MPE

TMoOS

Theoretical Modeling of Cosmic Structures

Max Planck Society

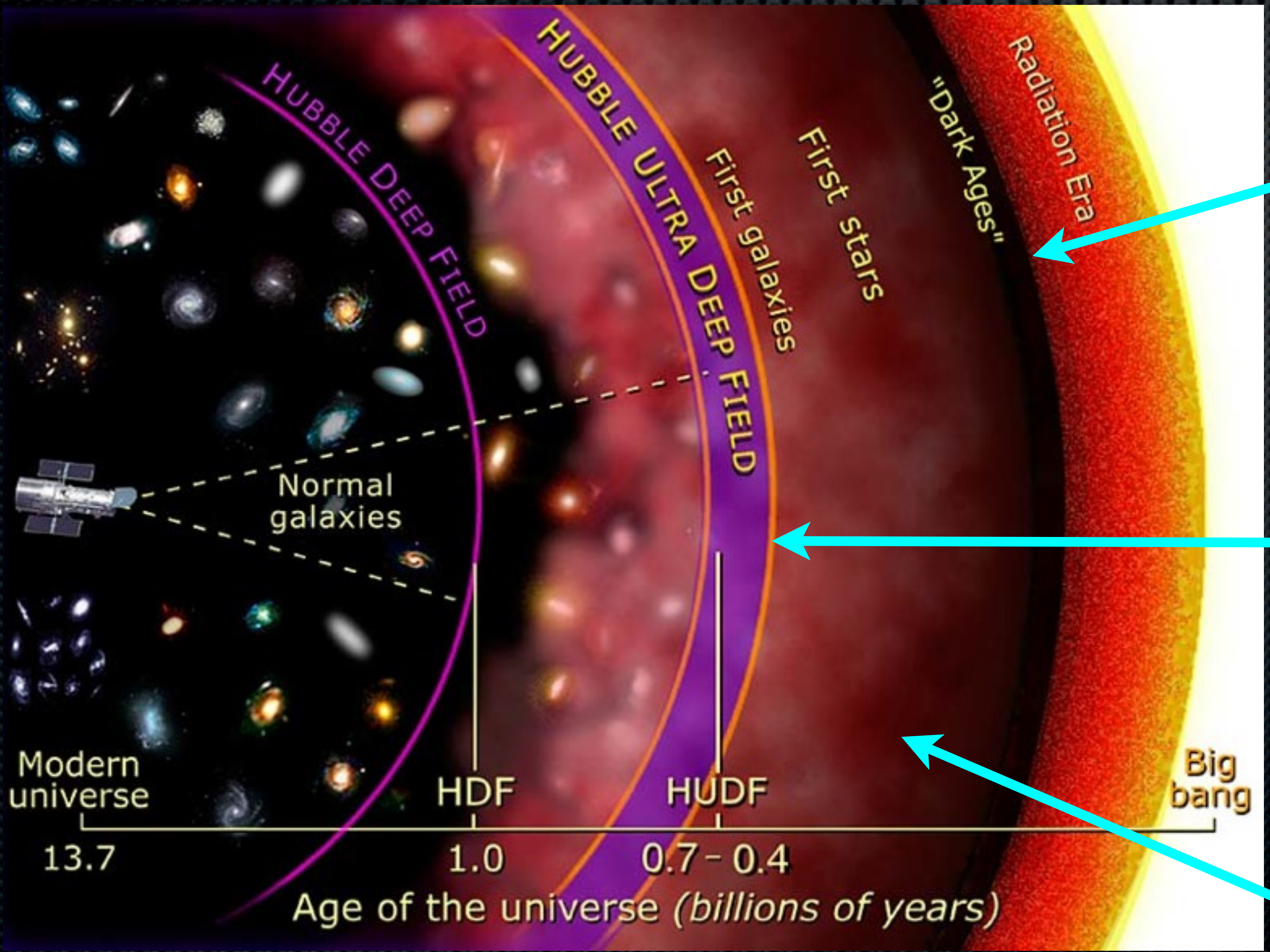
Growth Spurting Baby Galaxies

Sadegh Khochfar

with

C. Dalla Vecchia, J.P. Paardekooper,
A. Davies, B. Agarwal, J, Johnson

The First Billion Years

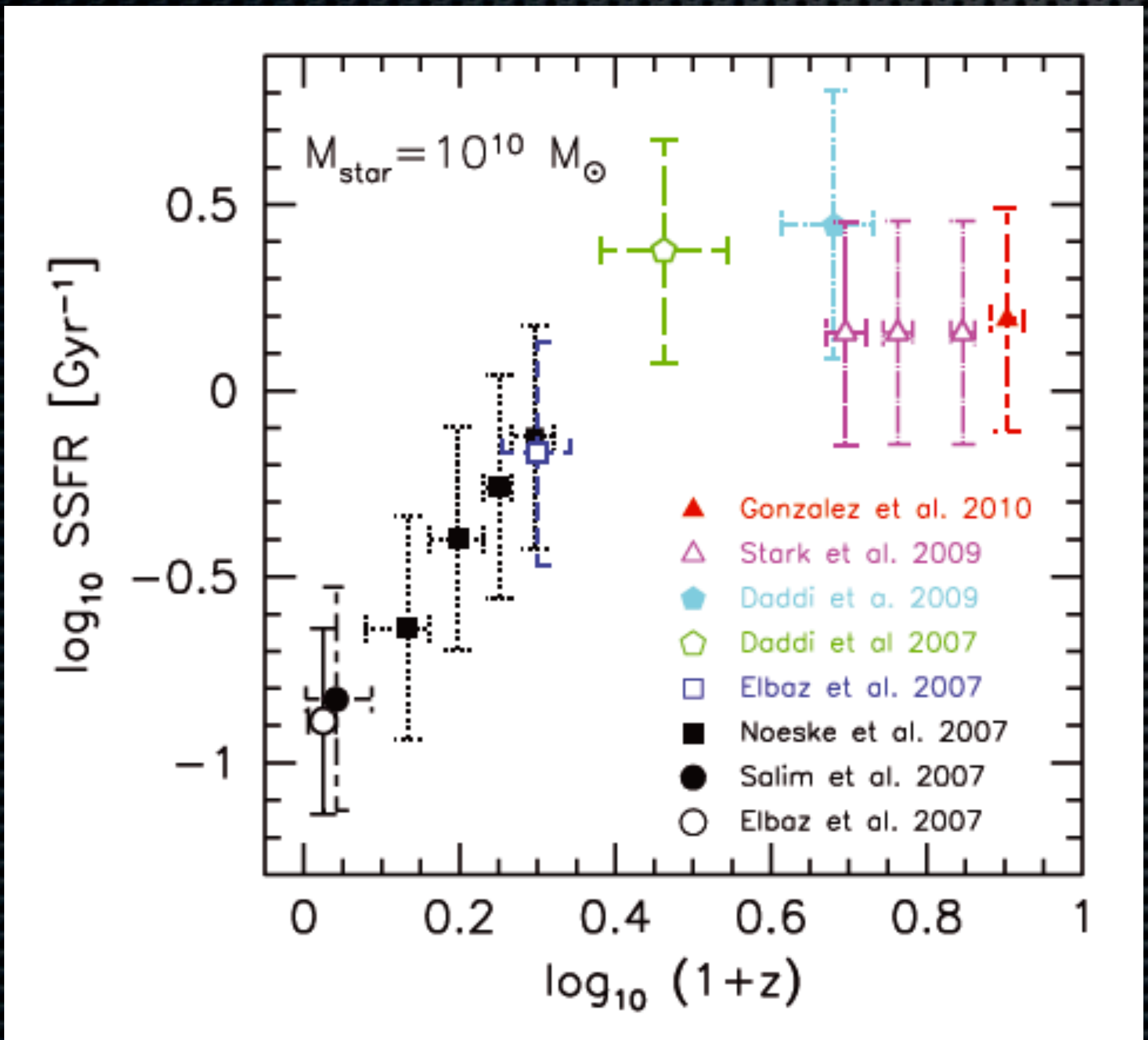


The cosmic microwave background is emitted

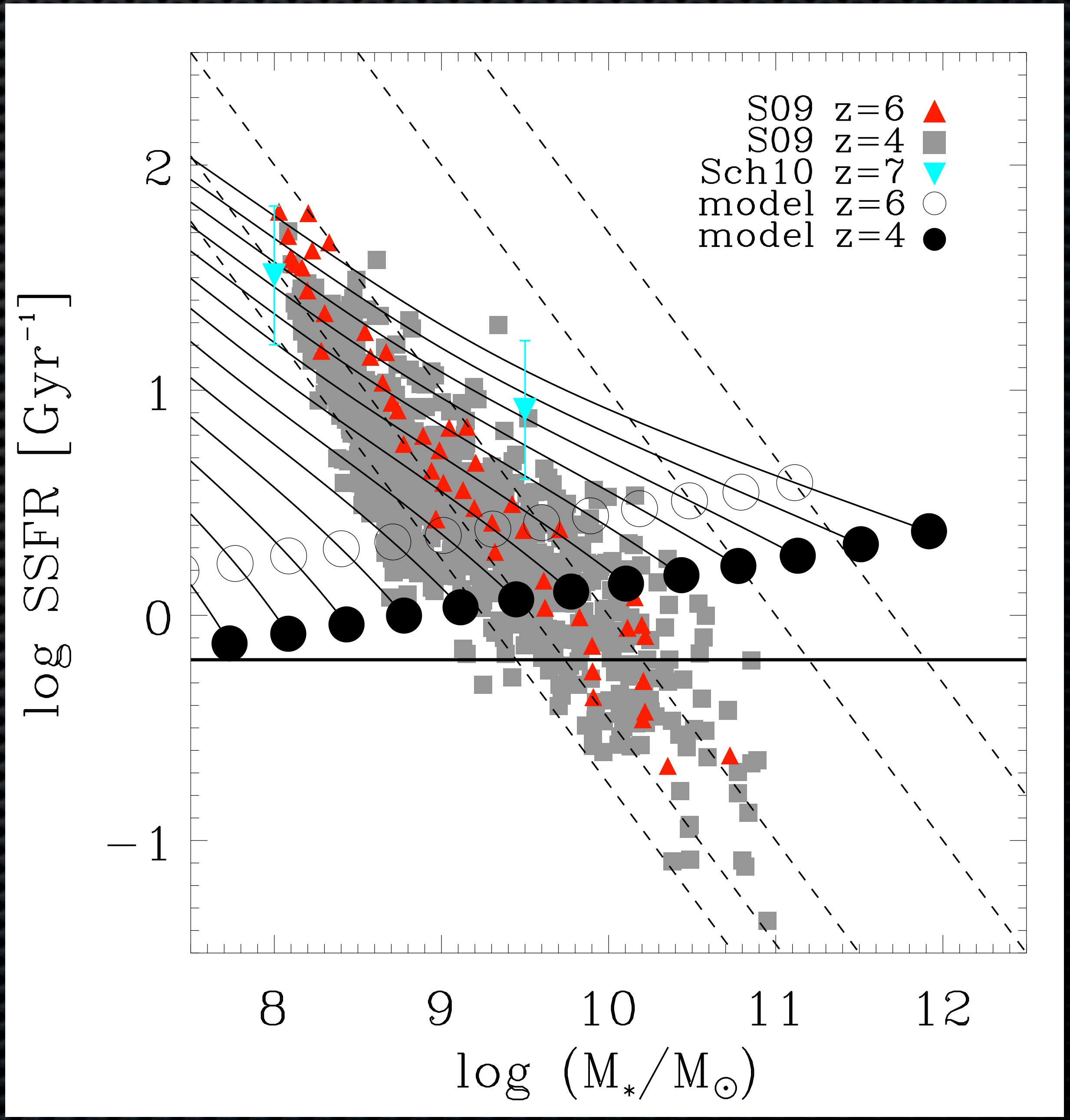
Most distant galaxies observed so far

First galaxies stars and black holes form!

