An Empirical Model for the Star Formation History in Dark Matter Halos

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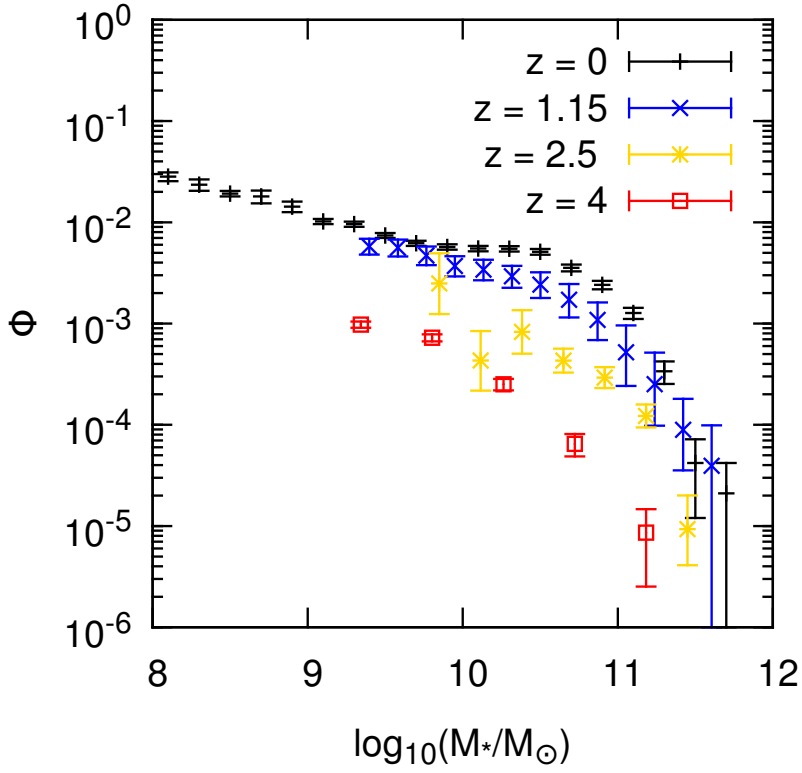
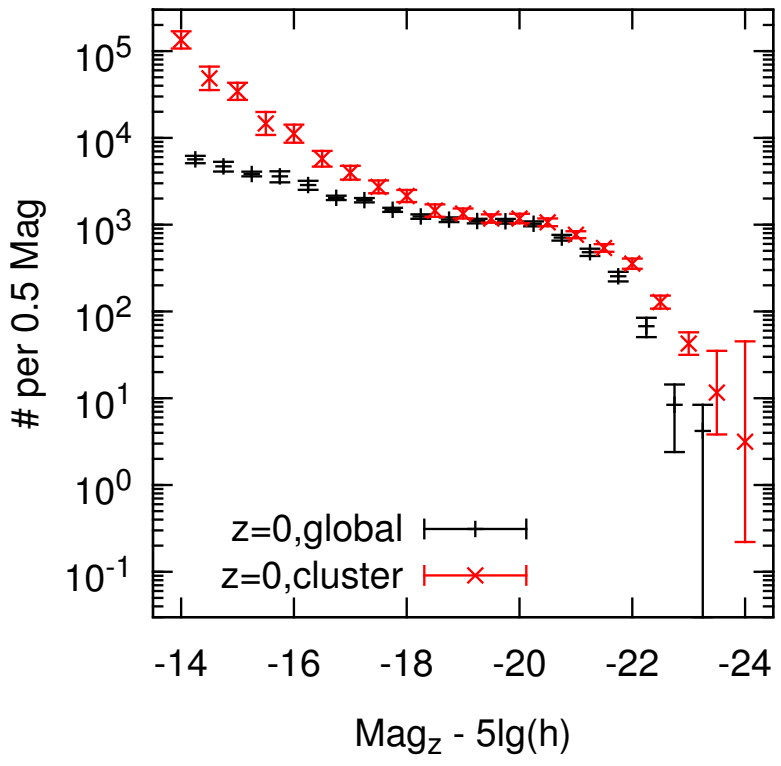
Observations

Global Stellar Mass functions:



Source: Baldry11, Marchesini09, Stark09

Cluster galaxy Luminosity function:



Source: Popesso06

The Empirical Model

Purely empirical model:

- Central galaxy

$$\dot{M}_\star = \mathcal{E}\frac{f_{\rm B} M_{\rm h}}{\tau_{dyn}}(X+1)^\alpha \left(\frac{X+\mathcal{R}}{X+1}\right)^\beta \left(\frac{X}{X+\mathcal{R}}\right)^\gamma$$

$$X = M_{\rm v}/M_1, \qquad \mathcal{R} = M_2/M_1$$

- Satellite galaxy

$$\dot{M}_\star = \dot{M}_{\star{\rm infall}} \exp\left(-\frac{t - t_{\rm infall}}{\tau_{\rm q}}\right)$$

