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On the origin of the galaxy star-formation-rate sequence: evolution and scatter

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Yale Galaxy Lunch
Sept 29, 2010

The Formation of Disk Galaxies

Disk galaxies are systems in centrifugal equilibrium

Structure of disks is governed by angular momentum content

- Halo growth obtained using extended Press-Schechter theory
- Angular momentum originates from cosmological torques
- Baryons and dark matter acquire identical ang. mom. distributions
- During cooling, gas conserves its specific angular momentum
- Gas settles in disk in centrifugal equilibrium:

$$\Sigma_{\rm disk}(R) \Longleftrightarrow M_{\rm bar}(j_{\rm bar}) \Longleftrightarrow M_{\rm dm}(j_{\rm dm})$$

- Halo contracts in response to formation of disk (adiabatic contraction)

The Star Formation Law

$$\Sigma_{\rm SFR} = \varepsilon_{\rm SF}\,\Sigma_{\rm mol,HCN}$$

Gao & Solomon 2004; Bigiel et al. 2008

$$\frac{\Sigma_{\rm mol,HCN}}{\Sigma_{\rm mol}} = 0.1\left(1+\frac{\Sigma_{\rm mol}}{200 M_\odot {\rm pc}^{-2}}\right)^{0.4}$$

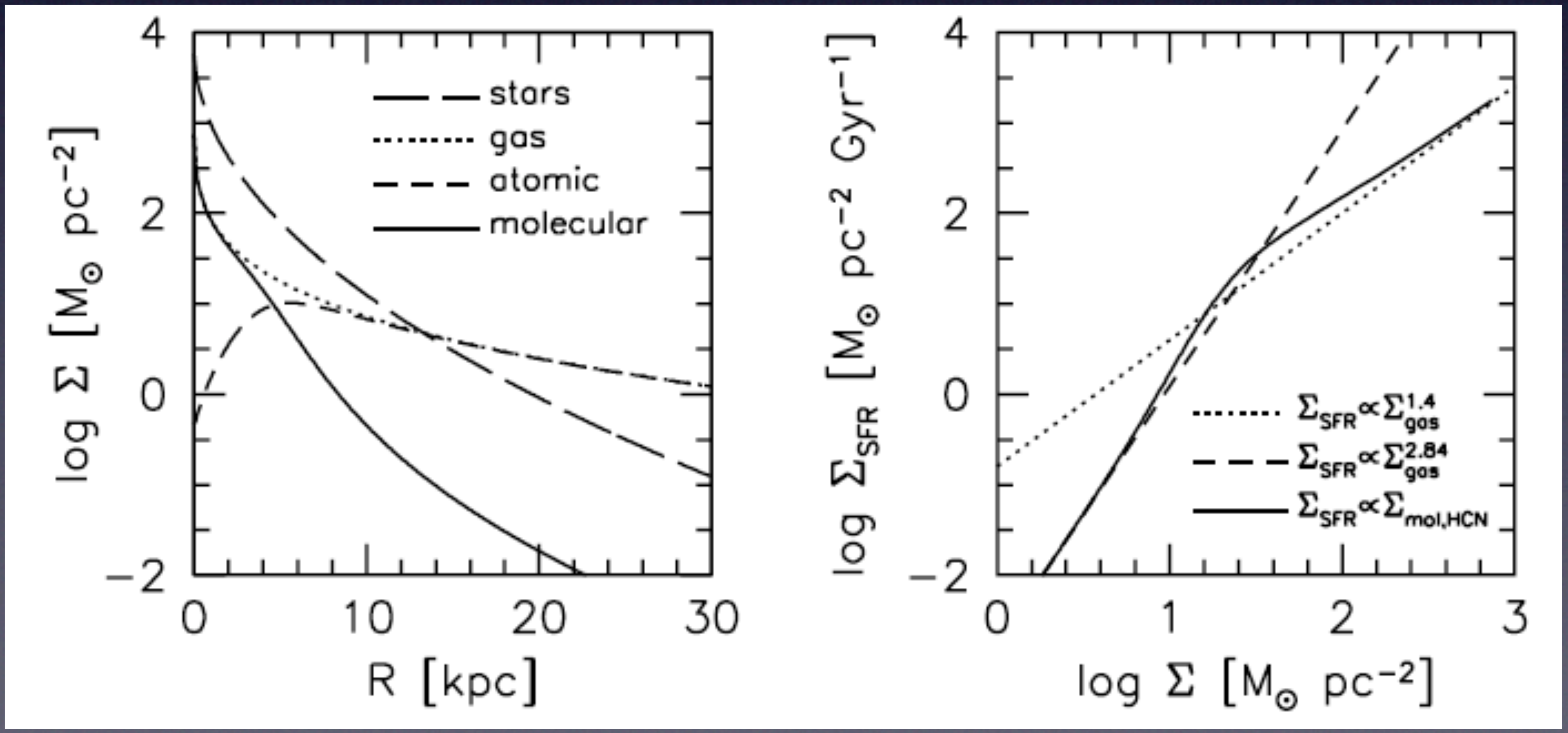
Blitz & Rosolowski 2006

$$\frac{\Sigma_{\rm mol}}{\Sigma_{\rm atom}} = \left[\frac{P_{\rm ext}/k_{\rm B}}{4.3\times 10^4}\right]^{0.92}$$

Blitz & Rosolowski 2006

$$P_{\rm ext} \simeq \frac{\pi}{2} G\Sigma_{\rm gas}\left[\Sigma_{\rm gas} + \left(\frac{\sigma_{\rm gas}}{\sigma_{\rm star}}\right)\Sigma_{\rm star}\right]$$

