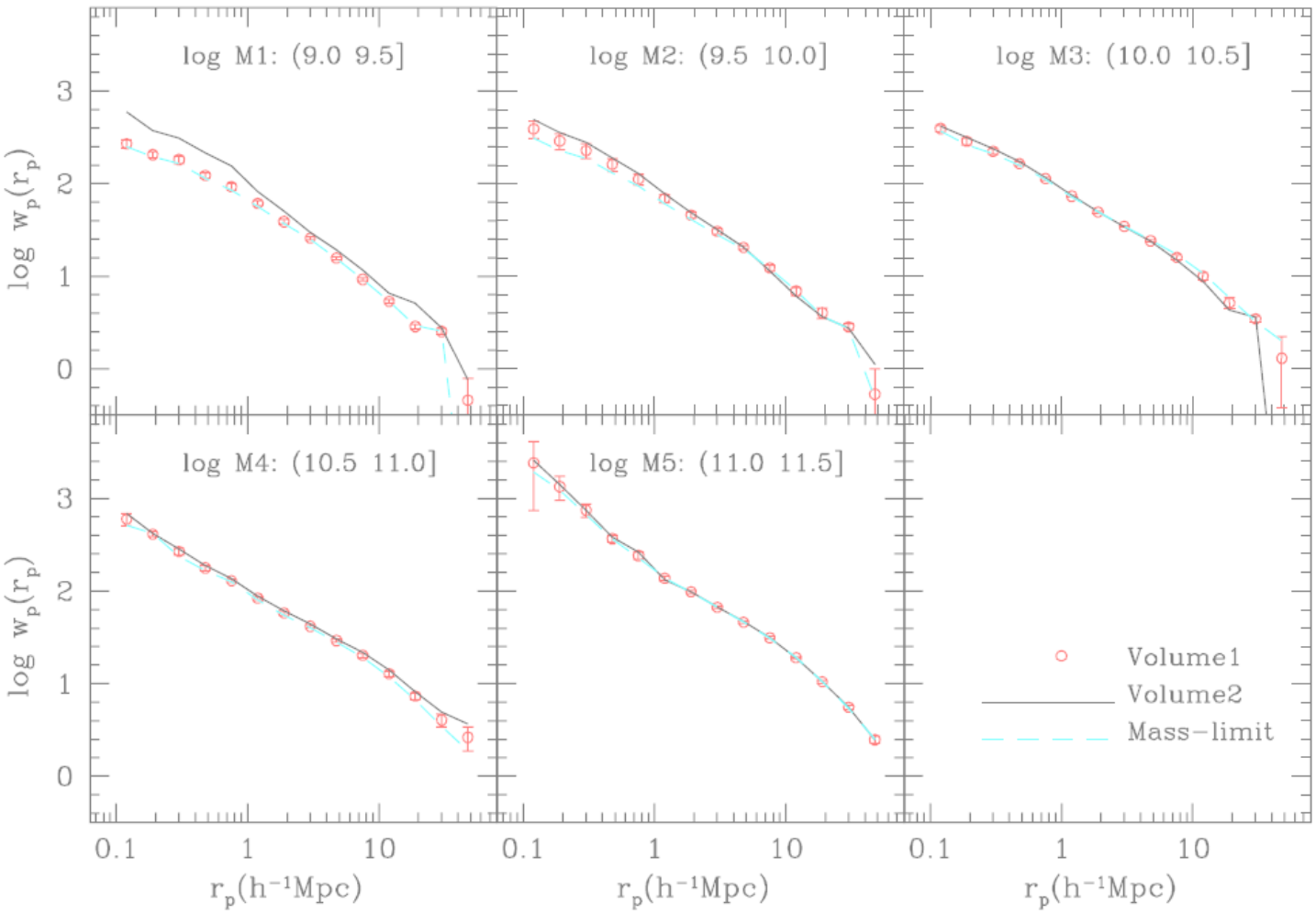
The subhalo major merger rate



Stellar mass functions at high redshift



The 2PCFs at low redshift



- **Given current observations, can we get better understanding of how central and satellite galaxies are evolved?**

$$\Phi_{\rm c}(M_*|M,z) = \frac{1}{\sqrt{2\pi}\sigma_c}\exp\left[-\frac{(\log M_*/M_{*,c})^2}{2\sigma_c^2}\right],$$

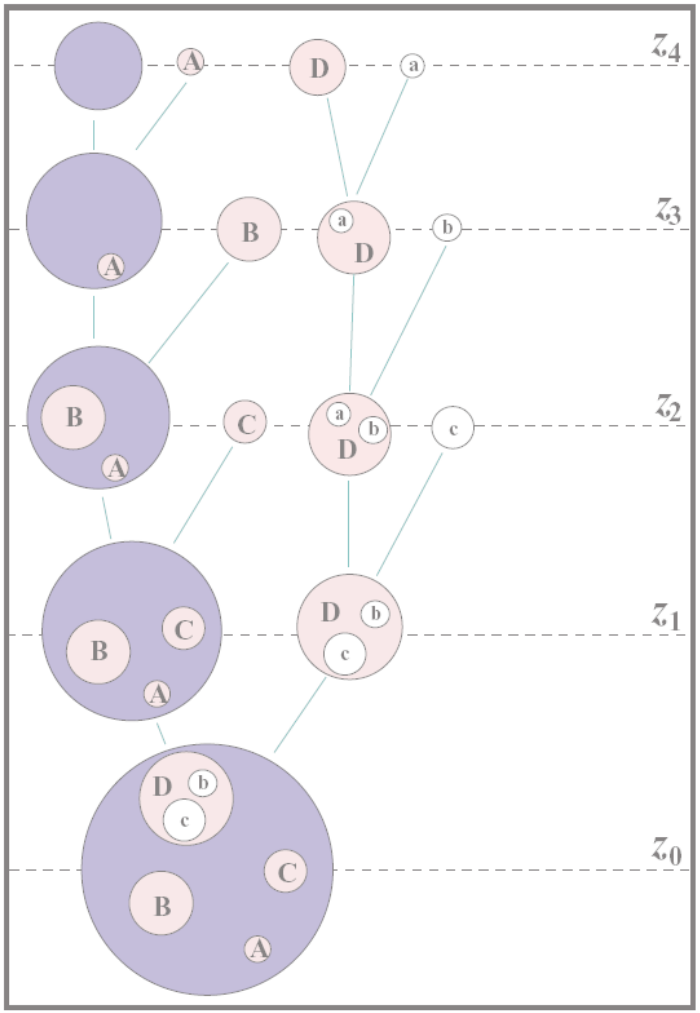
$$M_{*,c} = M_{*,0}\frac{(M/M_1)^{\alpha+\beta}}{(1+M/M_1)^{\beta}},$$

