2013 Santa Cruz galaxy workshop

Formation of Disk Galaxies

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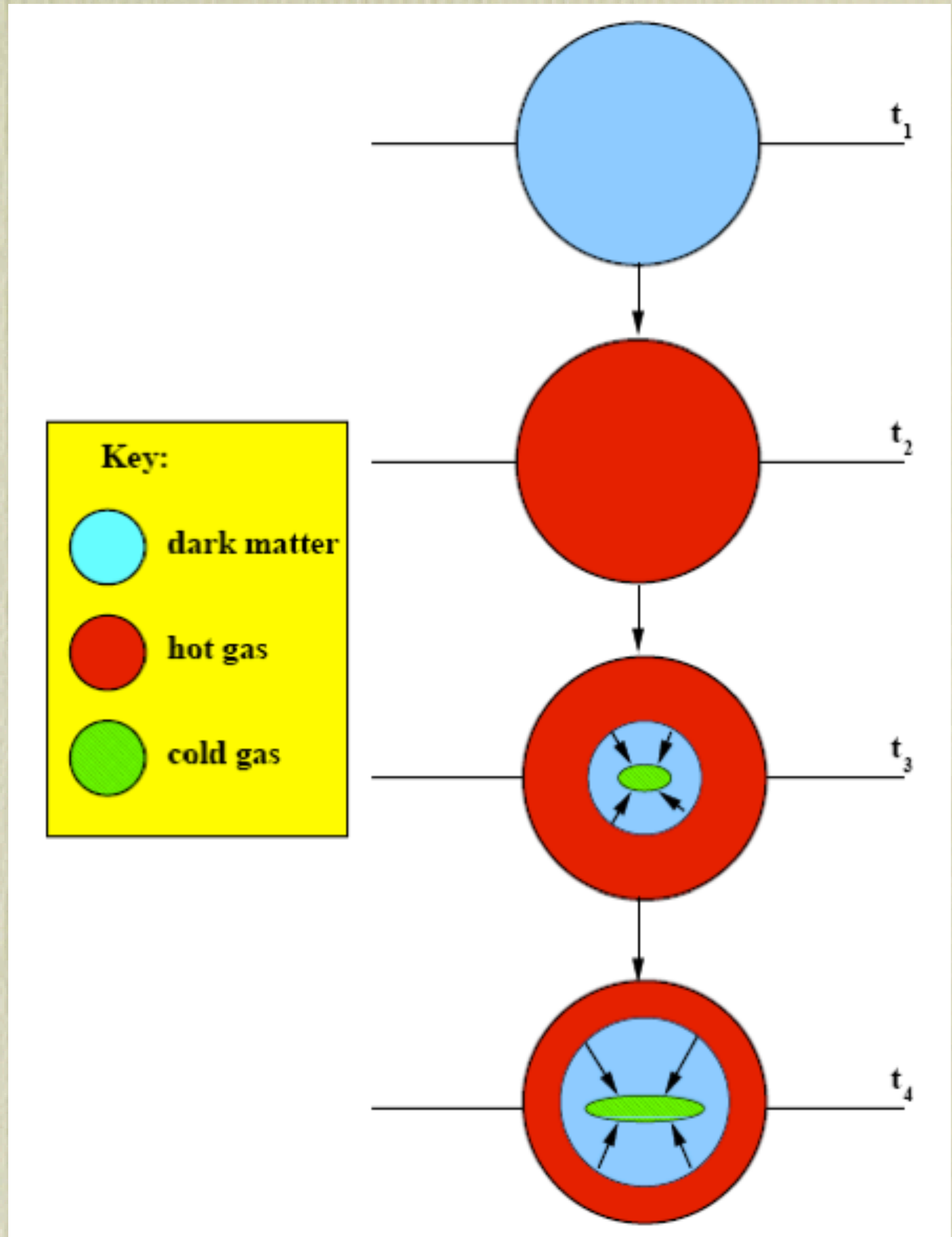
Model for disk formation

- Baryons follow dark matter to collapse into halos.
- Cooling gas (or cold accretion) collapses onto the central galaxy.
- Cold gas is rotationally supported.
- Cold gas in the disk fragments to form stars.
- Star formation feedback ejects some of the cold gas out of the galaxy (e.g. Dekel & Silk 1986).



