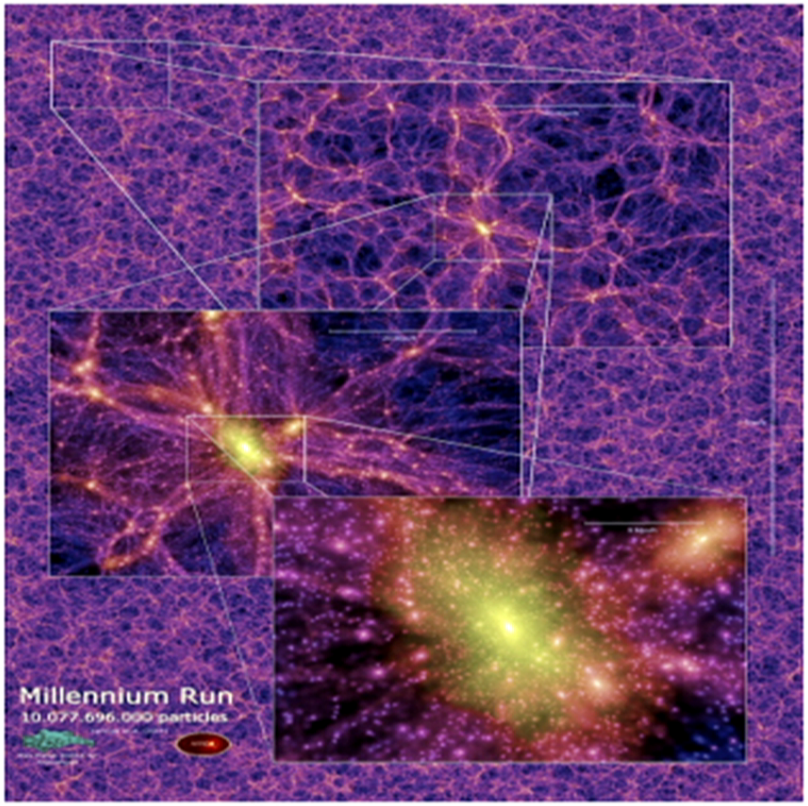
Title: Models of Galaxy formation: Current constraints on the star formation history and feedback

Date: Mar 14, 2016 02:00 PM

URL: http://pirsa.org/16030093

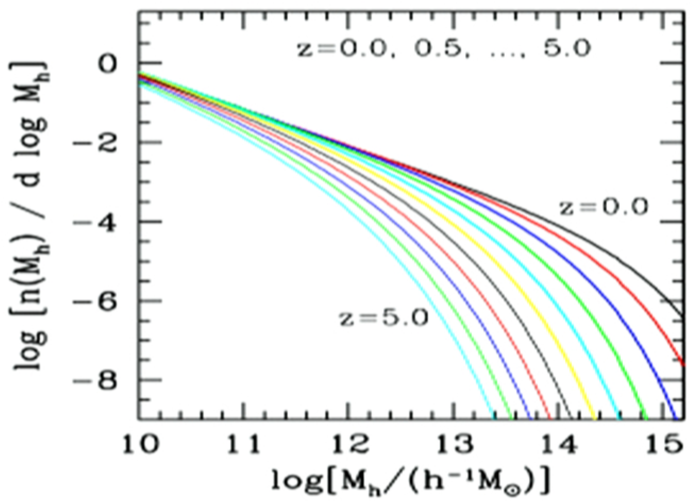
Abstract:

Galaxy formation in CDM paradigm



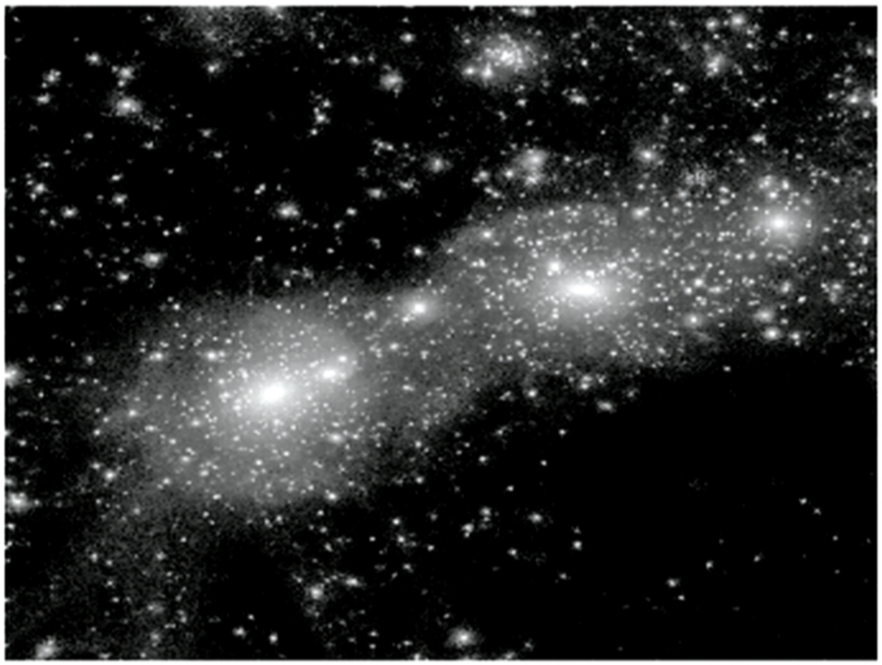
Dark matter halos: hosts of galaxies

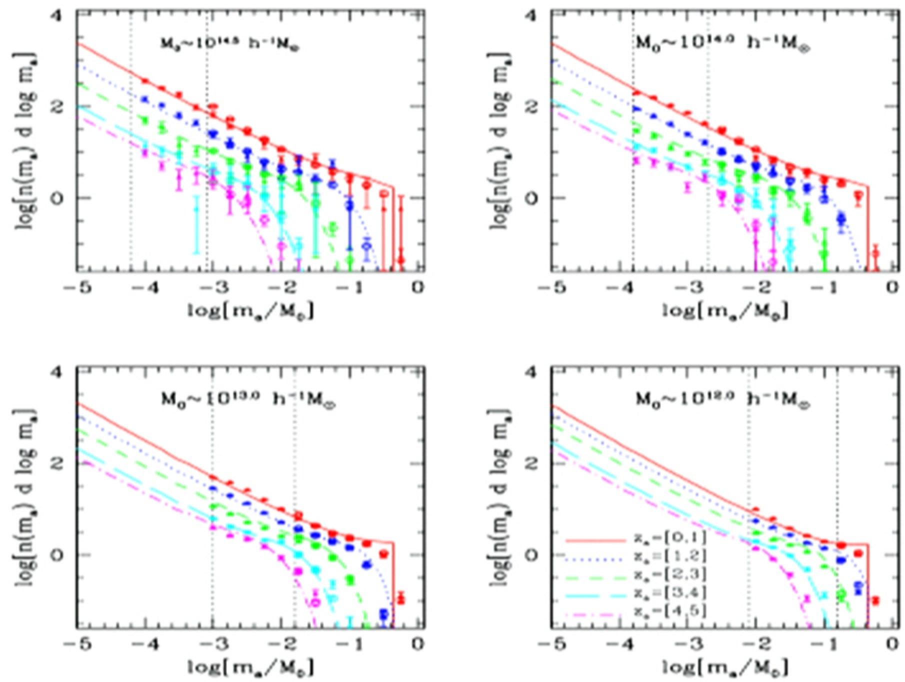
Halo mass function:
$n(M)dM \propto M^{-2}dM$ at low mass end;
break away at $M \gg M_*(z)$