- **Using a self-consistent modeling of the satellite population with the evolution component.**

$$\Phi_{\rm s}(m_*|M,z) = \int_0^M {\rm d}m_a \int_z^\infty \frac{{\rm d}z_a}{1+z_a} \int_0^M {\rm d}M_a \int_0^1 {\rm d}\eta$$
$$\Phi_{\rm e}(m_*|m_a,z_a,z)\, n_{\rm sub}(m_a,z_a|M,z)$$
$$P(M_a,z_a|M,z)\, P(\eta)\, \Theta(p_t\, t_{\rm df} - \Delta t)\,,$$

Yang et al. 2012

Modelling satellite galaxies in different halos



$$\Phi_s(m_*|M,z) = \int_0^M dm_a \int_z^\infty \frac{dz_a}{1+z_a} \int_0^M dM_a \int_0^1 d\eta$$

$$\Phi_e(m_*|m_a, z_a, z)\, n_{sub}(m_a, z_a|M, z)$$

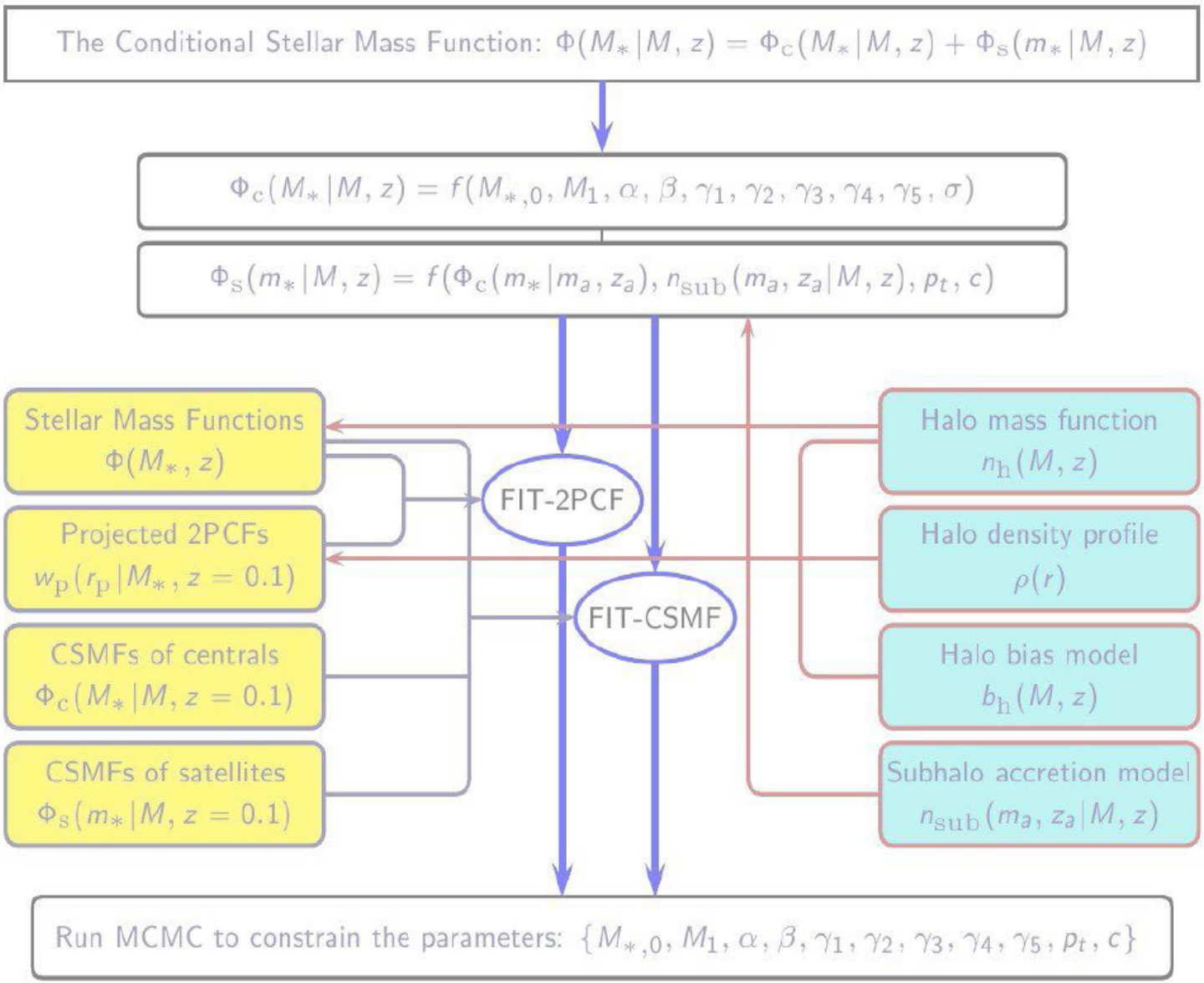
$$P(M_a|M,z)\, P(\eta)\, \Theta(t_t\, t_{df} - \Delta t),$$

In total: We only have two free parameters regarding the satellite population in the whole subhalo accretion framework:

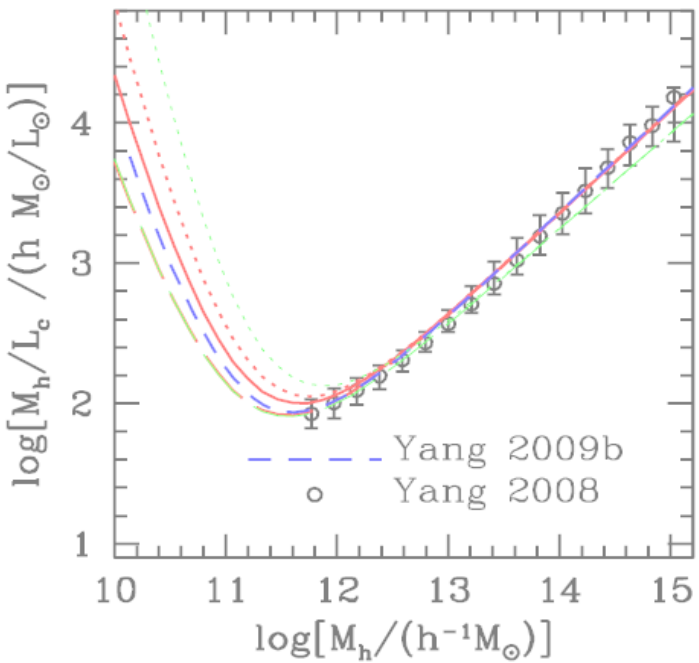
'c' – the stellar mass evolution;