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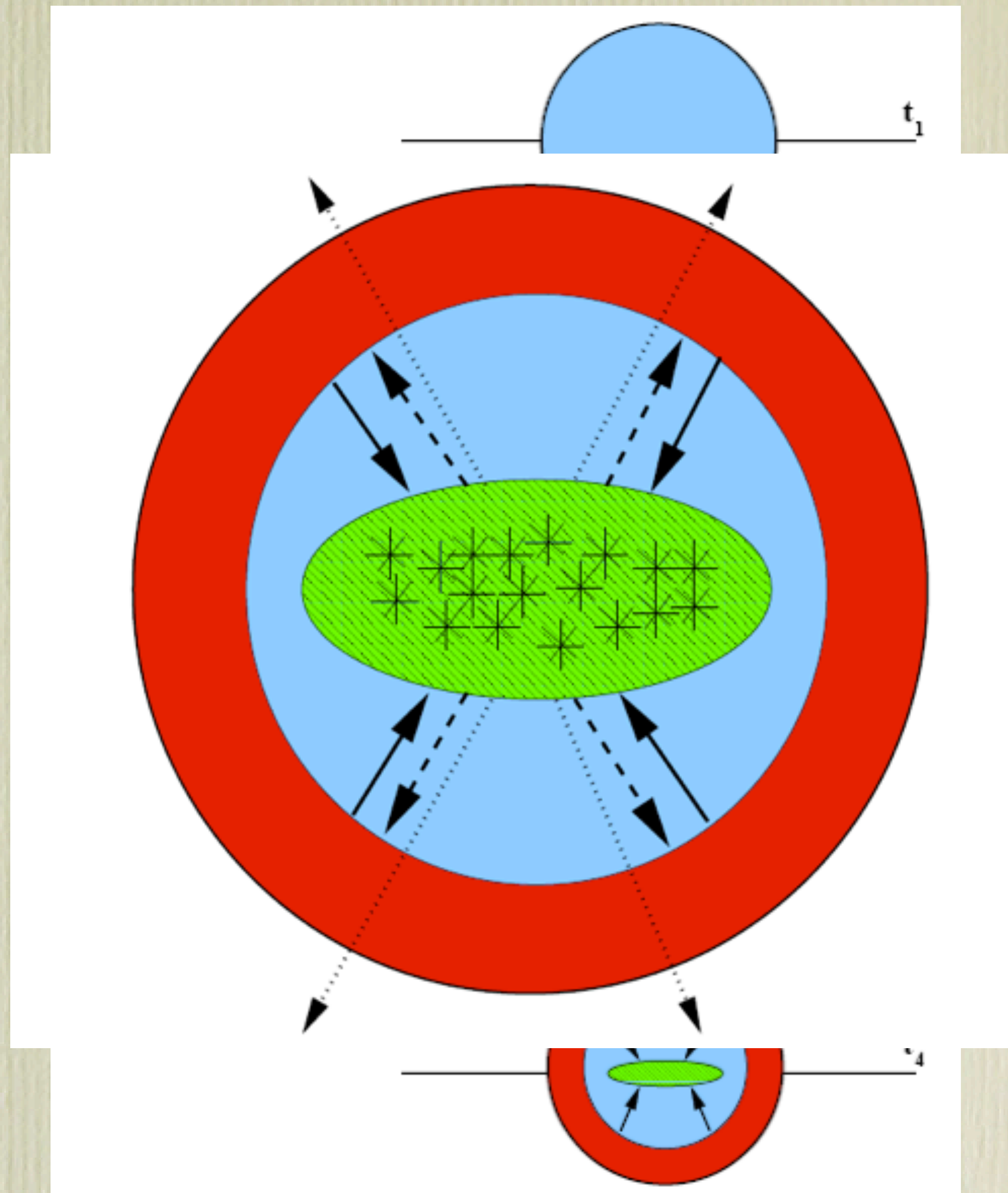
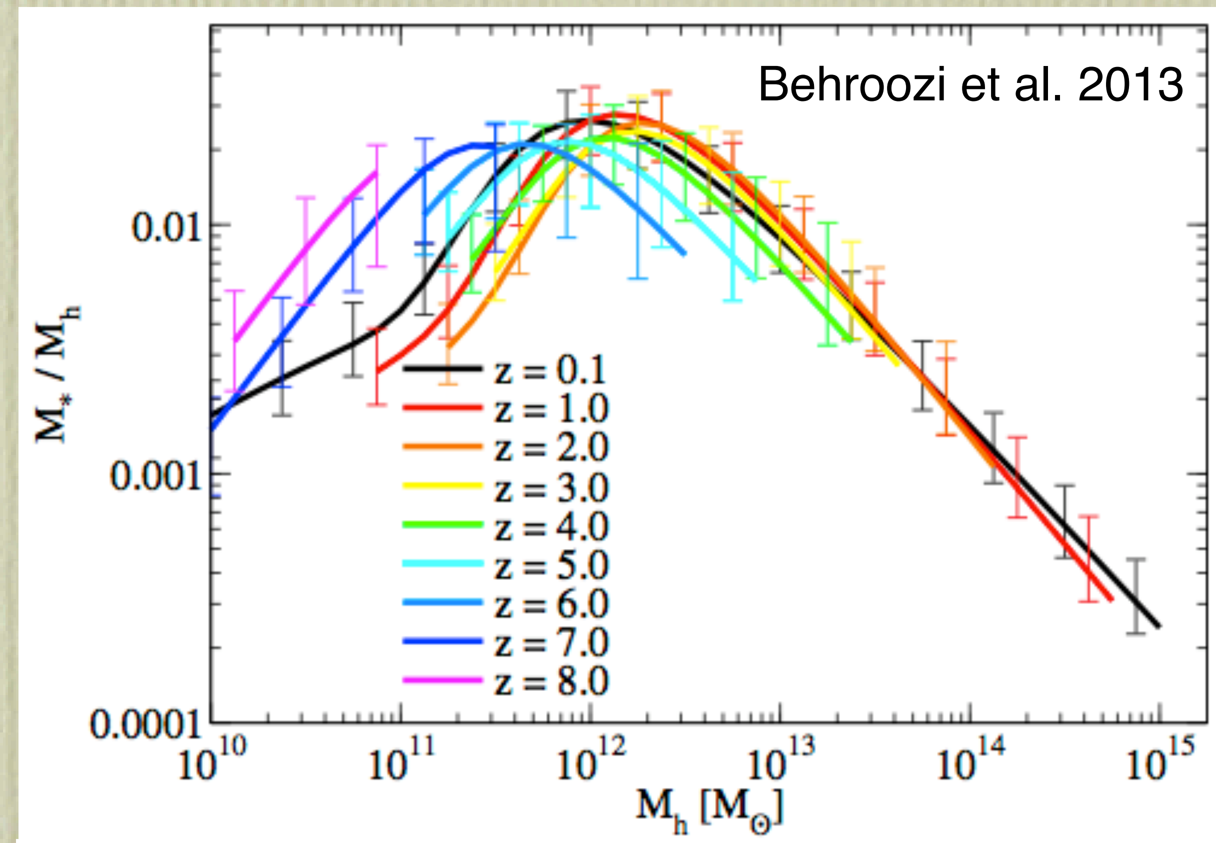
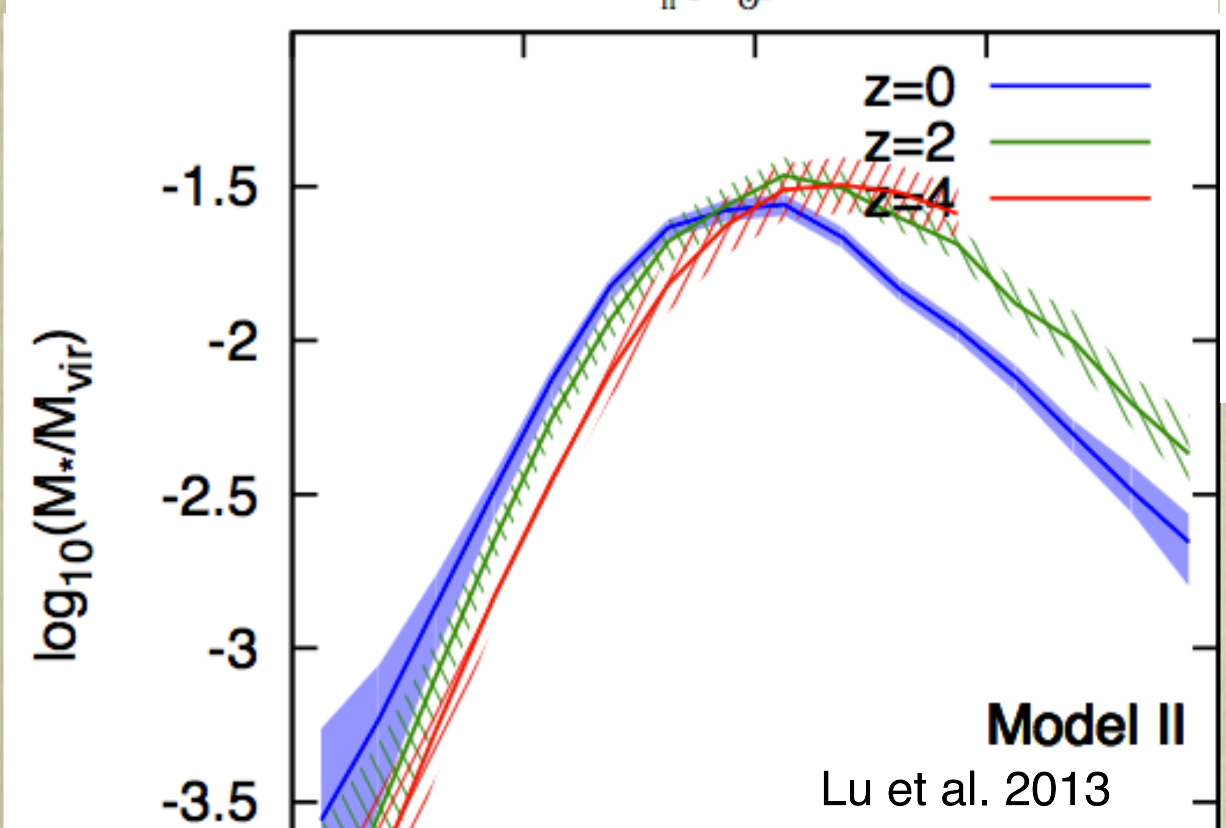
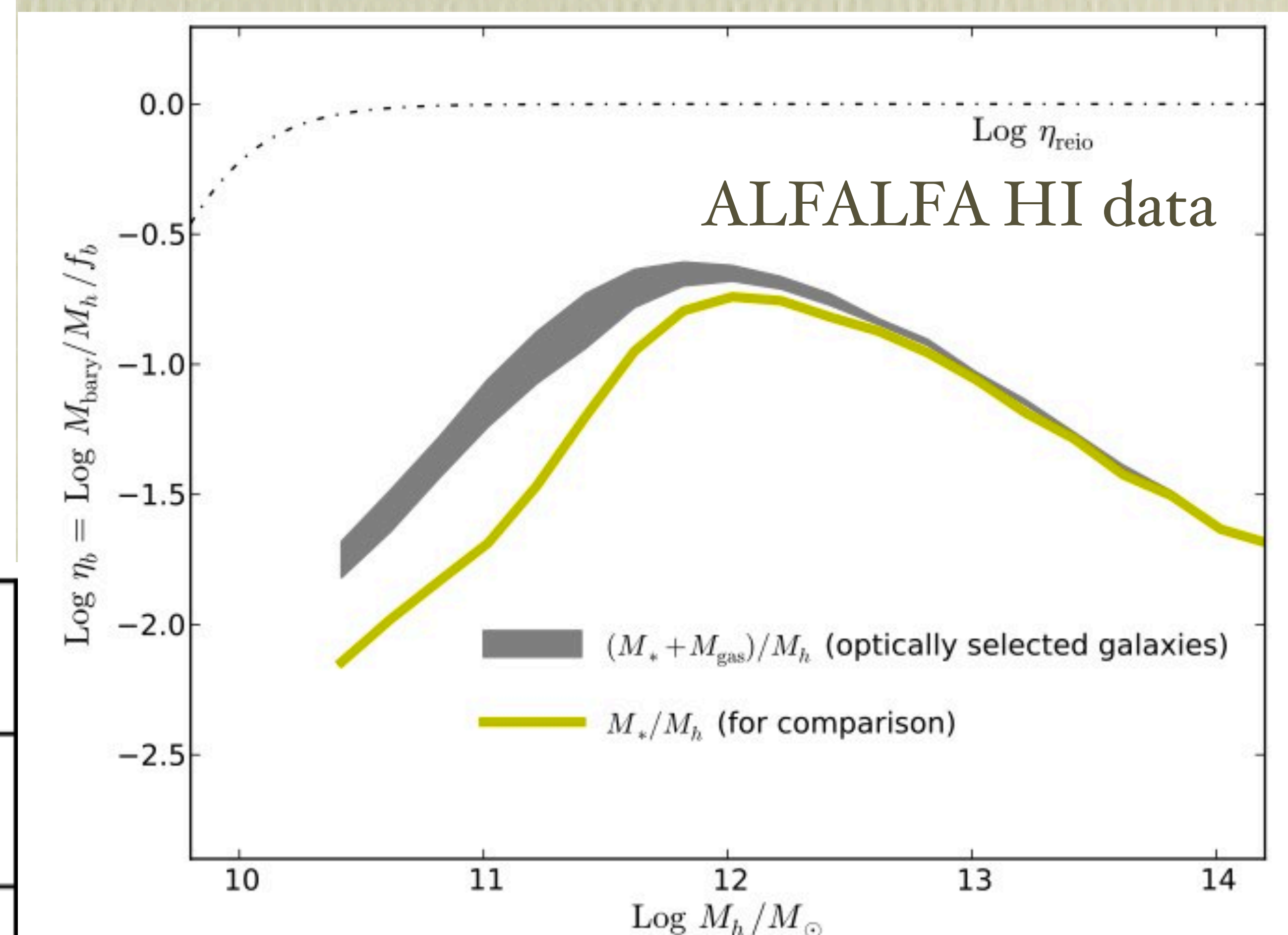