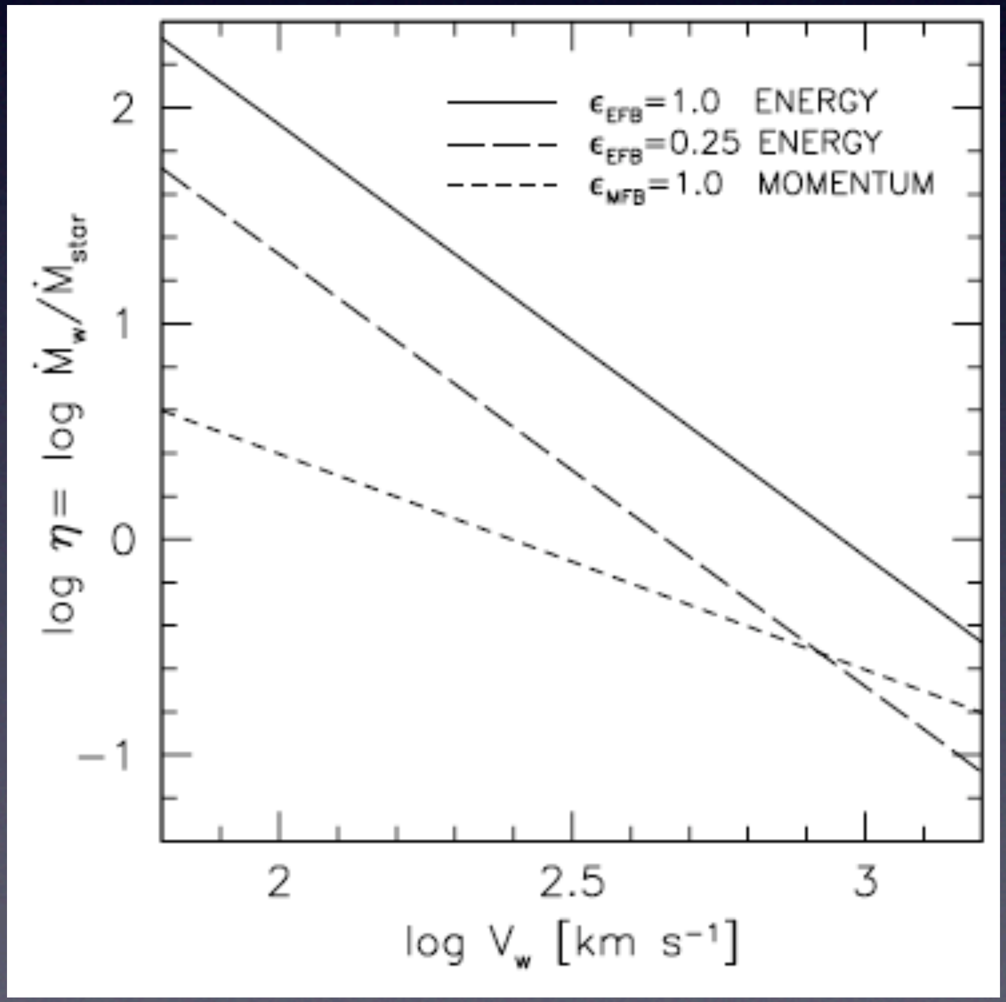
Elmegreen 1993



Supernova Feedback

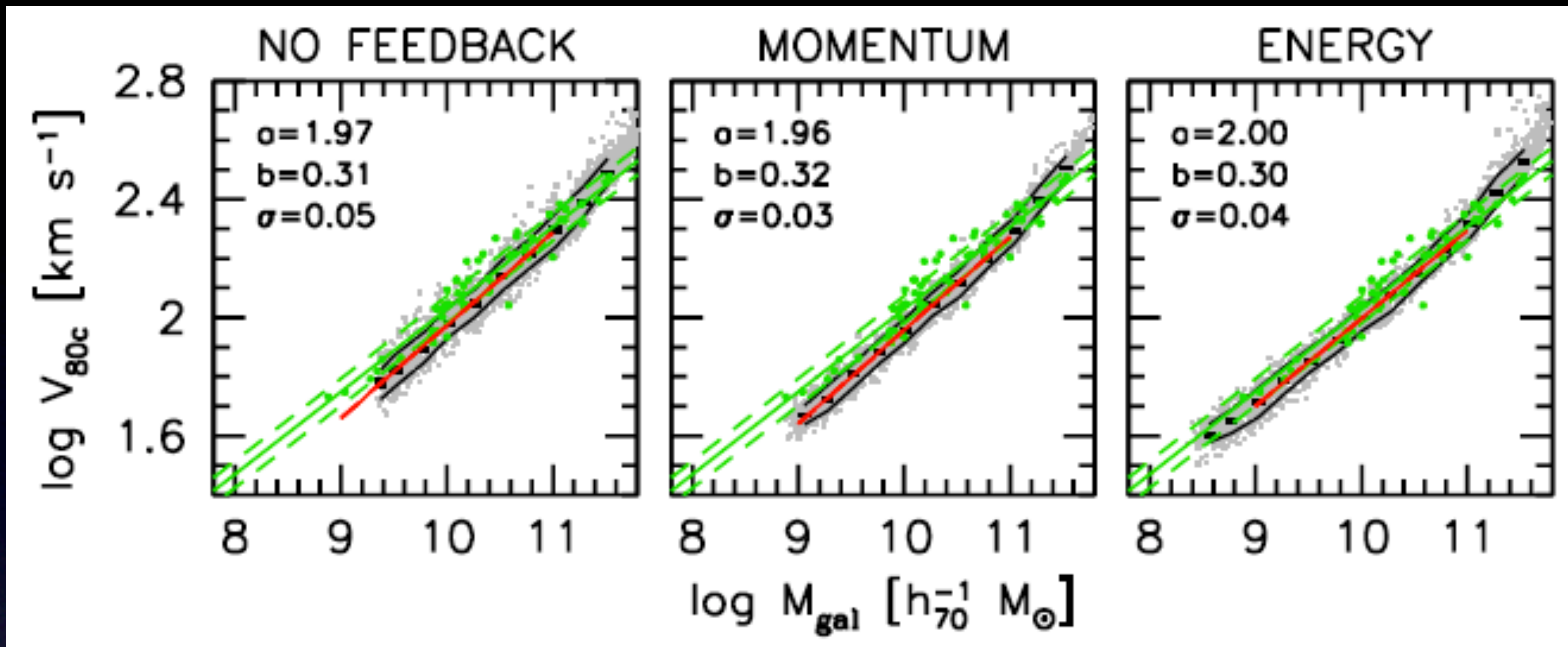
Energy-driven wind: $\dot{M}_{\rm wind}(R) = \frac{2\varepsilon_{\rm EFB}E_{\rm SN}\eta_{\rm SN}}{V_{\rm esc}^2(R)}\dot{M}_{\rm star}(R)$ Dekel & Silk 1986