Direct Observational Evidence



Dutton et al 2010



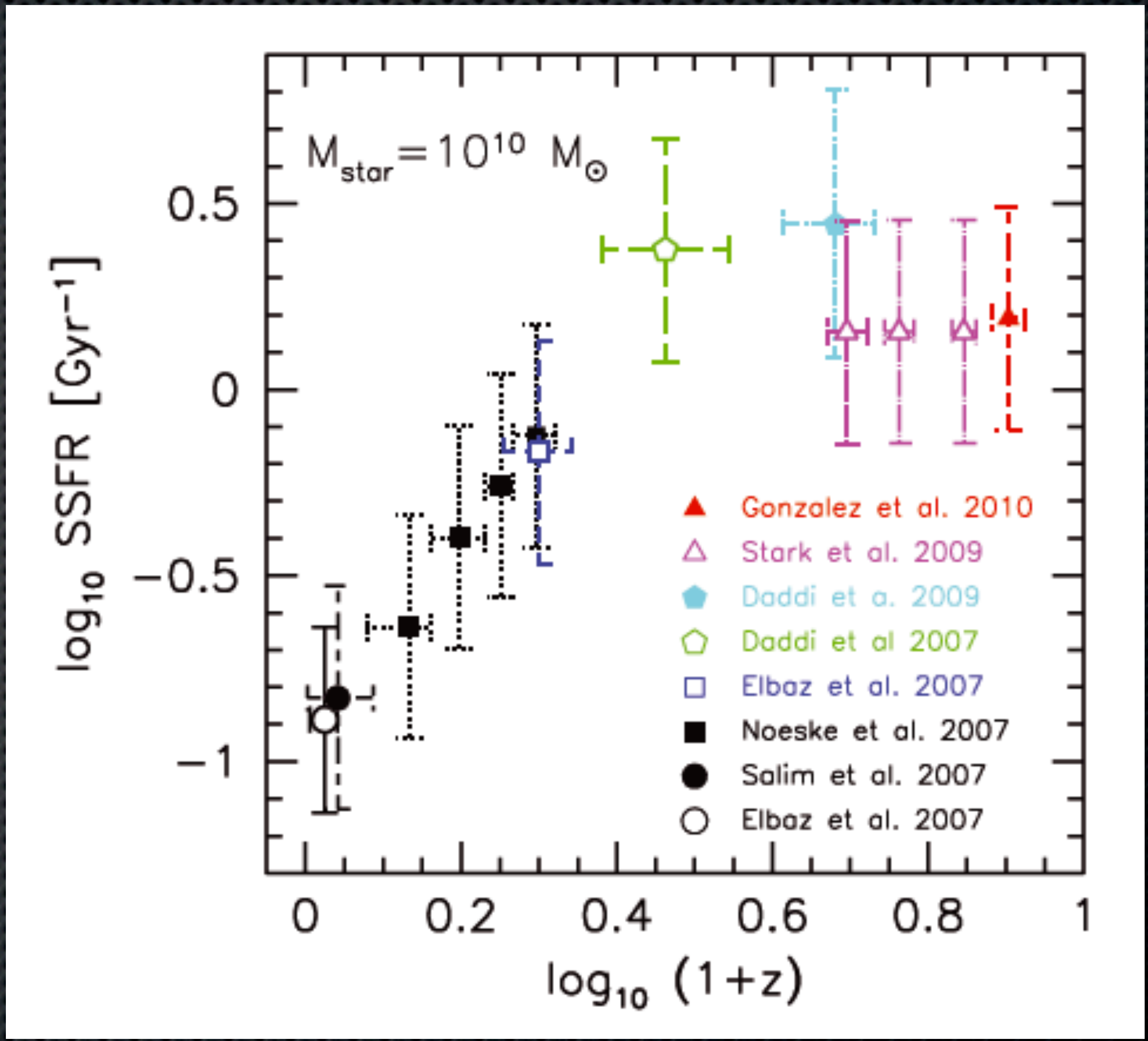
Khochfar & Silk 2011

Stellar assembly rate

Approximating stellar mass growth due to equal mass mergers by:

$$\dot{M}_{grow} = \frac{M_*}{t_{df}}$$

At z > 6 one equal mass merger can grow the stellar mass more than constant SF over the next ~0.6 Gyr. Mergers could be more important to the evolution of the mass function than star formation depending on their frequency.