Basic observational constraints



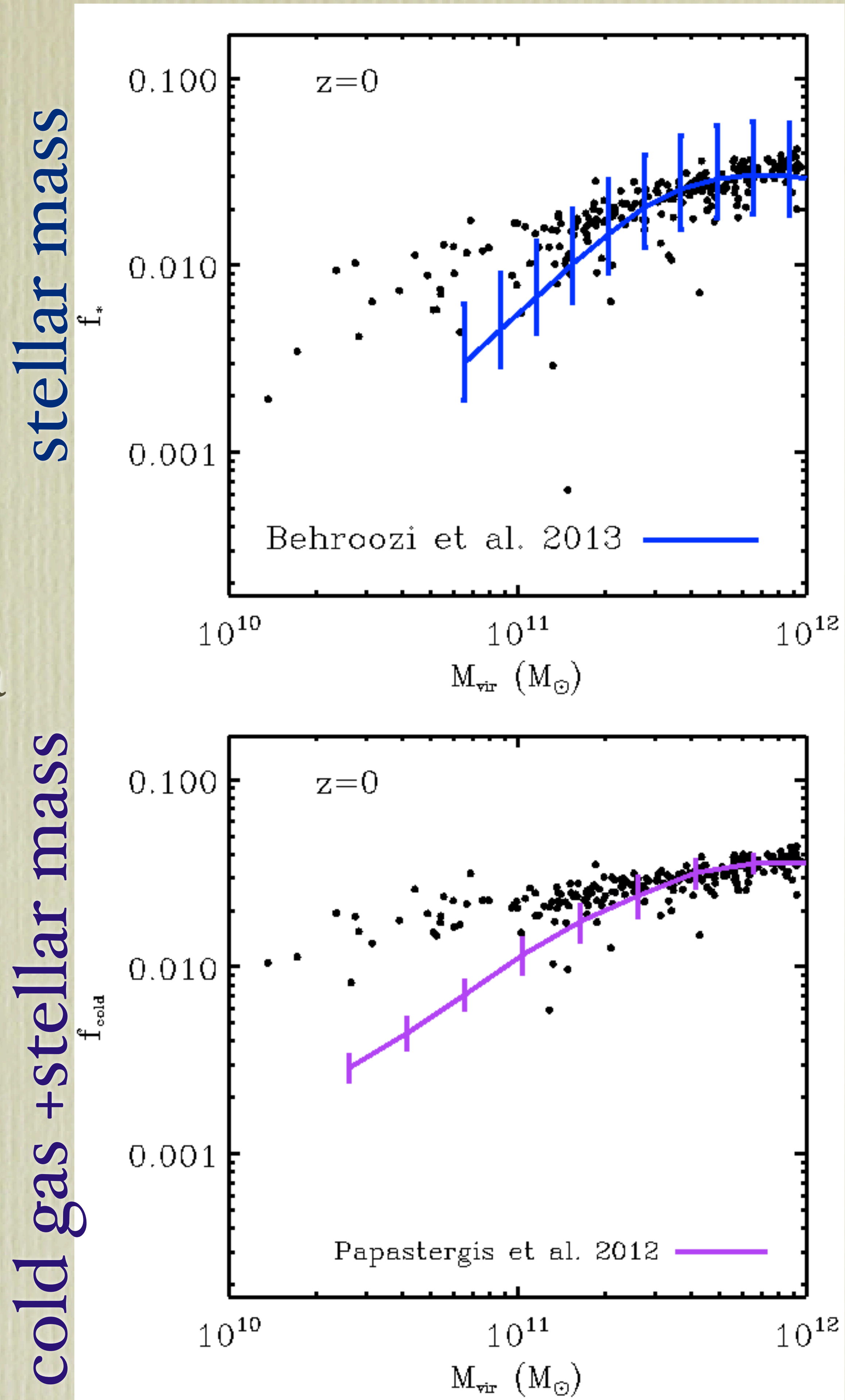




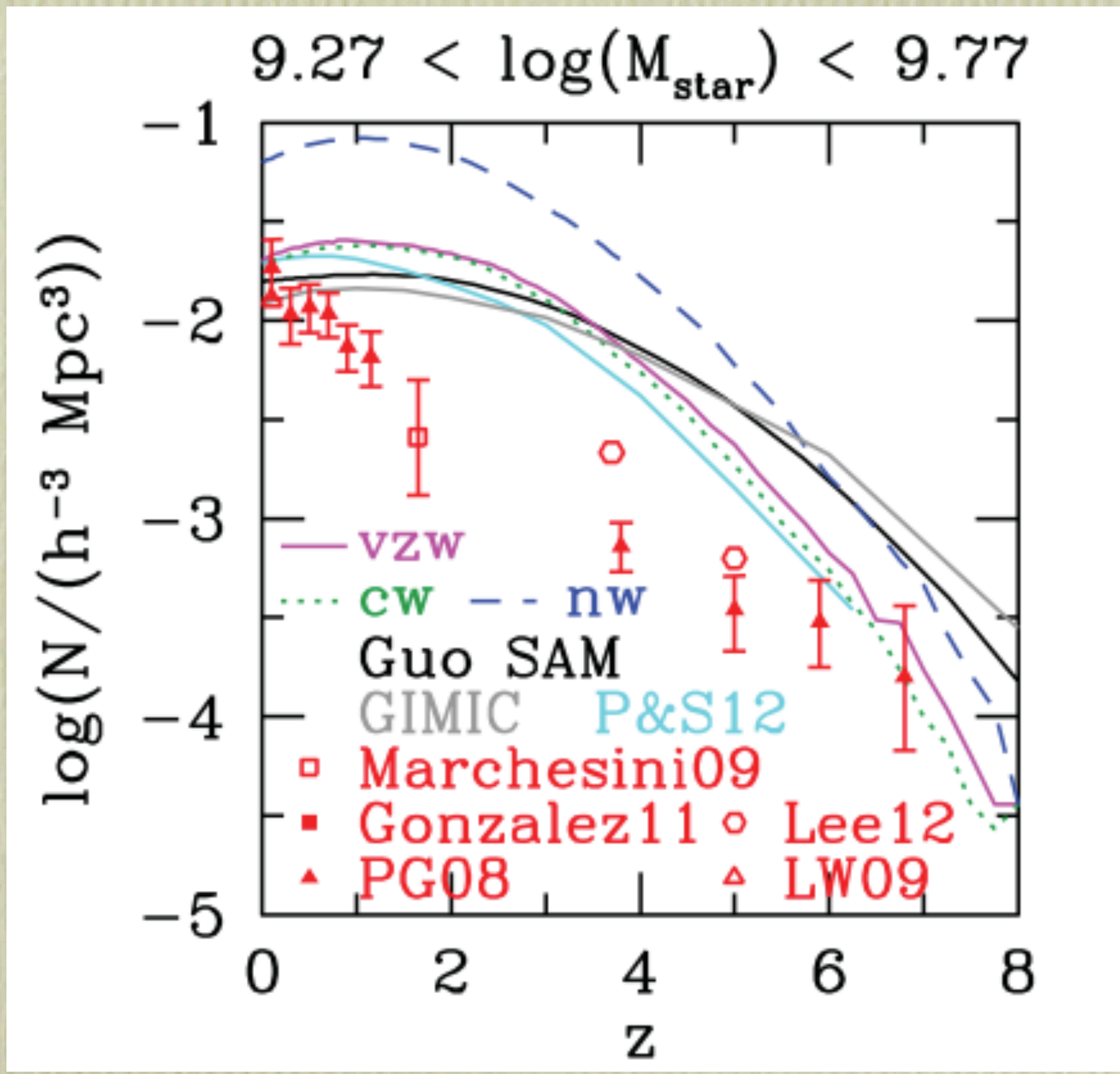
Papastergis et al. 2012

Cold baryon mass fractions in ejection models

- Baryons accrete into a dark matter halo at the cosmic baryon fraction, f_b.
- Gas cools and collapses on a galaxy too rapidly.
- Strong feedback is assumed. Mass loading factor increases with decreasing halo mass, ~20 for 10^11Msun halos.



Another side of the same problem



Weinmann et al. 2012

- Galaxy formation is too rapid in low mass halos at high redshift.
- We need a mechanism to delay star formation (cooling or gas accretion) in low mass halos.

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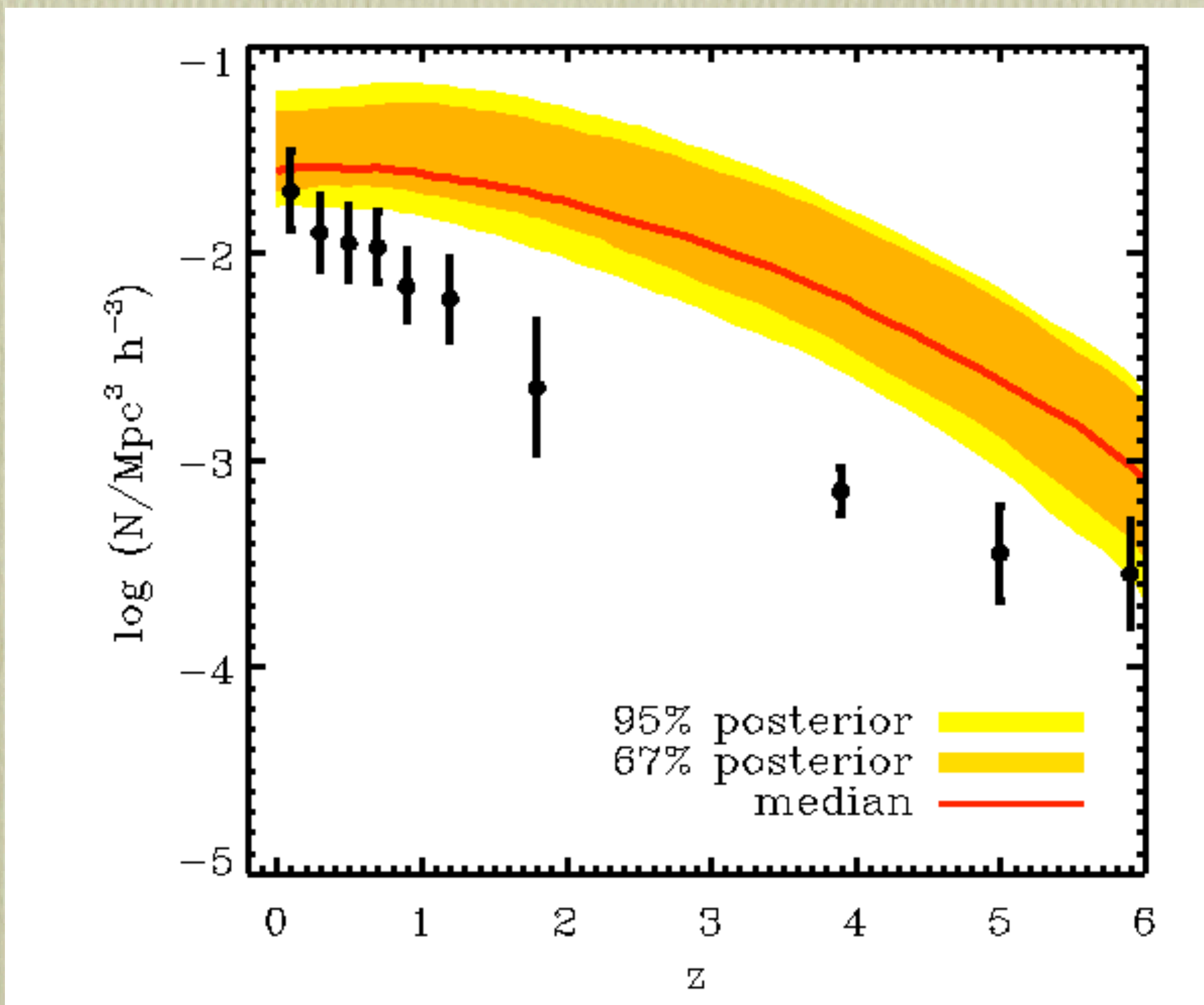