Momentum-driven wind: $\dot{M}_{\rm wind}(R) = \frac{\varepsilon_{\rm MFB}p_{\rm SN}\eta_{\rm SN}}{V_{\rm esc}(R)}\dot{M}_{\rm star}(R)$ Murray et al. 2005



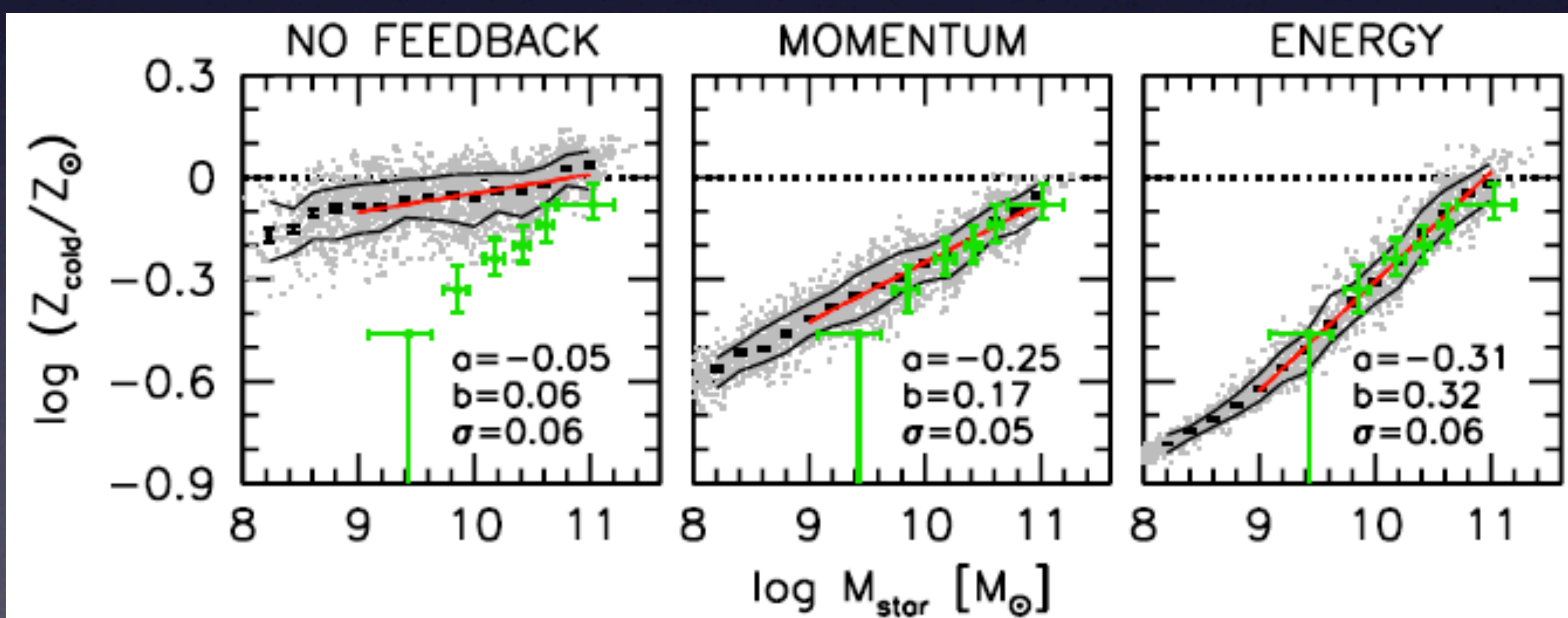
For a given efficiency, energy-driven winds typically result in a larger mass-loading factor than momentum-driven winds...

Comparison with data



Baryonic Tully-Fisher Relation

Data from Garnett 2002



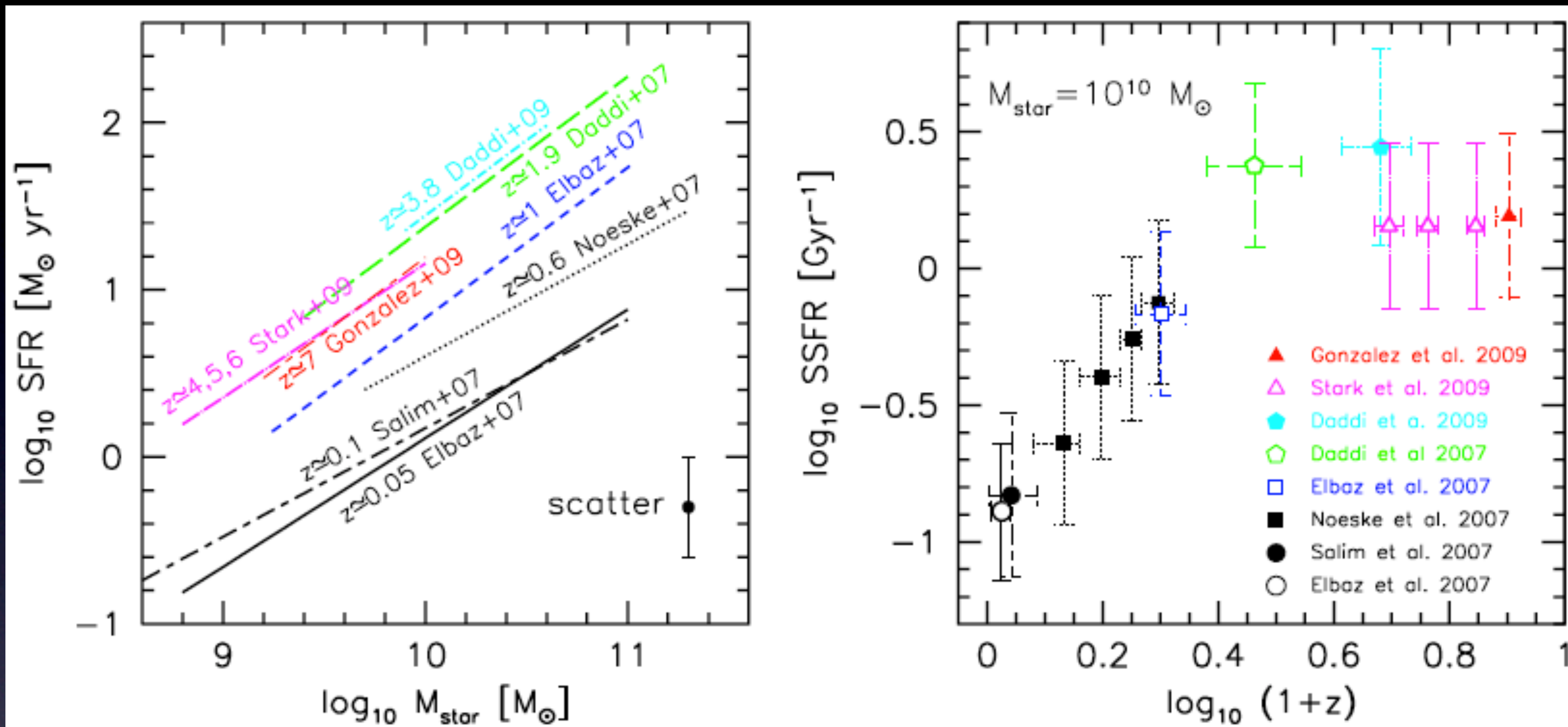
Stellar mass-gas metallicity relation at z = 2.26