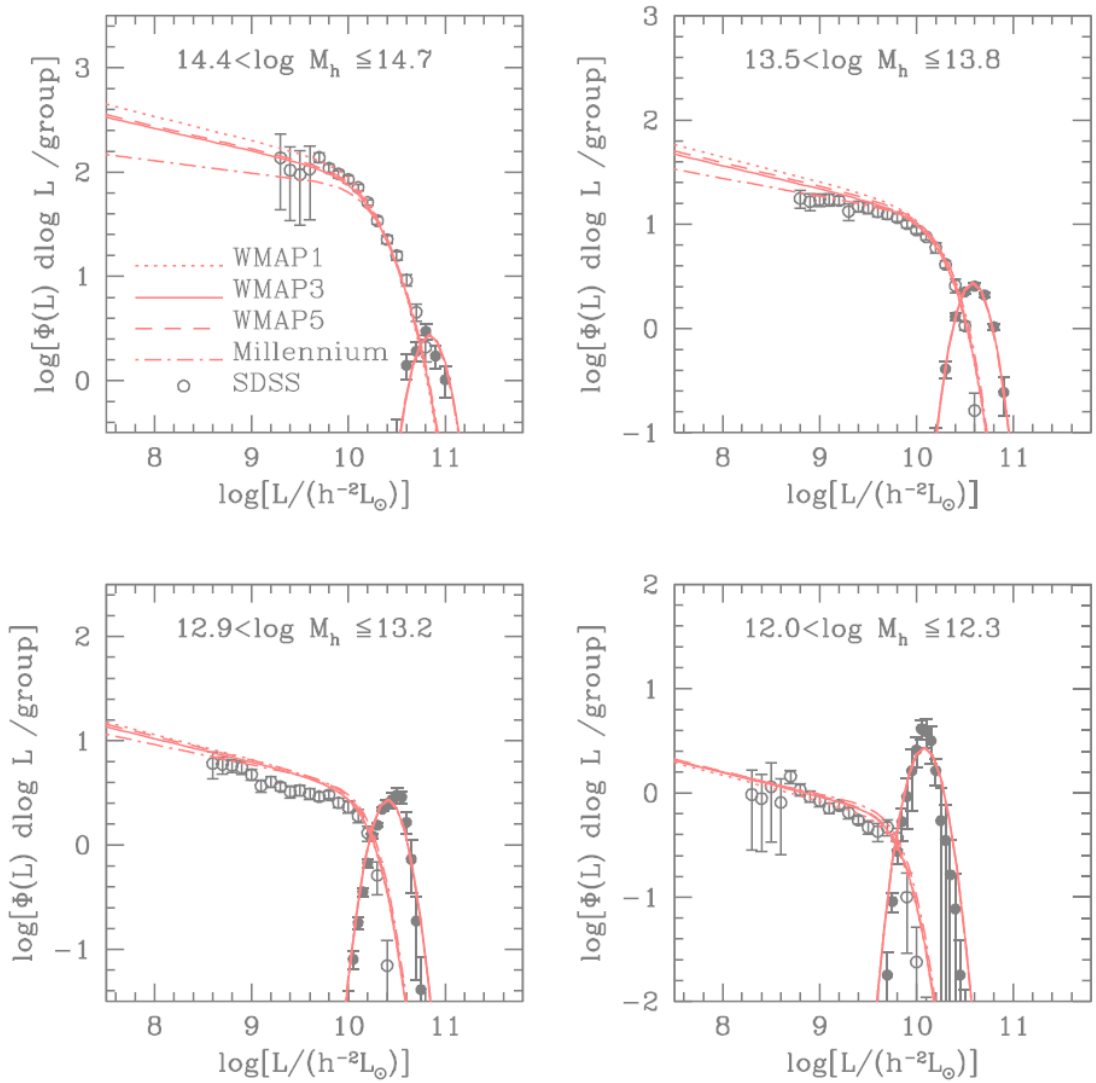
'p_t' -- the disruption of satellite galaxy with respect to the central.

galaxies.


The Conditional Stellar Mass Function: $\Phi(M_*|M,z) = \Phi_c(M_*|M,z) + \Phi_s(m_*|M,z)$
$\Phi_c(M_*|M,z) = f(M_{*,0}, M_1, \alpha, \beta, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, \sigma)$
$\Phi_s(m_*|M,z) = f(\Phi_c(m_*|m_a,z_a), n_{sub}(m_a,z_a|M,z), p_t, c)$
Stellar Mass Functions $\Phi(M_*,z)$
Projected 2PCFs $w_p(r_p|M_*, z=0.1)$
CSMFs of centrals $\Phi_c(M_*|M, z=0.1)$
CSMFs of satellites $\Phi_s(m_*|M, z=0.1)$
FIT-2PCF
FIT-CSMF
Halo mass function $n_h(M,z)$
Halo density profile $\rho(r)$
Halo bias model $b_h(M,z)$
Subhalo accretion model $n_{sub}(m_a, z_a|M,z)$
Run MCMC to constrain the parameters: $\{M_{*,0}, M_1, \alpha, \beta, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, p_t, c\}$