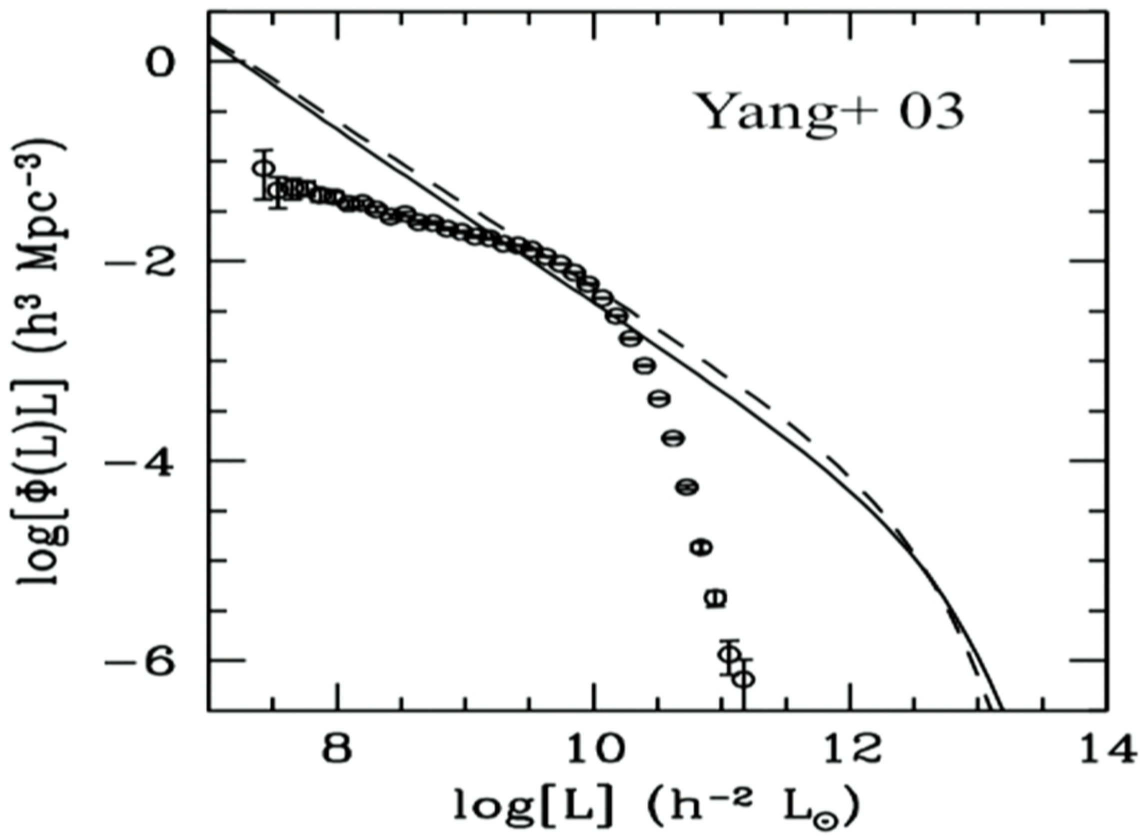
Sub-halos: they were halos at high z; galaxies formed in them are present satellite galaxies

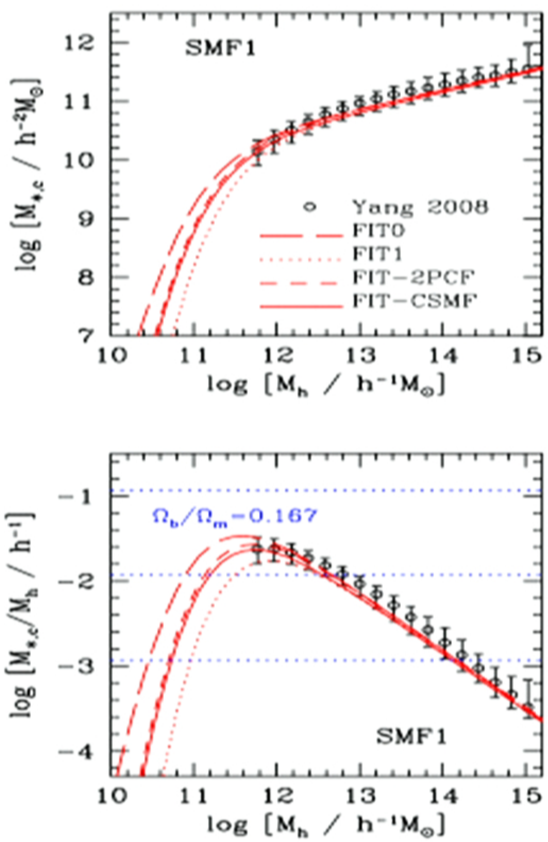
Sub-halo mass function:
$n(m|M_0)dm \propto (m/M_0)^{-1.8}dm$ at $m \ll M_0$;
break away at $m > 0.3M_0$





Shape very different from galaxy luminosity/stellar mass function



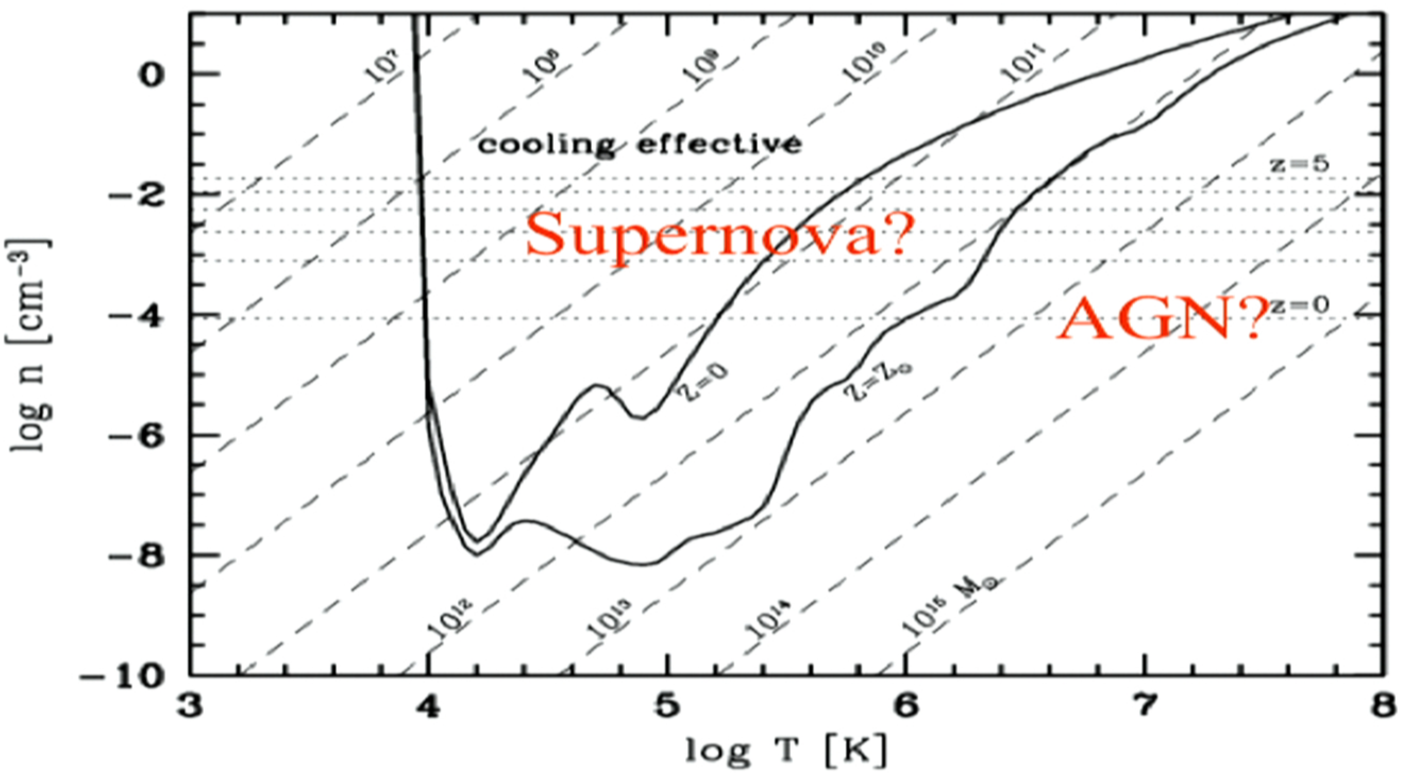


Yang+ 2012

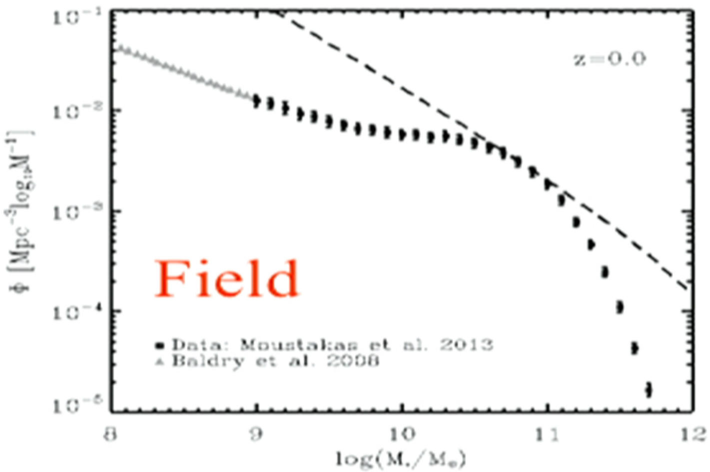
1. Star formation most efficient in Milky-Way size halos; only about 1/4 - 1/3 of the halo gas forms stars.