Data from Erb et al. 2006

Dutton & vdB 2009

Overall, energy-driven wind models is most succesful

The Cosmic Star Formation History



factor 20

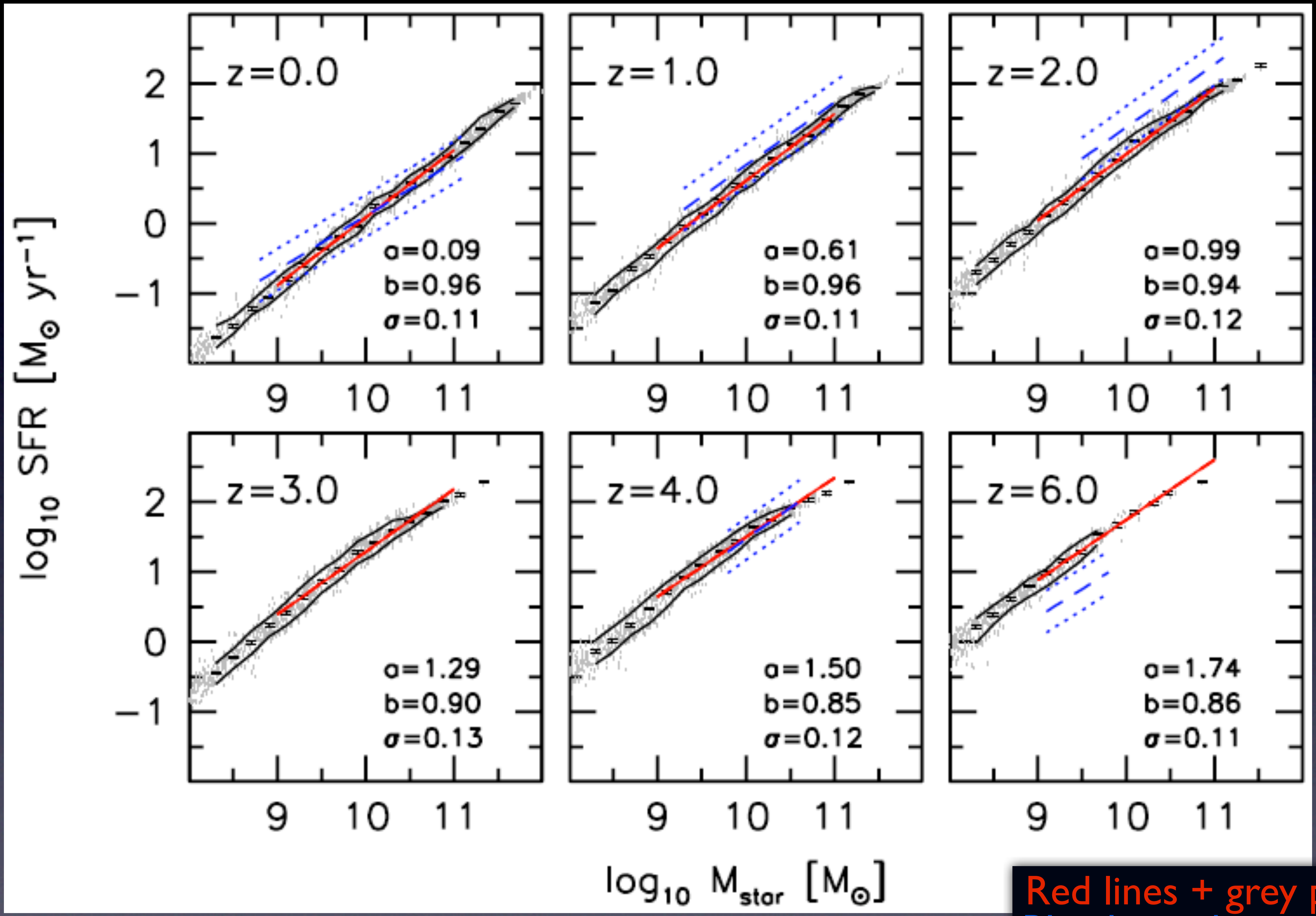
$$\Sigma_{\rm SFR} = \varepsilon_{\rm SF}\Sigma_{\rm gas}^{n}$$

$$\Sigma_{\rm gas} = \Sigma_0 \exp(-R/R_{\rm gas})$$

$$\frac{\dot{M}_{\rm star}}{M_{\rm star}} = 2\pi \int_0^\infty \Sigma_{\rm SFR}\, R\, {\rm d}R \propto \varepsilon_{\rm SF} \frac{M_{\rm gas}}{M_{\rm star}} \Sigma_0^{n-1}$$

Decline in SSFRs may be due to evolution in gas mass fractions, or in gas surface densities (assuming that SF efficiency is governed by micro-physics)