Model predictions at low redshift

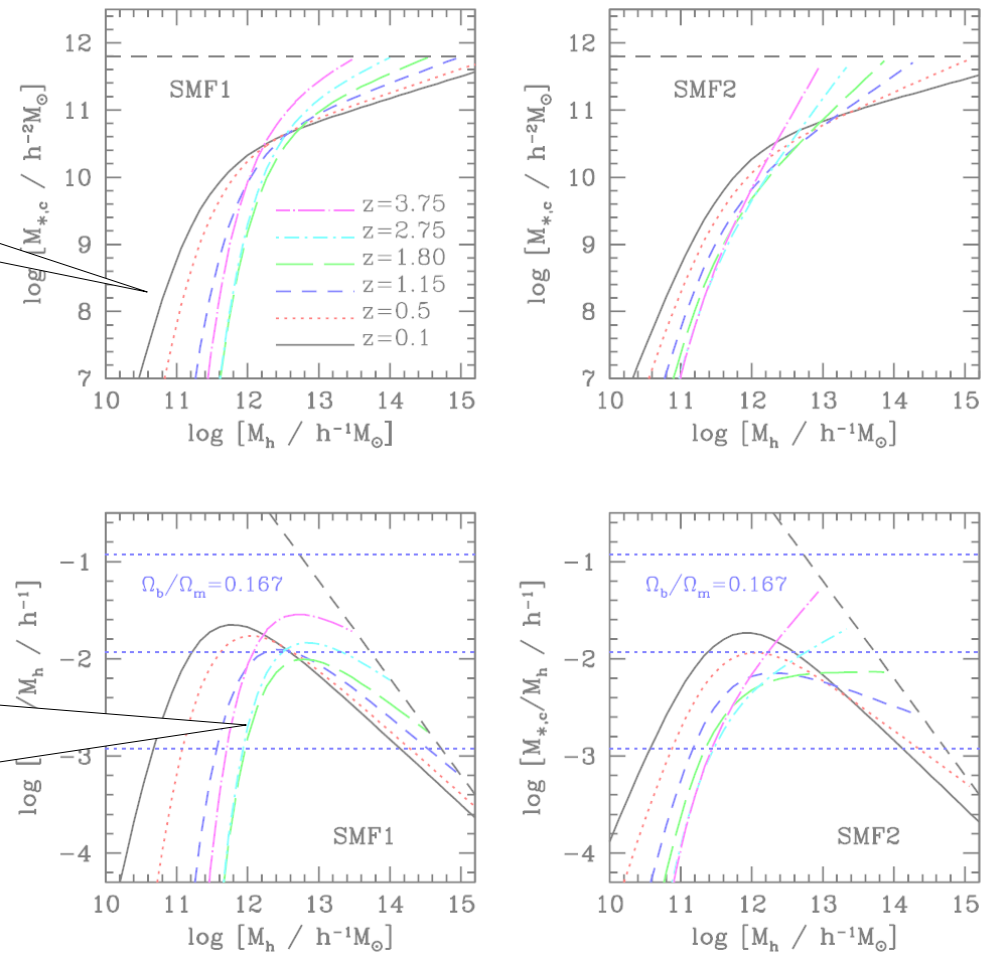




The central-host halo relation at different redshifts:

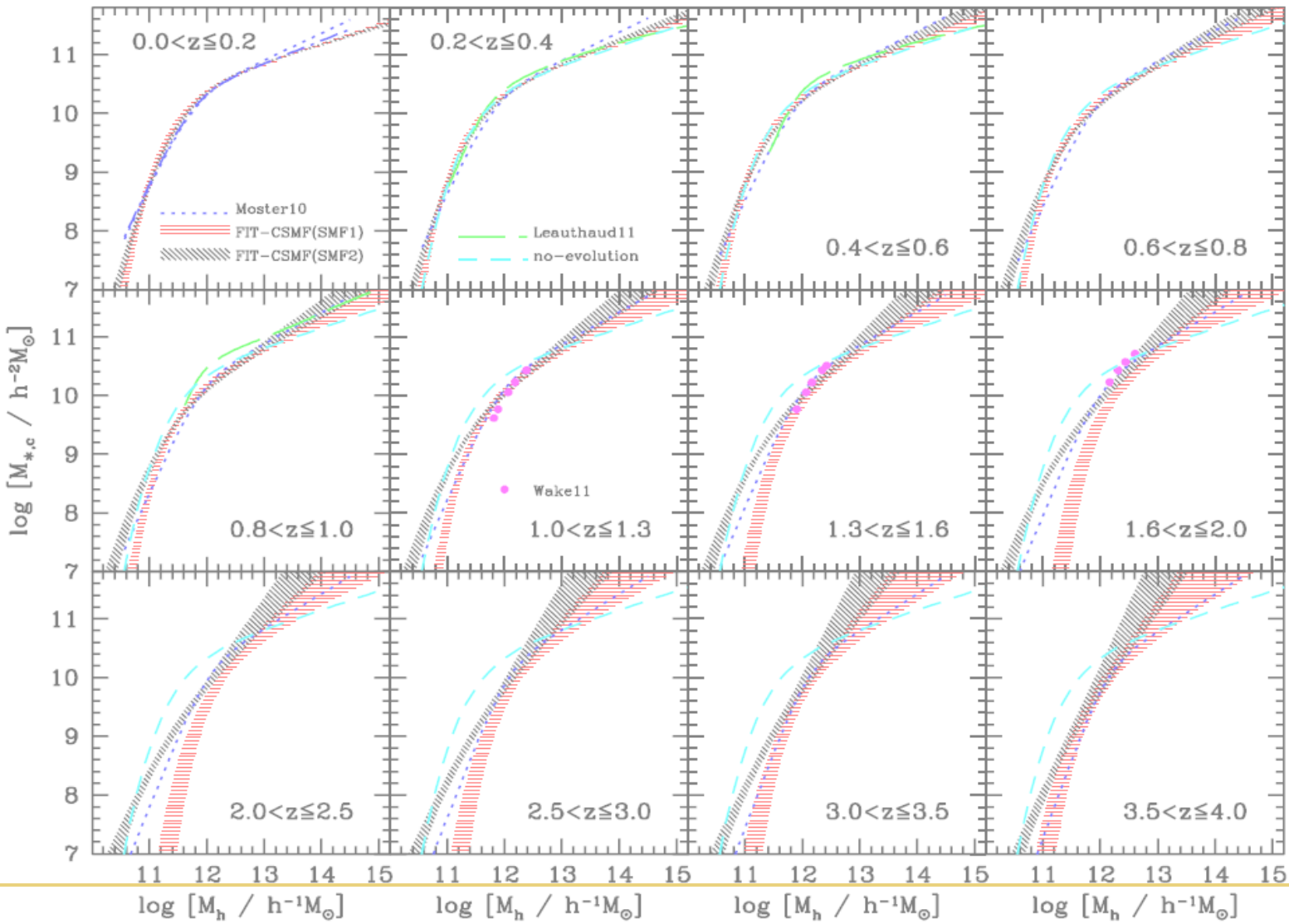
The star formation in small halos at high redshift is significantly suppressed!