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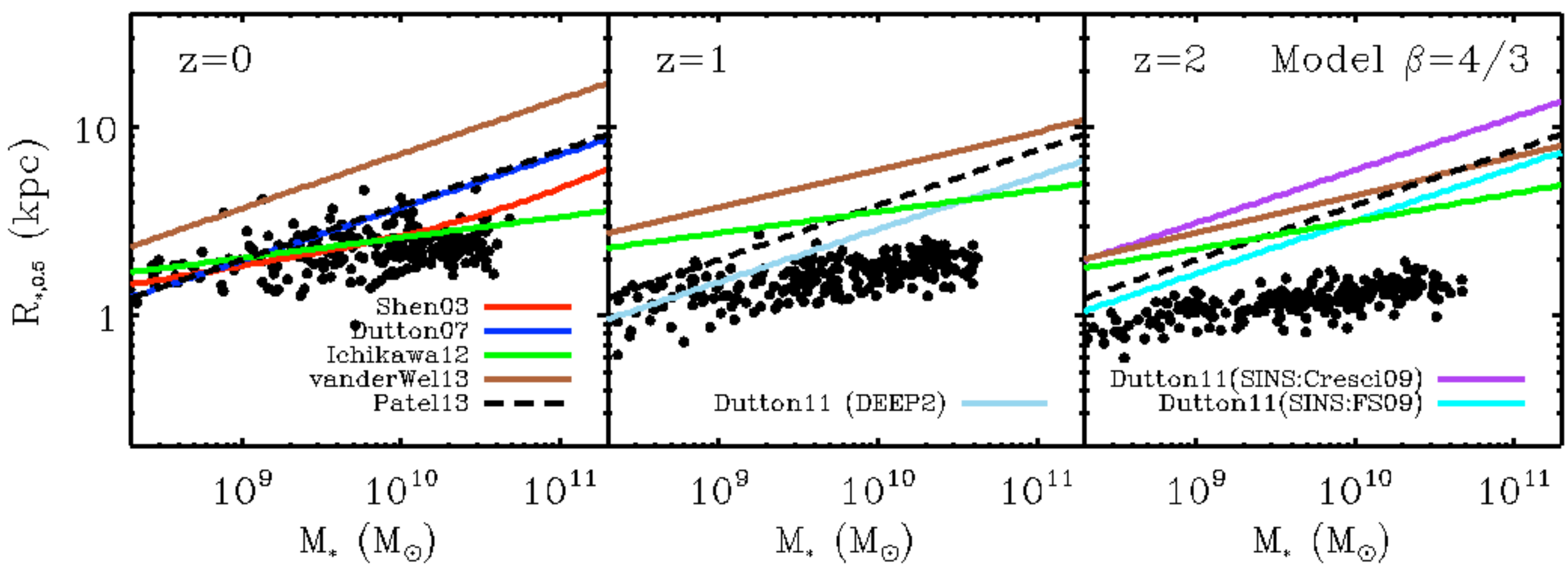
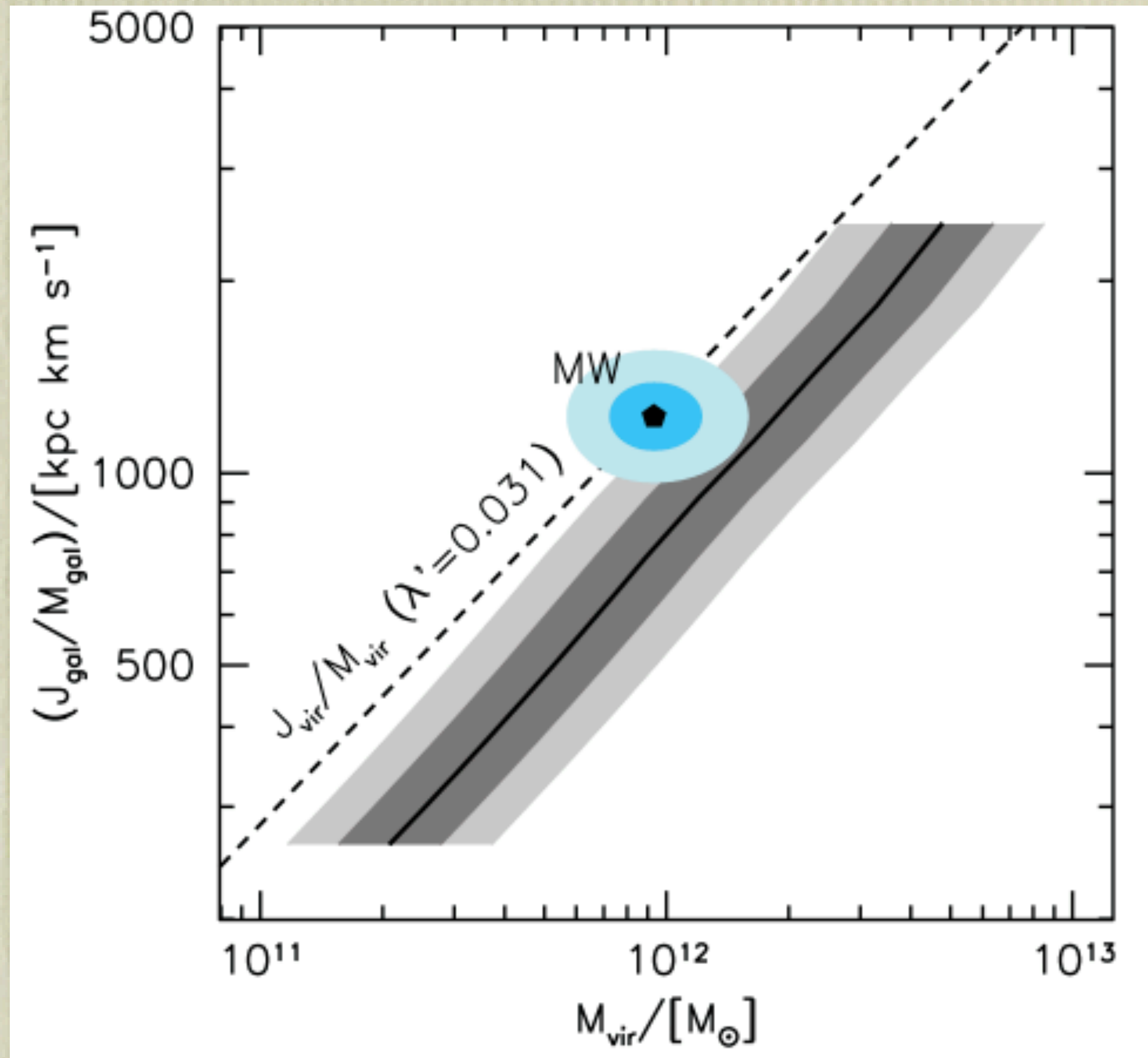
Another outstanding problem: disk size - stellar mass relations



half-mass radius of stellar disk

Angular momentum

- The spin parameter of galactic disk is about that of the host halo.
- It is difficult to predict in models and simulations:
    - j distribution is more extended to large radii.
    - The fuel is always from inner halo.