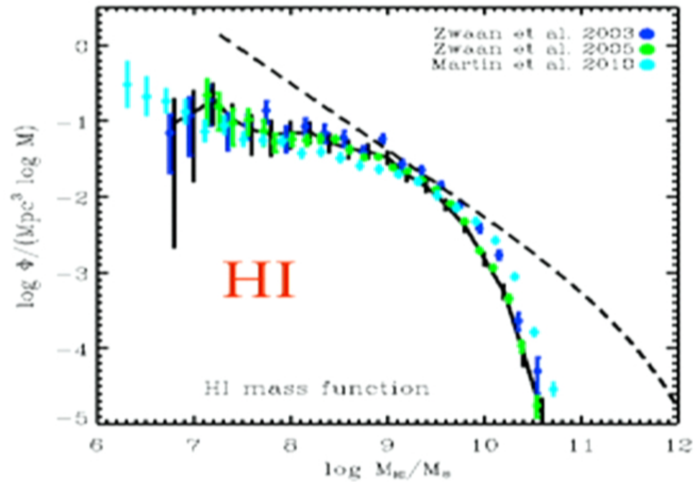
2. Star formation efficiency is even lower for both lower and higher halo masses

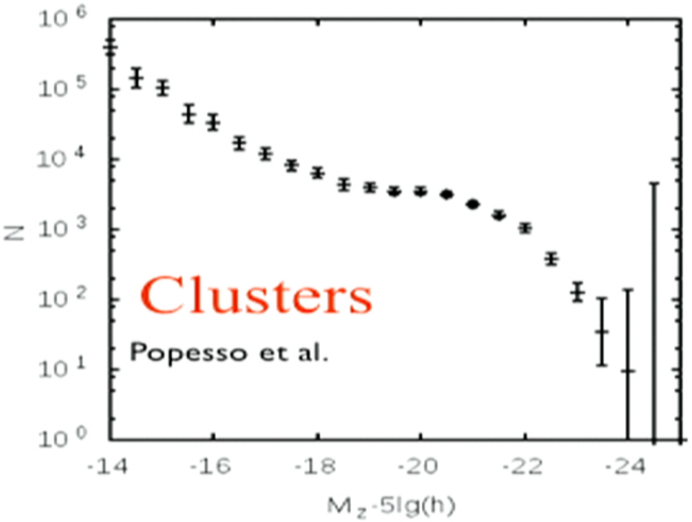
Radiative cooling not the solution; feedback needed