Dutton et al 2010

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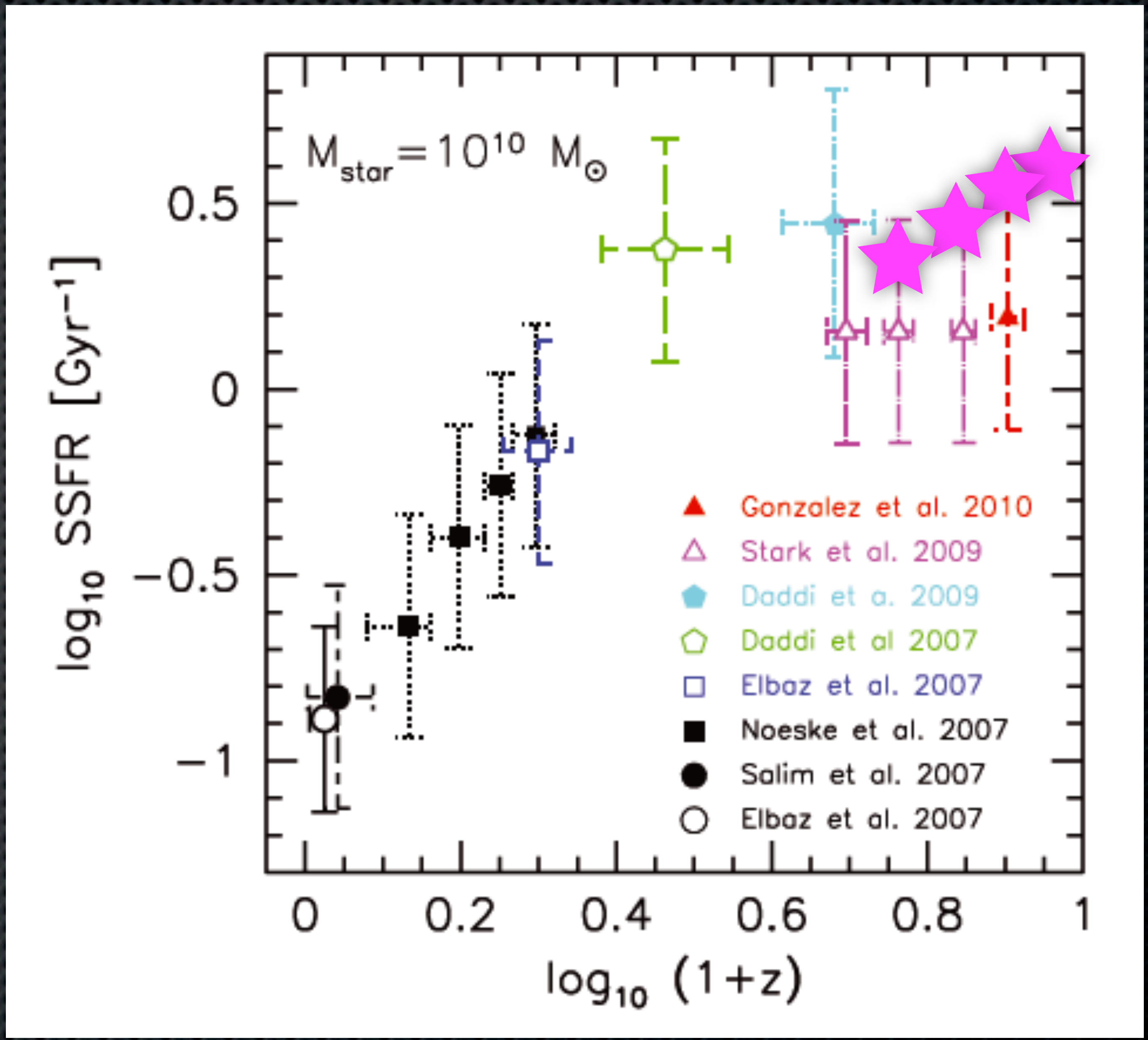


Dutton et al 2010

Simulation

$$(\Omega_m, \Omega_b, \Omega_\Lambda, h) = (0.258, 0.742, 0.0441, 0.719)$$

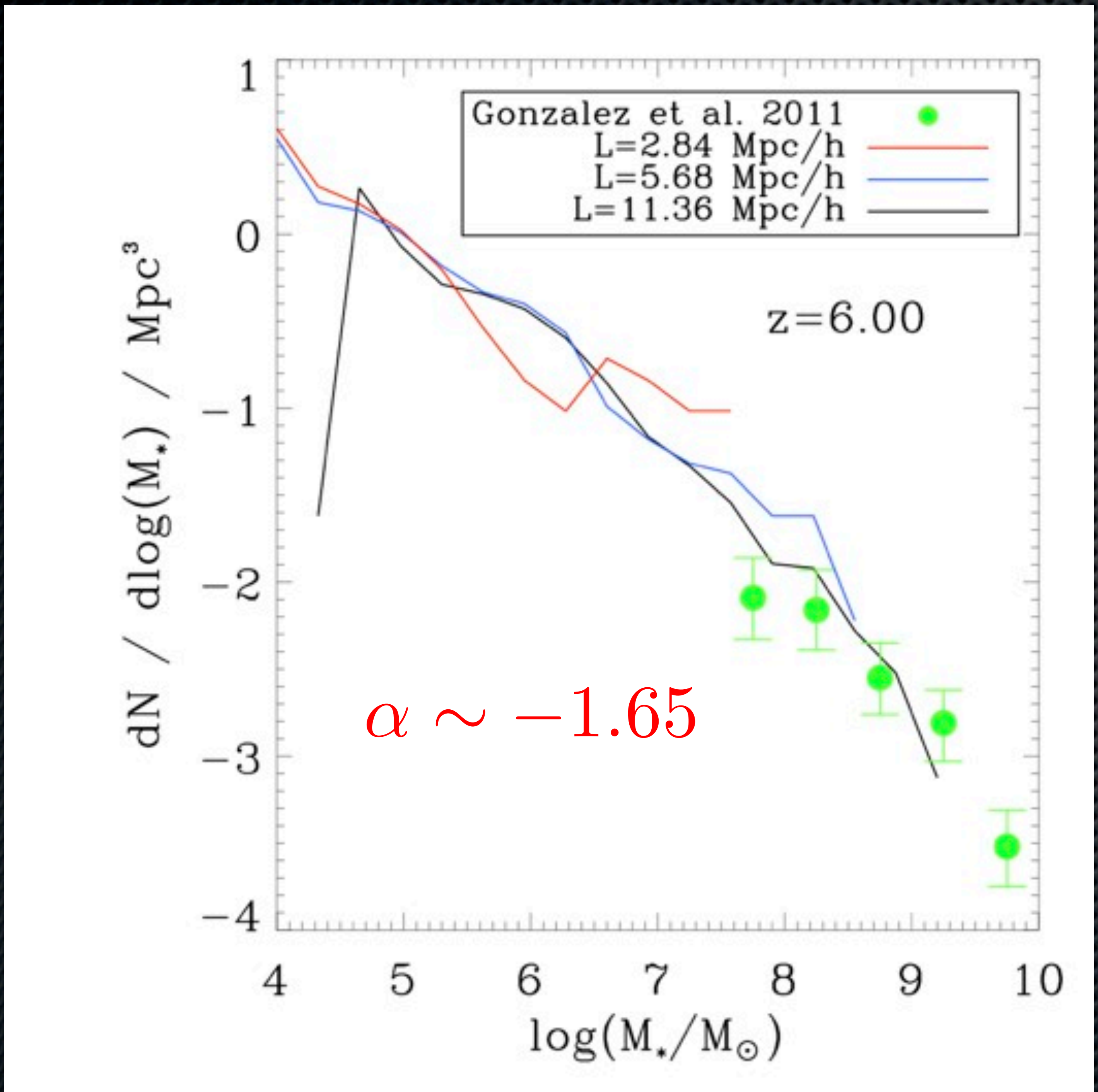
- GADGET-2 version used for the OWLS project (Schaye et al. 2010): SF; metal enrichment; metal line cooling from 11 elements; BH growth and feedback; SN feedback
- Added molecular networks and cooling
- Added POPIII formation and evolution, seed BHs
- Added dust from PISN, AGB & SNII; thermal sputtering
- Inclusion of Lyman-Werner background (11.3 - 13.6 eV)
- Coupled to radiative transfer scheme SIMPLEX in post-processing

$$V = (8\mathrm{Mpc})^3$$
$$N = 2 \times 1368^3$$
$$m_{gas} = 890 M_\odot h^{-1}$$
$$m_{DM} = 4375 M_\odot h^{-1}$$