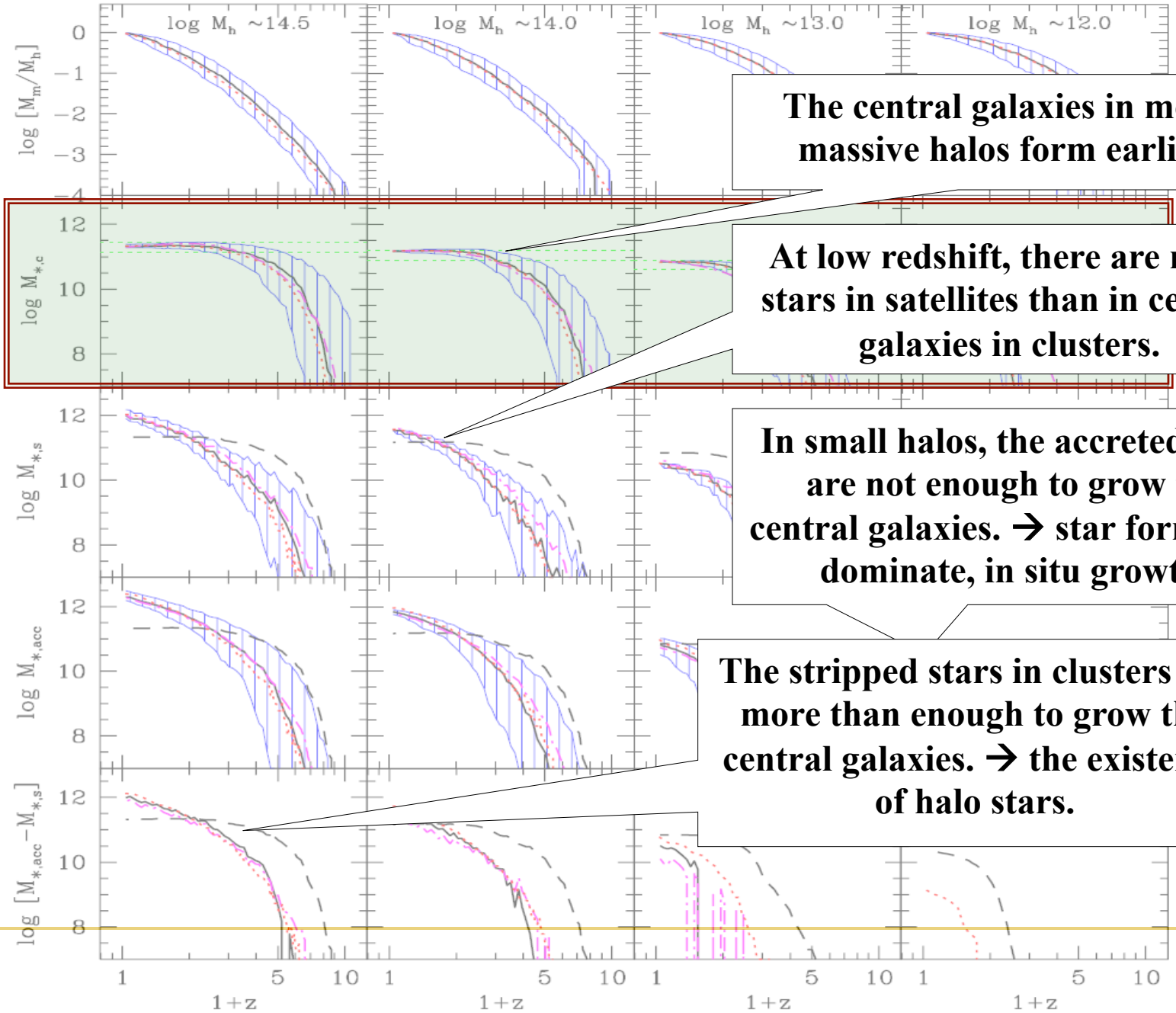
The overall M/L at redshift z~2 is much smaller than those at both high and low redshifts.



Yang et al. 2012

Comparisons with other similar constraints





The central galaxies in more massive halos form earlier

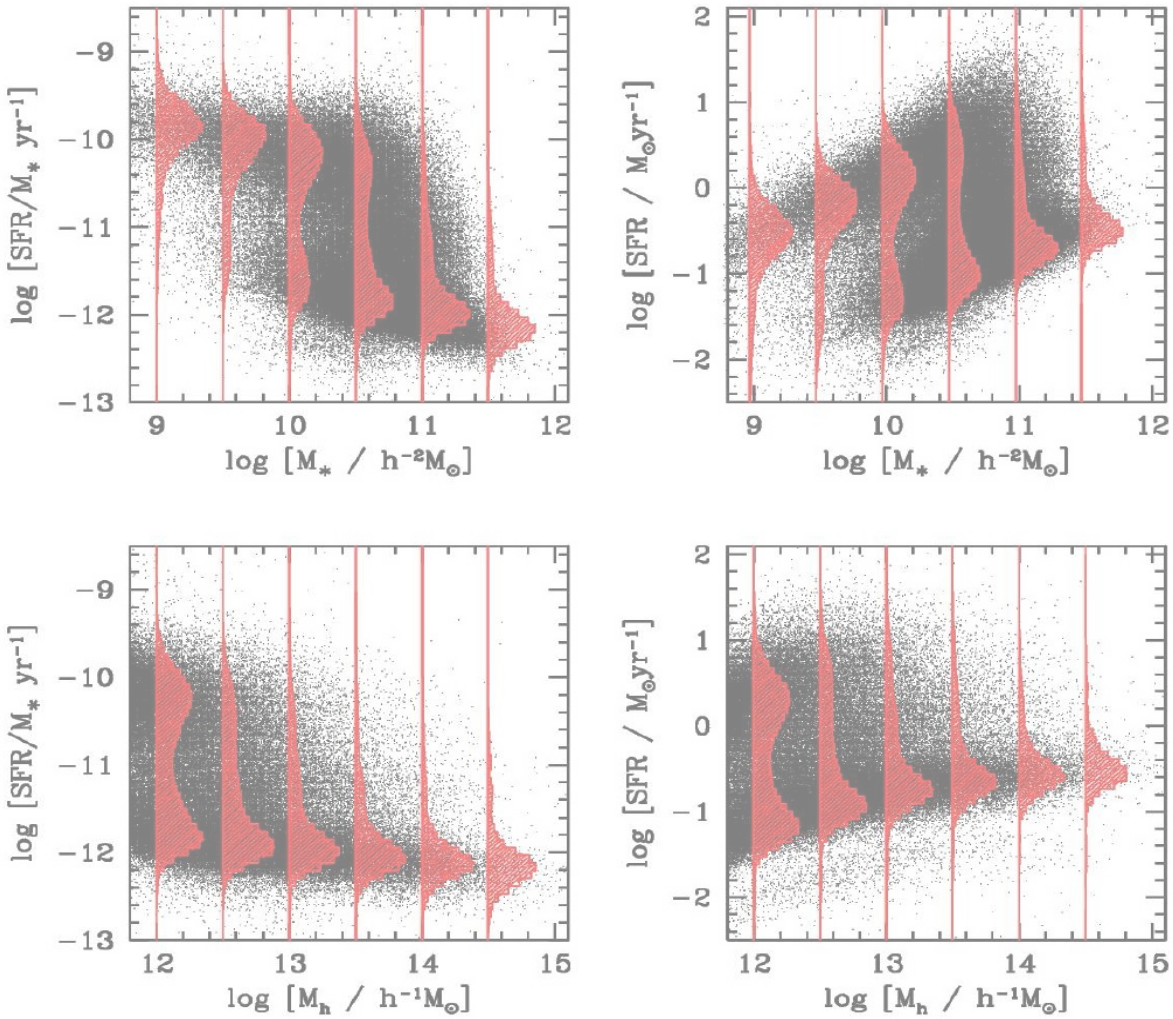
At low redshift, there are more stars in satellites than in central galaxies in clusters.