Dutton & van den Bosch 2012

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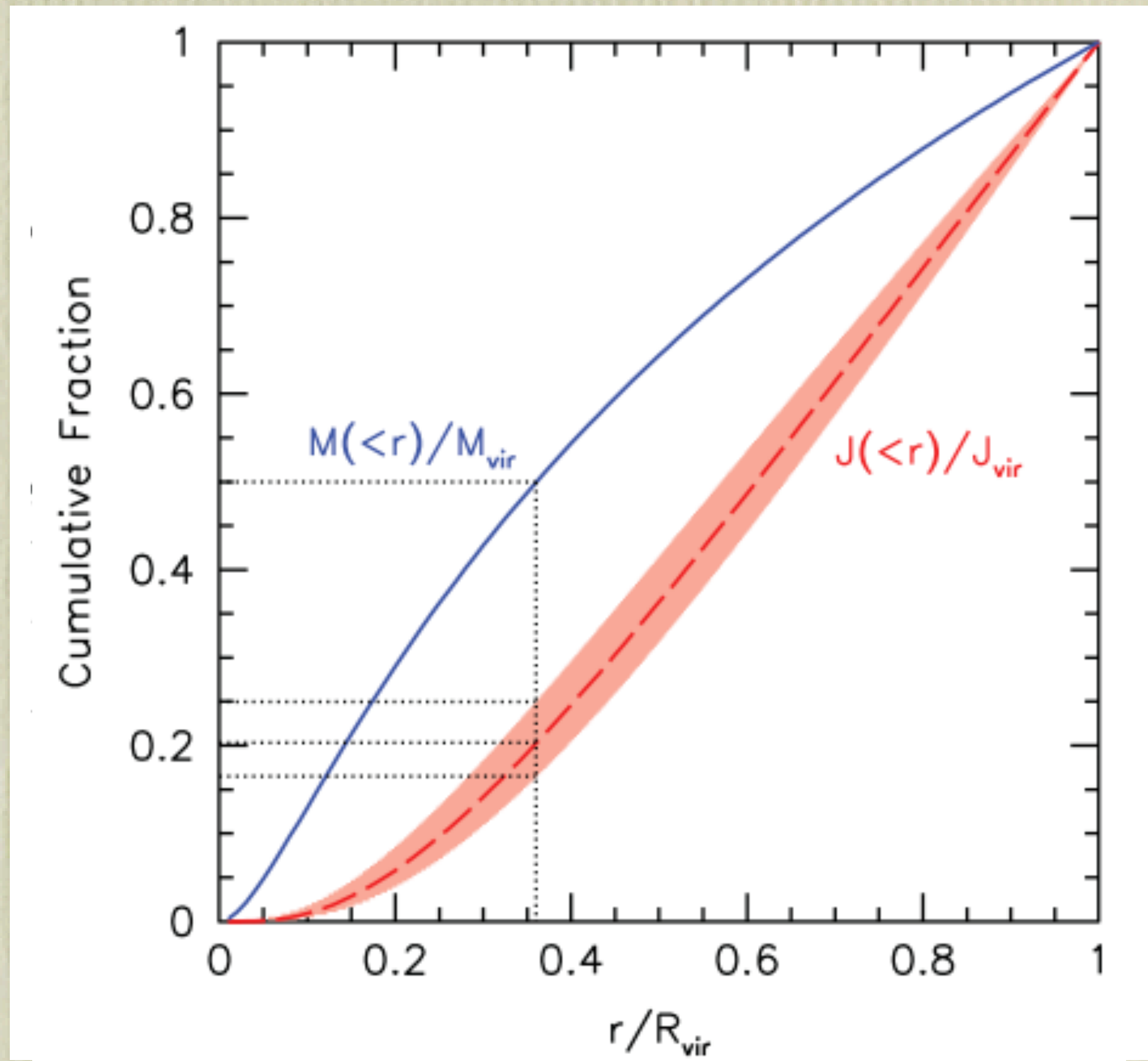
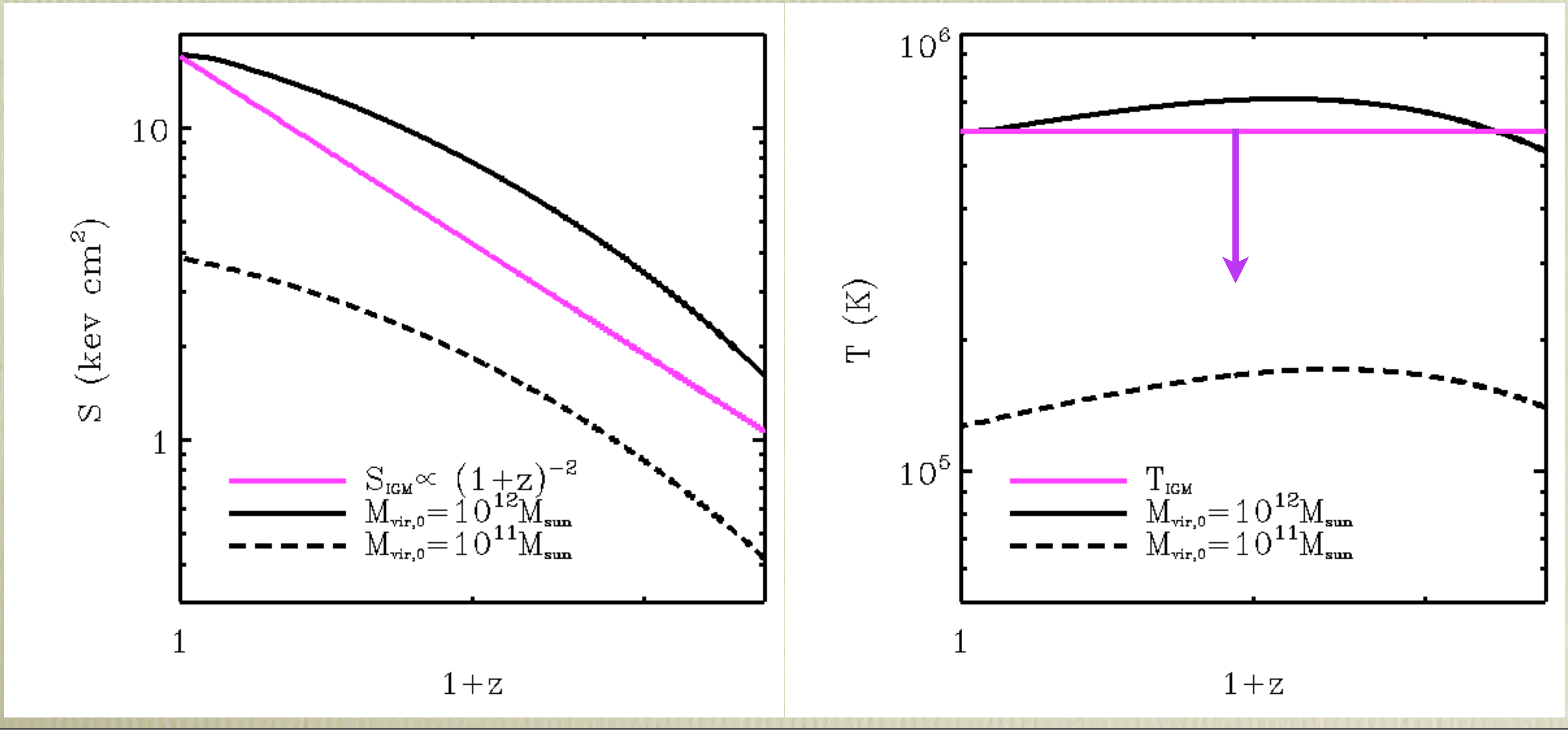


Dutton & van den Bosch 2012

Preventive model

- The IGM is preheated to a finite entropy uniformly. At z=0, S~15kevcm^2, which happens to be the virial entropy of 10^12Msun halos. $S_{\rm vir} = \frac{T_{\rm vir}}{n_{e,\rm vir}^{2/3}}$
- The IGM entropy evolves with z as S~1/(1+z)^2, which implies T_IGM<6x10^5K.



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- The IGM entropy evolves with z as S~1/(1+z)^2, which implies T_IGM<6x10^5K.
- Solve hydrostatic equilibrium for the halo hot gas configurations, and predict cooling out of the hot halo.
- Assuming a j distribution (Bullock et al. 2001) and j conservation, we predict the cold gas profile in the central disk (Mo, Mao & White 1998).
- Follow star formation with Krumholz et al. model (2009, and updated version).
- Minor outflow (mass loading factor =1 for MW halos, decreases to 0.1 for 10^11Msun halos).

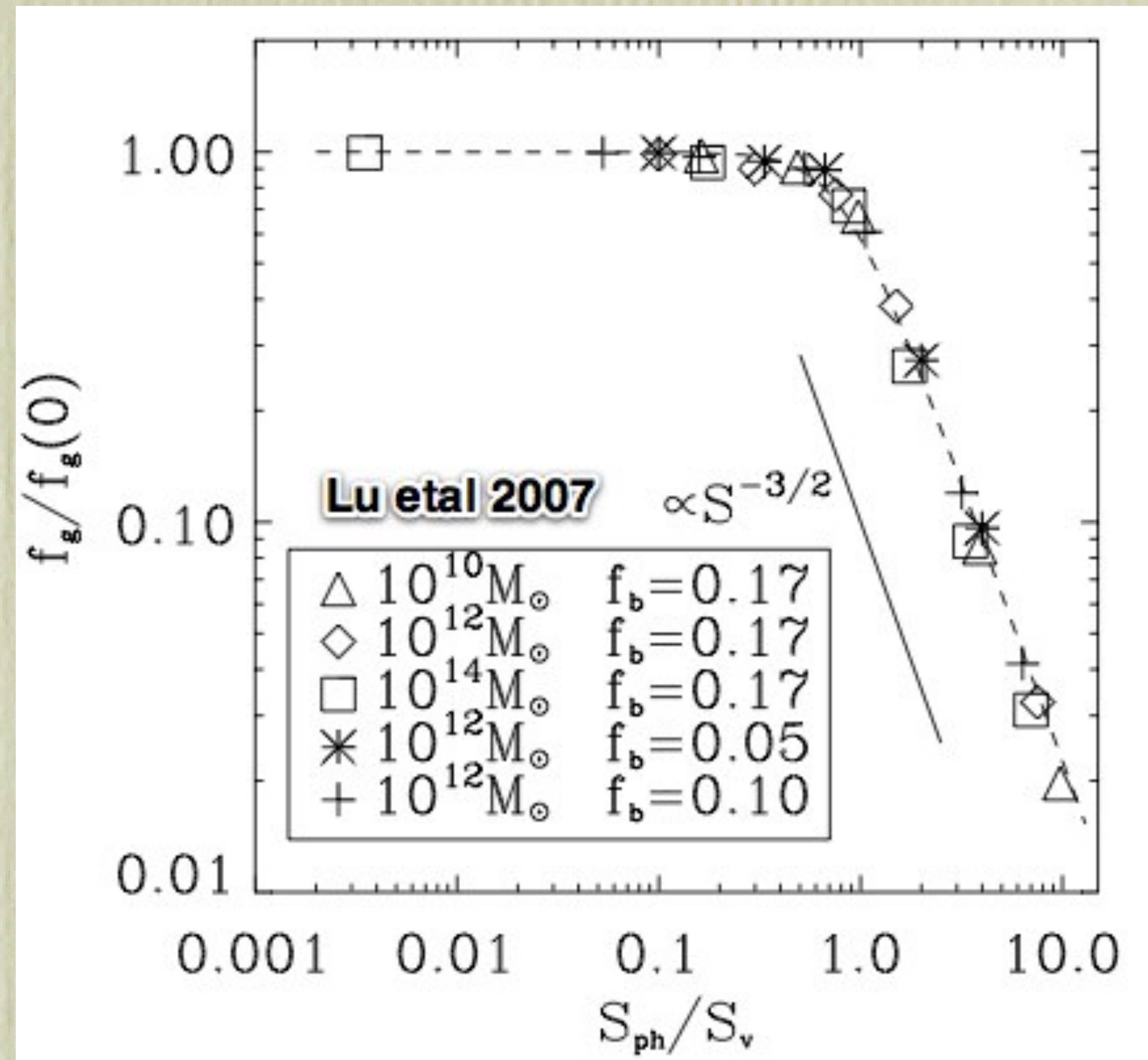
How entropy affects the halo baryon fraction