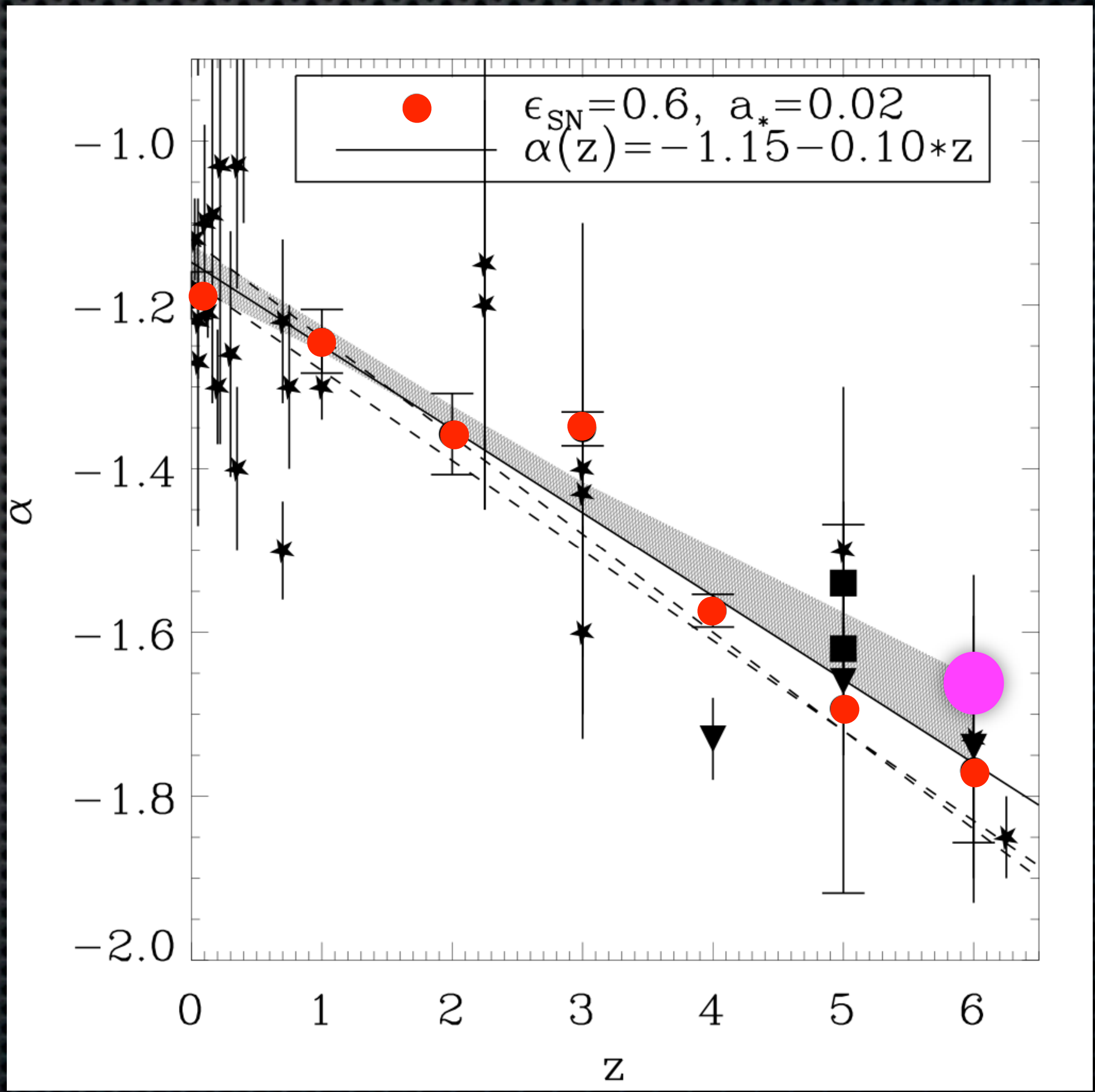
The First Billion Years Simulation

Khochfar et al 2012

The Mass Function

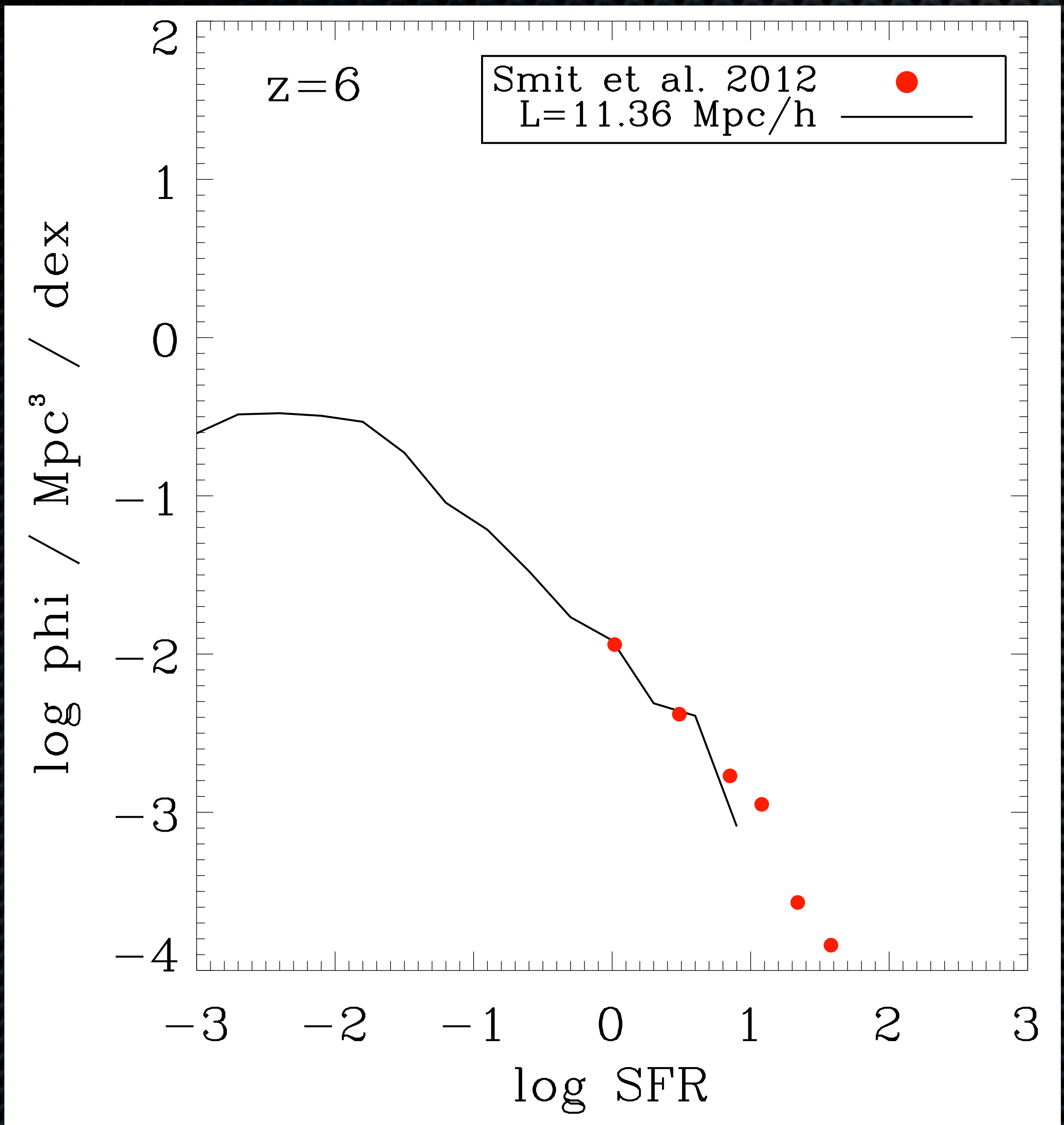


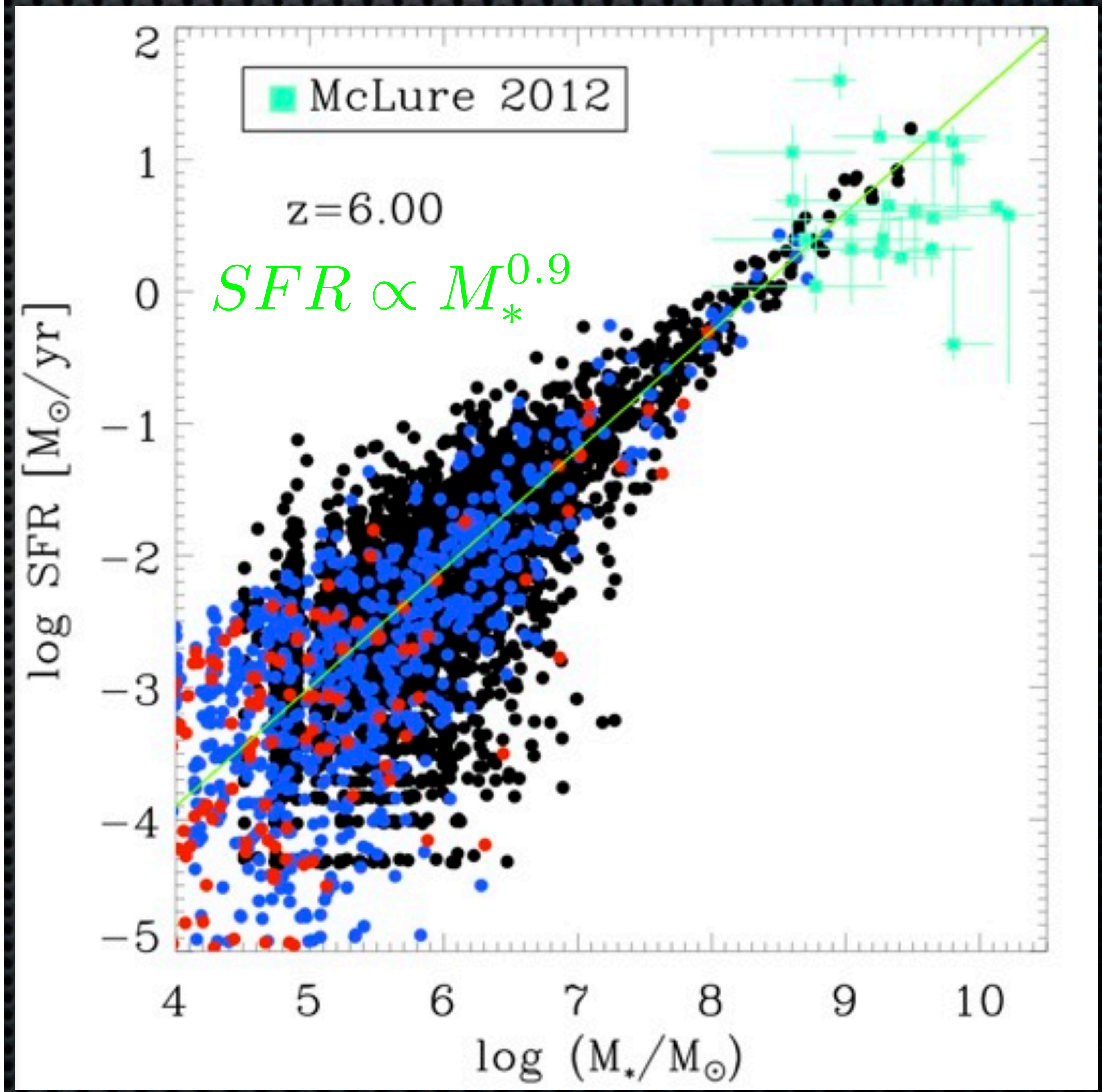
Khochfar et al. 2012



Khochfar et al. (2007)
Ryan et al (2007)