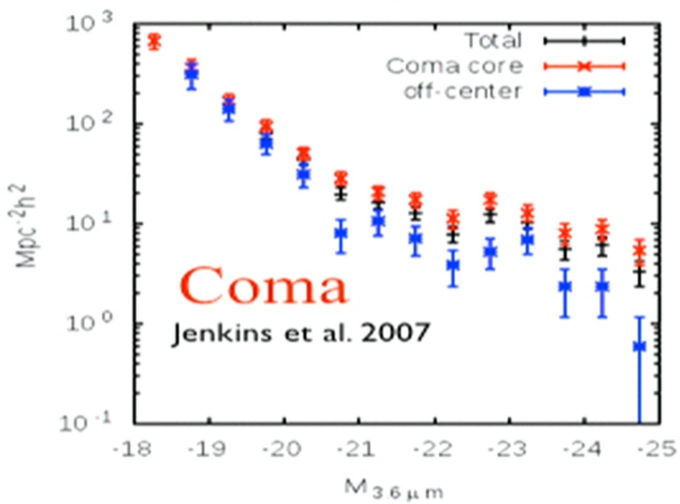


Observational constraints in more detail



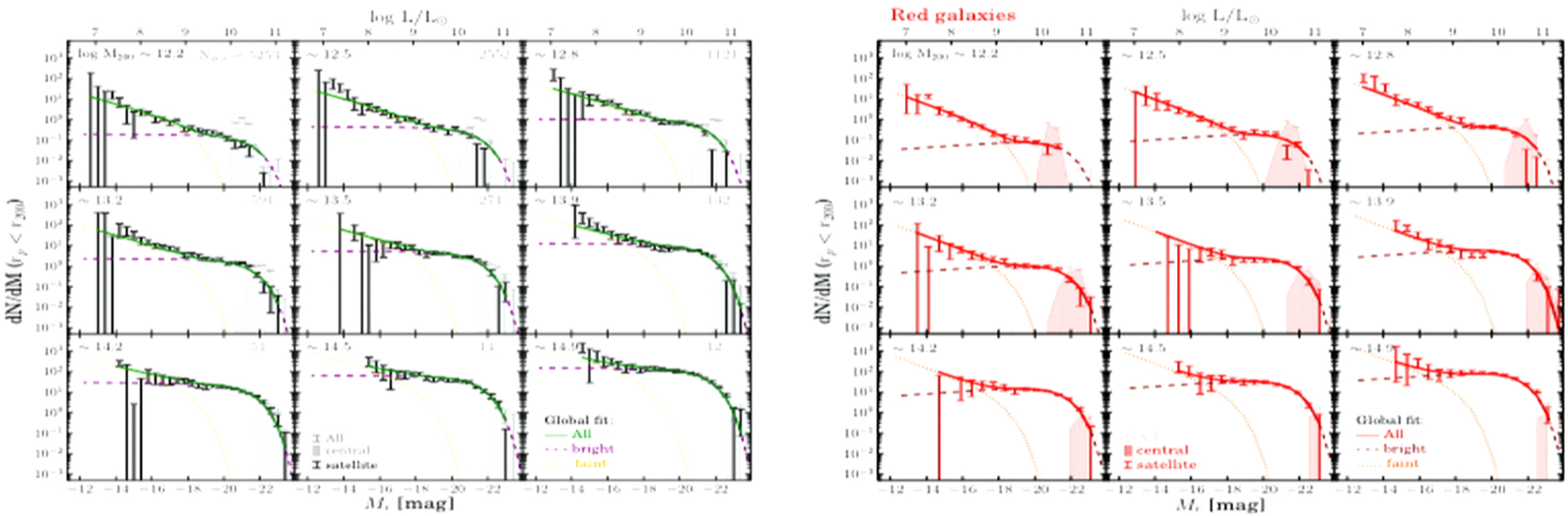






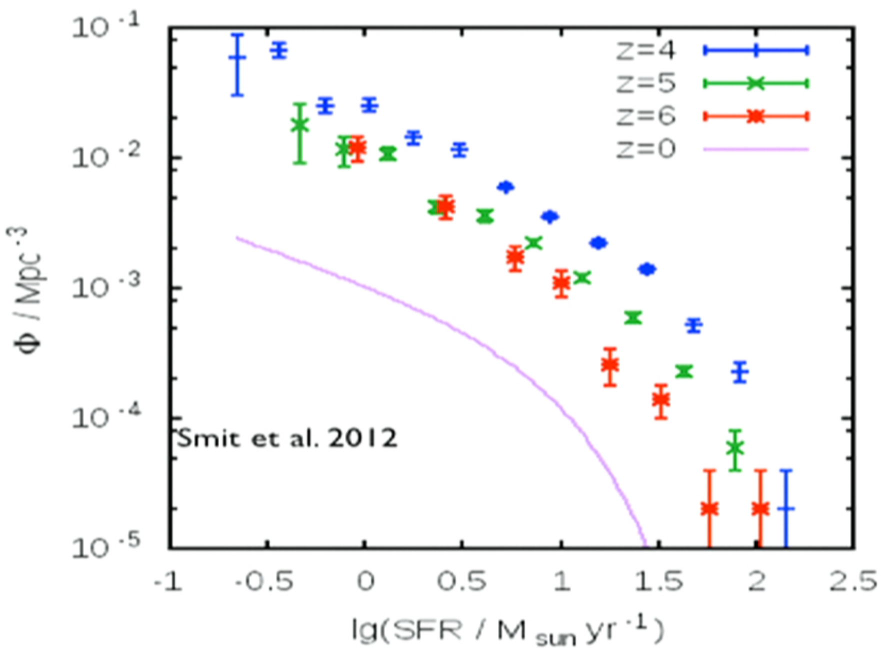
Faint-end upturn

Faint-end upturn ubiquitous

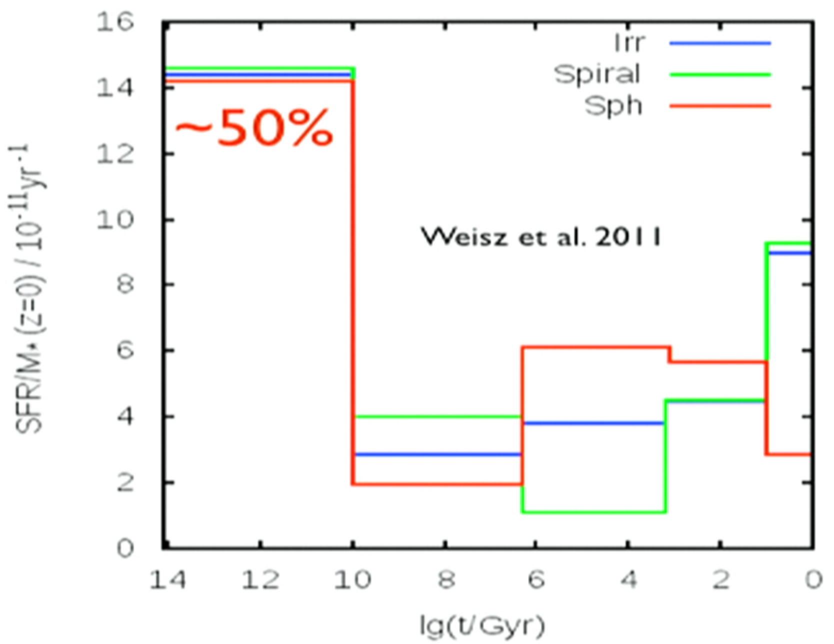


Lan+ 2016

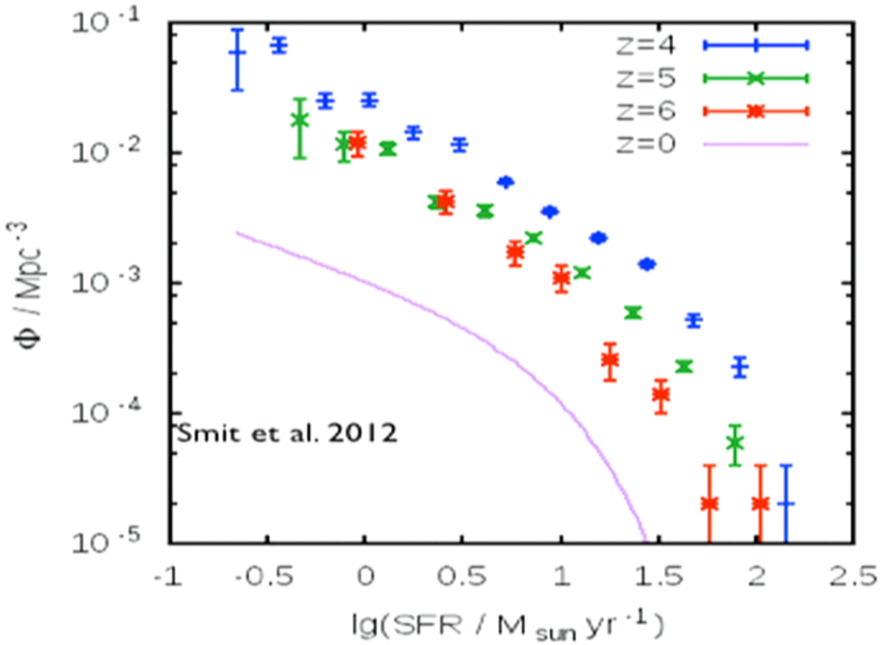
SFR function steepens at high z



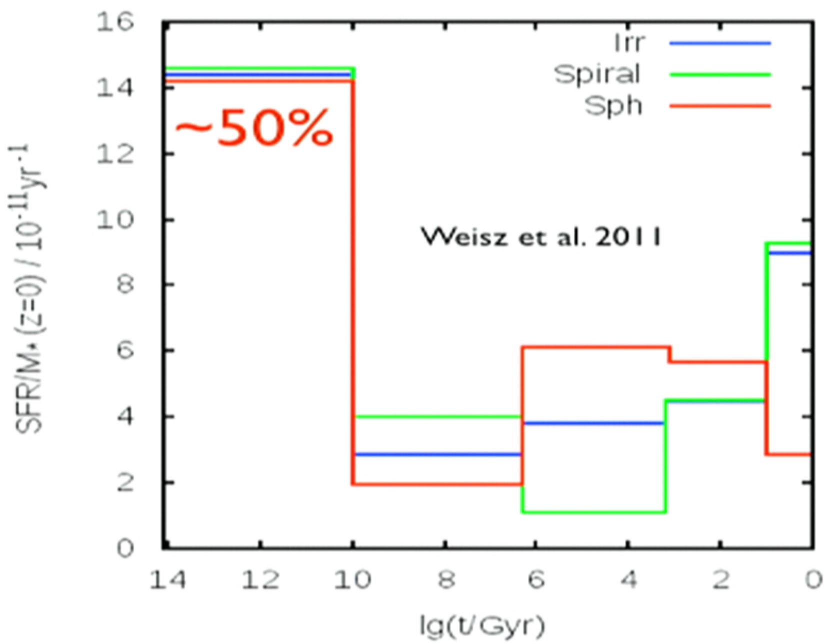
HST, CMR of dwarf galaxies: half of the stars formed at z>2



SFR function steepens at high z



HST, CMR of dwarf galaxies: half of the stars formed at z>2



A simple empirical model to understand what is going on

$$\dot{M}_\star = \mathcal{E}\,\frac{f_b M_{\rm vir}}{\tau_0}\,(1+z)^\eta\,(X+1)^\alpha \left(\frac{X+\mathcal{R}}{X+1}\right)^\beta \left(\frac{X+\mathcal{R}}{X}\right)^\gamma$$

where $\mathcal{E}$ overall efficiency; f_b cosmic baryon mass fraction; τ_0 is the dynamic timescale at present day, and $\eta = \eta' + 3/2$.

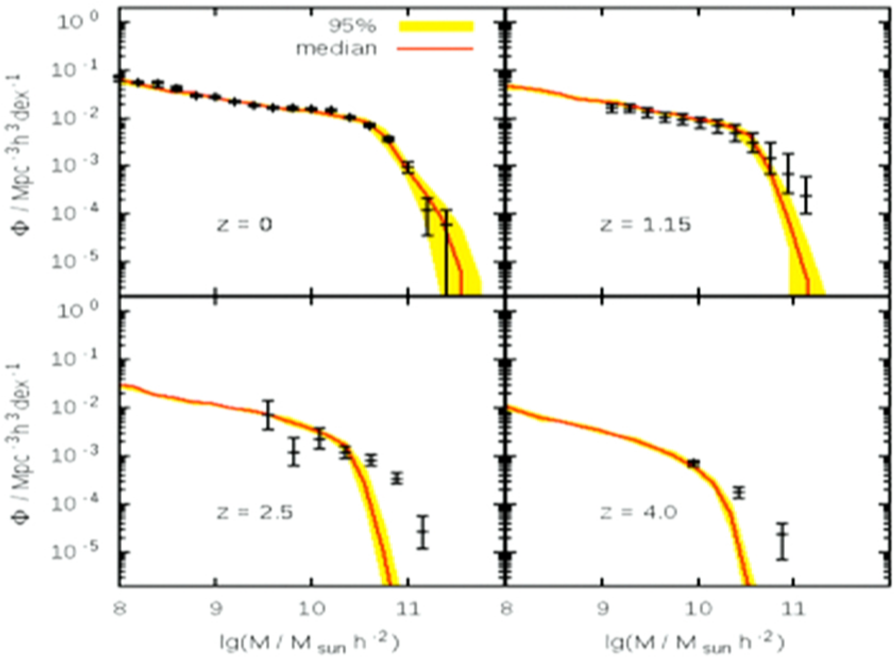
$$X \equiv M_{\rm vir}/M_{\rm c}; \qquad \mathcal{R} < 1.$$

Two characteristic masses: M_c and $\mathcal{R}M_c$, and three slopes: α, β and γ. All of them may depend on z.

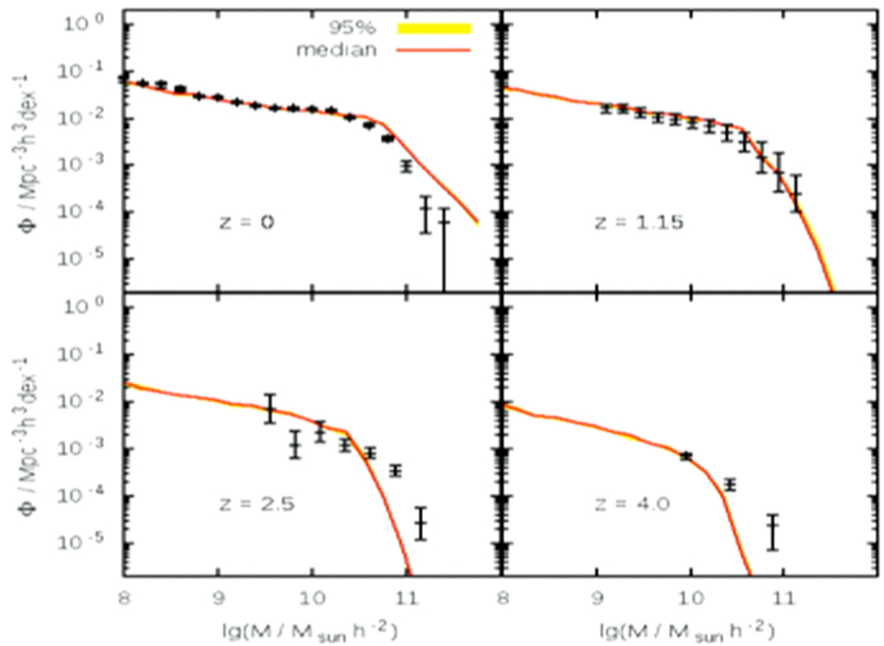
Halo merger trees and galaxy stripping and merger treated as in semi-analytic model.