$$S = \frac{T}{n_e^{2/3}}$$

$$T_{\rm vir} \propto V_{\rm c}^2 \propto M_{\rm vir}^{2/3}$$

$$f_b \propto M_{\rm vir}$$

$$M_b \propto M_{\rm vir}^2$$



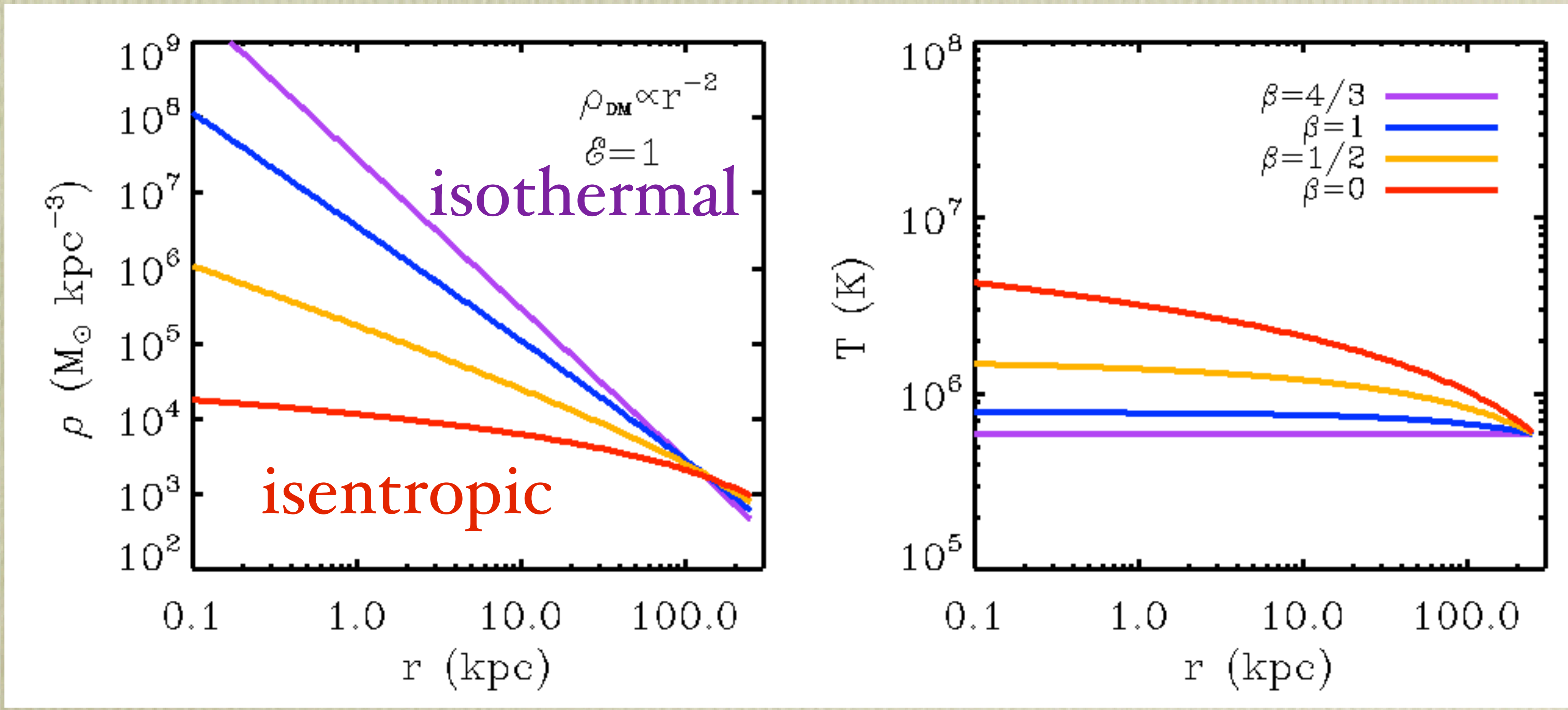
How entropy affects the distribution and cooling of hot halo gas

- We solve hydrostatic equilibrium in a halo potential:

$$\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}r} = -G\frac{M(<r)}{r^2} \qquad S(r) = S_0\left(\frac{r}{r_{\mathrm{vir}}}\right)^{\beta}$$

$$\rho(x) = \rho_{\mathrm{vir}}\left\{1 + \frac{4}{5}\mathcal{E}\frac{c}{\ln(1+c) - \frac{c}{1+c}}\left[\frac{\ln(1+cx)}{cx} - \frac{\ln(1+c)}{c}\right]\right\}^{3/2}$$

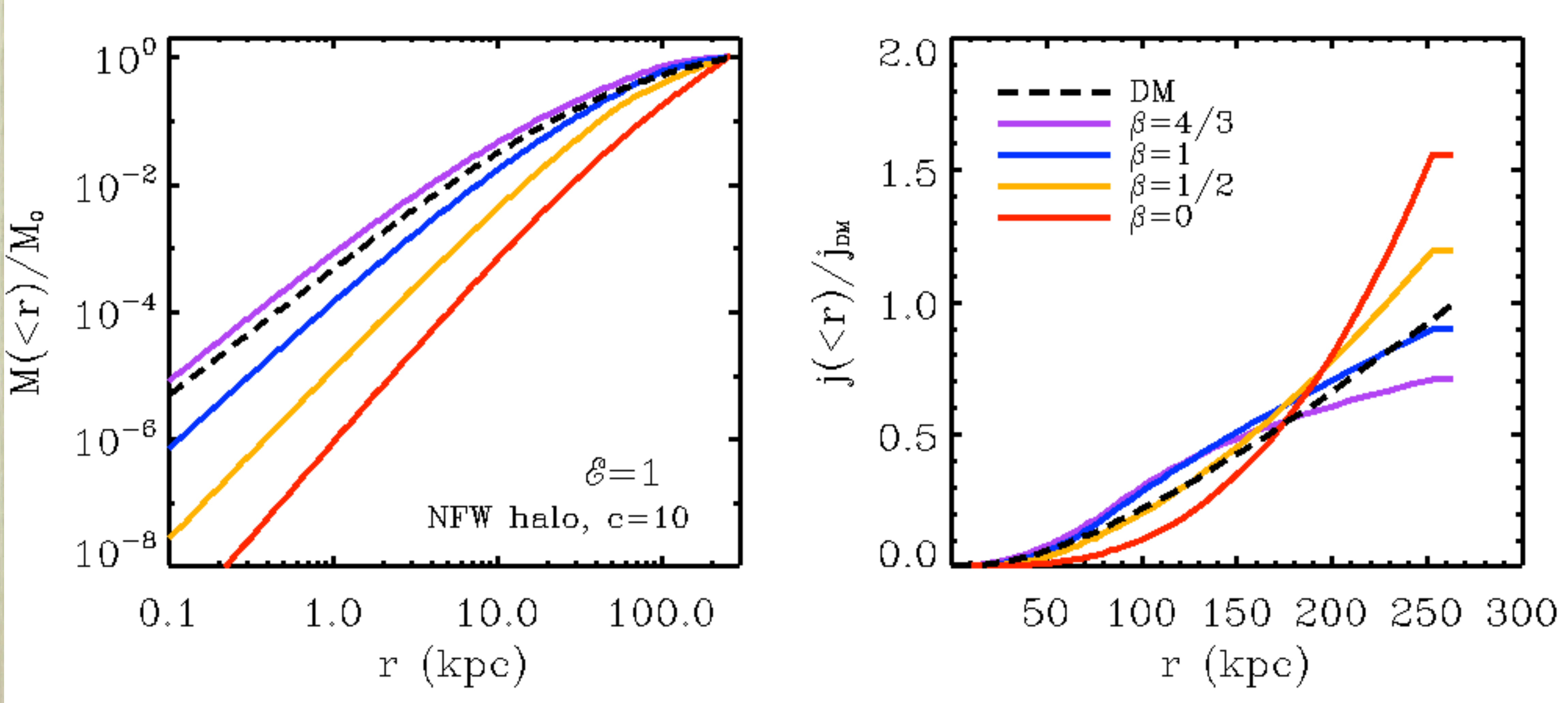
Hot gas distributions with different entropy profiles