Star formation





Khochfar et al. 2012

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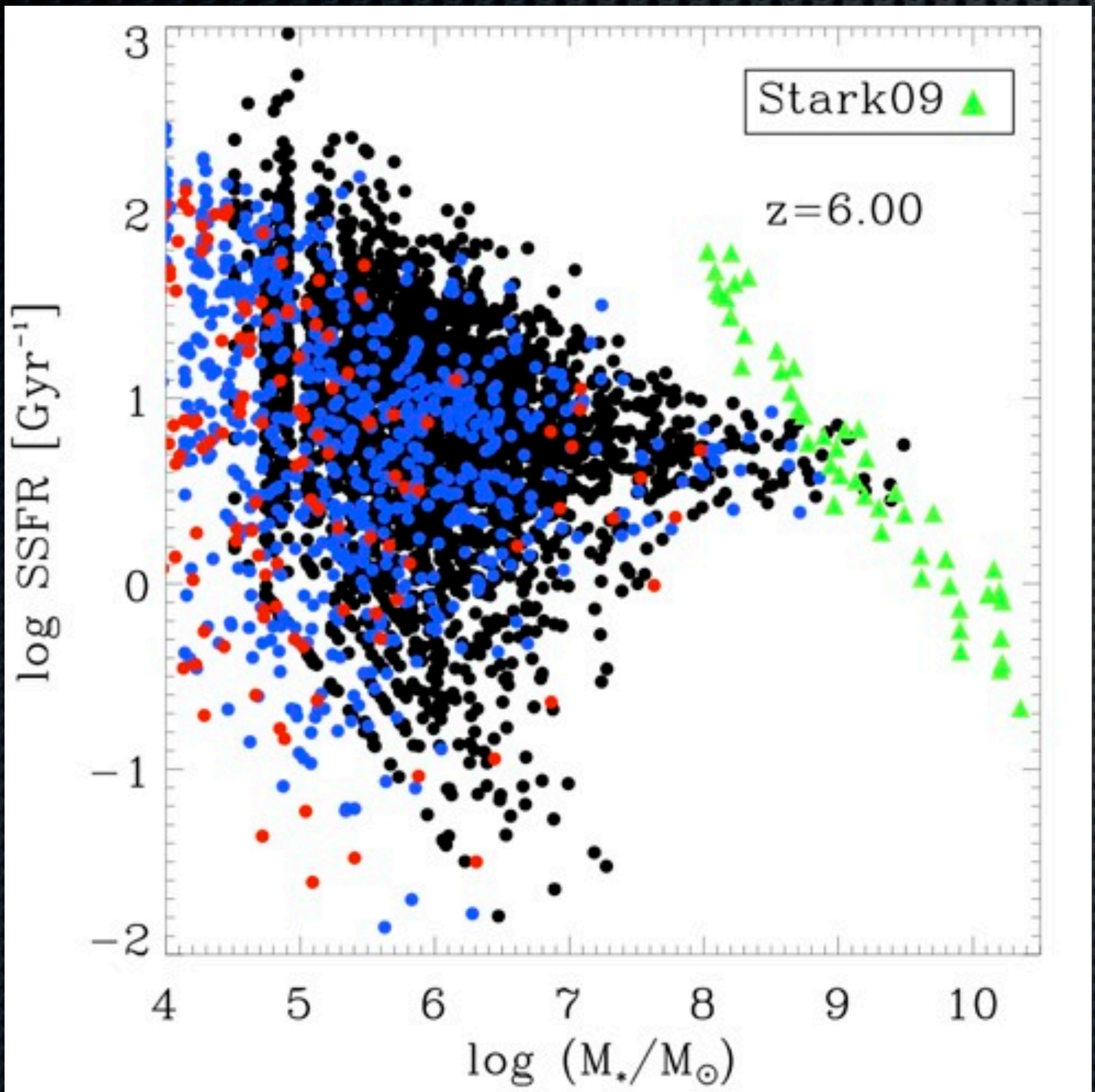
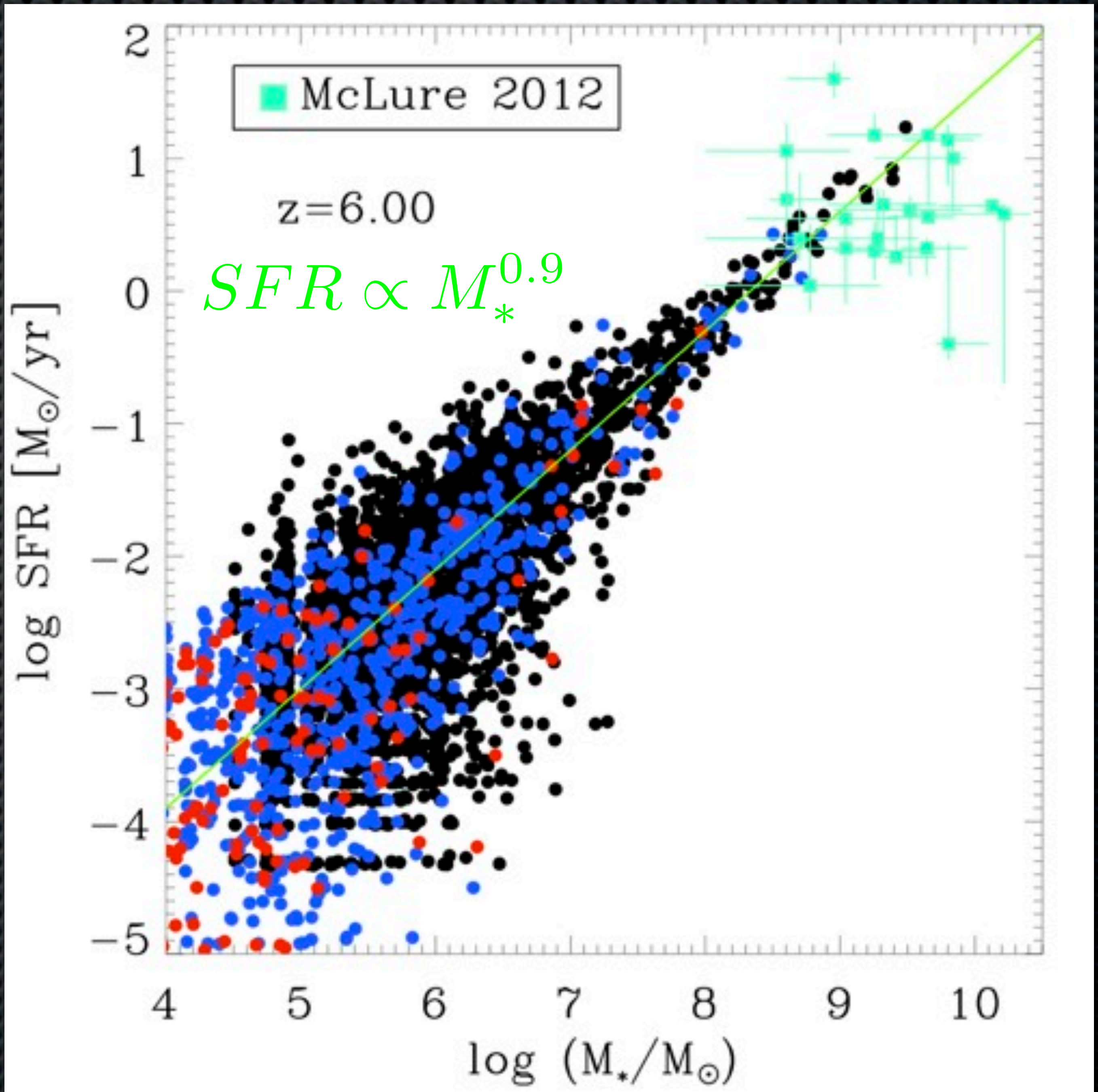
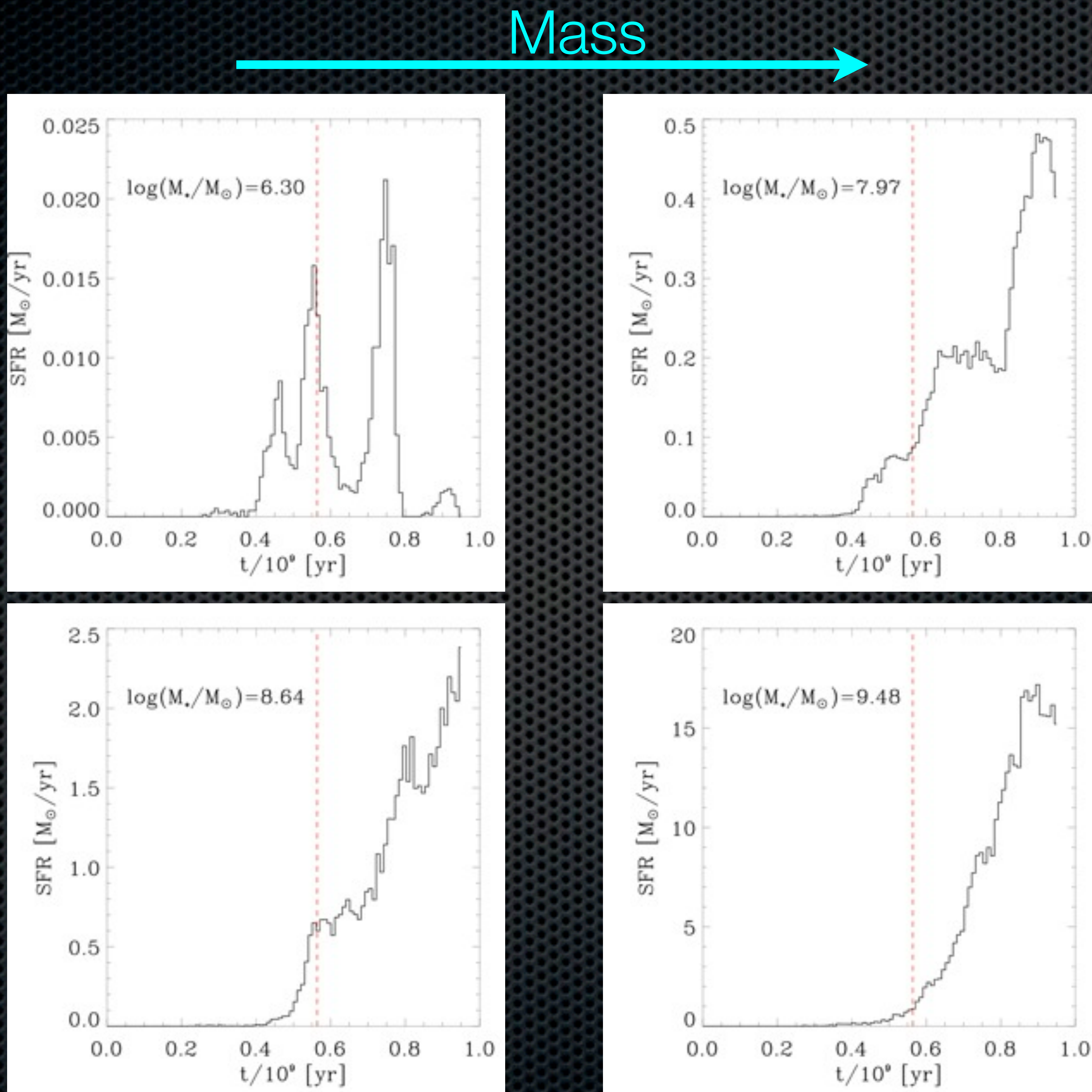