Lu+ 2014, 2015

Model-I: all model parameters are independent of z



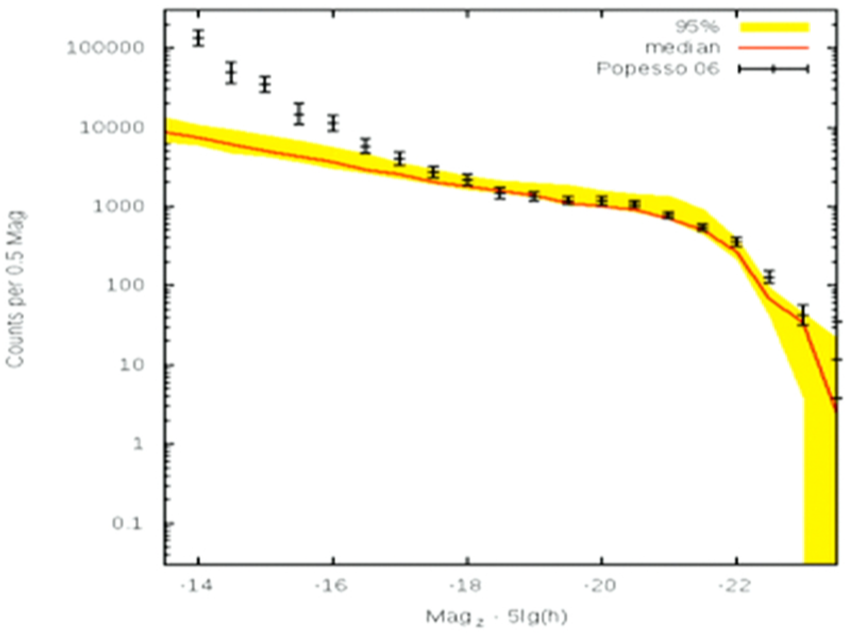
Only z=0 constrained



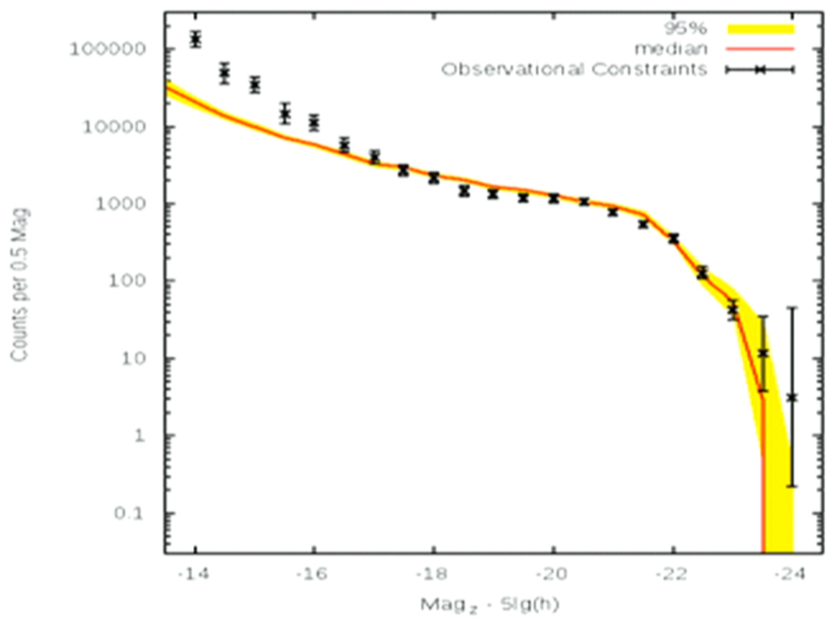
all as constraints

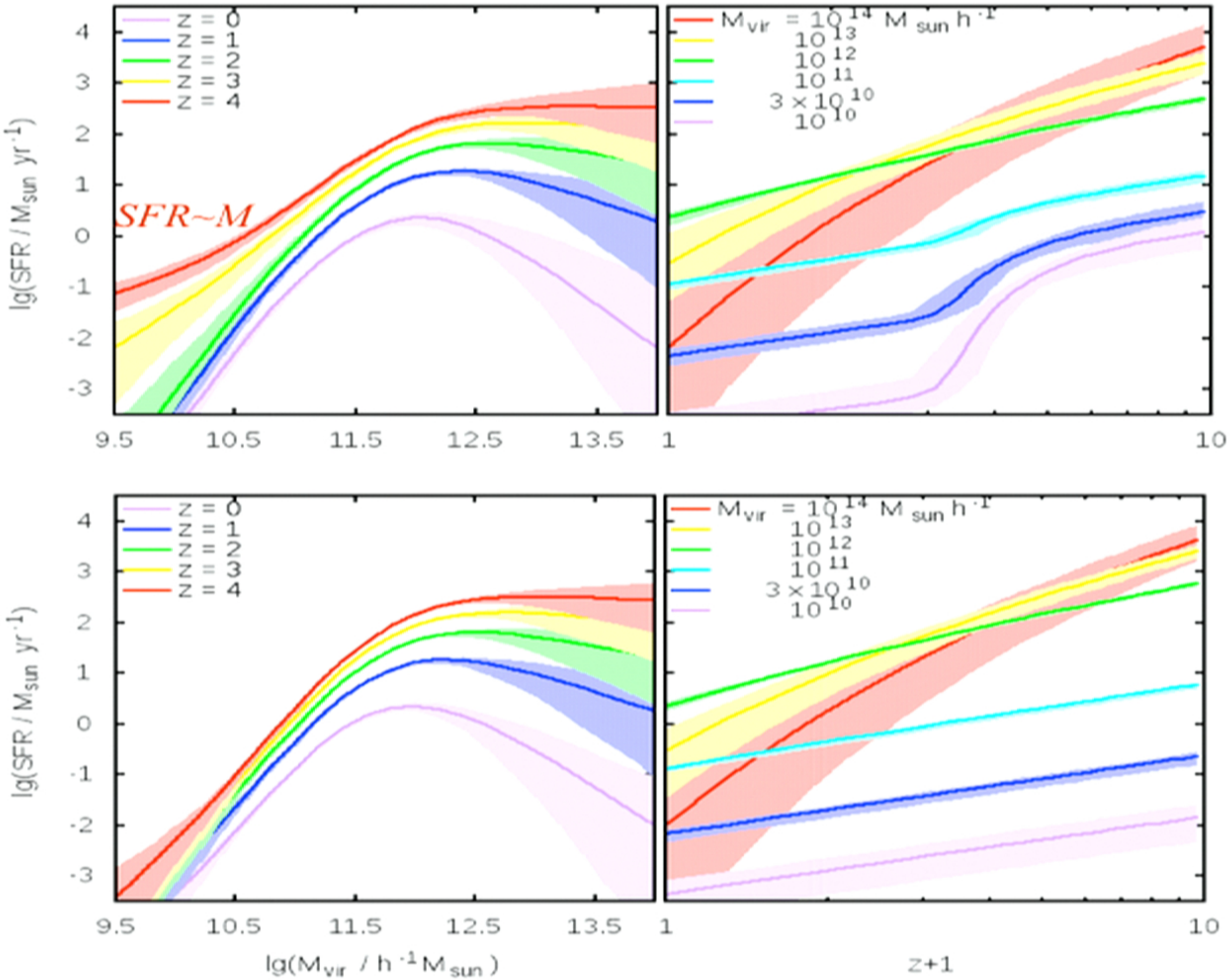
Problem with the cluster galaxy luminosity function

