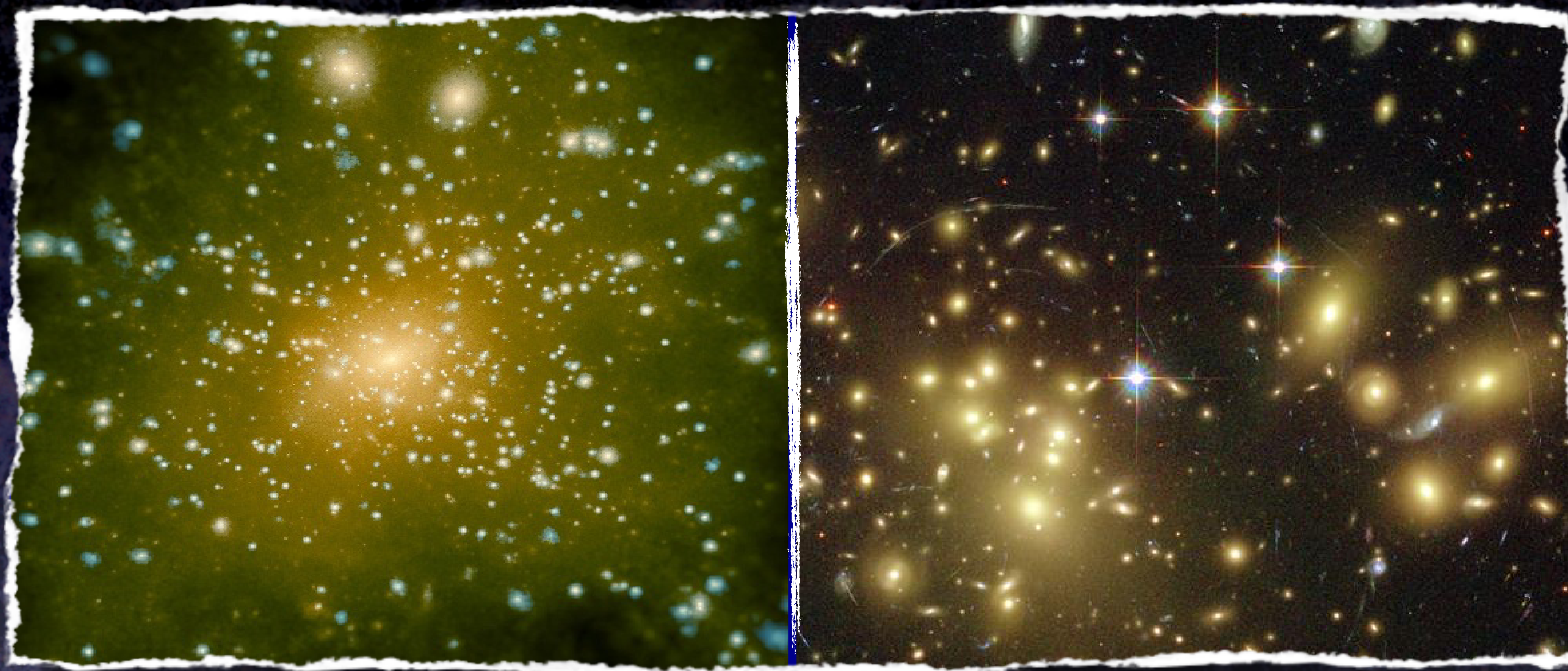
A Self-Consistent, Dynamic Model for the Evolution of the Galaxy-Dark Matter Connection across Cosmic Time



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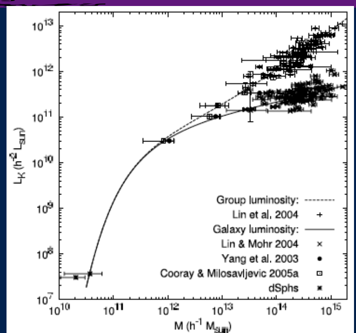
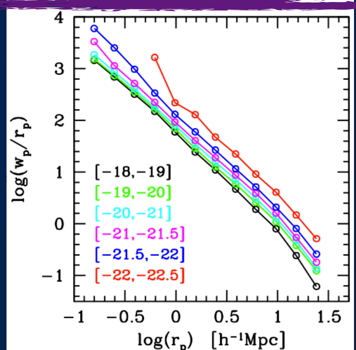
Static Methods



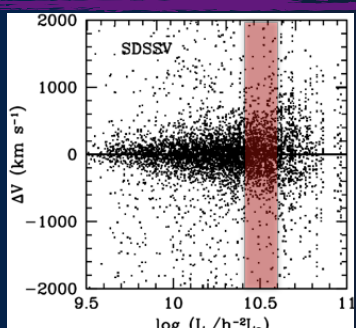
Sub-Halo Abundance Matching

Vale & Ostriker 2004, 2006; Conroy et al. 2006; Shankar et al. 2006; Conroy & Wechsler 2009; Moster et al. 2010; Behroozi et al. 2010; Wetzel & White 2010



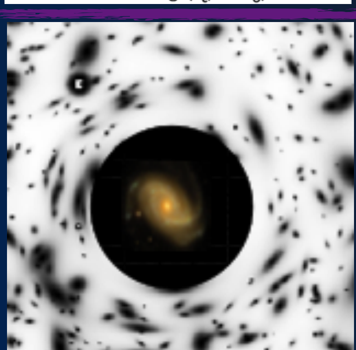
Galaxy Clustering

Jing, et al. 1998; Peacock & Smith 2000; Berlind & Weinberg 2002; Zheng 2004; Yang, Mo & vdB 2003; vdB, Yang & Mo 2003; Tinker et al. 2005; vdB et al. 2007



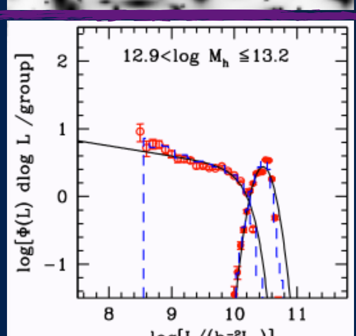
Satellite Kinematics

Zaritsky & White 1994; McKay et al 2002; Prada et al. 2003; vdB et al. 2004; Conroy et al. 2005; Norberg, Frenk & Cole 2008; More et al. 2009, 2011;