Khochfar et al. 2012

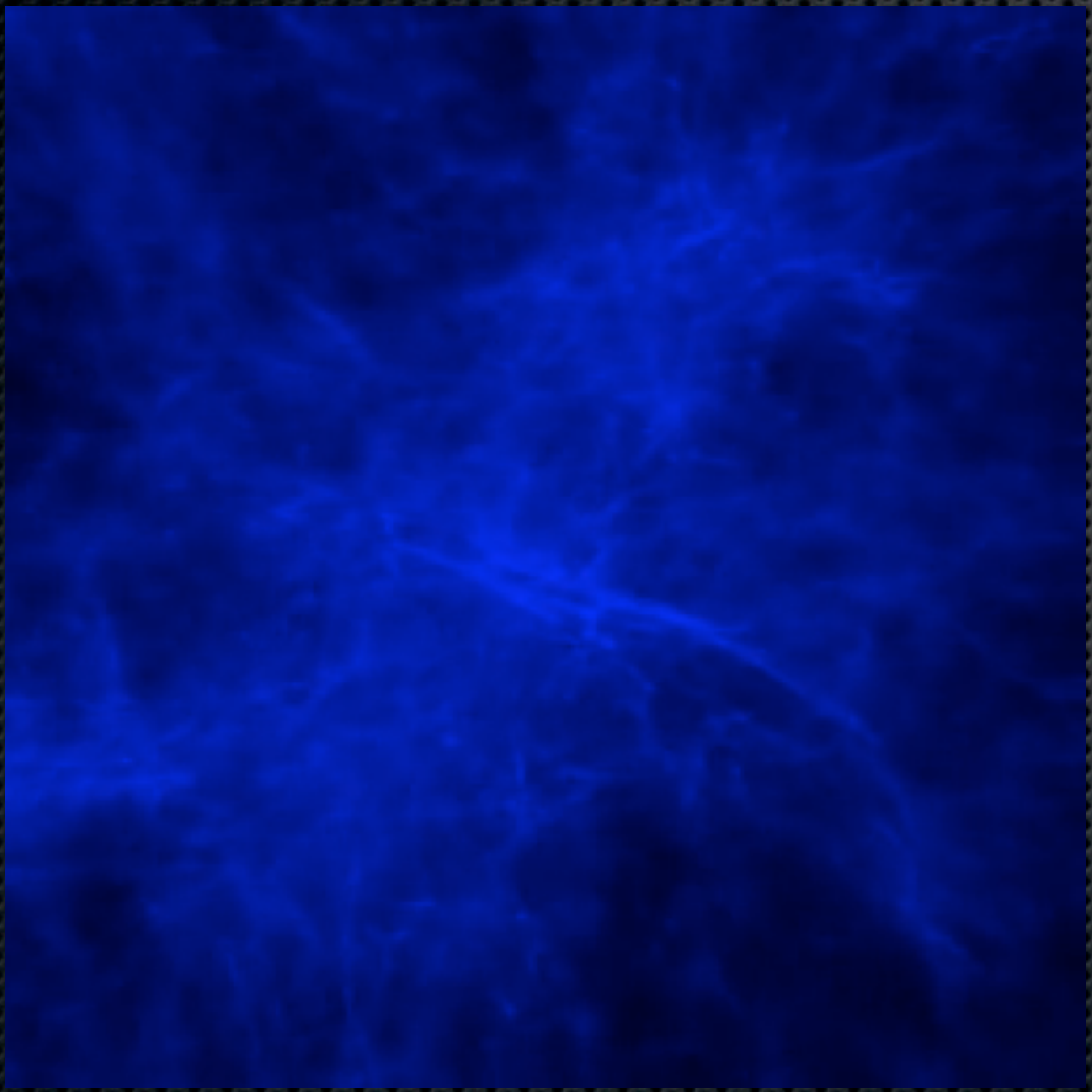
Star formation histories



Khochfar et al. 2012

SN-Feedback

Density + Temp



Metallicity

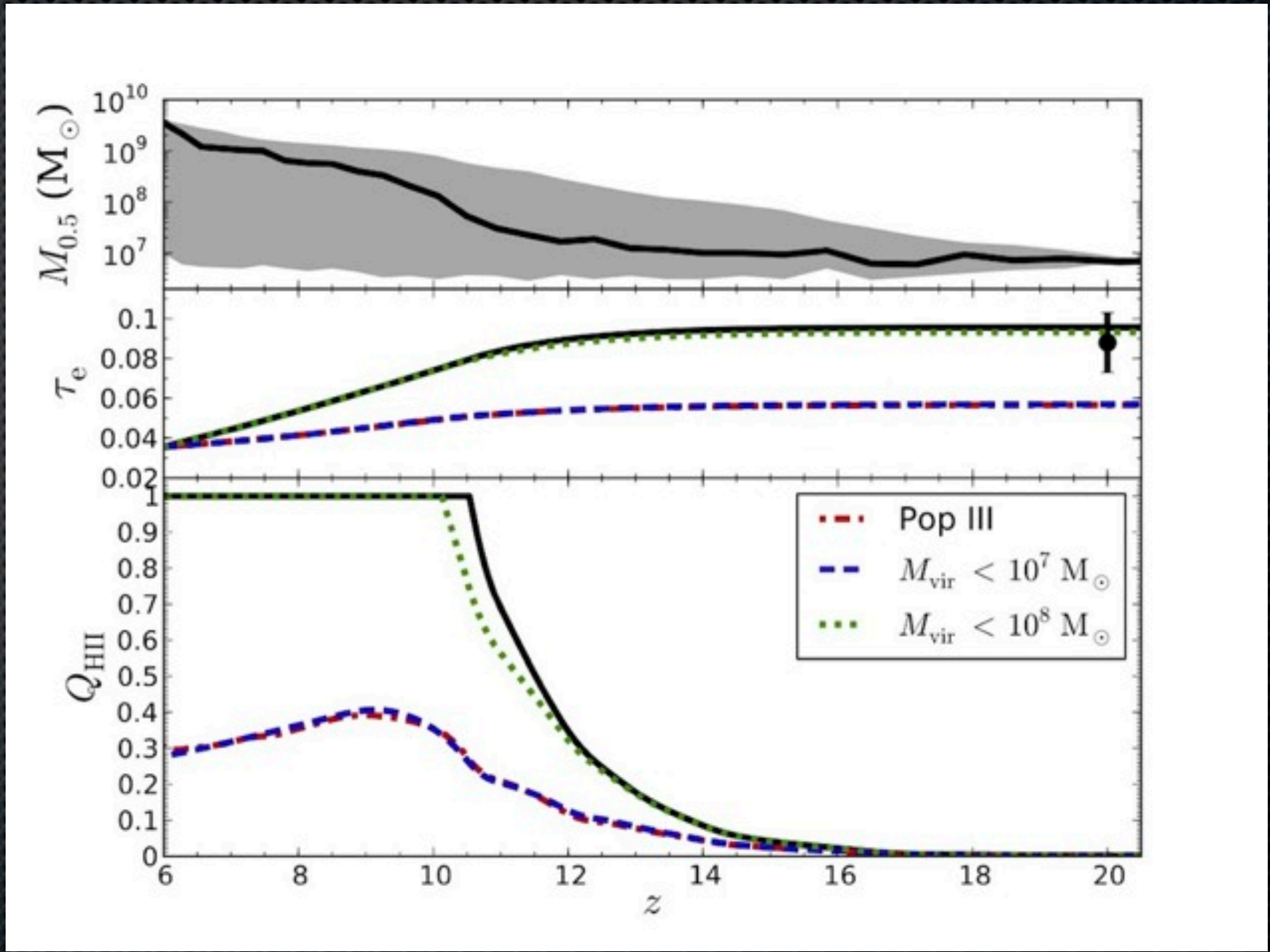
Movie: C. Dalla Vecchia

Reionization

$$\frac{\mathrm{d}Q_{\mathrm{H\,II}}}{\mathrm{d}t} = \frac{\dot{N}_{\mathrm{ion}}}{\bar{n}_{\mathrm{H},0}} - Q_{\mathrm{H\,II}} C \bar{n}_{\mathrm{H},0} \alpha(T)(1+z)^3$$