The Empirical Model

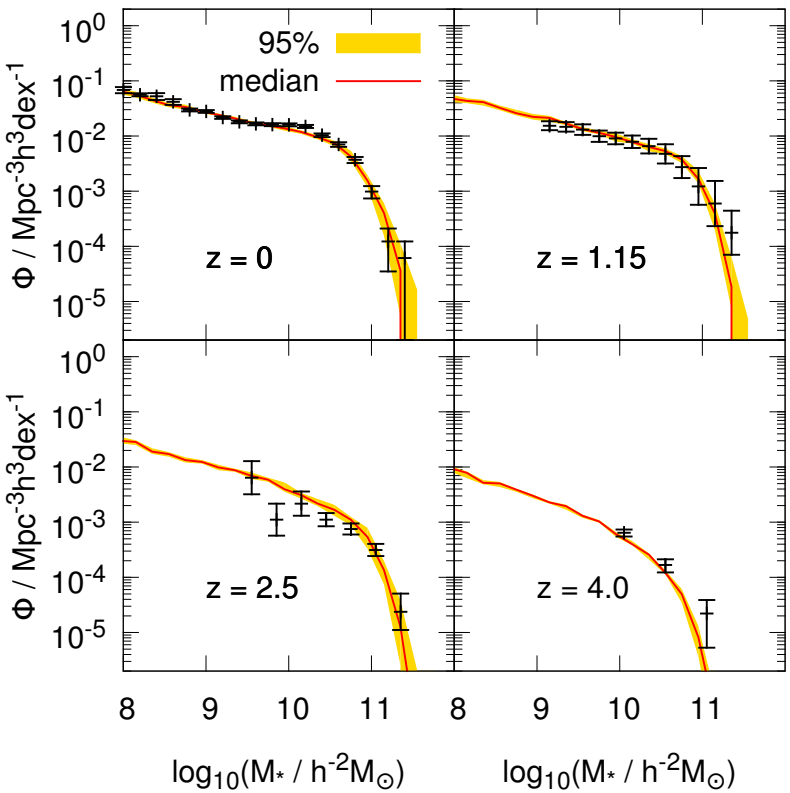
To avoid overfitting:

- build up the model bit by bit
- justify the extra complexity introduced into the model using Bayes Evidence
- avoid overcomplexity, still give good fit to the constraints