Prediction



Used as a constraint





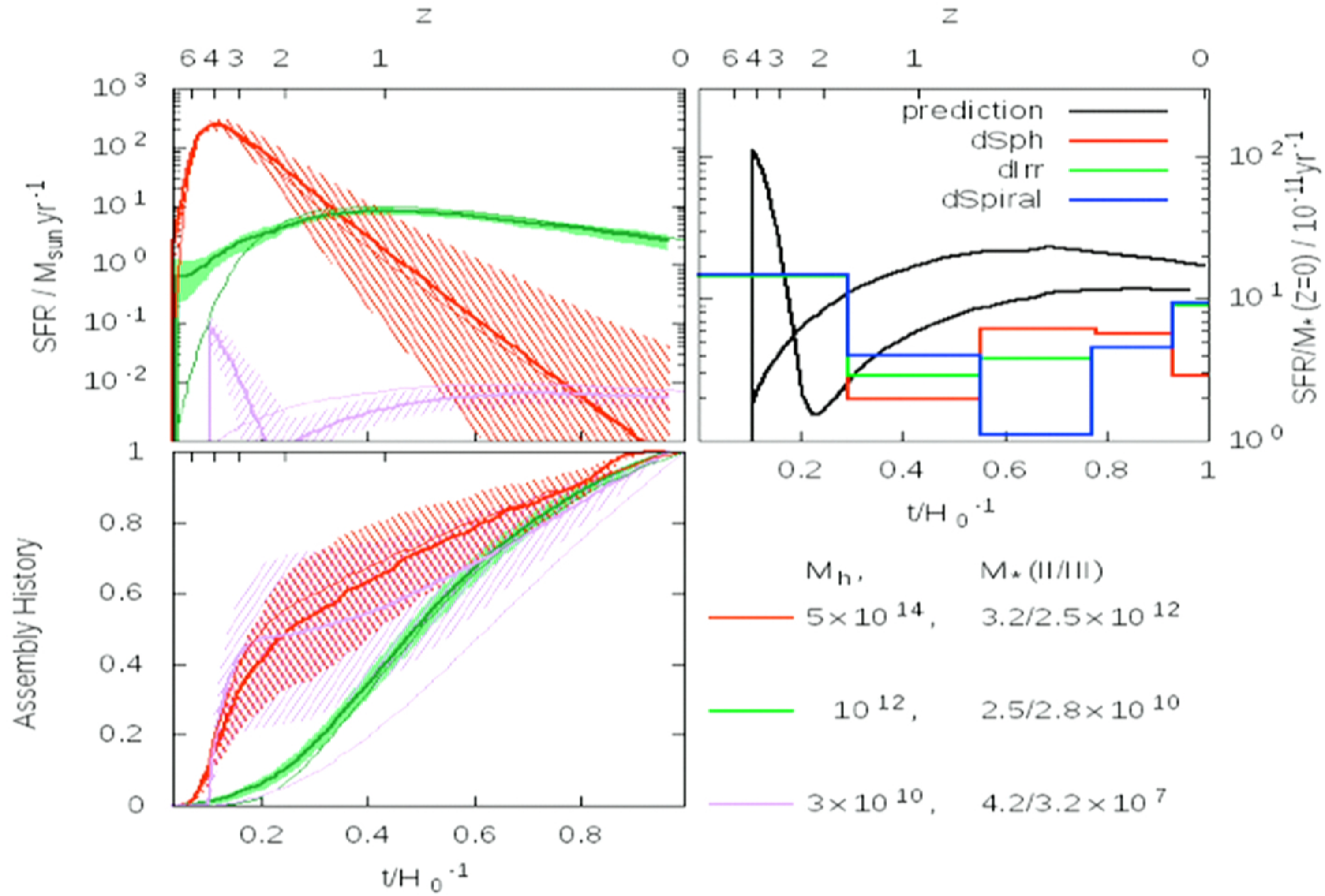
Model-III

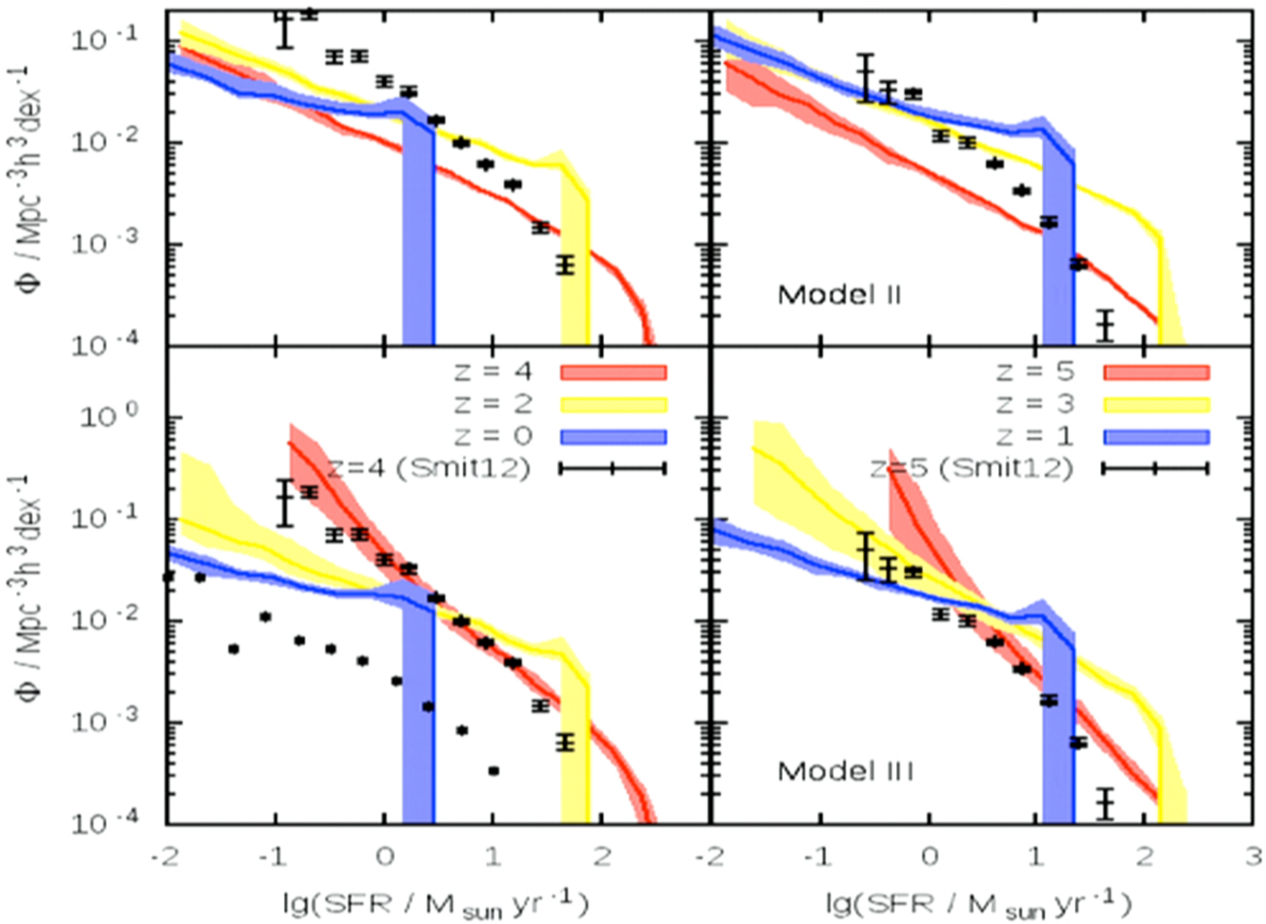
$z_c = 2.2 \pm 0.5$

A new time scale

Model-II

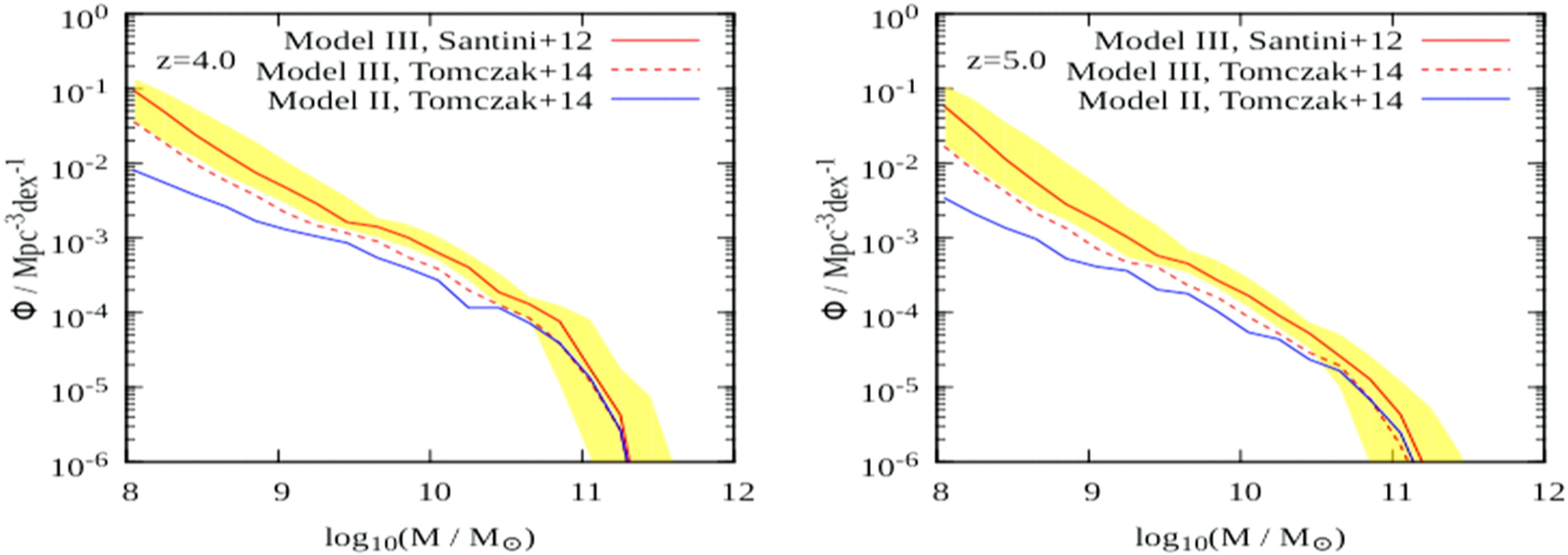
Model Predictions



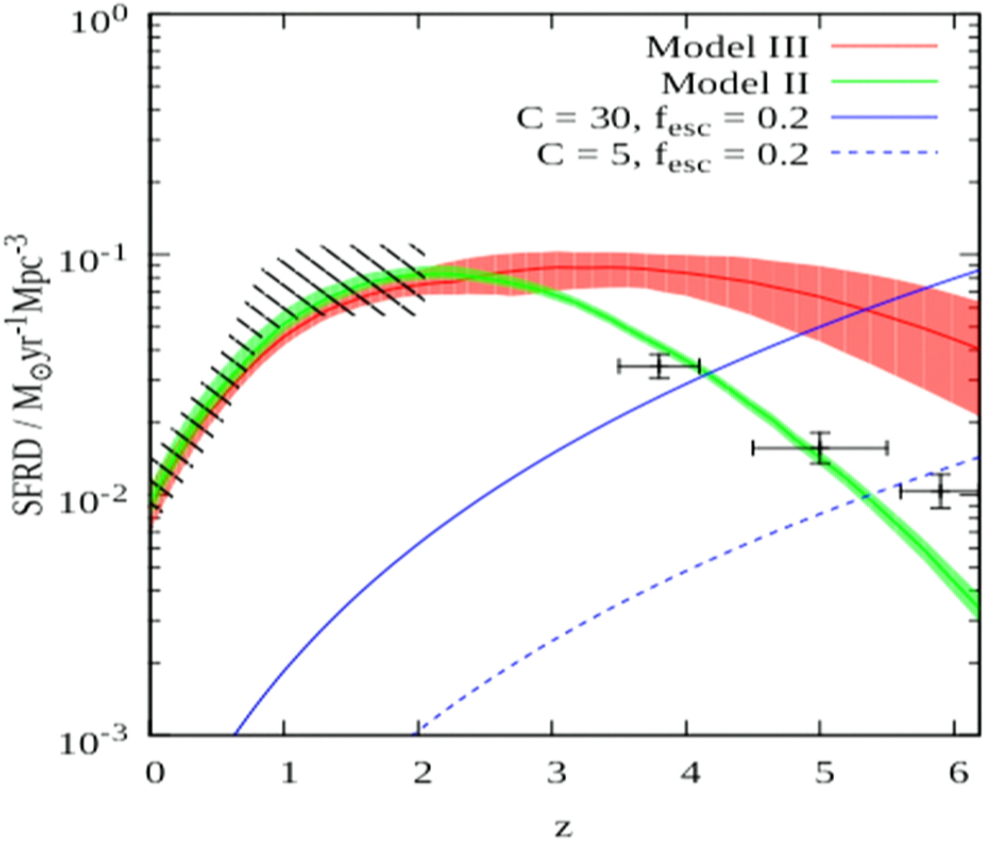


Φ / Mpc⁻³h³dex⁻¹
Model II
Model III
z = 4
z = 2
z = 0
z=4 (Smit12)
z = 5
z = 3
z = 1
z=5 (Smit12)
lg(SFR / M sun yr⁻¹)

Prediction of SMFs at high z



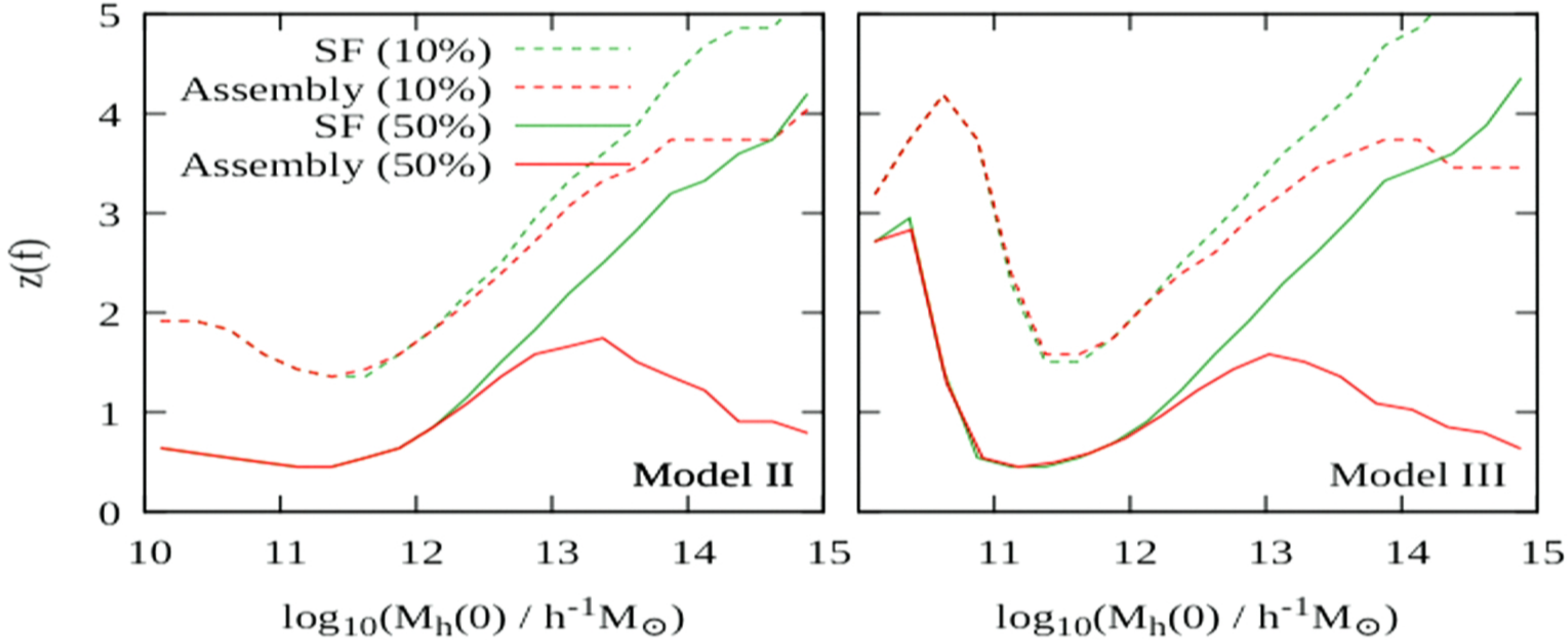