$$\tau_{\mathrm{e}} = \int_0^{z_{\mathrm{rec}}} \mathrm{d}z \left| \frac{\mathrm{d}t}{\mathrm{d}z} \right| Q_{\mathrm{H\,II}}(z) \bar{n}_{\mathrm{H},0} (1+z)^3 \sigma_{\mathrm{T}}$$

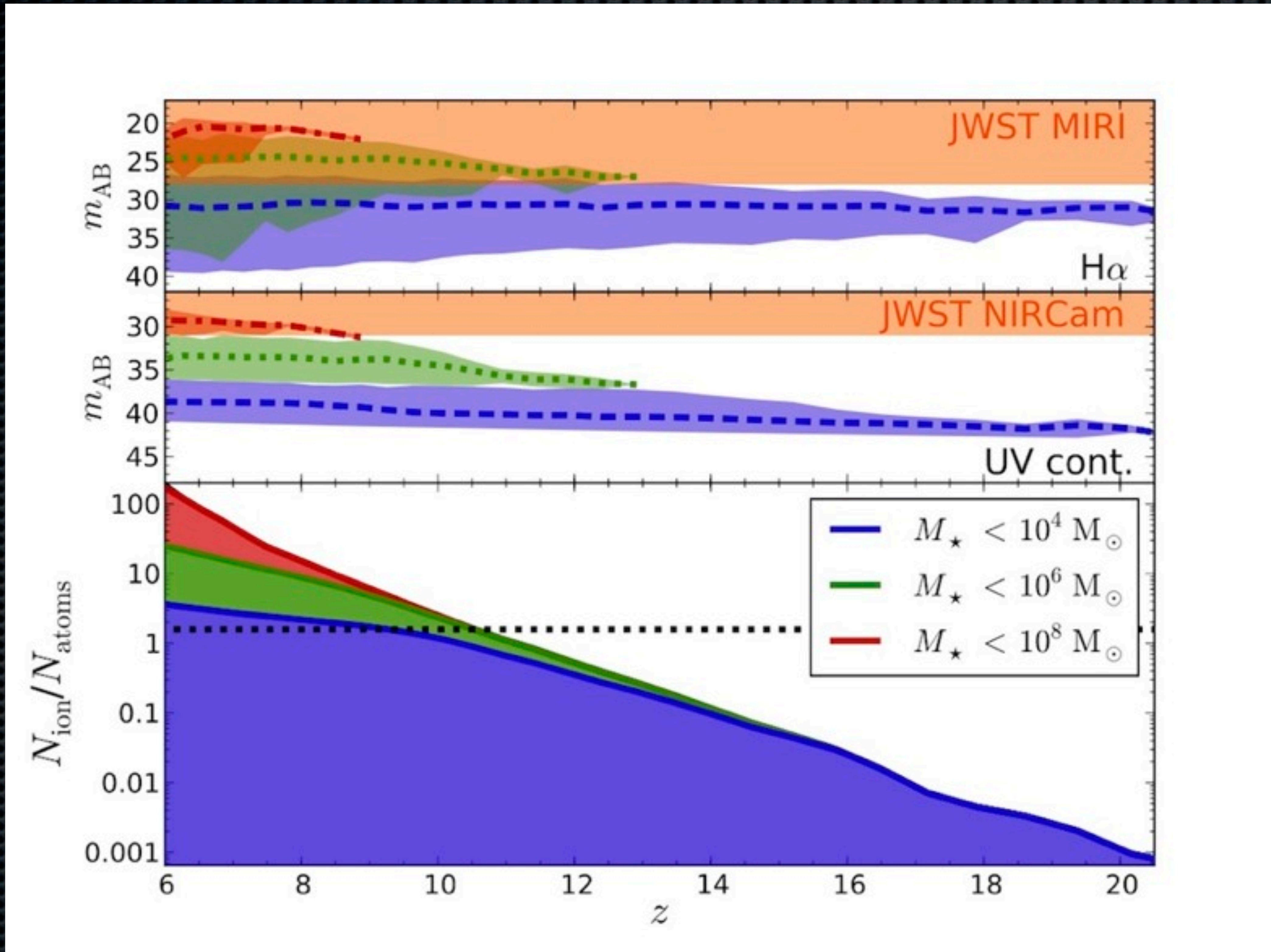
SimpleX code including H + He ionization, following 10 frequency bands



- Galaxies in haloes below 10^8 M_{sun} are able to reionize the Universe initially
- Massive haloes only host dominant sources of photons at later times