Galaxy-Galaxy Lensing

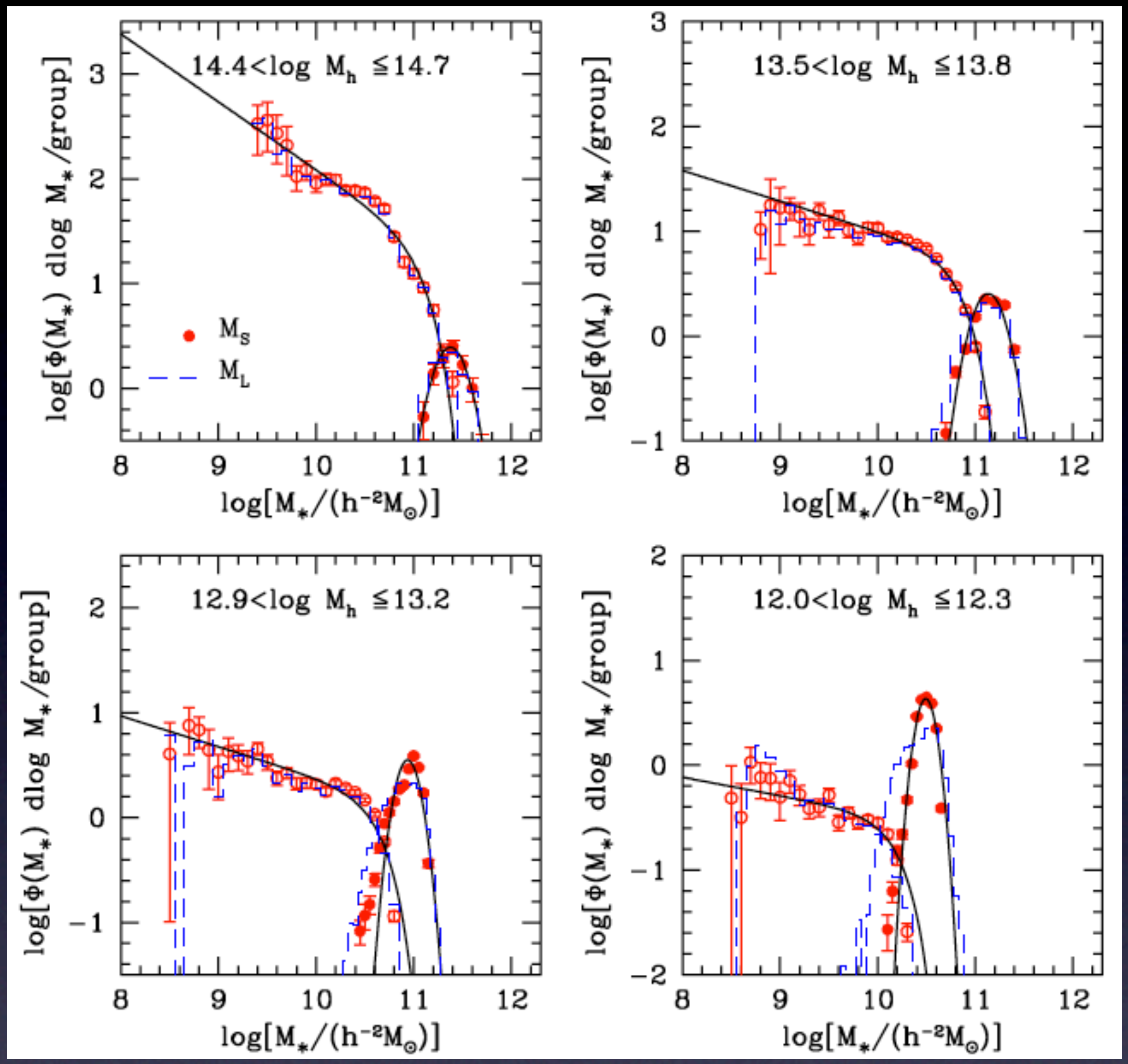
Guzik & Seljak 2002; Seljak et al. 2005; Mandelbaum et al. 2006; Yoo et al. 2006 Cacciato et al. 2009; van Uitert et al. 2011; Leauthaud et al. 2012;



Galaxy-Group Catalogues

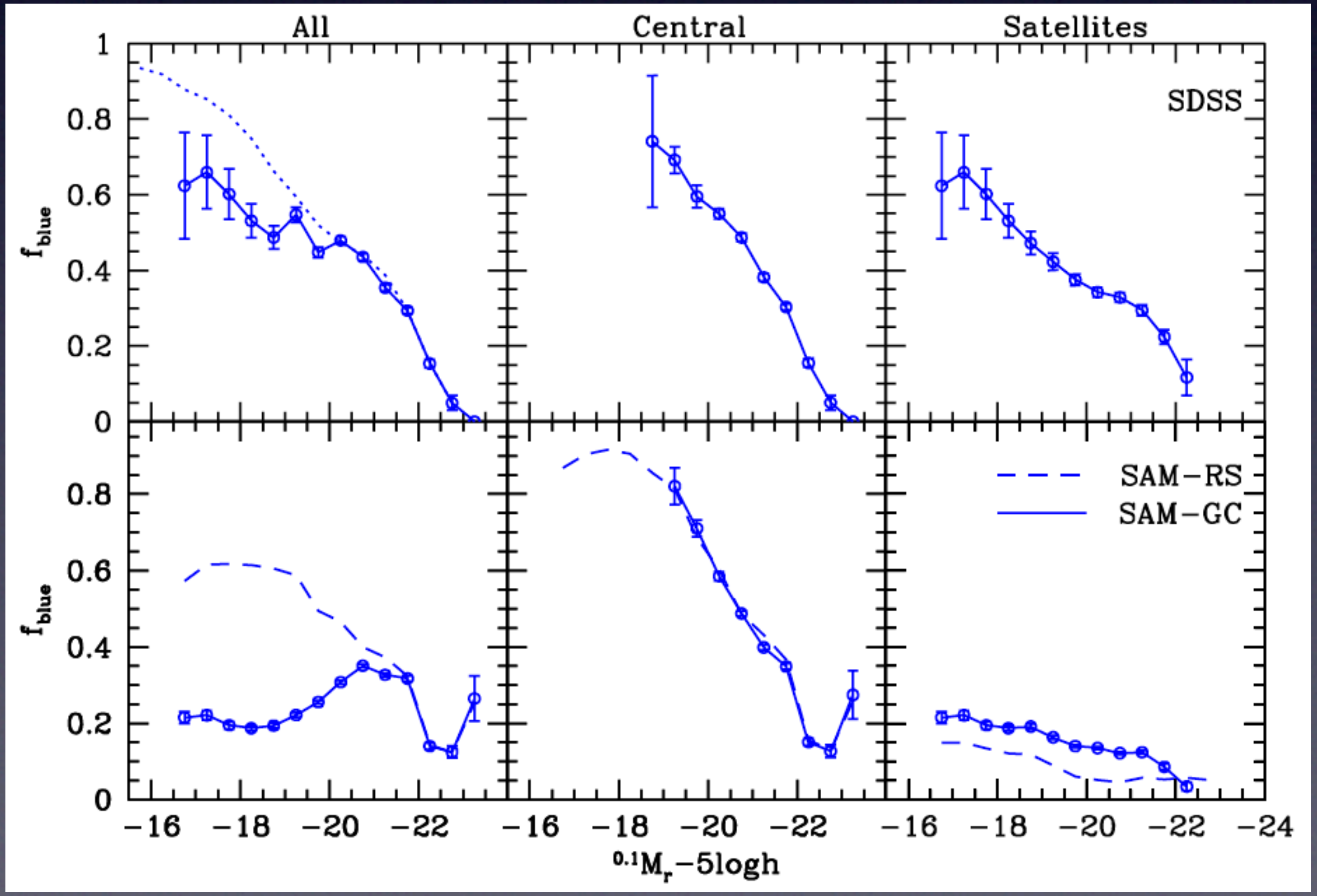
Eke et al. 2004; Yang et al. 2005, 2007, 2008, 2009; vdB et al. 2008; Weinmann et al. 2006a,b; Pasquali et al. 2010, 2012; Wetzel et al. 2012

New Insights from Galaxy Group Catalogues



Source: Yang, Mo & vdB et al. 2009, ApJ, 695, 900

- Group Catalogues allow distinction between centrals and satellites.
- Comparing centrals to satellites provides insight into satellite-specific processes.