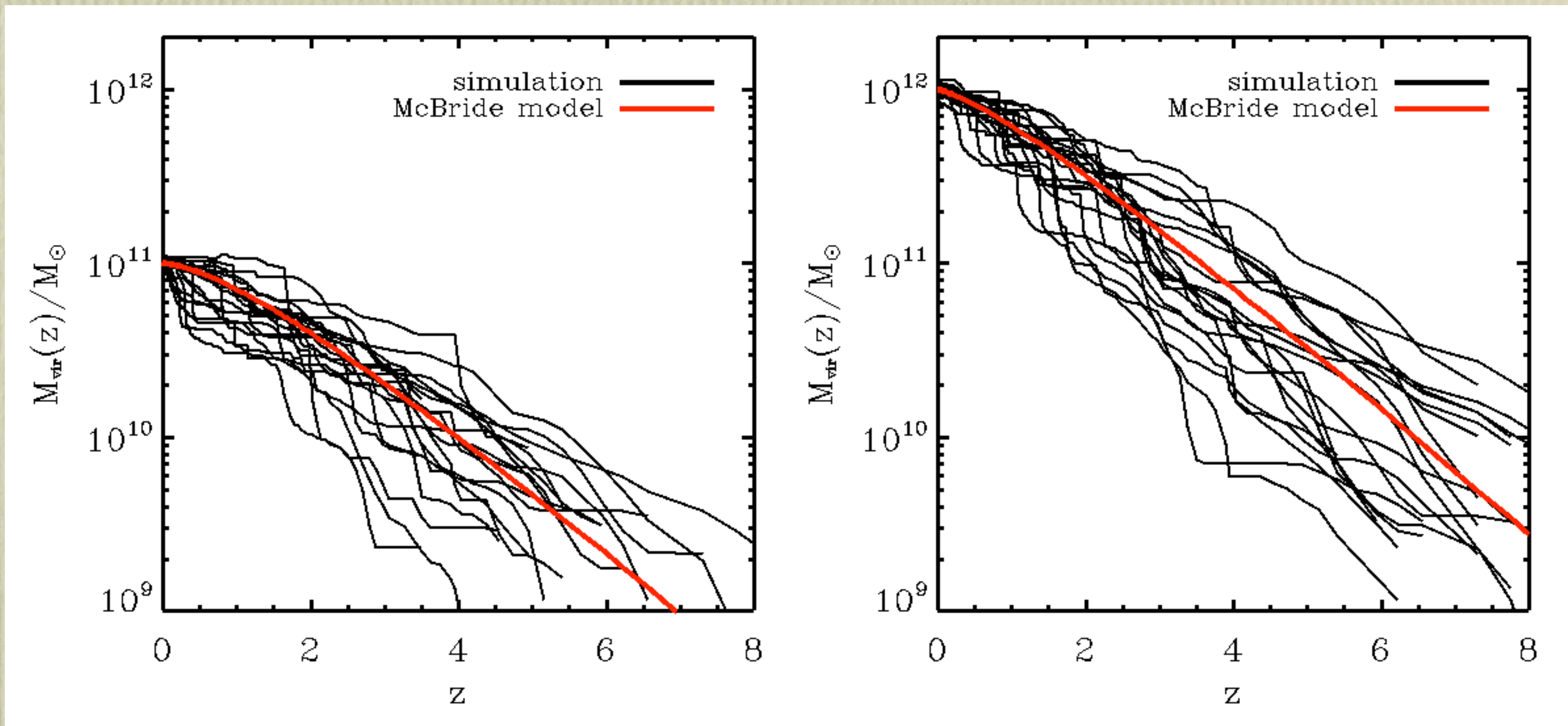
Gas cooling in halos with different entropy profiles

mass distribution of cooling baryons

j distribution of cooling baryons



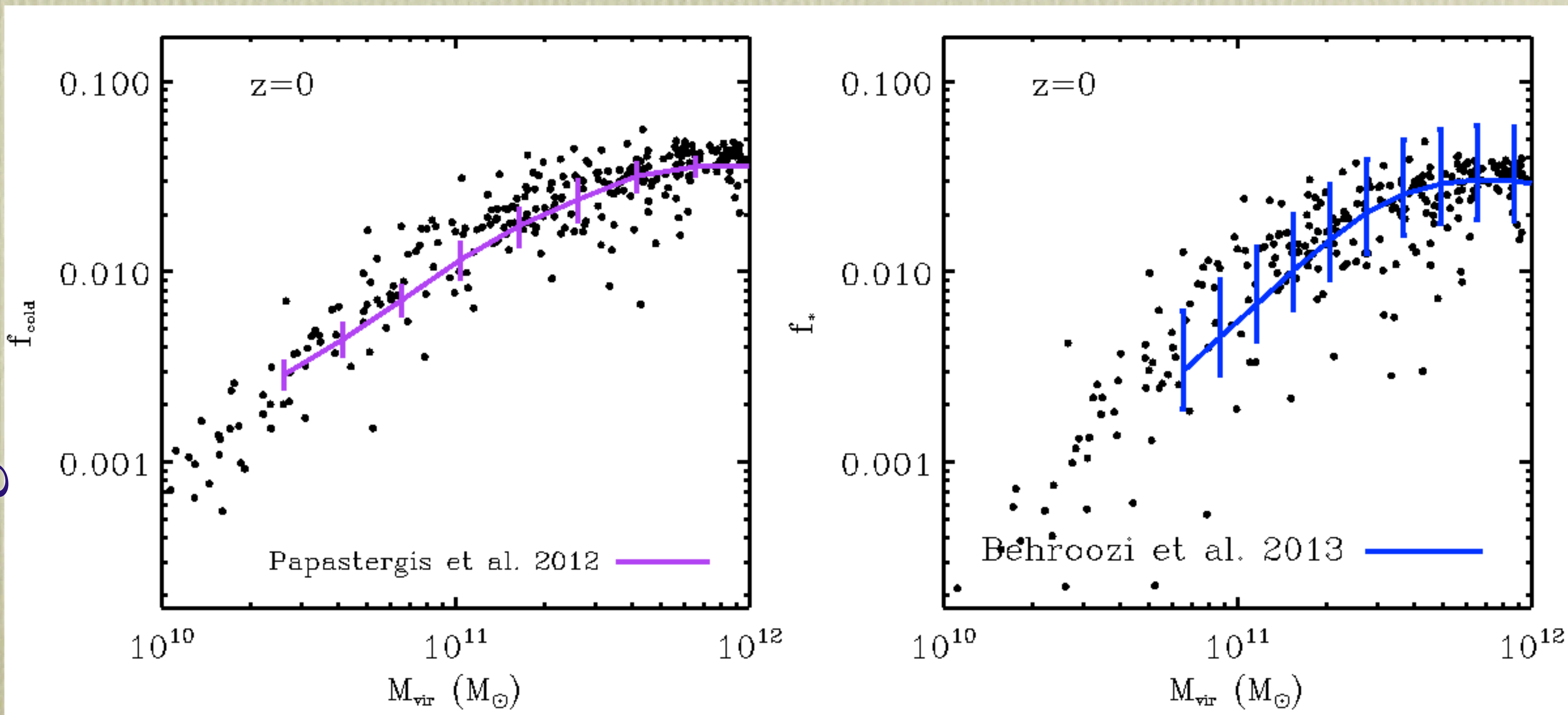
Halo mass assembly histories



Simulation: Bolshoi (klypin et al. 2012)