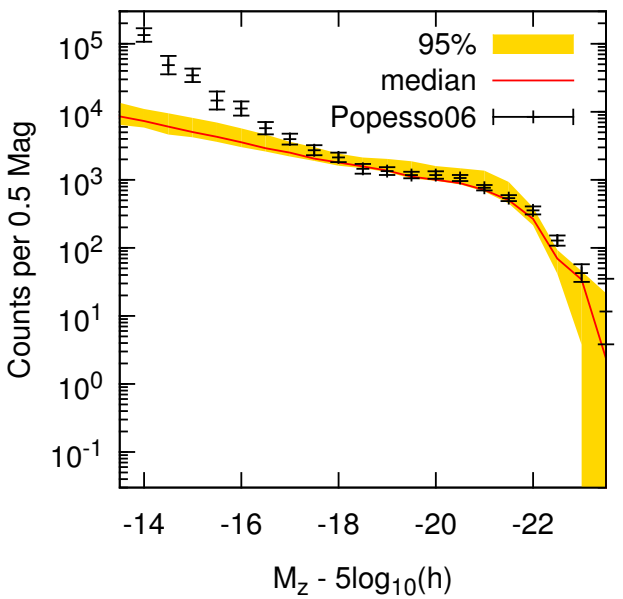
The Empirical Model

Model A: only required to reproduce the SMFs

$$\alpha = \alpha_0(1+z)^{\alpha'}$$



Used as constraints

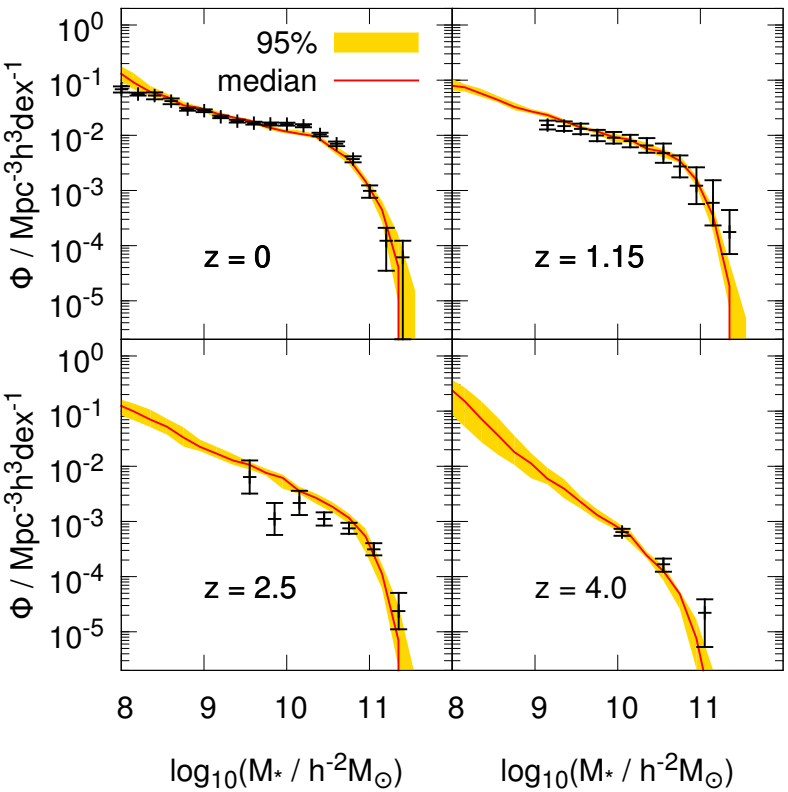


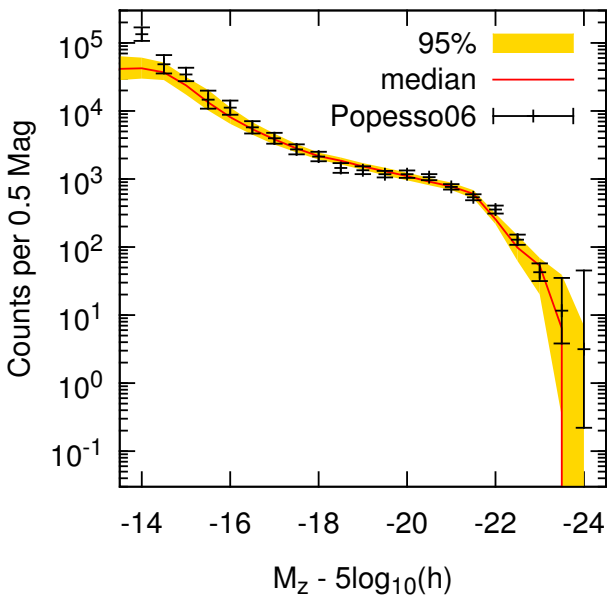
This is prediction!

The Empirical Model

Model B: required to reproduce the SMFs + cluster galaxy LF

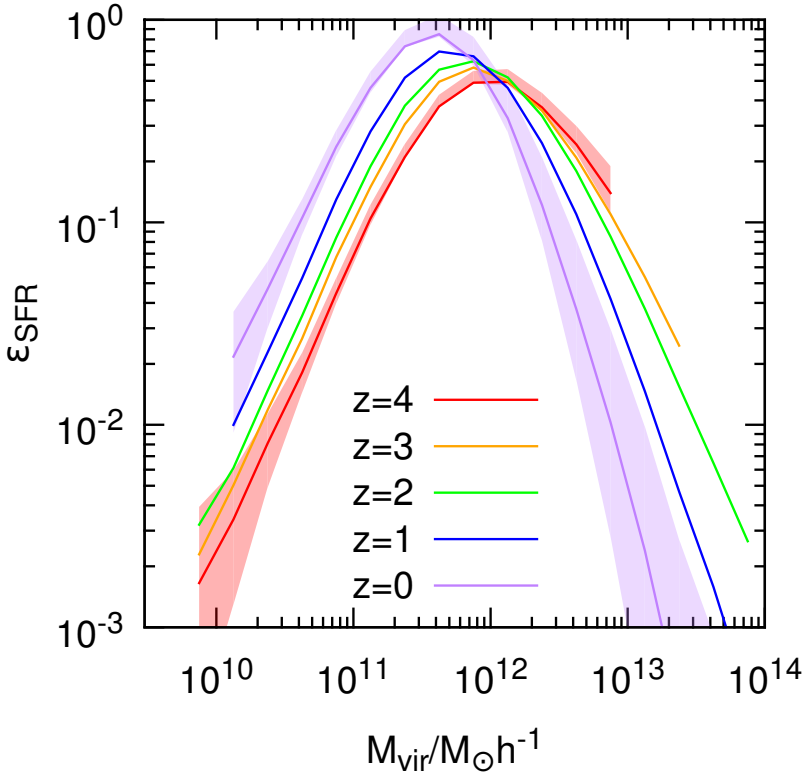
$$\gamma = \begin{cases} \gamma_{\rm a} & \text{if } z < z_c \\ (\gamma_{\rm a} - \gamma_{\rm b}) \left(\frac{z+1}{z_c+1} \right)^{\gamma'} + \gamma_{\rm b} & \text{otherwise .} \end{cases}$$