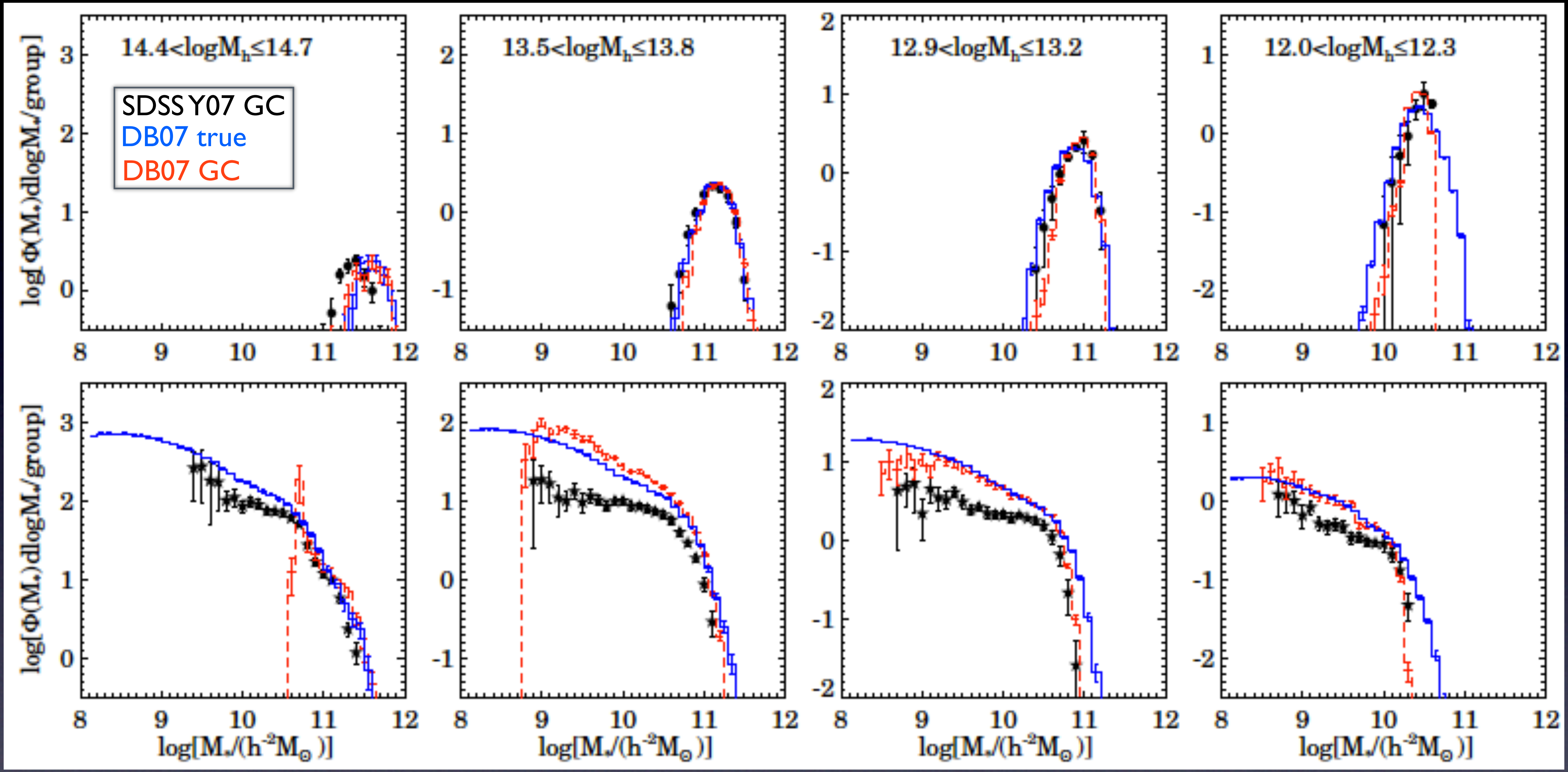


Source: Weinmann, vdB et al. 2006, MNRAS, 372, 1161

SAMs over-quench satellites

See also: vdB et al. 2008; Kimm et al.2009; Wetzel et al. 2012.

The Abundance of Satellite Galaxies



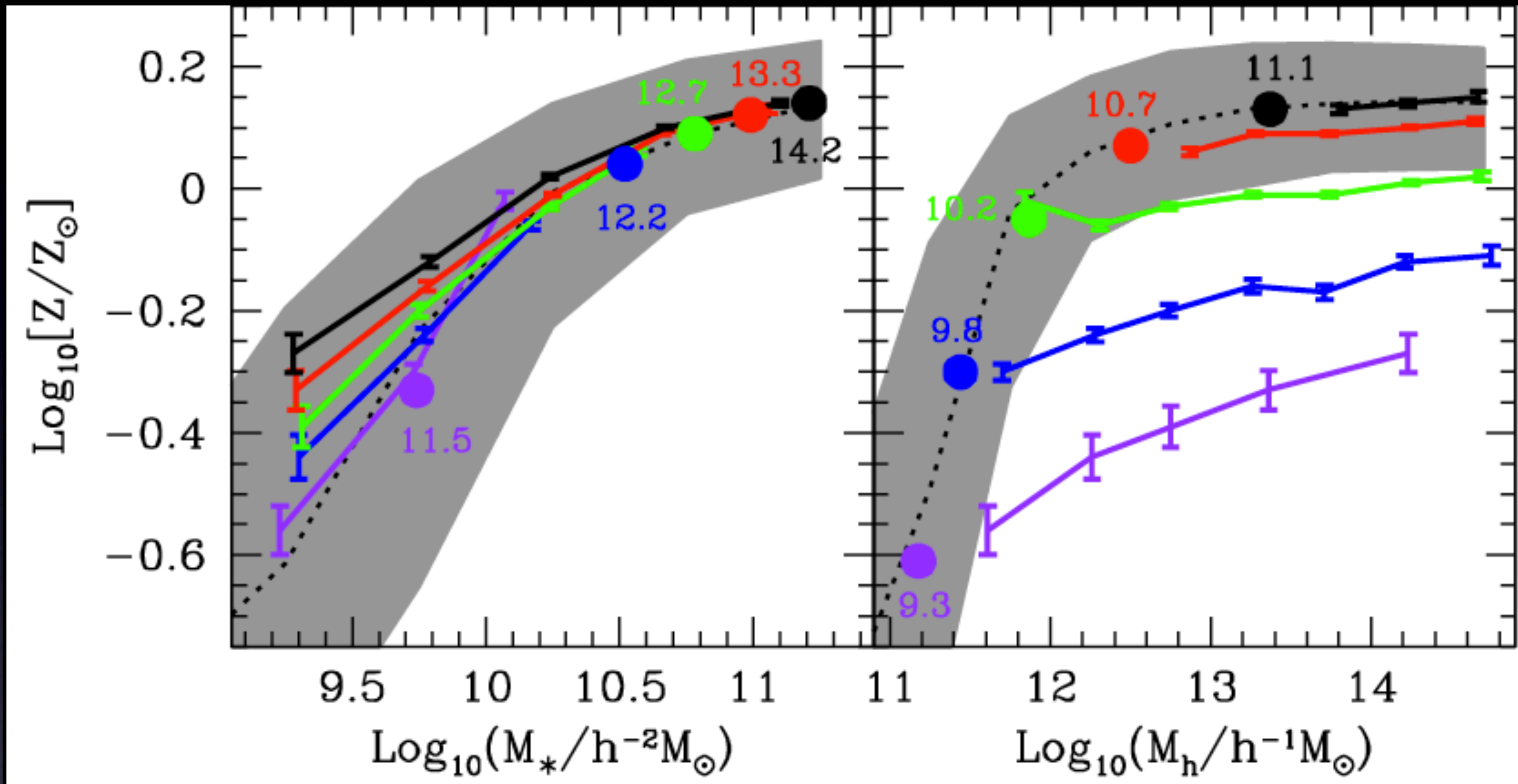
Source: Liu, Yang Mo, vdB & Springel, 2010, ApJ, 712, 734

Semi-Analytical Models predict too many satellite galaxies

See also: Conroy, Ho & White 2007; Conroy, Wechsler & Kravtsov 2009; Kang & vdB 2008; Yang, Mo & vdB 2009; Henriques & Thomas 2009