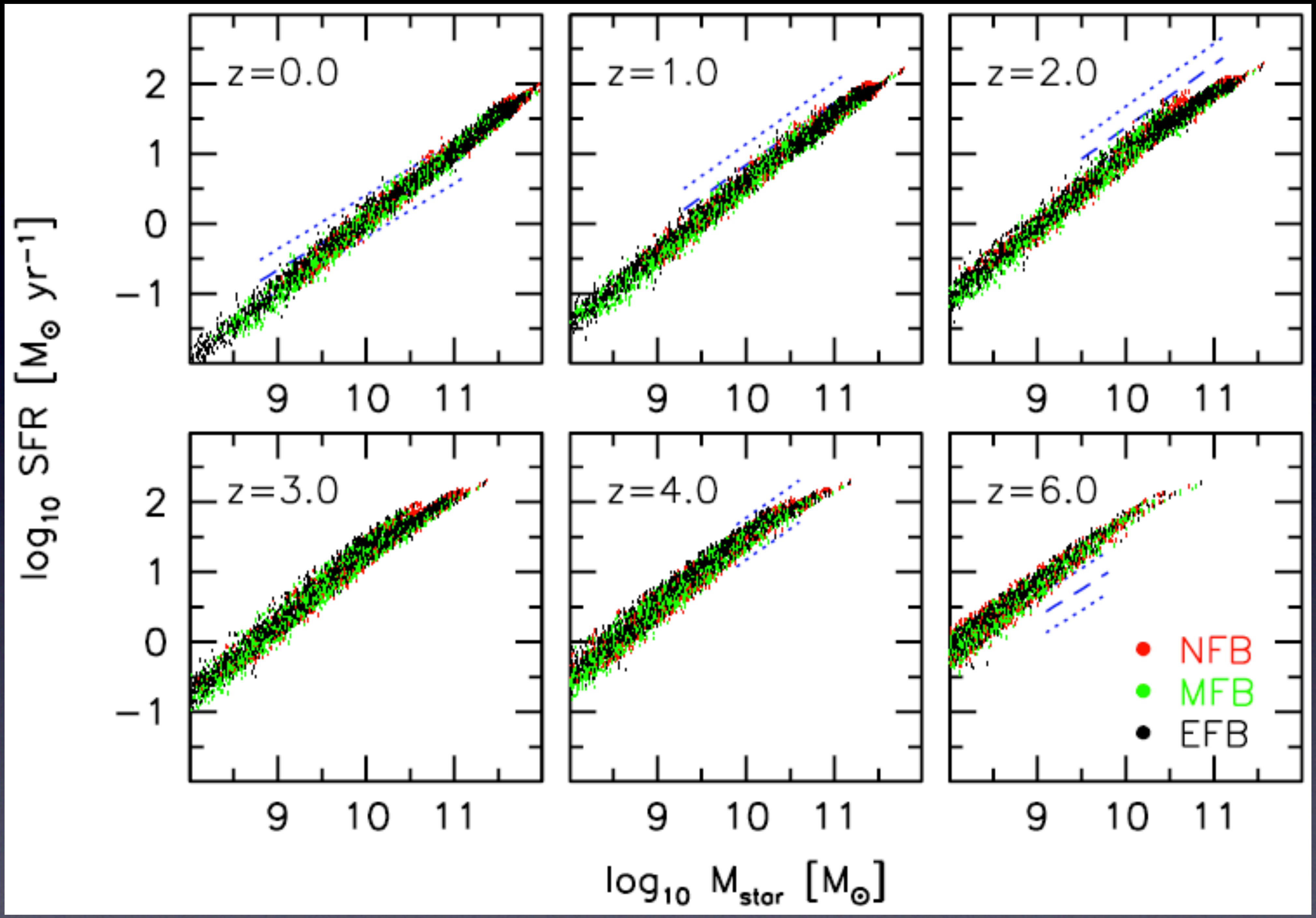
and what our model predicts (no fine-tuning)



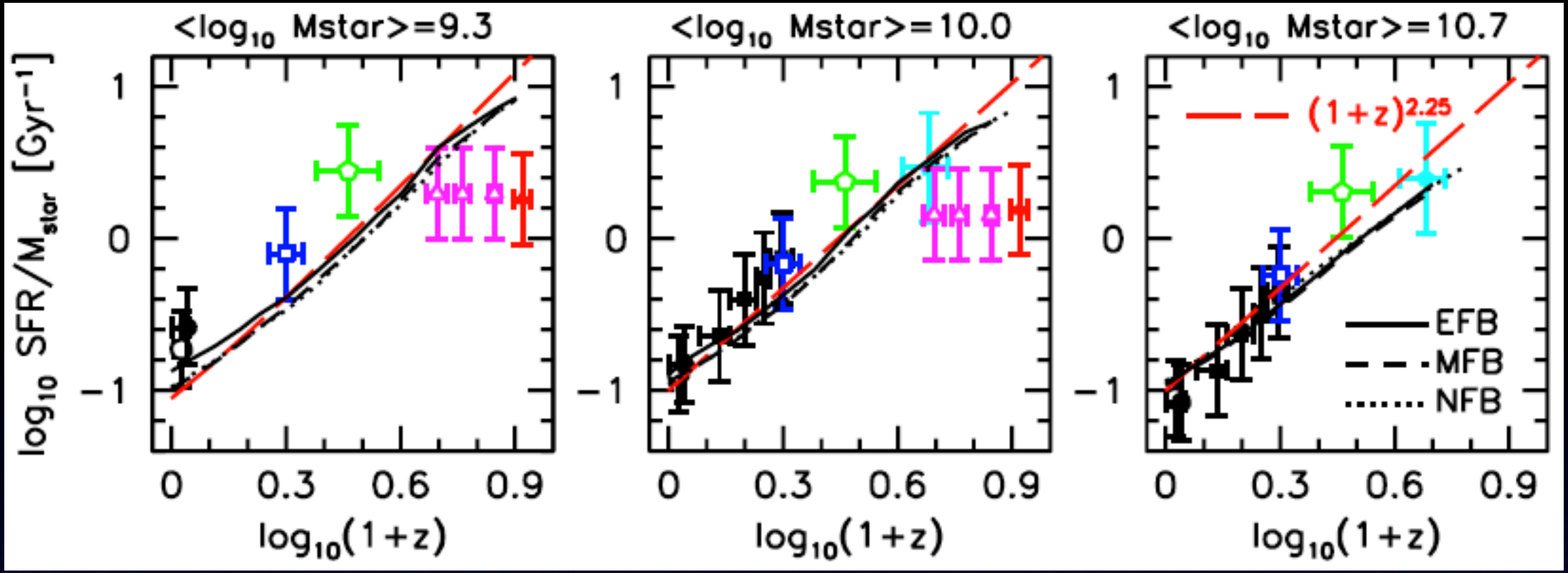
EFB model

Red lines + grey points: model
Blue lines: data

Results are independent of feedback prescription!!!