In small halos, the accreted stars are not enough to grow the central galaxies. → star formation dominate, in situ growth.

The stripped stars in clusters are more than enough to grow the central galaxies. → the existence of halo stars.

Model the SFH of central galaxies

The SFR of local galaxies:

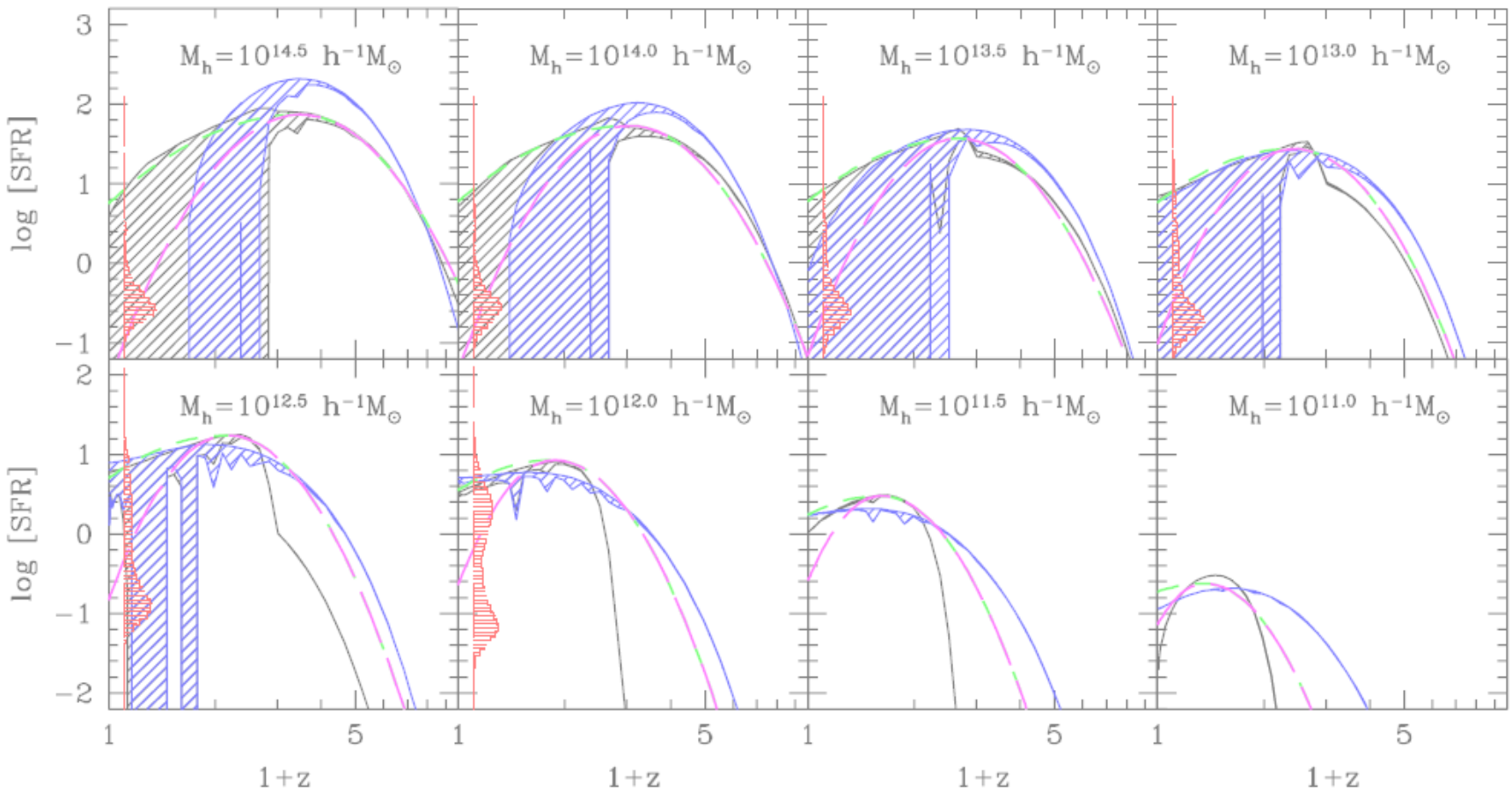


The SFH of central galaxies

- **The growth of central galaxies:**
  - **The in situ star formation**
  - **The accretion of satellite stars**
  - **The passive evolution of existing stars** (provided by Stephane Charlot)