Stellar Metallicities of Centrals and Satellites

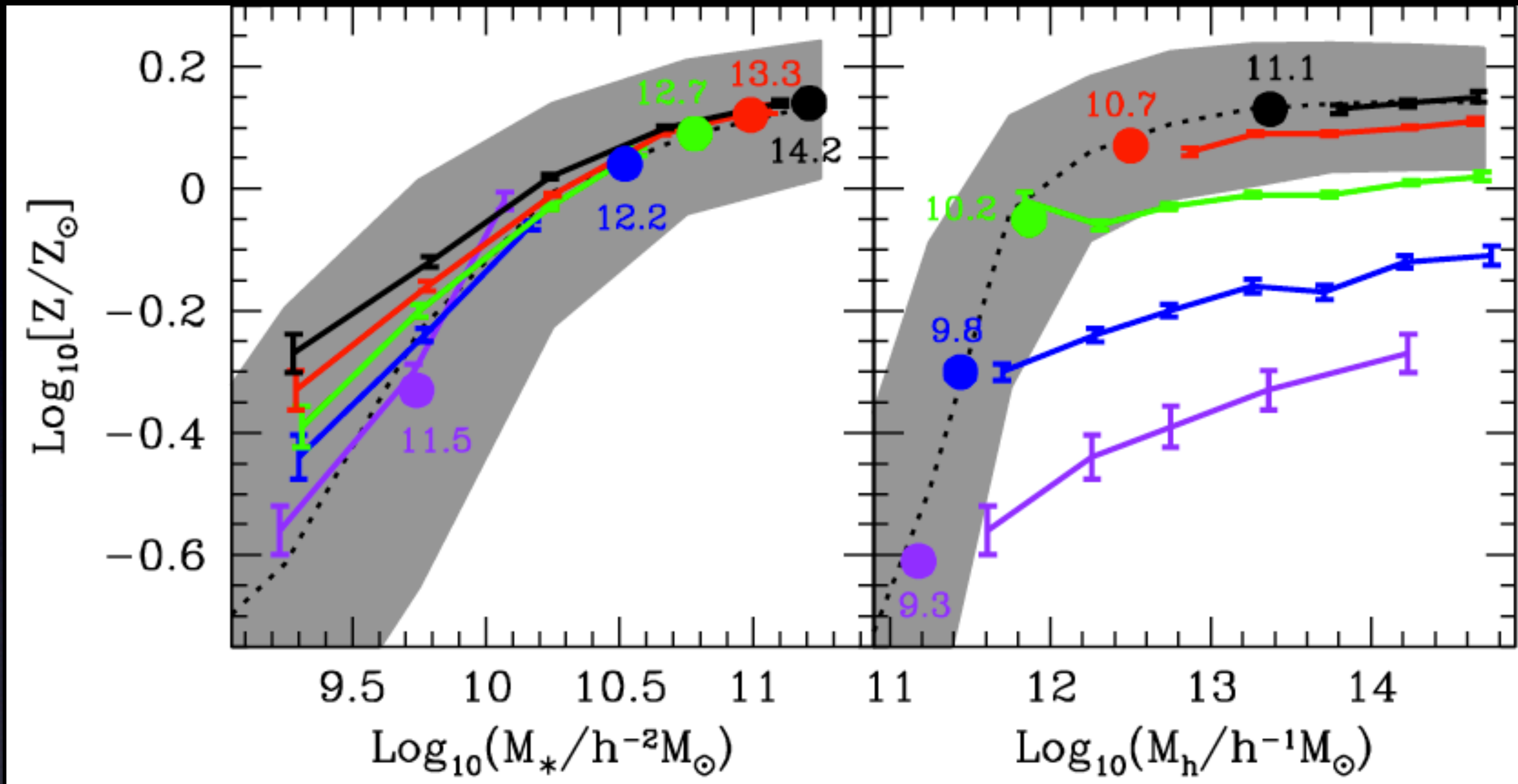
Source: Pasquali et al. 2010, MNRAS, 407, 937



- Satellites have higher metallicity than centrals of same stellar mass.
- Satellites of given M_* have higher metallicity in more masive host halo

Stellar Metallicities of Centrals and Satellites

Source: Pasquali et al. 2010, MNRAS, 407, 937



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Satellite Galaxies experience large amount of mass stripping

A Dynamic, Self-Consistent Model

Yang et al. 2011, ApJ, 741, 13
Yang et al. 2012, ApJ, 752, 41

central galaxies

$$\Phi_{\rm c}(M_*|M,z) = \frac{1}{2\pi\sigma_{\rm c}} \mathrm{EXP}\left[-\frac{(\log M_*/\overline{M}_*)^2}{2\sigma_{\rm c}^2}\right]$$

$$\overline{M}_* = \overline{M}_*(M,z)$$

$$\sigma_{\rm c} = \sigma_{\rm c}(z)$$

} 9 free parameters

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$$\left.\begin{array}{l} \overline{M}_* = \overline{M}_*(M,z) \\ \sigma_{\rm c} = \sigma_{\rm c}(z) \end{array}\right\} \text{9 free parameters}$$

satellite galaxies are centrals at infall:

$$\Phi_{\rm s}(M_*|M,z) = \int_0^\infty {\rm d}M_{*,a} \int_0^M {\rm d}m_a \int_z^\infty {\rm d}z_a \int_0^M {\rm d}M_a \int_0^1 {\rm d}\eta \; \Phi_{\rm c}(M_{*,a}|m_a,z_a)\, n_{\rm sub}(m_a,z_a|M,z)$$

$$P(M_*,z|M_{*,a},z_a;m_a;M_a,\eta)\, P(M_a,z_a|M,z)\, P(\eta)$$

A Dynamic, Self-Consistent Model

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$$P(M_*,z|M_{*,a},z_a;m_a;M_a,\eta)\, P(M_a,z_a|M,z)\, P(\eta)$$

a simplified model for the evolution of satellites:

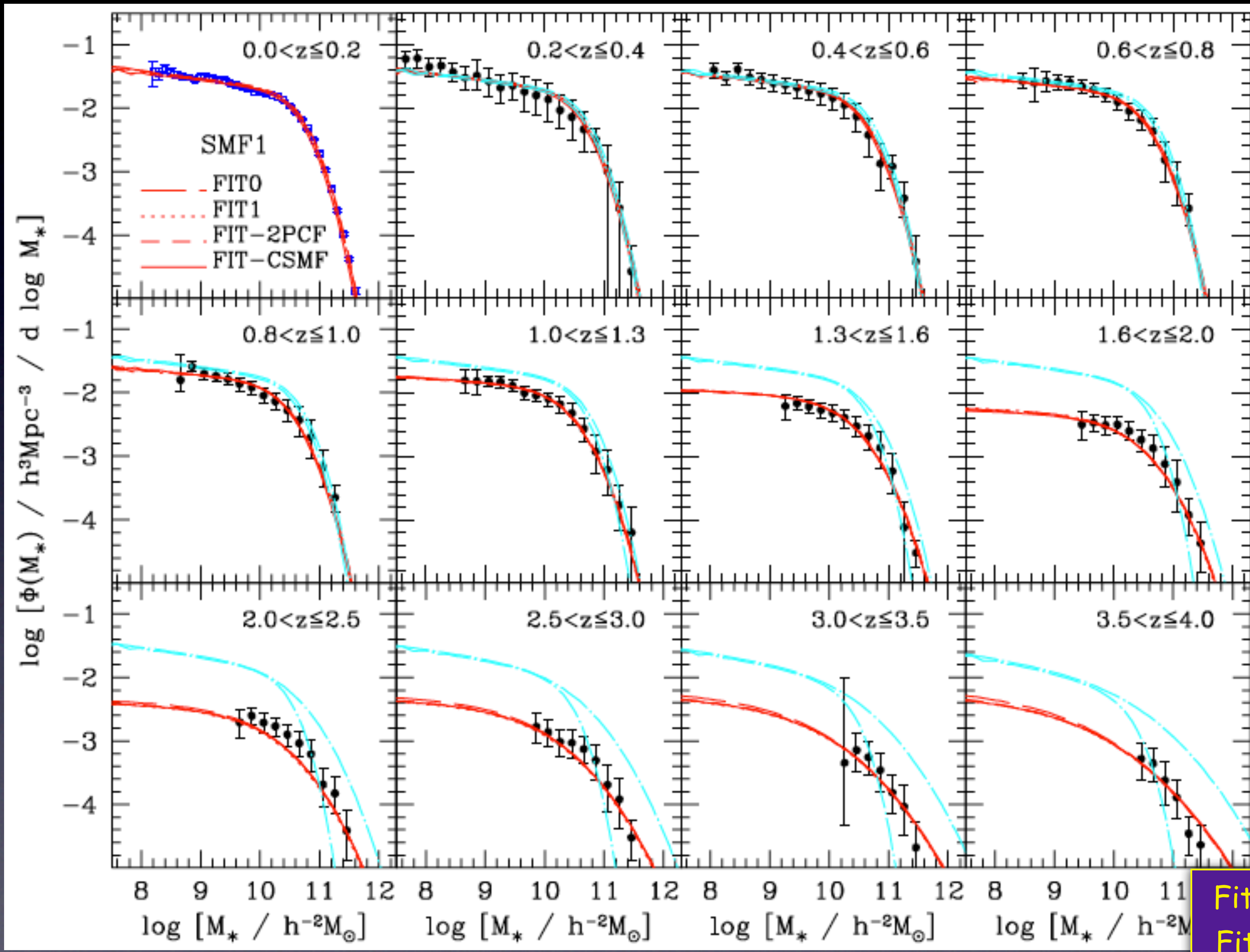
$$P(M_*,z|M_{*,a},z_a;m_a;M_a,\eta) = \begin{cases} \delta^{\rm D}(M_* - M_*') & \text{if } \Delta t < \alpha\, t_{\rm df}(m,M,z,\eta) \\ 0 & \text{otherwise} \end{cases}$$