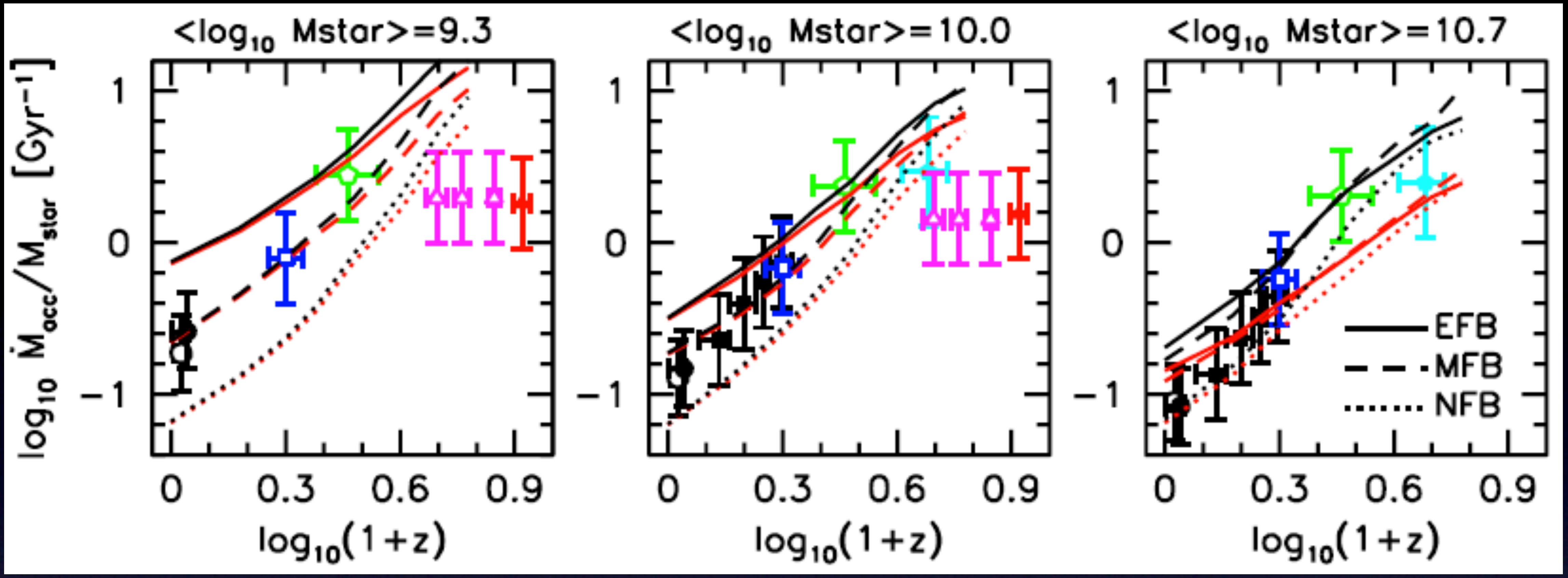
Star Formation is self-regulating...



average halo mass accretion rate $\dot{M} \propto (1+z)^{2.25}$

(Noeske et al. 2007; Birnboim et al. 2007)

- Models are in reasonable agreement with the data, independent of feedback implementation
- Models predict strong evolution at z > 2, in apparent conflict with observation.
- Evolution in SSFRs of galaxies appears to be mainly driven by evolution in accretion rate onto dark matter haloes