Implication for re-ionization



Downsizing versus upsizing

z(f): redshift by which a fraction f of final stellar mass has been formed or assembled

A new mass scale



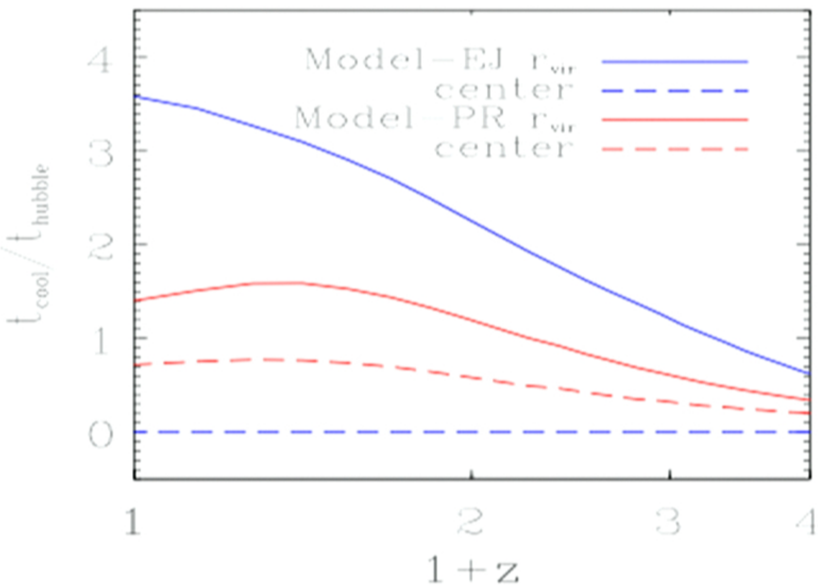
Implications for feedback

The key is to reduce gas accretion efficiency; Feedback must be preventative, at least at z<2

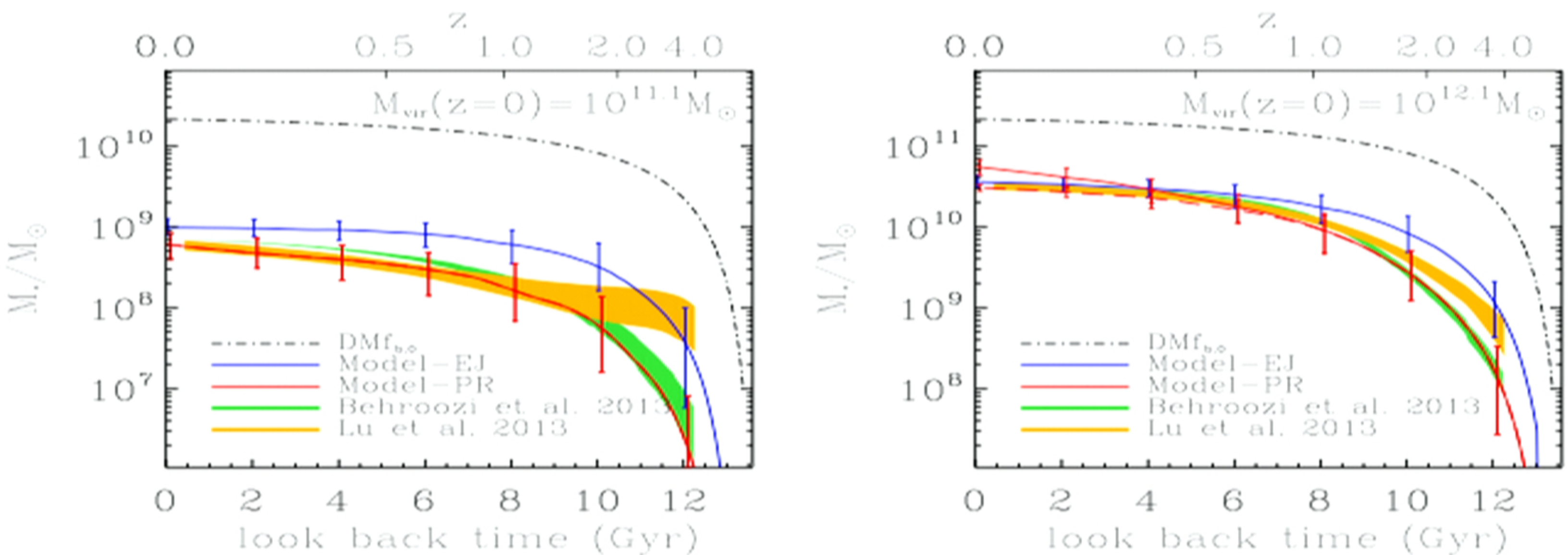
A preheating model: proto-galaxy gas is preheated to finite entropy by early star formation/AGN activities