$$M_*' = (1-c)\, M_{*,a} + c\,\overline{M}_{*,c}(m_a,z)$$

α `satellite disruption' parameter
c `satellite mass growth' parameter

Fit to Stellar Mass Functions across Cosmic Time

Data: Yang et al (2009; z~0.1)
Perez-Gonzales et al. (2008)

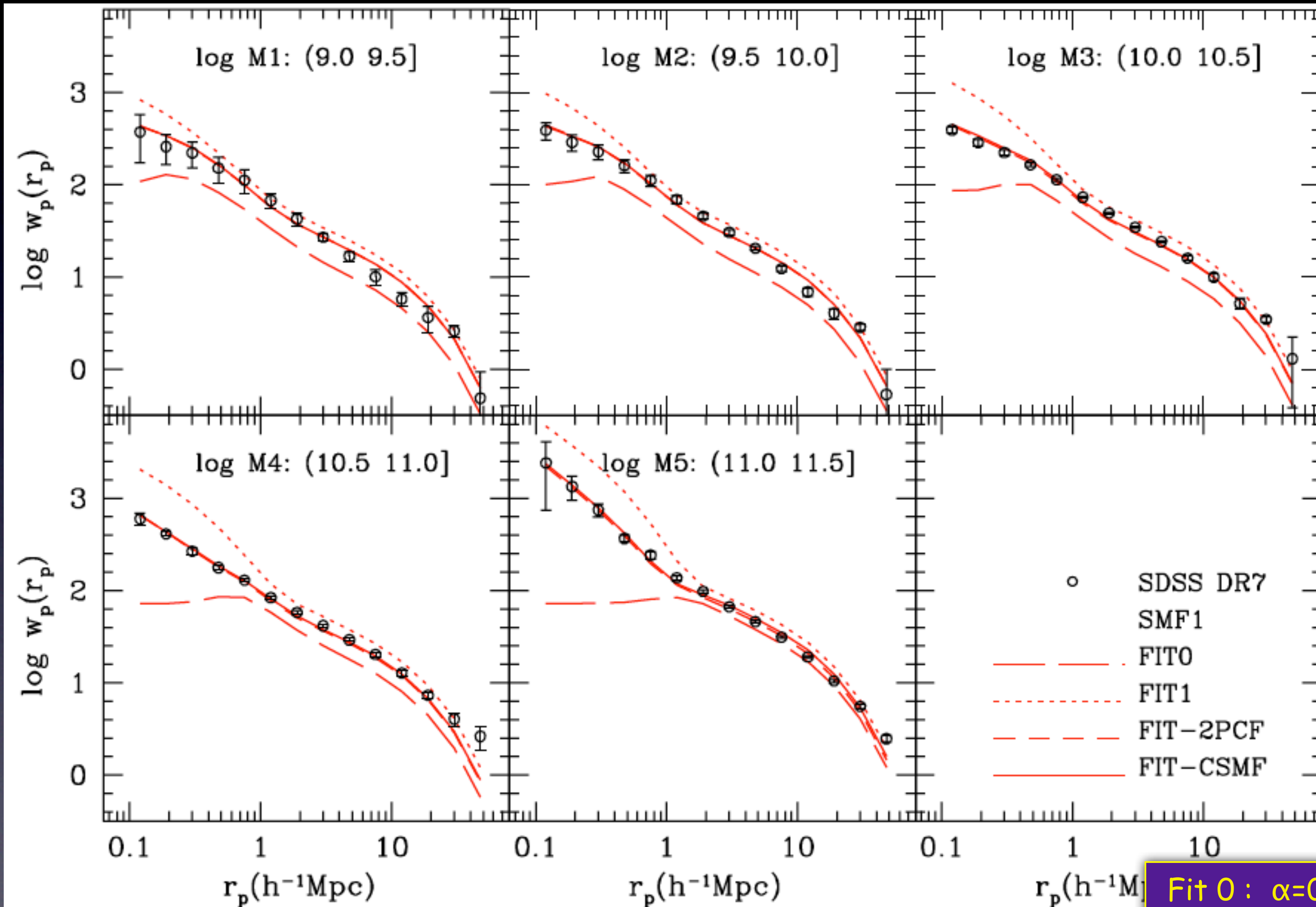


Source: Yang et al. 2012, ApJ, 752, 41

Fit 0 : α=0 --> no sats
Fit 1 : α=∞ --> no evolution
2PCF : fit to $\Phi(M_\star)$ + 2PCF
CSMF : fit to $\Phi(M_\star) + \Phi(M_\star|M,z=0)$

Fit to Two-Point Correlation Functions at z=0.1

Data: SDSS DR7
(Yang et al. 2012)