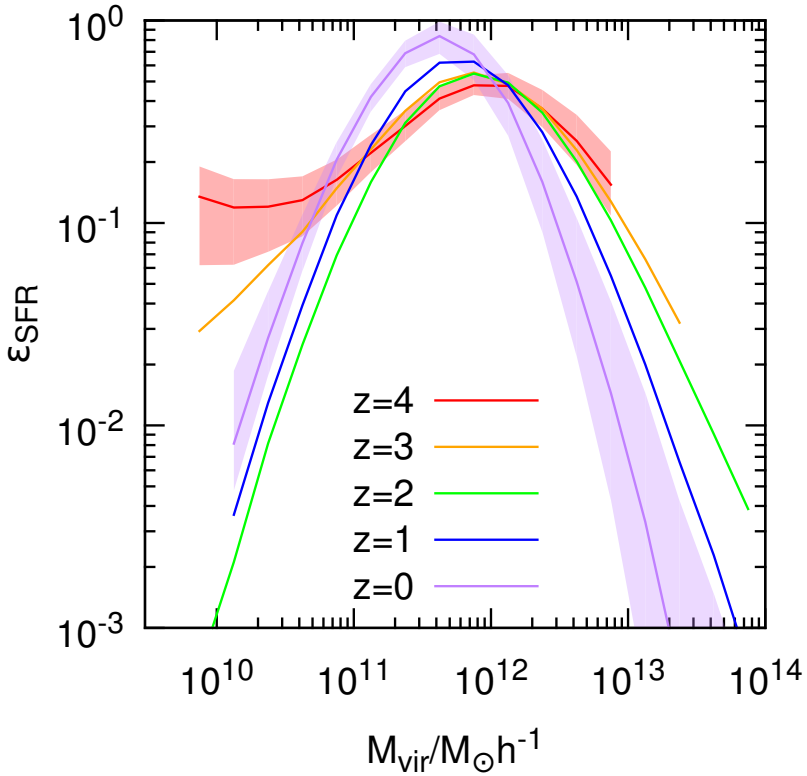


Star Formation Efficiency

Model A



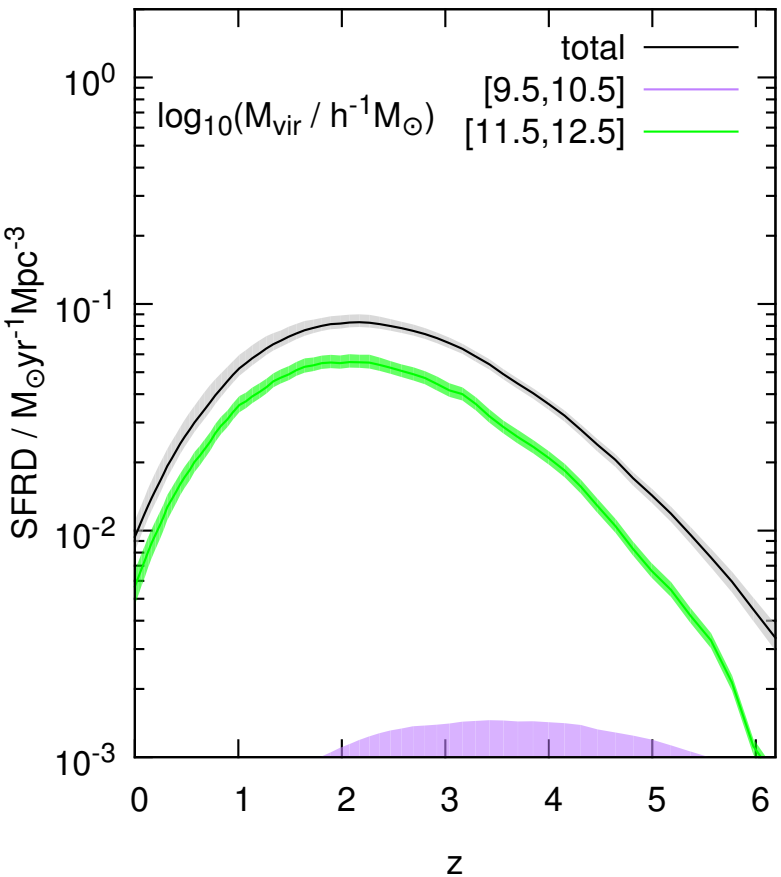
Model B



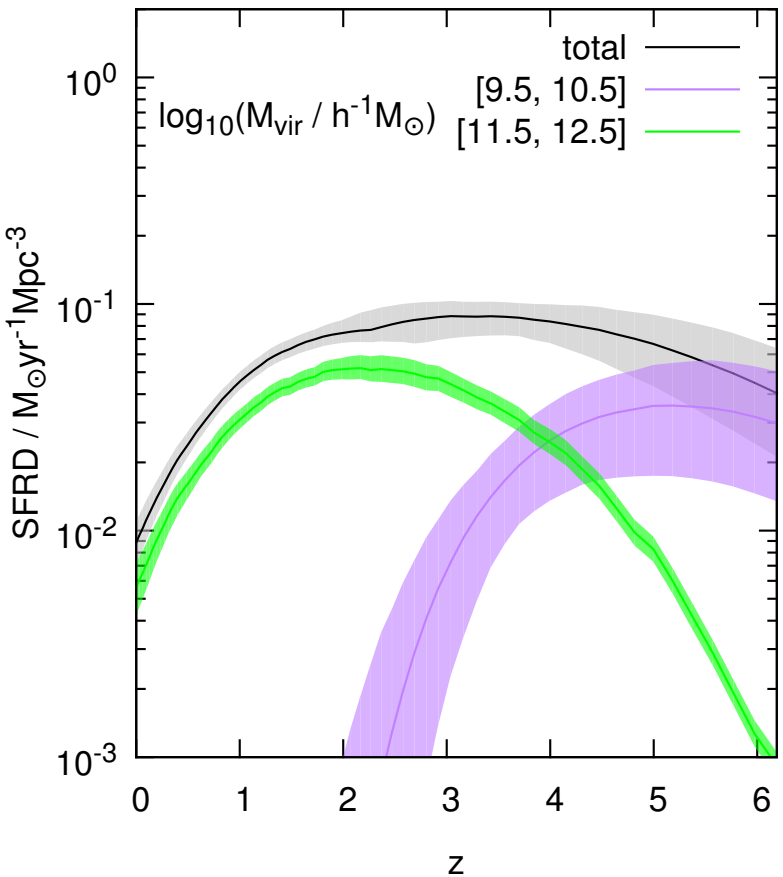
- The star formation band
- A new characteristic redshift: ≈ 2.2