(Mo&Mao02, 04; Mo+ 05; Lu+ 15)

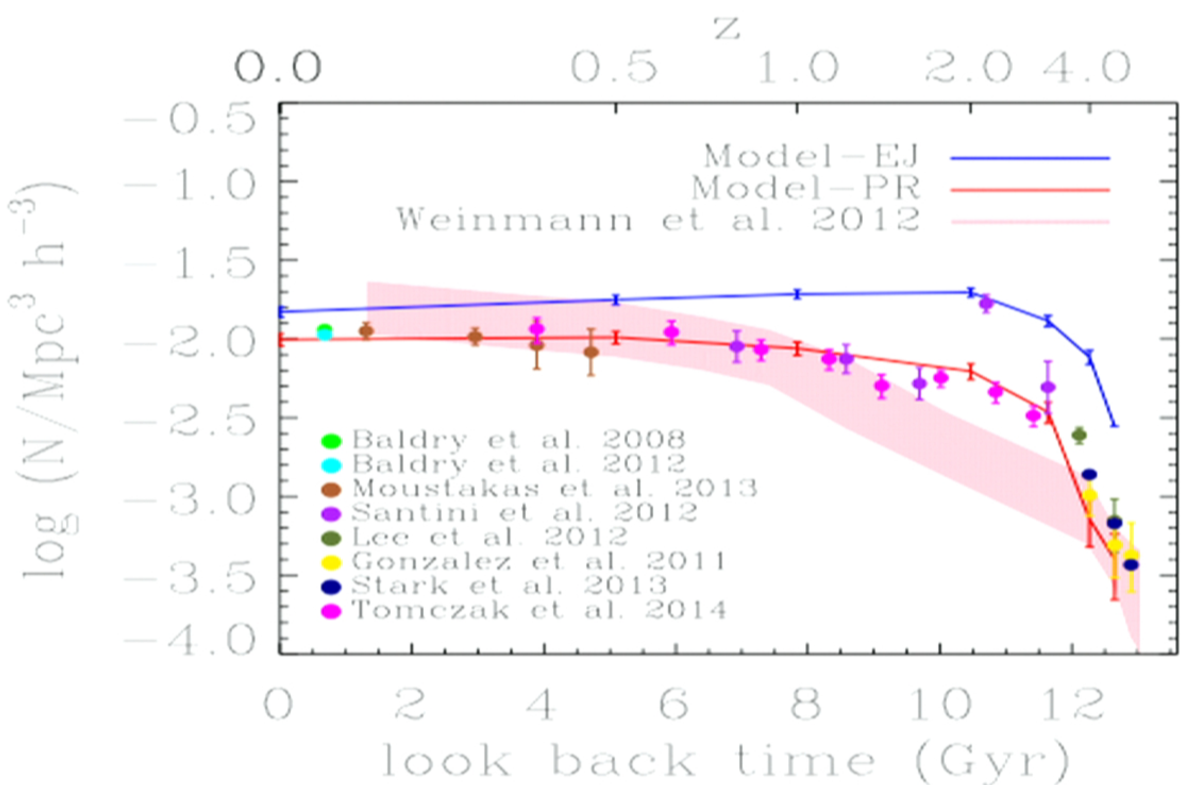
Required preheating temperature: 10^5 K at mean density



With preheating, cooling time comparable to Hubble time; cooling not inside-out anymore


z
0.0
0.5
1.0
2.0 4.0
$M_{vir}(z=0)=10^{11.1}M_{\odot}$
10^{10}
10^{9}
10^{8}
10^{7}
$M_{*}/M_{\odot}$
$DMf_{b,\odot}$
Model−EJ
Model−PR
Behroozi et. al. 2013
Lu et al. 2013
0
2
4
6
8
10
12
look back time (Gyr)
z
0.0
0.5
1.0
2.0 4.0
$M_{vir}(z=0)=10^{12.1}M_{\odot}$
10^{11}
10^{10}
10^{9}
10^{8}
$M_{*}/M_{\odot}$
$DMf_{b,\odot}$
Model−EJ
Model−PR
Behroozi et. al. 2013
Lu et al. 2013
0
2
4
6
8
10
12
look back time (Gyr)

Number density of low-mass galaxies [9.27 - 9.77]

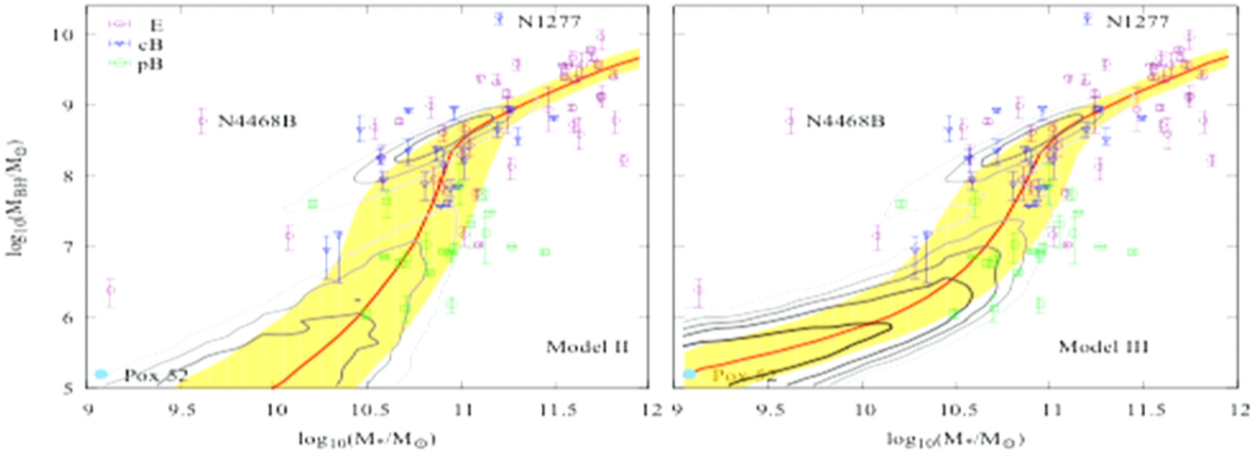


Implications for feedback

- The observed overabundance of low-mass galaxies in clusters and groups suggests two stages of star formation separated at z~2-3
- At z<2, preventative scenario better explains observation than ejective feedback.
- Preheating provides a possible solution, but what are the preheating sources?

Starbursts and AGNs associated with the
early stage of star formation;
Early galaxies were gas rich
and experienced frequent mergers,
which may drive starbursts and SMBH formation

Preheating by AGNs in high-z low-mass galaxies



Energy:

$$E = \bar{\epsilon} M_{\rm BH} c^2 \, ,$$

Preheating temperature $kT \lambda f_{\rm B} M_{\rm h}/\mu = f_\epsilon \bar{\epsilon} M_{\rm BH} c^2 \, .$
Assuming gas mass preheated: $\lambda f_B M_{\rm h}$, then preheated temperature is

$$\frac{kT}{\mu} = \frac{f_\epsilon \bar{\epsilon} c^2}{\lambda f_{\rm B}} \left(\frac{M_{\rm BH}}{M_\star} \right) \left(\frac{M_\star}{M_{\rm h}} \right) \, .$$

Taking $M_{\rm BH}/M_\star \approx 0.3\%$, $\bar{\epsilon} = 0.1$, and $M_\star/M_{\rm h} \approx 10^{-2.5}$, then

$$\frac{T}{10^6 {\rm K}} \approx 1.0 \times \left(\frac{f_\epsilon}{0.03} \right) \left(\frac{\lambda}{10} \right)^{-1} \, .$$

Summary

- The average star formation and stellar mass assembly histories in dark matter halos can be inferred from the observed stellar mass/luminosity functions at different redshifts combined with the observed stellar mass/luminosity function of galaxies in halos of different masses at low z.
- The inferred star formation and stellar mass assembly histories show different characteristics in different stellar mass/halo mass scales.
- Low-mass galaxies show two stage of star formation, with a characteristic redshift $z \sim 2$-3. At higher z, SFR ~ M; lower z, SFR increases steeply with M.
- At $z<2$ preventative scenario matches observation better than ejective one.
- Preheating by starbursts and AGNs at $z>2$ may provide a viable preventative feedback scenario.
- Observations can provide important insight into feedback processes.