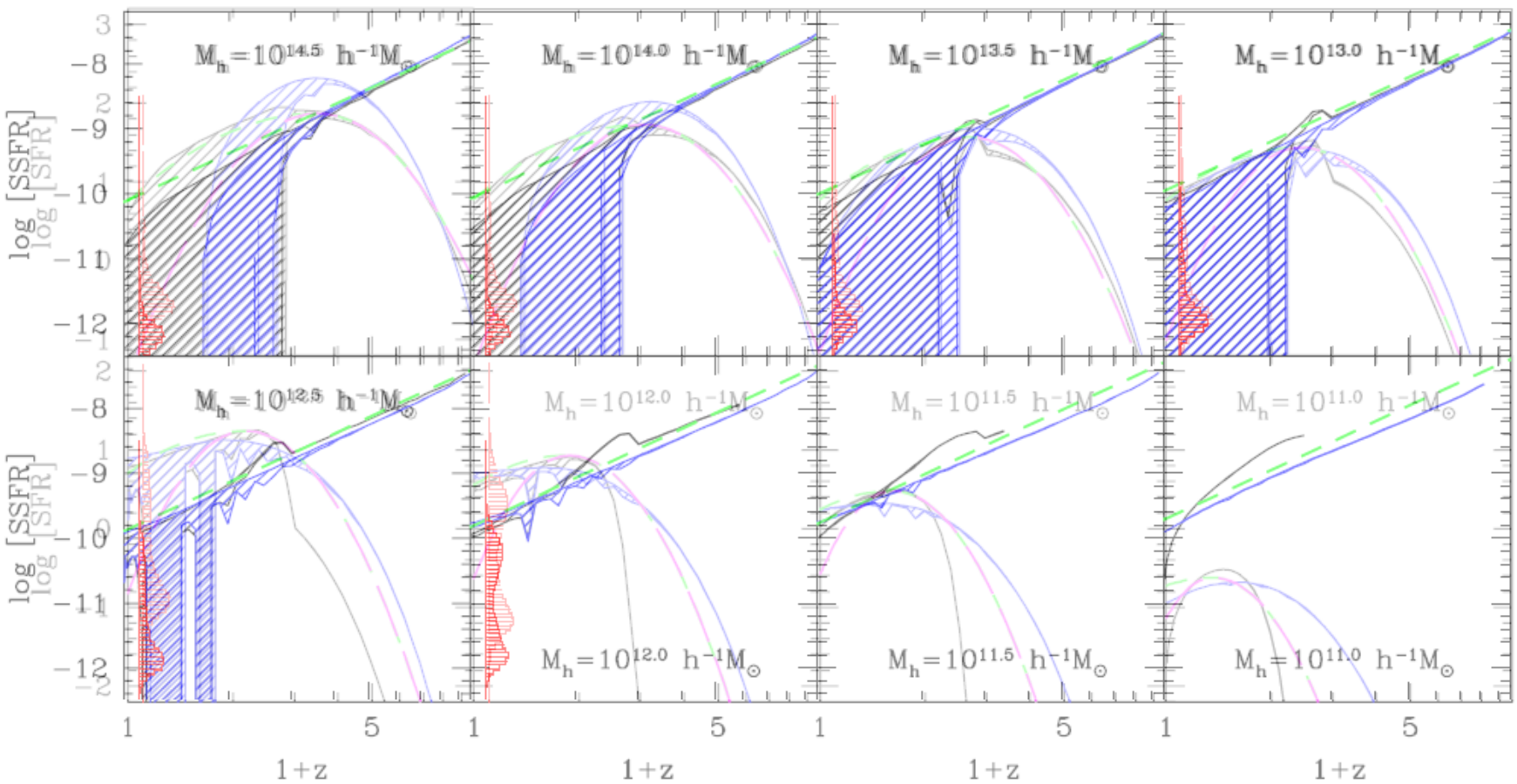
Yang et al. in preparation

The SFH of central galaxies



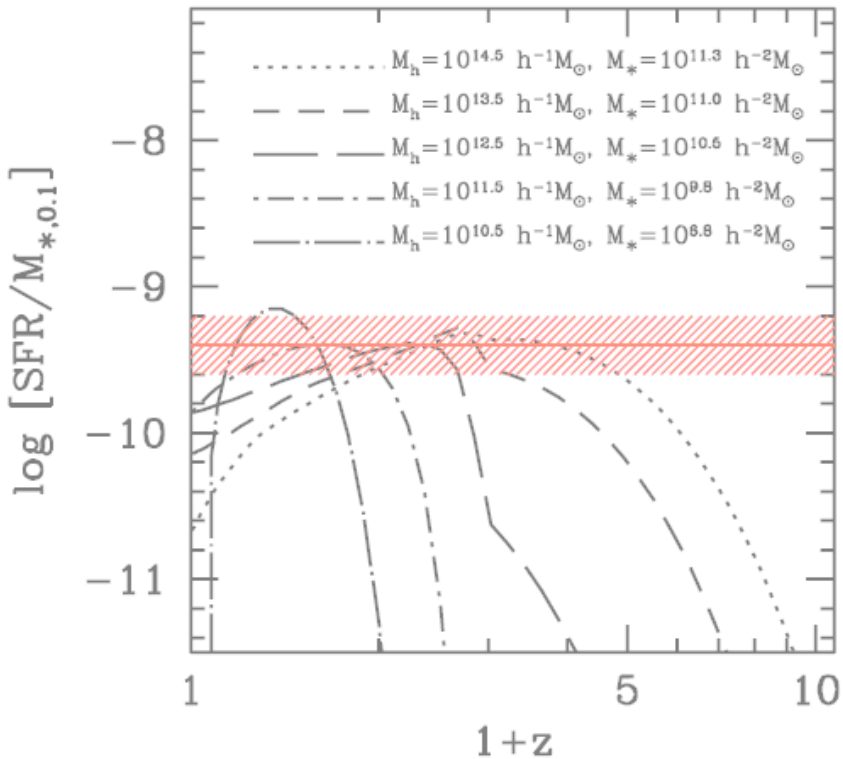
Yang et al. in preparation

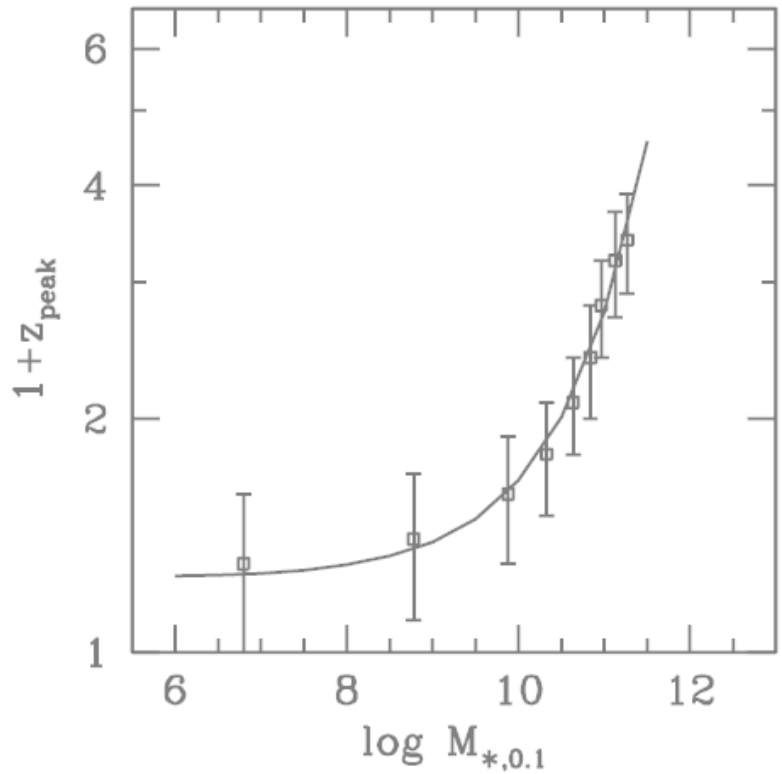
The SFH of central galaxies



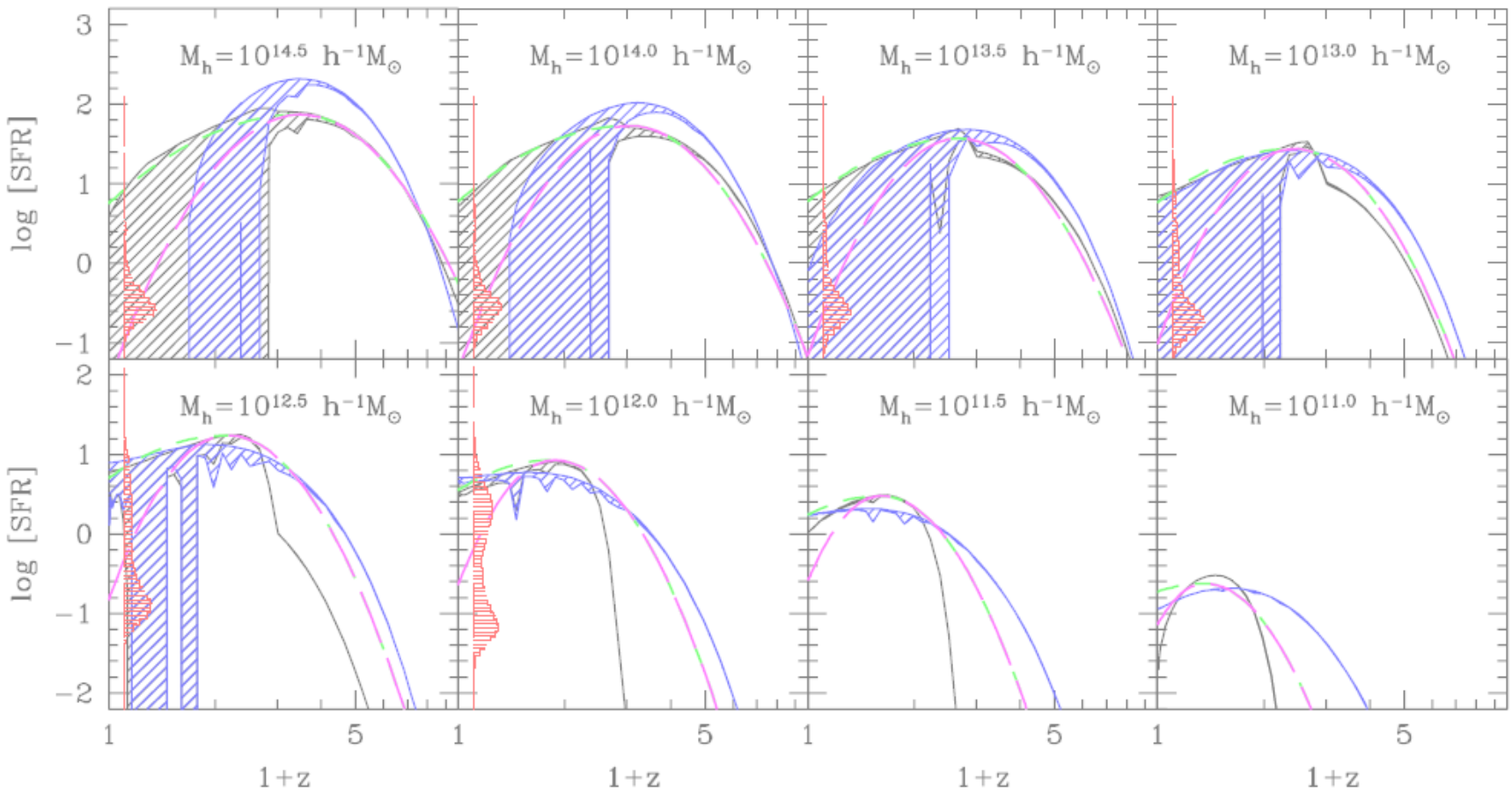
Yang et al. in preparation

The universal SFR peak





The SFH of central galaxies



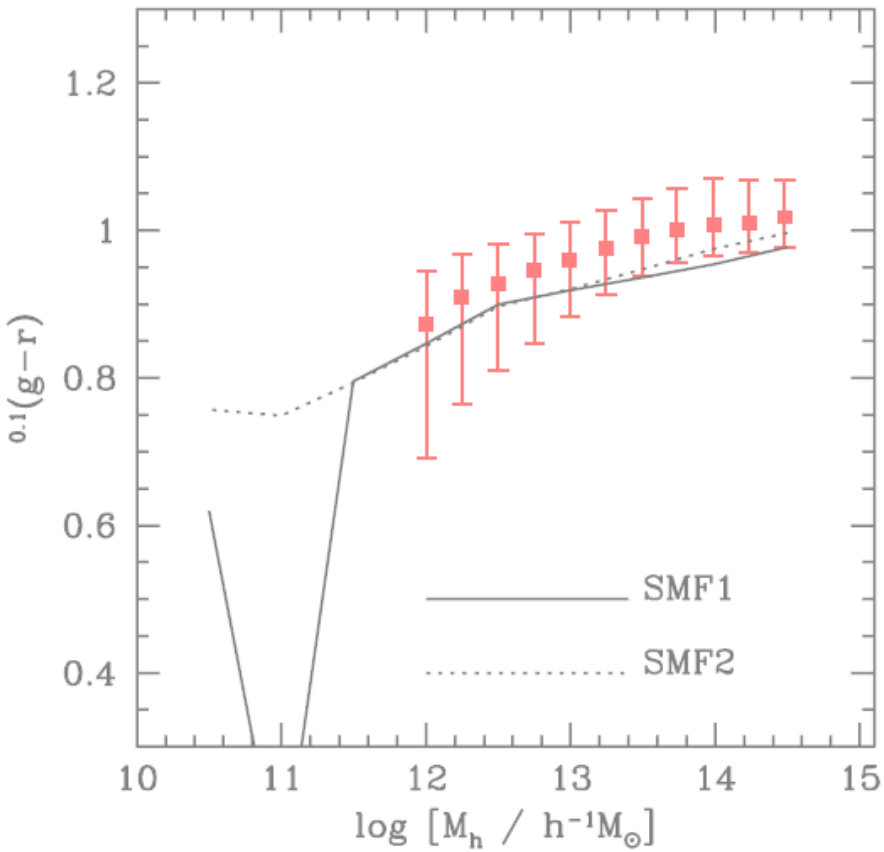
Yang et al. in preparation

Model predictions

- SFH map
- SFD
- In situ forming star fraction

The color of galaxies can be correctly predicted

As we have the SFH of central galaxies in halos of different masses, we can predict the Spectra for these galaxies according to BC03.



Summary

- **SHAM and HOD/CLF are useful tools to link galaxies and dark matter halos.**

- **Traditional HOD/CLF can only be well modeled with clustering measurements, etc., e.g., using the large redshift survey data from SDSS.**

- **If combined with subhalo accretion models, by constructing a selfconsistent population of satellite galaxies, it can be used to probe the evolution of galaxies using the current observational data at high redshift already!**

- **The SFHs of central (and satellite) galaxies can be constrained from these models……**

Thank you!