SFR Density

Model A



Model B



SFR Density

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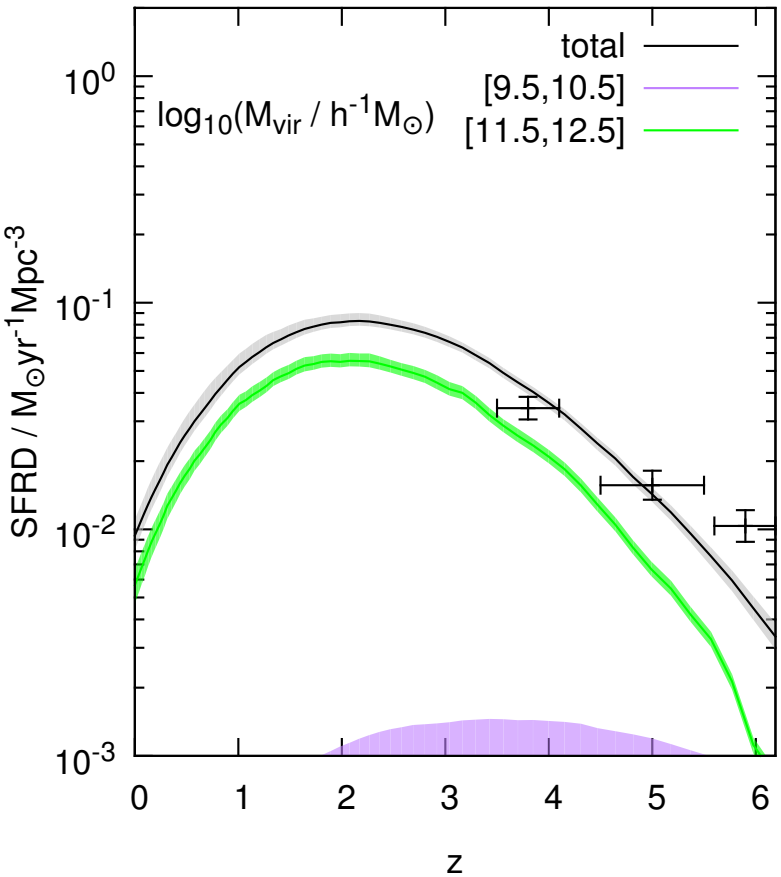
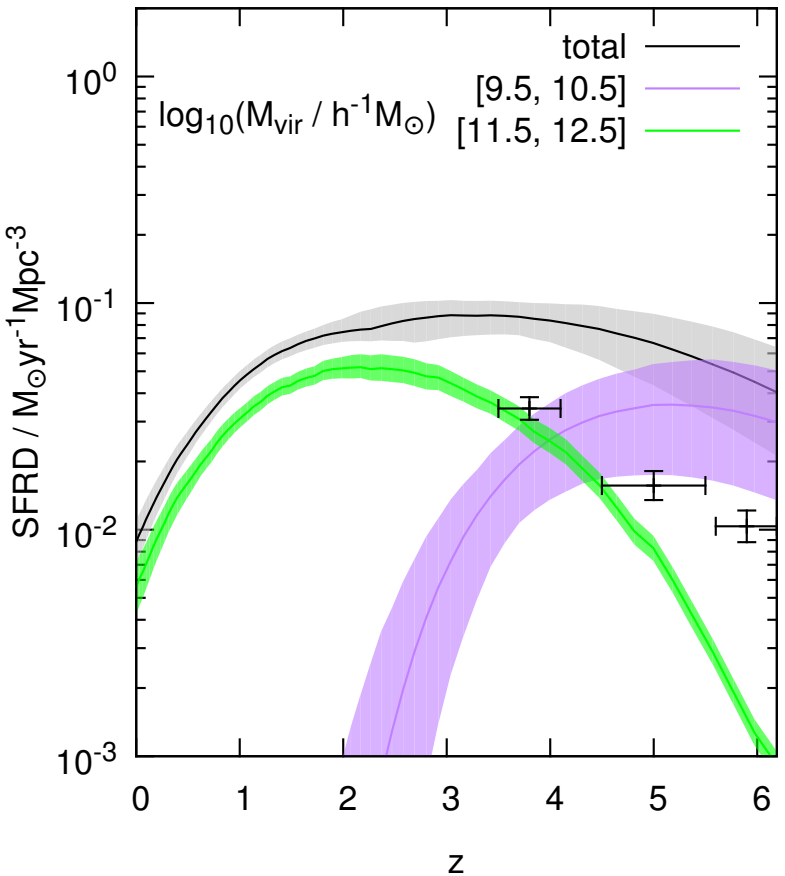