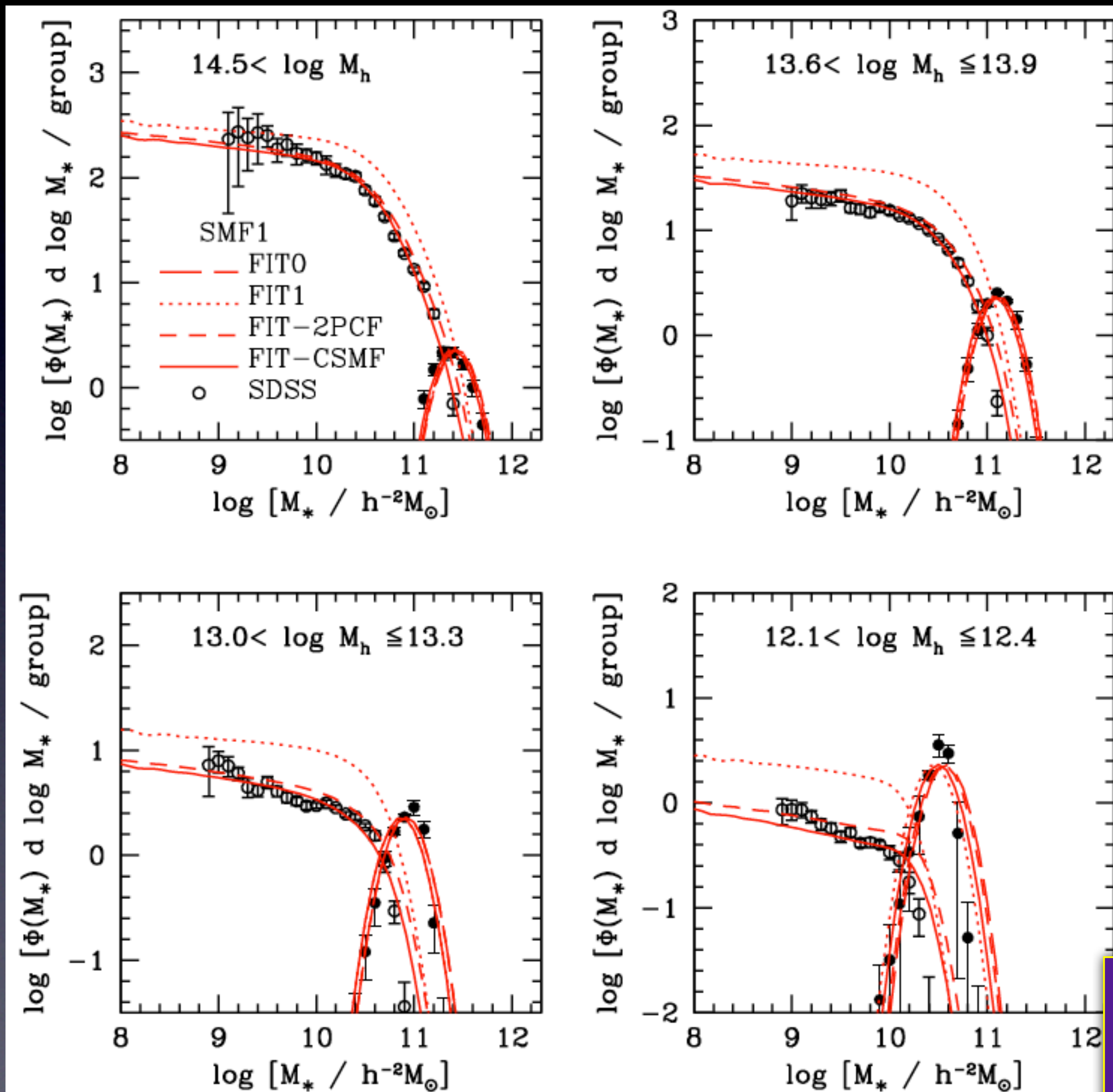


Source: Yang et al. 2012, ApJ, 752, 41

Fit 0 : α=0 --> no sats
Fit 1 : α=∞ --> no evolution
2PCF : fit to $\Phi(M_\star)$ + 2PCF
CSMF : fit to $\Phi(M_\star)$ + $\Phi(M_\star|M,z=0)$

Fit to Conditional Stellar Mass Functions at z=0.1

Data: SDSS Galaxy Group Catalogues (Yang et al. 2009)

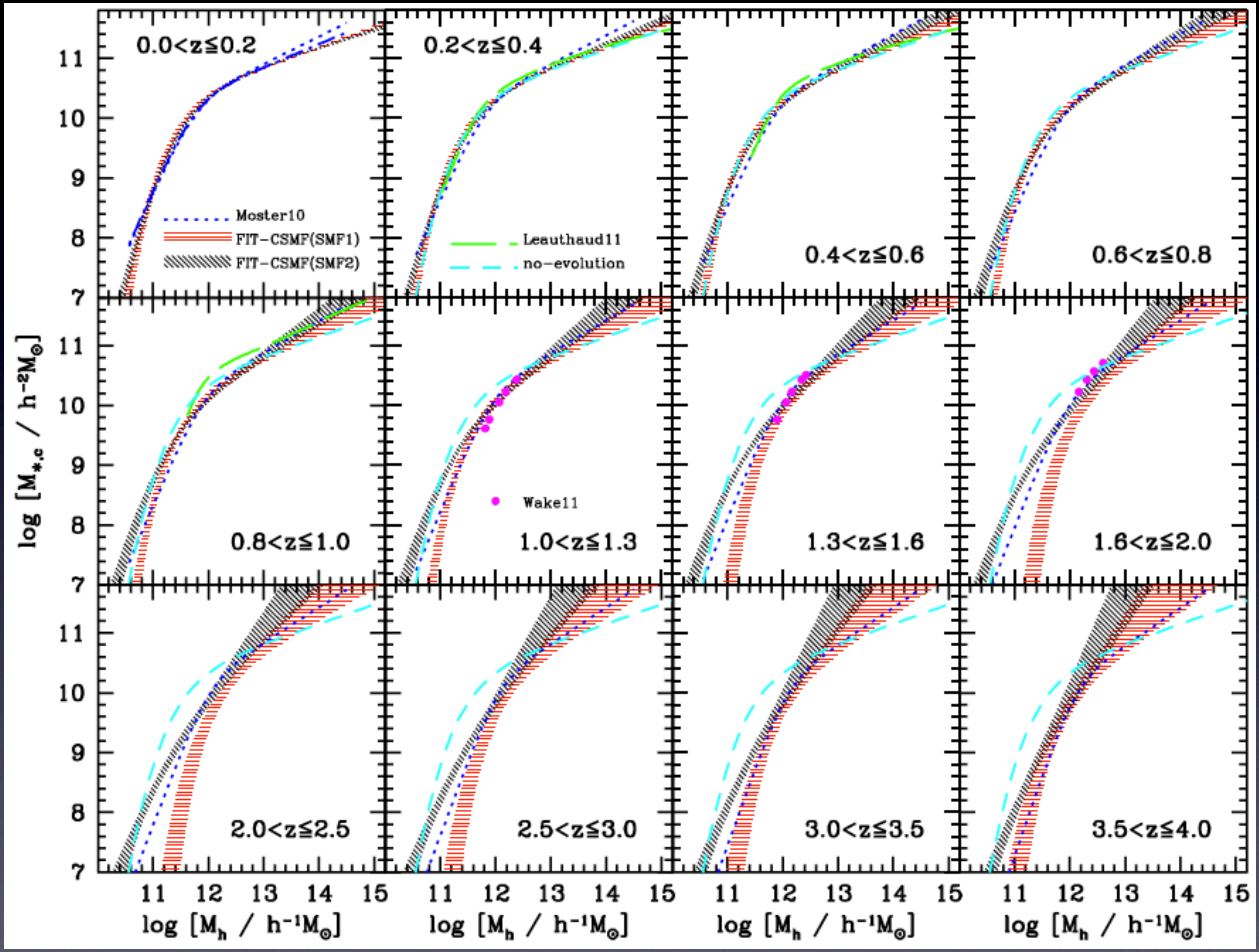


Source: Yang et al. 2012, ApJ, 752, 41

best-fit value for c ~ 0.95 +/- 0.05 indicating that sats continue to grow in stellar mass after accretion, in excellent agreement with recent results by Wetzel et al. (2012)

Fit 0 : α=0 --> no sats
Fit 1 : α=∞ --> no evolution
2PCF : fit to $\Phi(M_\star)$ + 2PCF
CSMF : fit to $\Phi(M_\star) + \Phi(M_\star|M,z=0)$