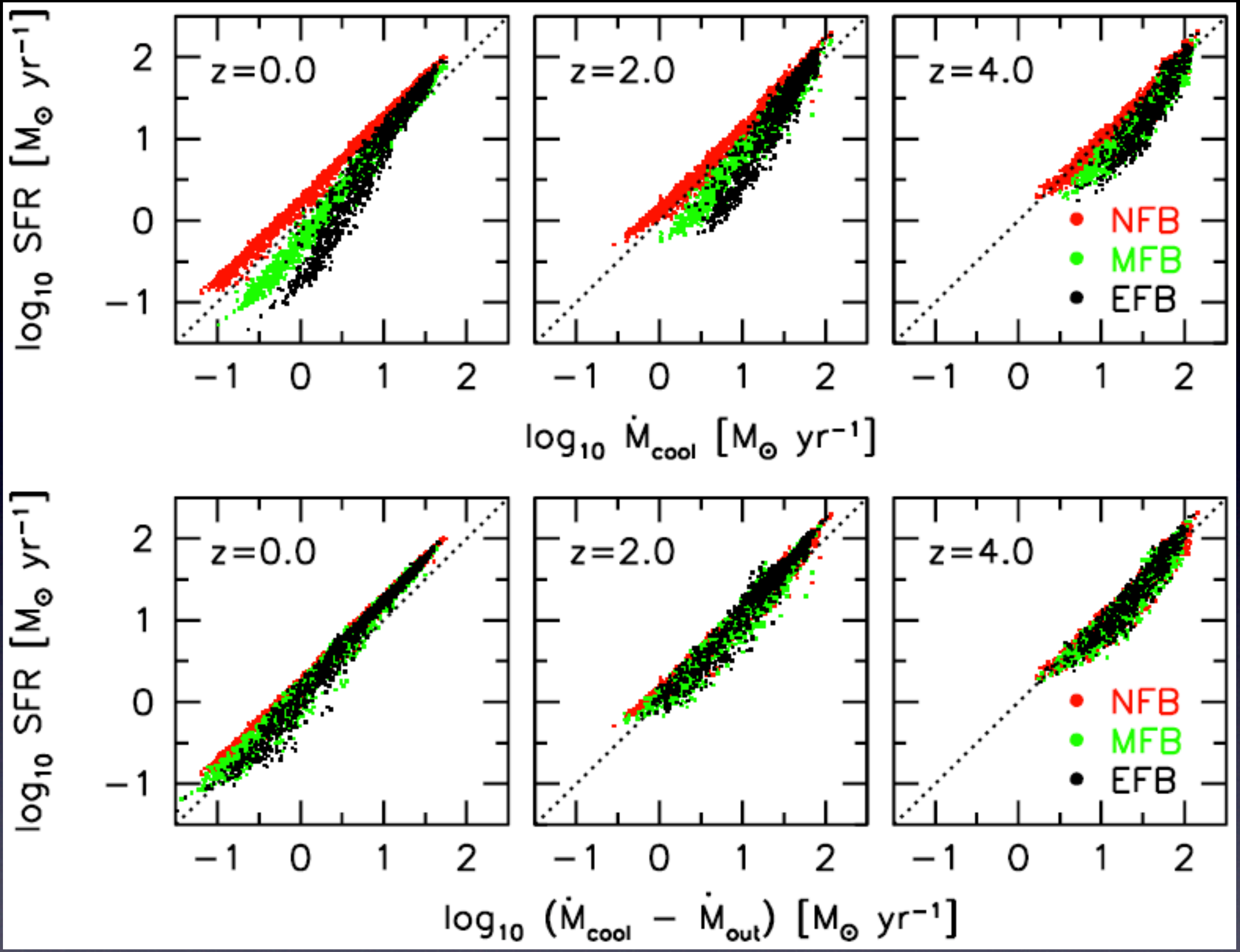


NFB dotted lines; EFB solid lines; MFB dashed lines

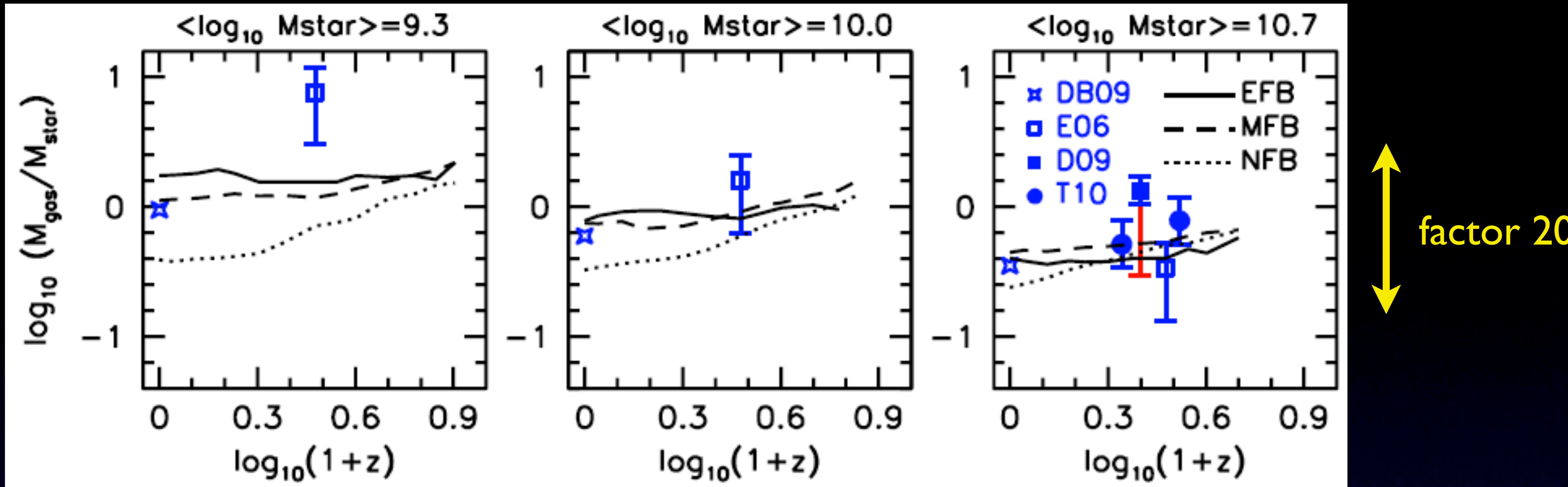
Low mass haloes: cooling time < free-fall time (cold mode)

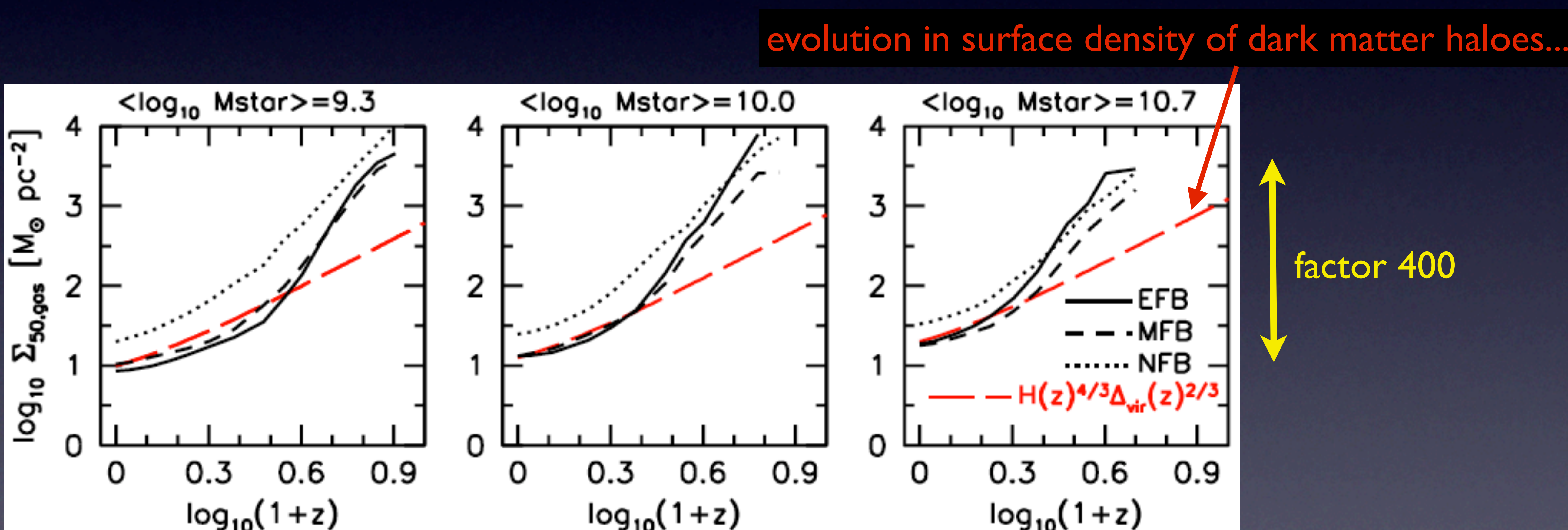
High mass haloes: cooling time > free-fall time (hot mode)

Cosmic star formation rate appears related to the halo accretion rate, but there is more to it...