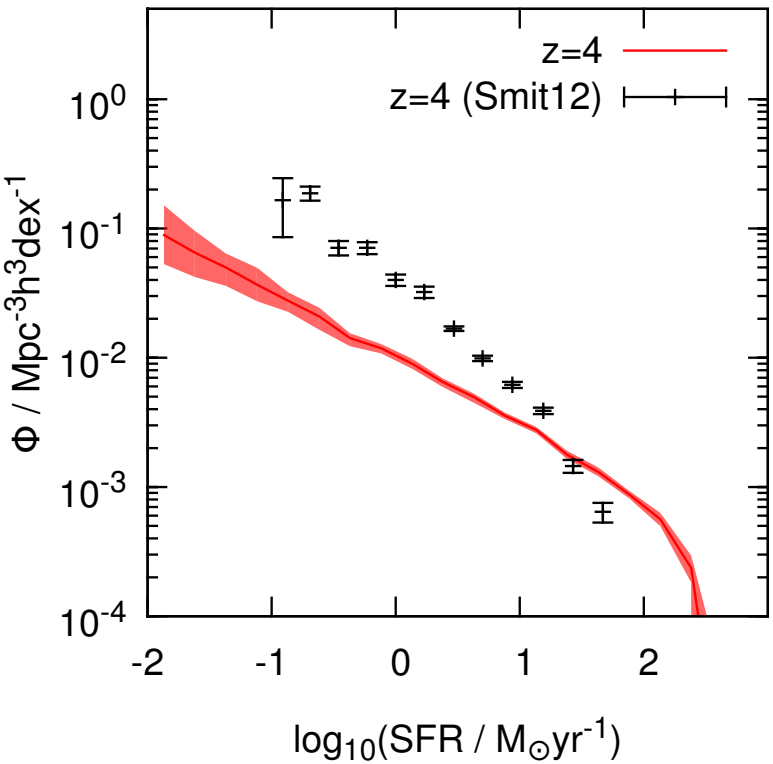
Model B



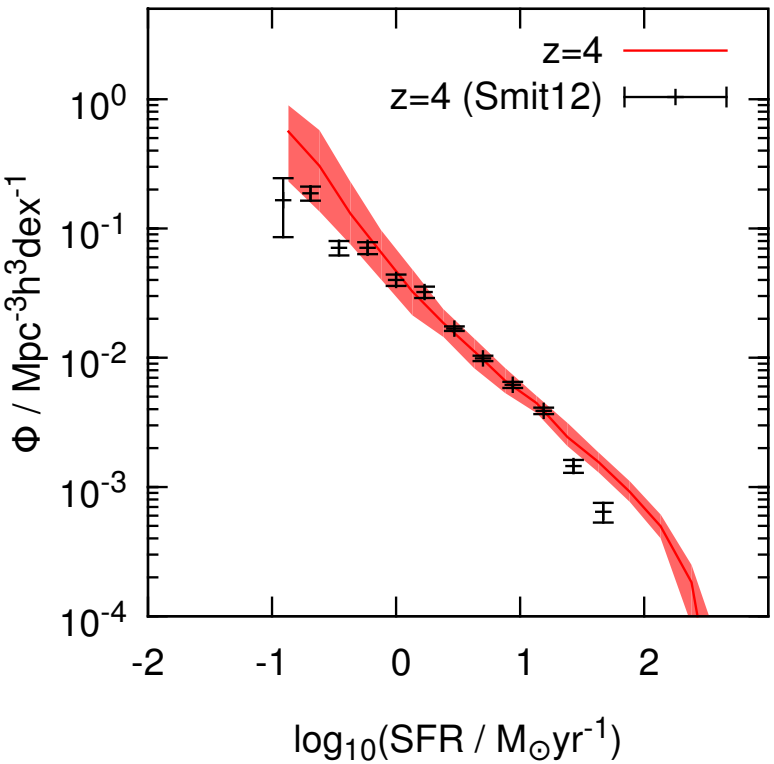
Source: Bouwens11

SFR Functions

Model A

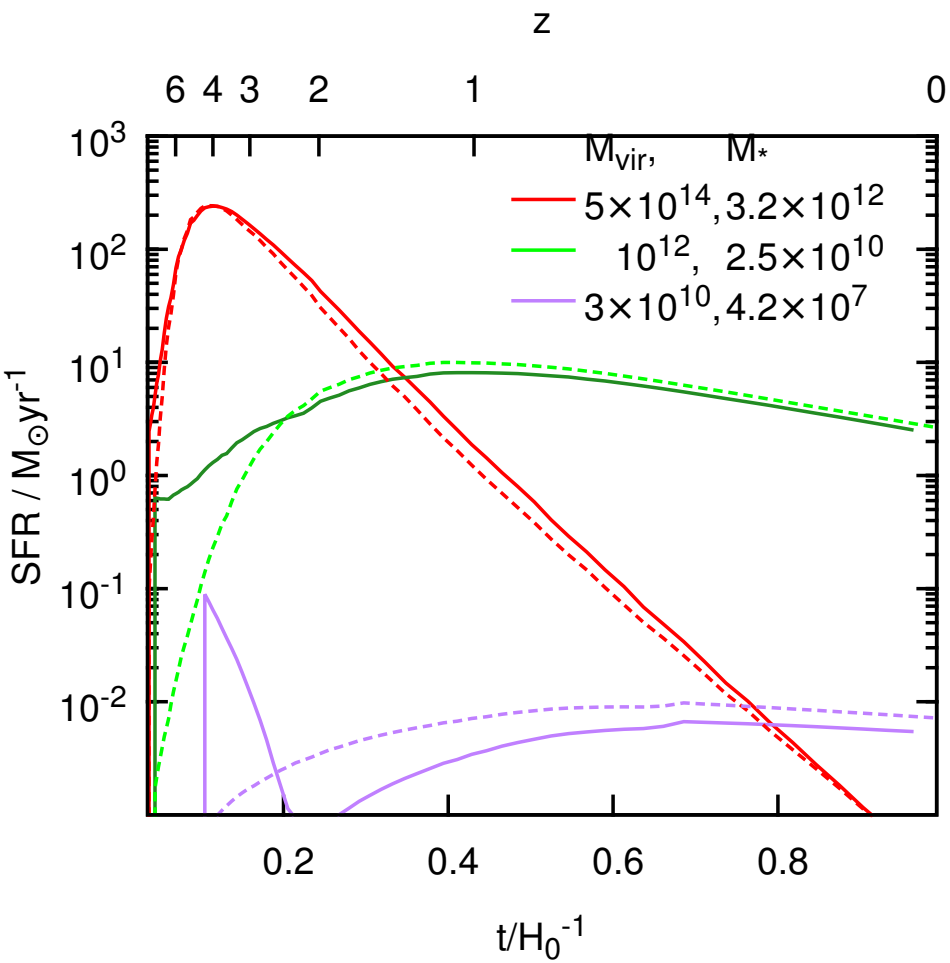