Comparison of Stellar Mass - Halo Mass Relations

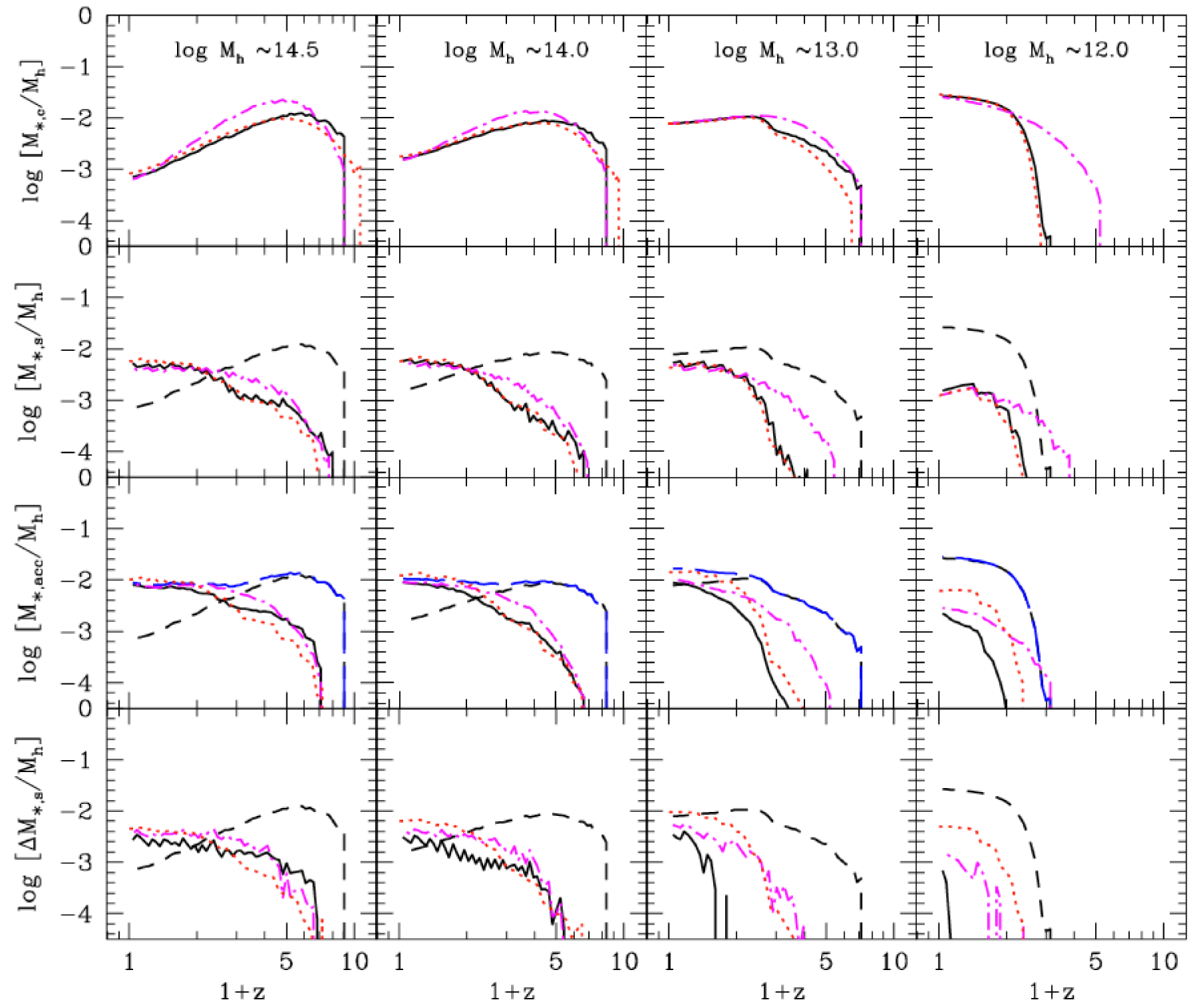


Source: Yang et al. 2012, ApJ, 752, 41

Main uncertainty arises from uncertainties in observational constraints on stellar mass functions at high redshift

SMF1: Perez-Gonzales et al. (2008)
SMF2: Drory et al. (2005)