Cold baryon mass fractions

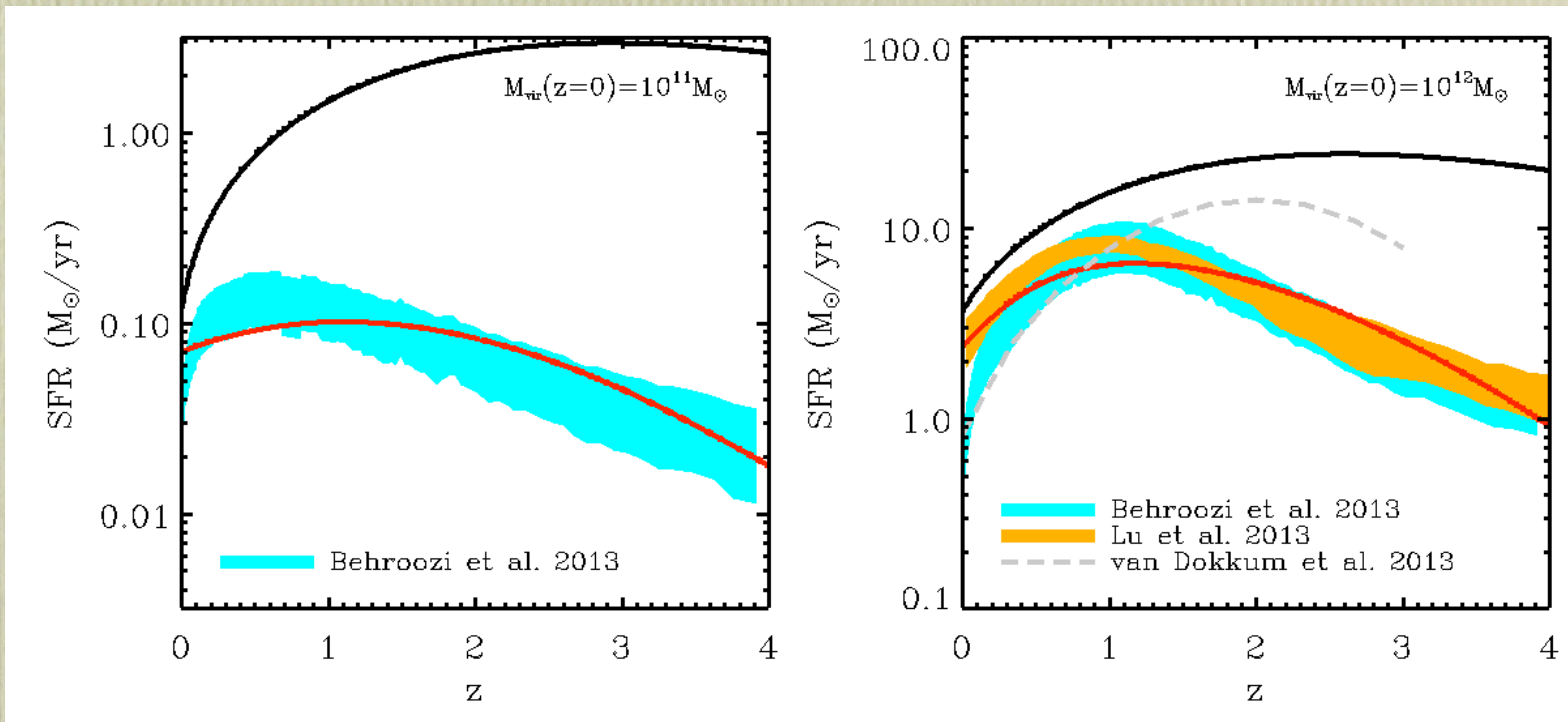
cold gas +stellar mass



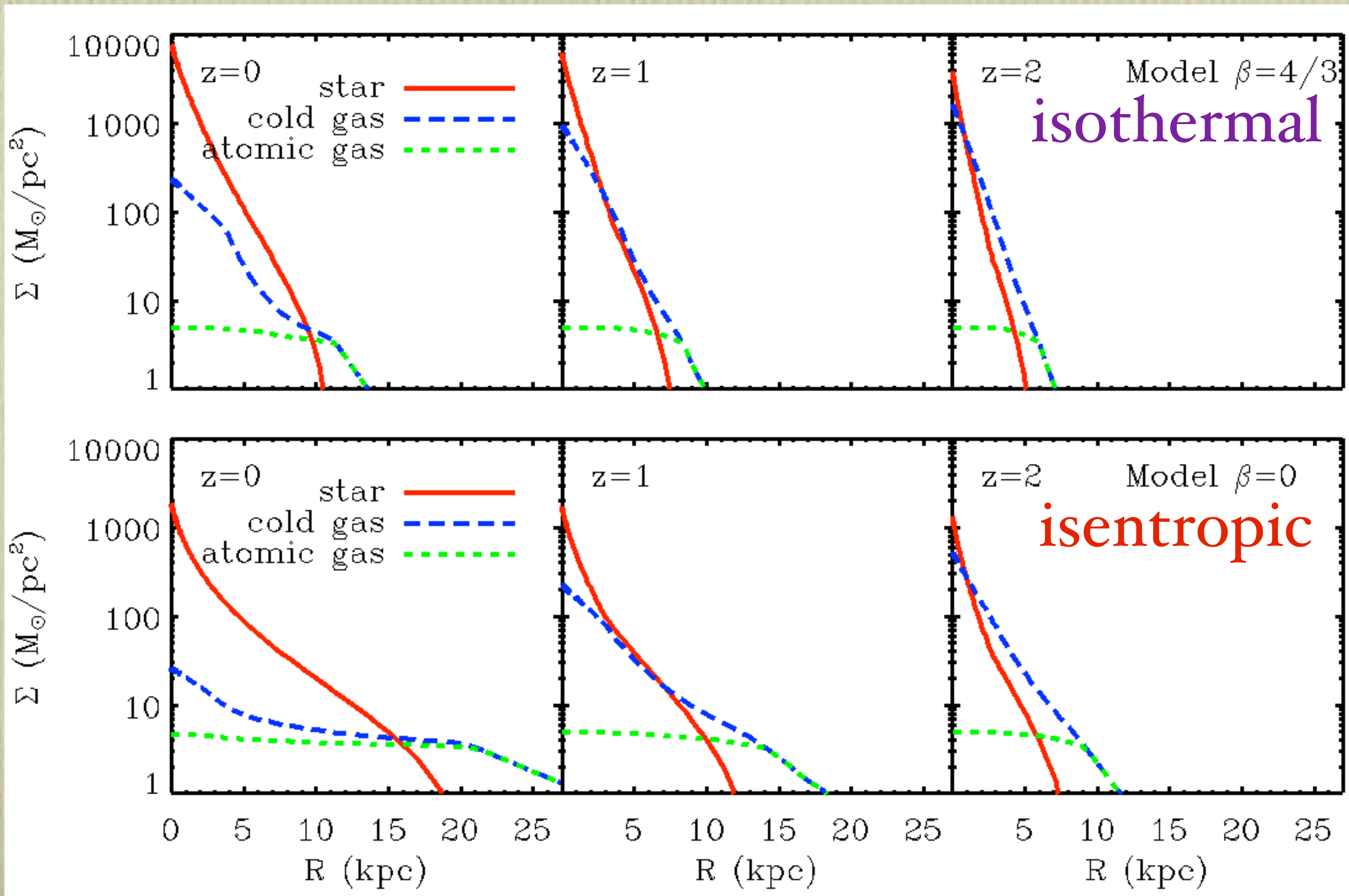
stellar mass

Halo mass

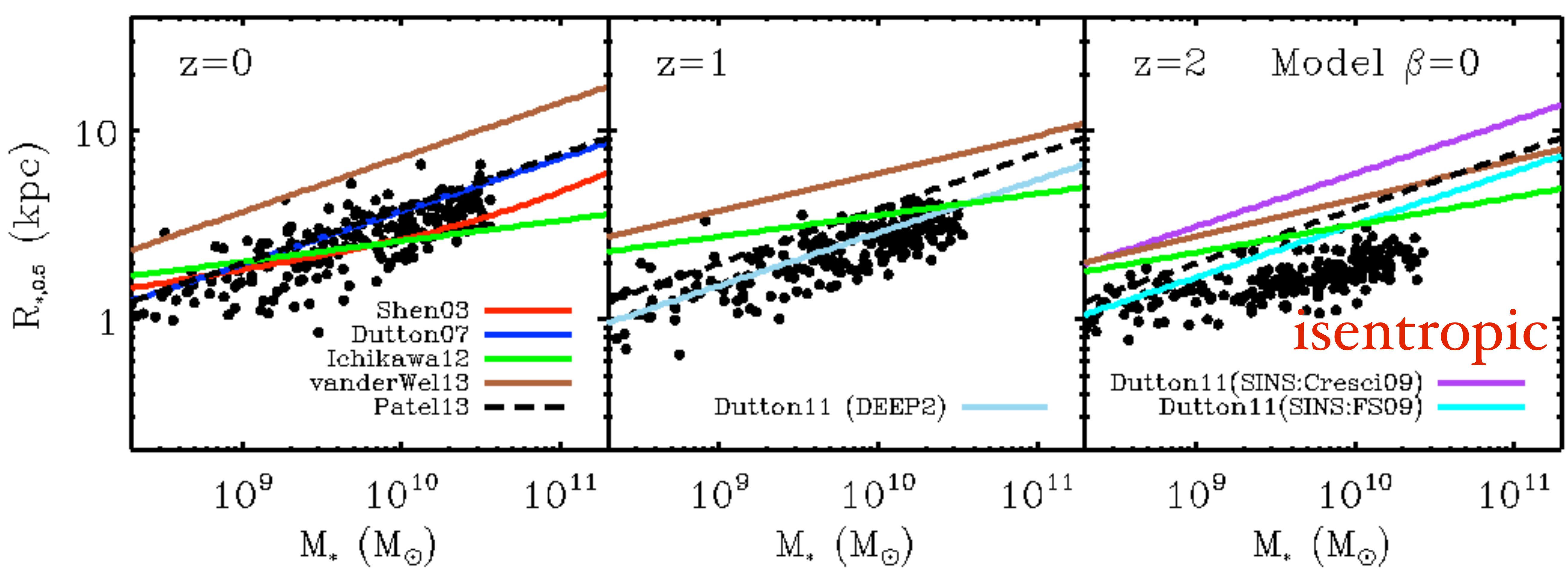
SFR histories



The growth of galactic disks



Disk size - stellar mass relations



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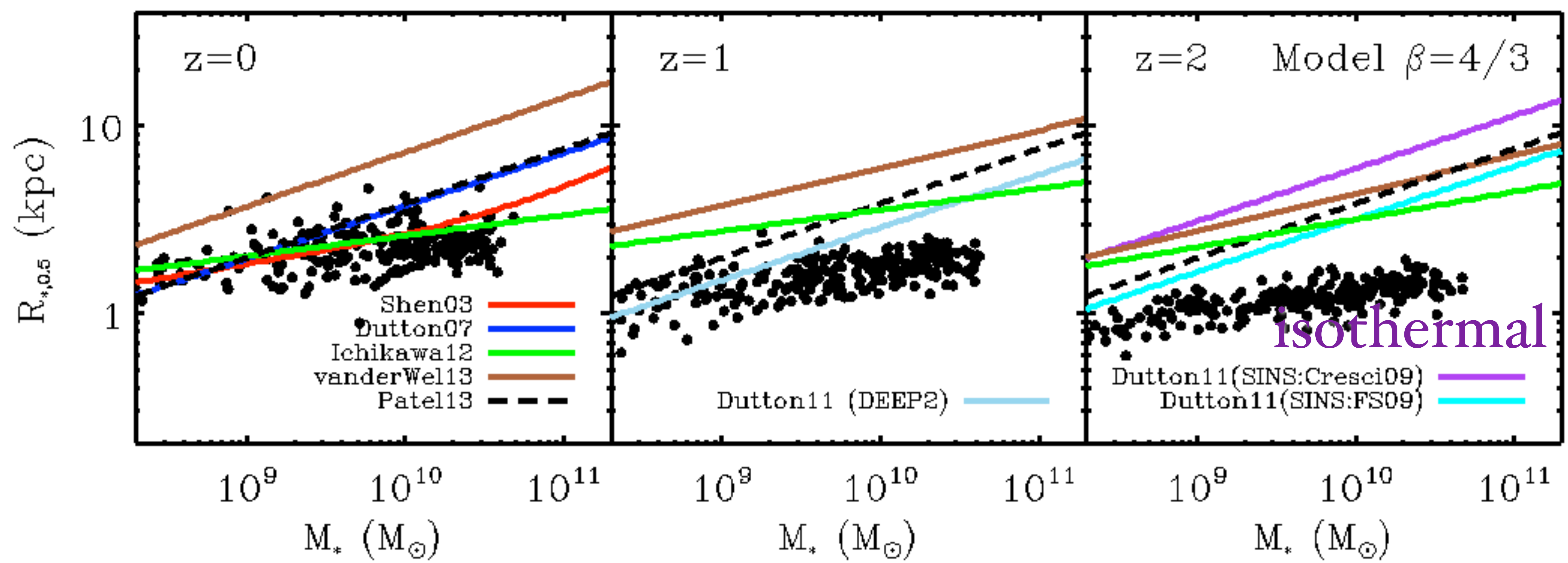

Summary

- Physically motivated model for hot halo gas (accretion fraction and hot gas distribution)
- Key quantity: entropy. A uniform entropy distribution in IGM is assumed. The entropy may be enhanced by feedback of early starburst galaxies (Mo & Mao 2003), gravitational shocks of pancake formation(Mo et al. 2005), Blazers heating (Pfrommer et al. 2012), multiphase cooling (Maller & Bullock 2004).
- When $S_{IGM} \sim S_{12}$, the diffused baryon is prevented from accreting into low mass halos, resulting $M_b \sim M_h^2$.
- Hot halo gas has an extended distribution when it has been preheated. Cooling of the hot gas is from a large range of radii.
- The model reproduces f_*-M_{halo}, f_{cold}-M_{halo} relations for low mass galaxies.
- The model reproduces the disk size - stellar mass relations.
- No strong feedback is needed for low-z low-mass galaxies.