Model B



SFH of Present Day Galaxies

- Model A: dashed
- Model B: solid



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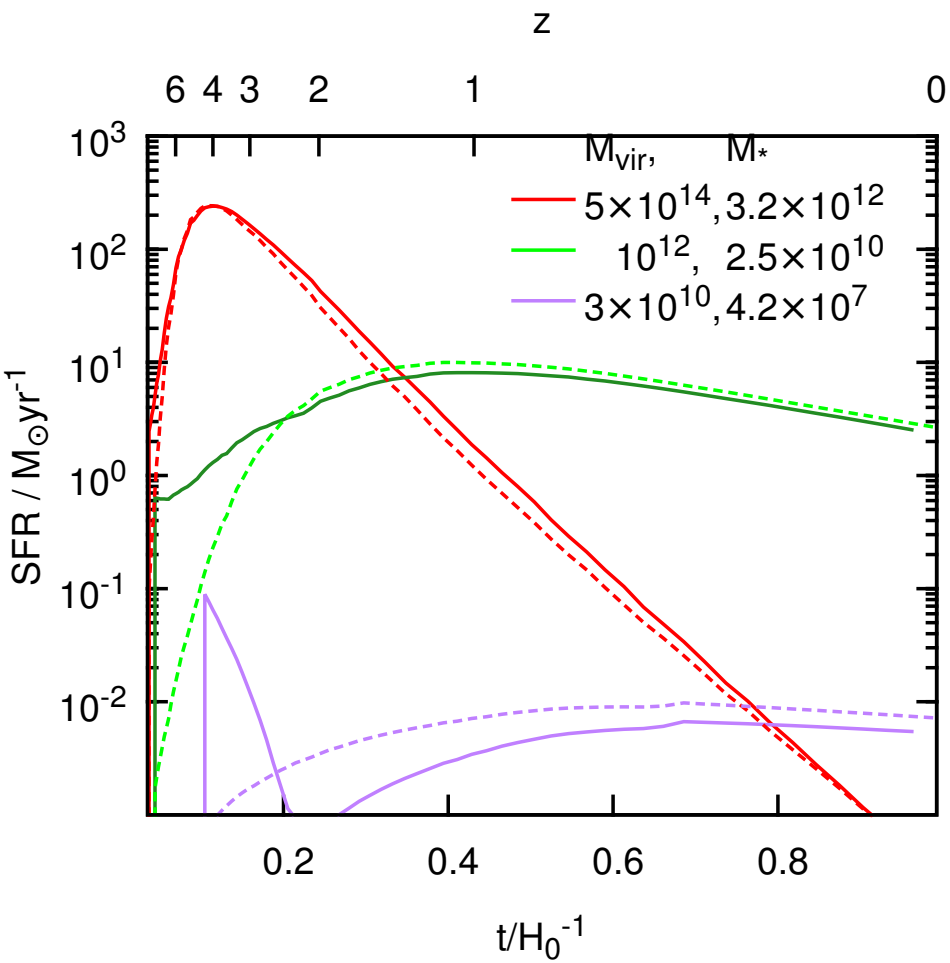