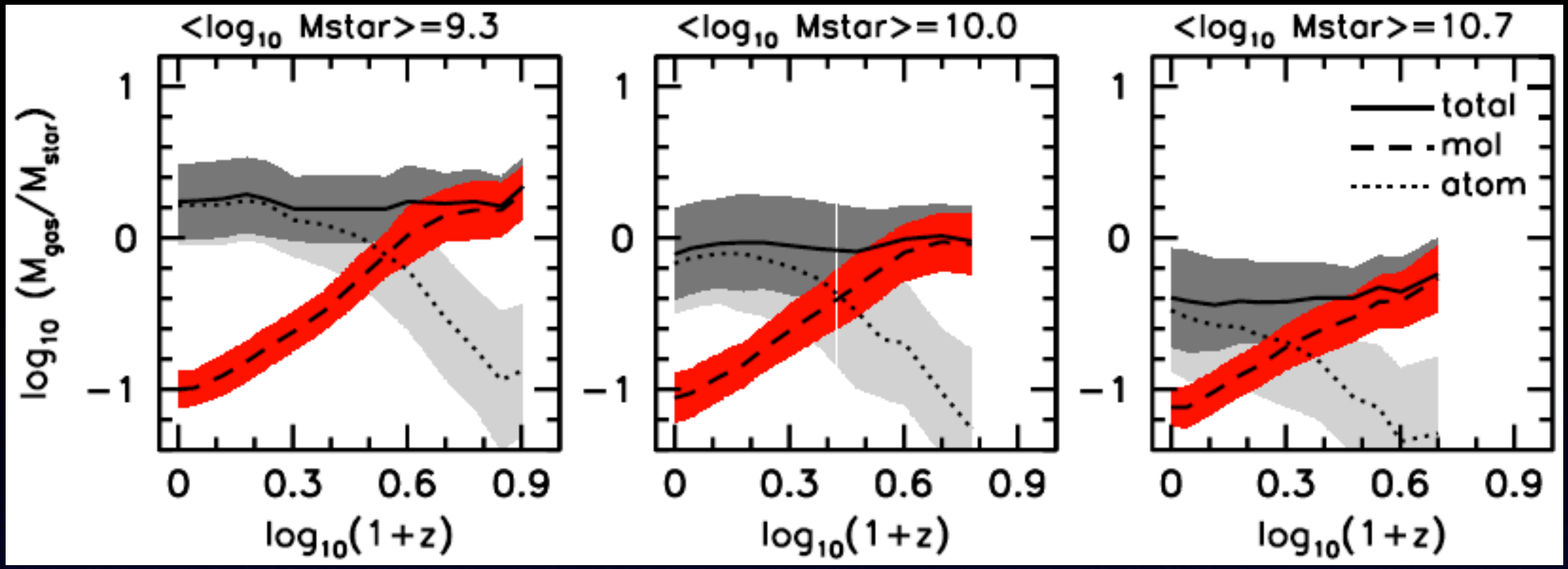
Galaxy disks are in steady-state in which SFR is roughly equal to the net gas inflow rate...

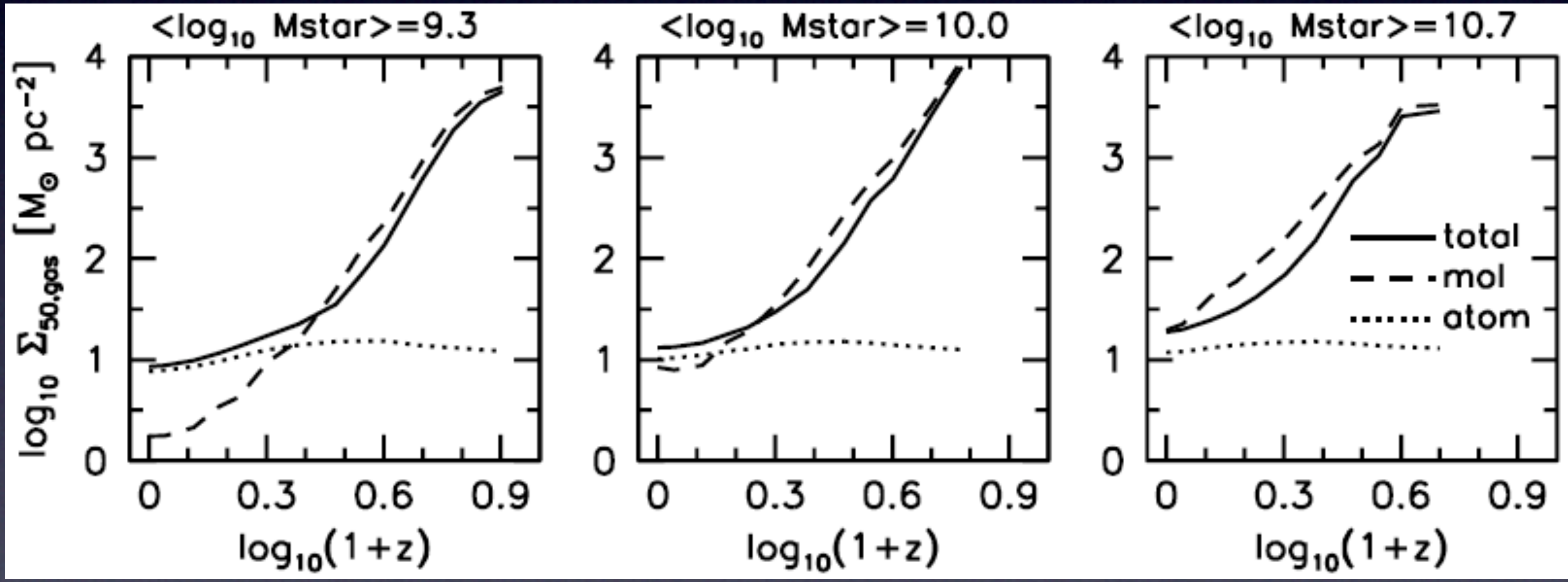




Evolution in SSFRs driven by evolution in gas densities, not by evolution in gas mass fractions!!!

Higher densities --> higher molecular fractions --> higher SSFRs





High-z studies of galaxies: { ALMA / SKA