Stellar Assembly Histories of Galaxies



centrals

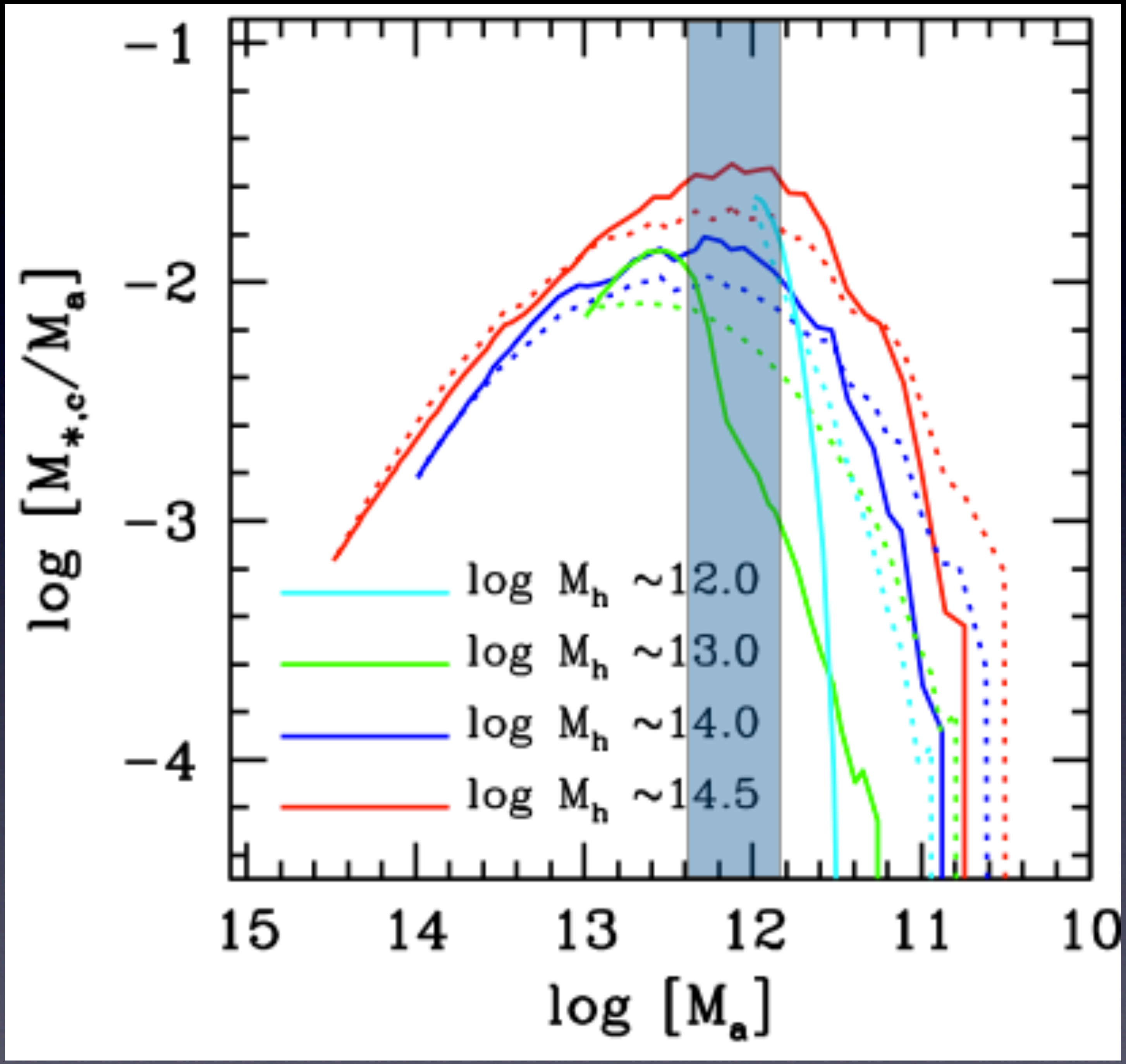
surviving satellites

accreted satellites

stellar halo

Source: Yang et al. 2012, ApJ, 752, 41

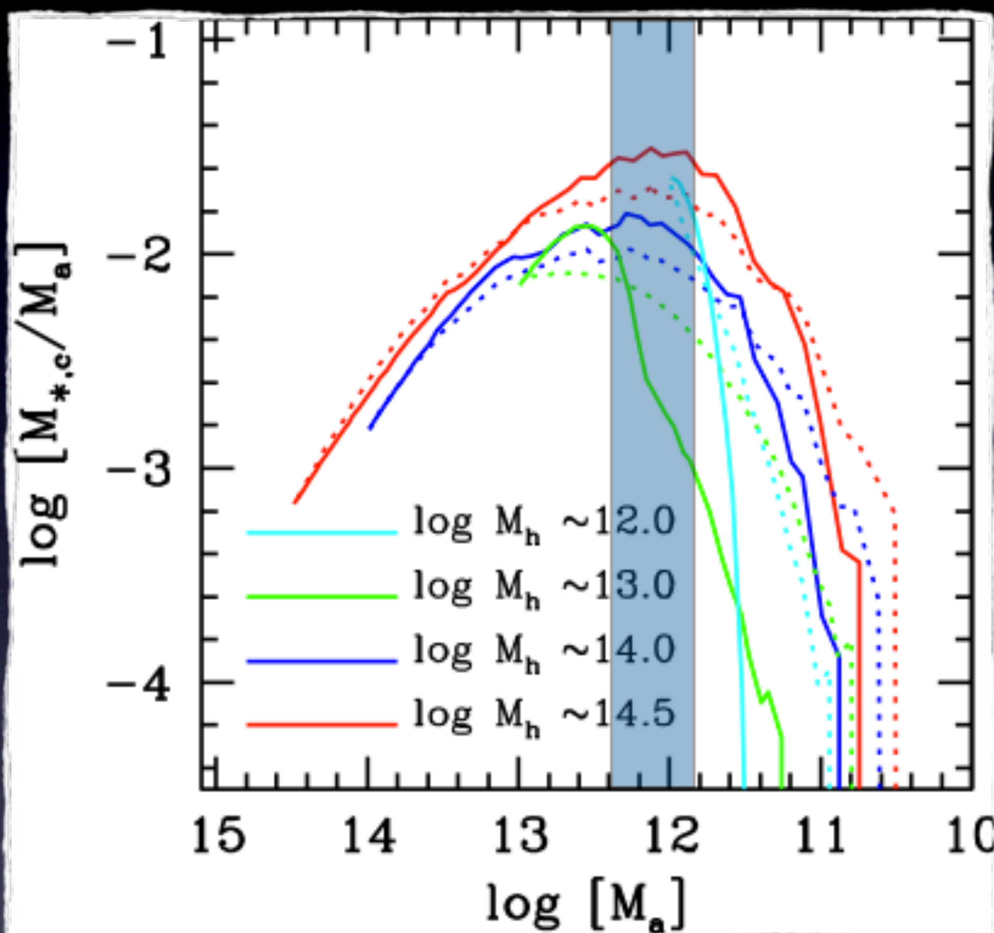
The Stellar Assembly History of Central Galaxies



Stellar Mass Growth is truncated ones halo mass reaches $\sim 10^{12}h^{-1}M_{\odot}$

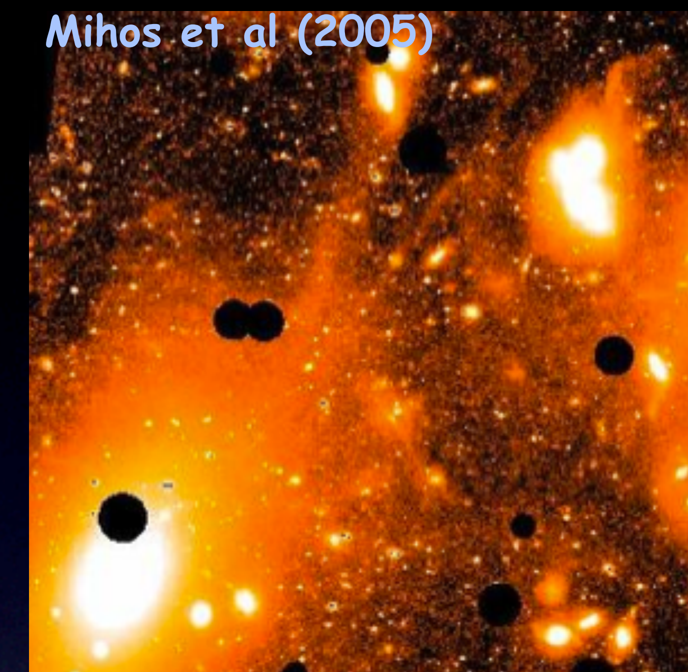
Mass growth, quenching & stripping

Central galaxies grow in stellar mass until host halo mass $\sim 10^{12} h^{-1} M_{\odot}$



Yang et al. 2012, ApJ, 752, 41

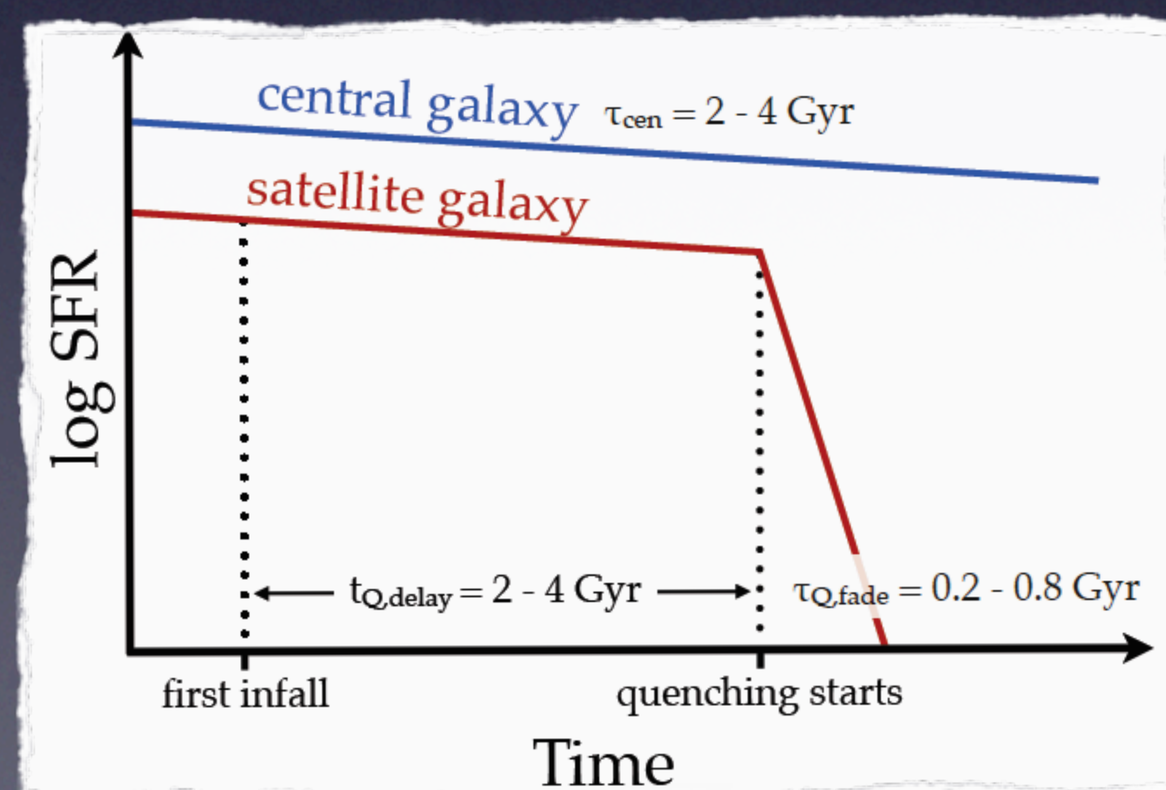
Tidal disruption of satellite galaxies is an important ingredient. It explains both satellite abundances and ICL/stellar halos.



See also: Conroy et al. 2007; Kang & vdBosch 2008; Yang, Mo & vdBosch 2009; Pasquali et al. 2010

Satellites continue to grow in stellar mass after accretion for 2-4 Gyr. After that they quench rapidly (in 0.2 - 0.8 Gyr).

See also: Weinmann et al. 2006, 2009; vdB et al. 2008; Kimm et al. 2009; Wetzel et al. 2012



Wetzel et al. 2012 (arXiv:1206.3571)

CONCLUSIONS

- Satellite Galaxies are very different from Central Galaxies.
- We presented the first fully self-consistent, dynamic model of the galaxy-dark matter connection across cosmic time.
- The model accurately matches all data (stellar mass functions, correlation functions, conditional stellar mass functions)
- Limiting factor is accuracy of stellar mass functions at high z.
- Time scale for satellite disruption ~ dynamical friction time.
- Satellites continue to grow in stellar mass very much like centrals of the same stellar mass (see also Wetzel et al. 2012)
- Central galaxies `quench' once halo mass reaches ~10^{12}Msun
- Stellar mass growth is COMPLETELY decoupled from halo mass growth; star formation only happens over ~1 decade in halo mass: 10^{11} - 10^{12}Msun