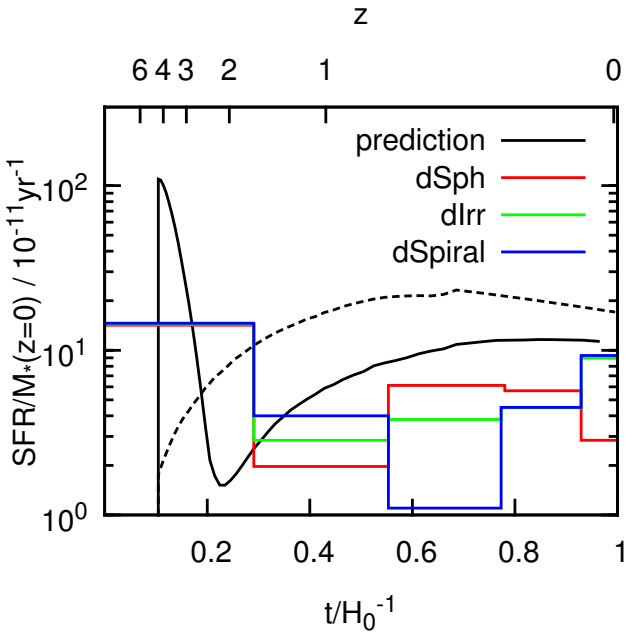

Source: Weisz11

SFH of Present Day Galaxies

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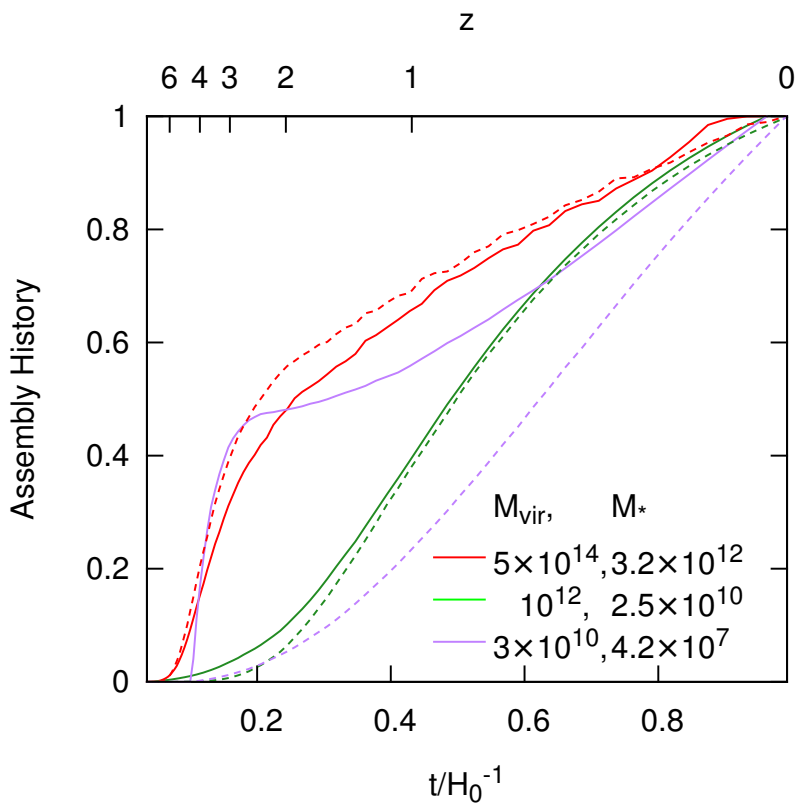

- Cluster Centrals:
  grow linearly with time after the SFR peak due to accretion;
- MW-sized:
  were $\sim 10^9 M_\odot$ at $z = 2$;
- Dwarves:
  initial burst contribute 50% of the present day stellar mass.

Summary

1. We infer the average star formation rate in dark matter halos from the observed stellar mass functions at different redshift combined with the luminosity function of local cluster galaxies.
2. Data on dwarf galaxies suggest **a new characteristic redshift (z_c)** above which the star formation efficiency in low mass halos ($< 10^{11} h^{-1} M_\odot$) must be enhanced relative to that at lower z.
3. Present-day galaxies of different mass show distinct star formation histories and assembly histories.
   - Dwarf galaxies ($< 10^9 M_\odot$): two stages of star formation;
   - Massive galaxies (cluster centrals): form stars early but assemble much later;
   - Milky Way-size galaxies: formed and assembled late ($z \approx 0.5$).