J.-P. Paardekooper, SK, Dalla Vecchia 2012

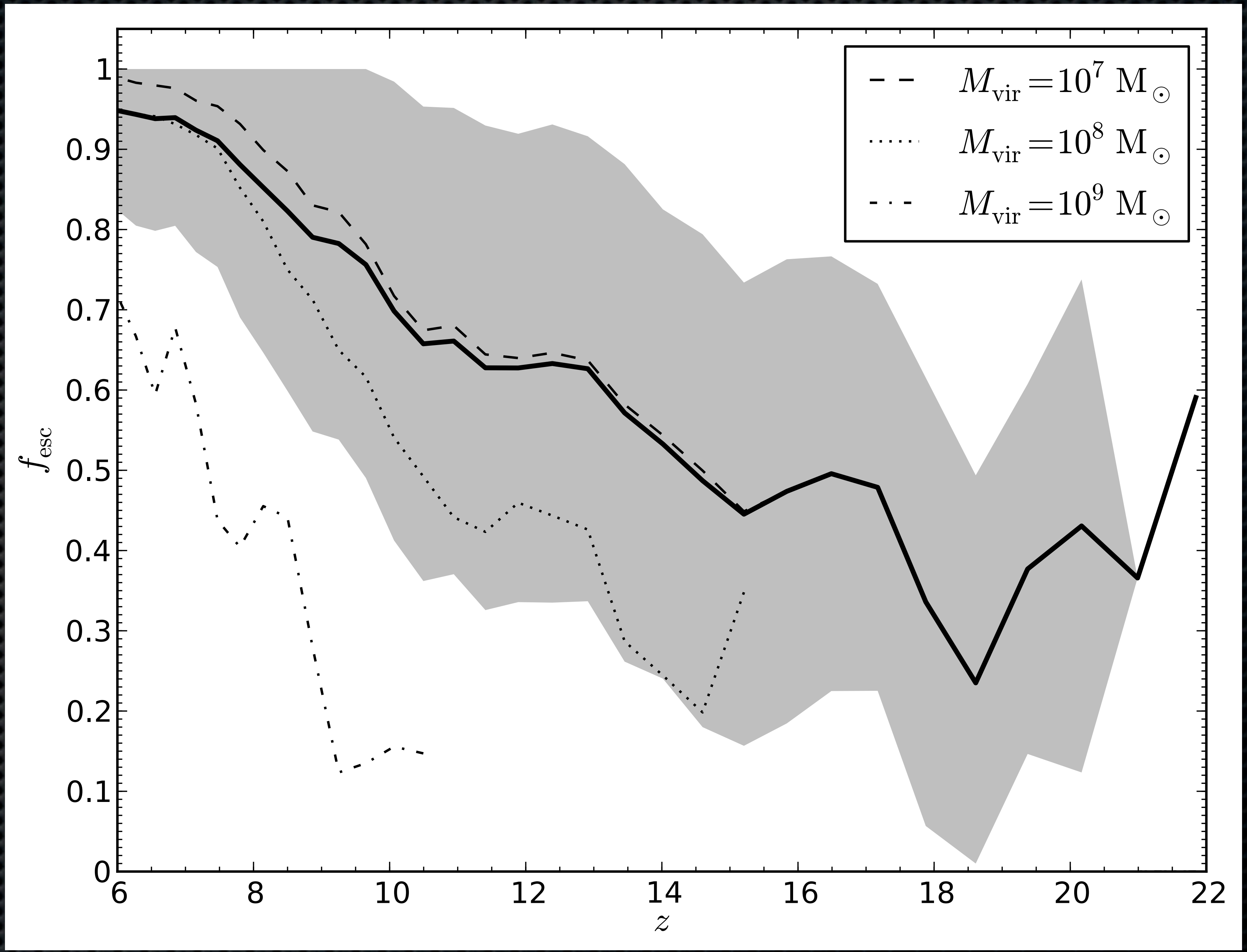
Sources Reionizing the Universe



J.-P. Paardekooper, SK, Dalla Vecchia 2012

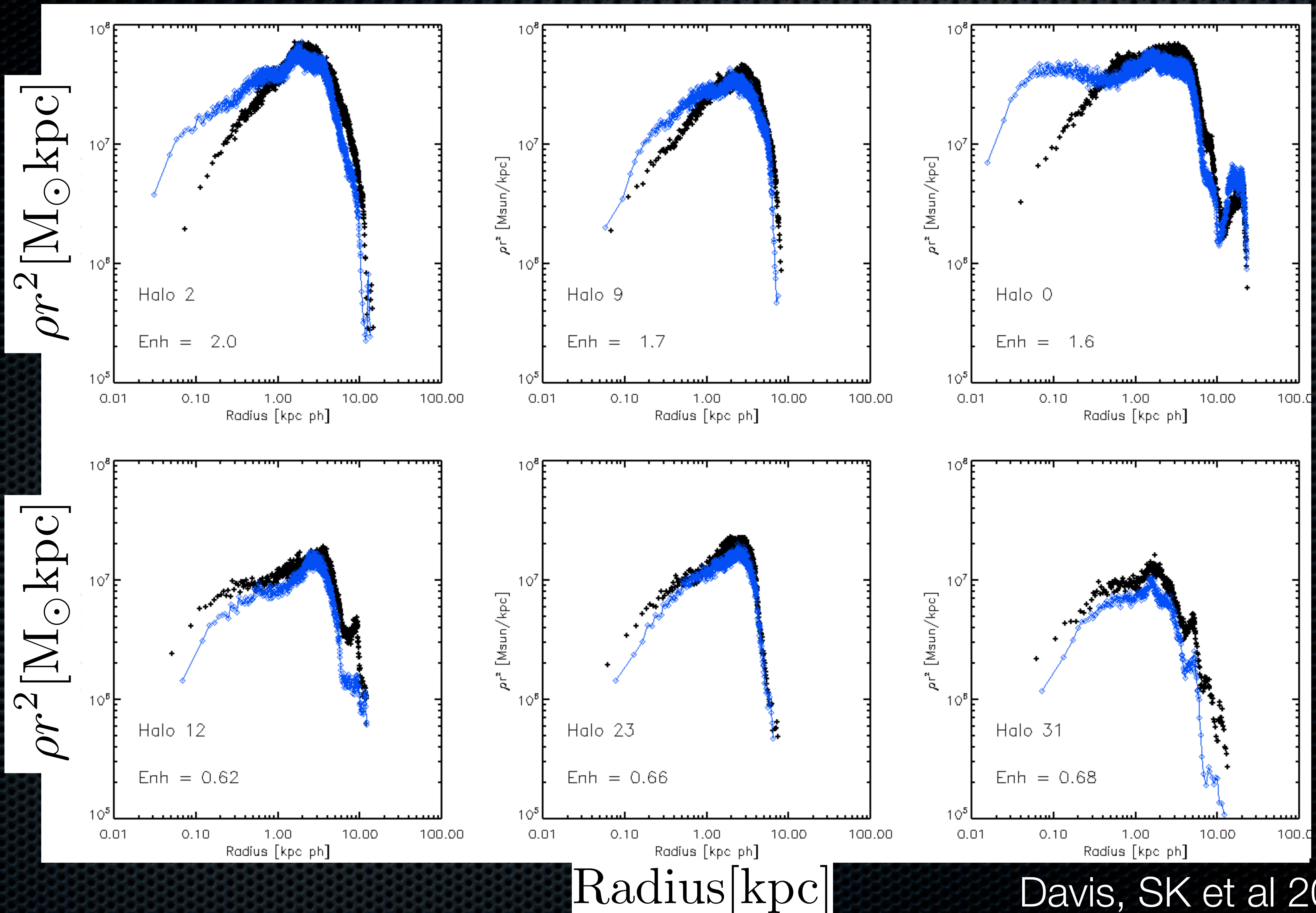
Escape fractions

- Escape fraction are a strong function of time
- Feedback increases the escape fraction
- Low mass galaxies have higher escape fraction due to a more dramatic effect of feedback



J.-P. Paardekooper, SK, Dalla Vecchia 2012

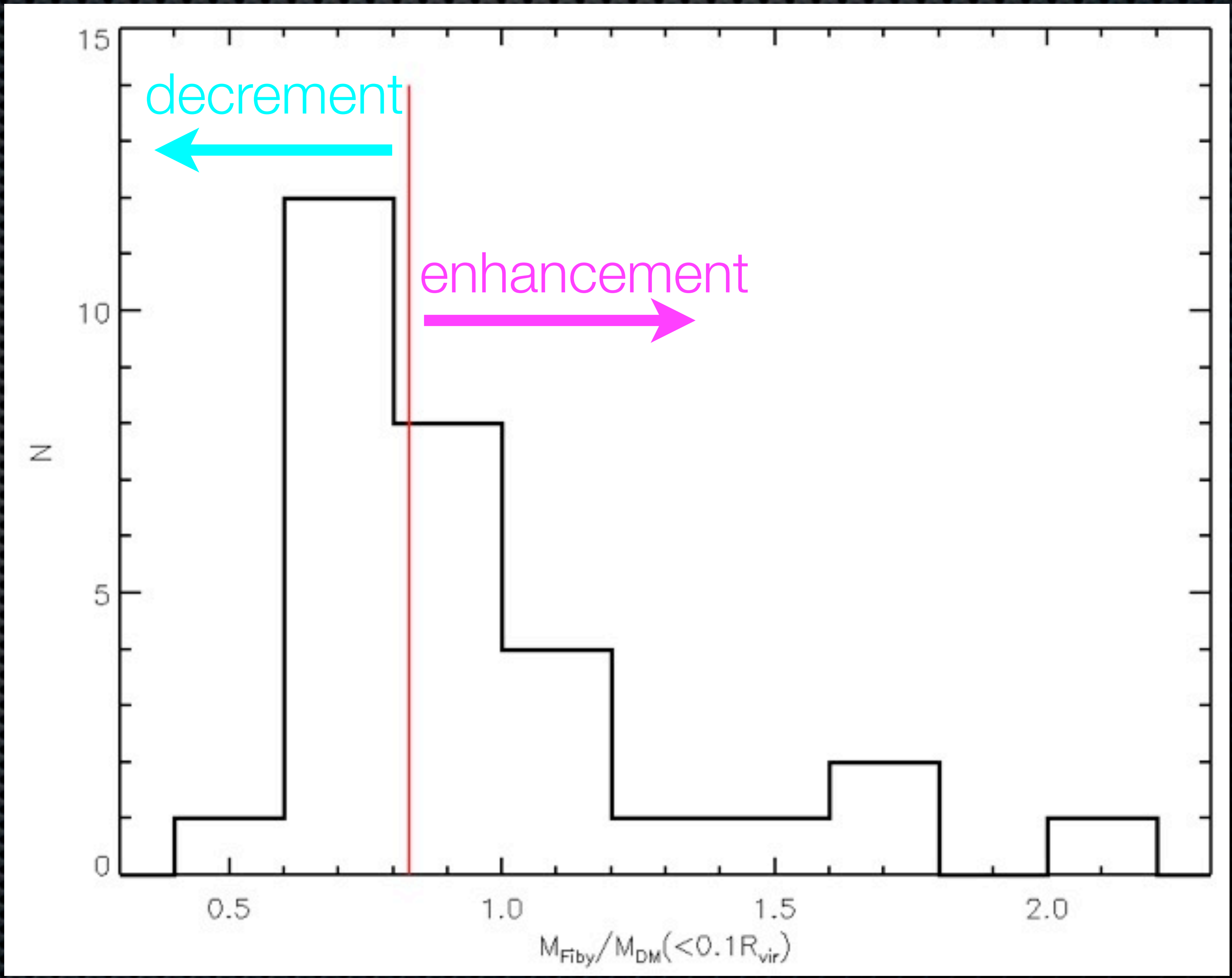
Dark Matter Profiles



Davis, SK et al 2012

Distribution of profiles

Roughly 50% of massive haloes at z~6 show a density decrement, with a long tail to density enhancements.



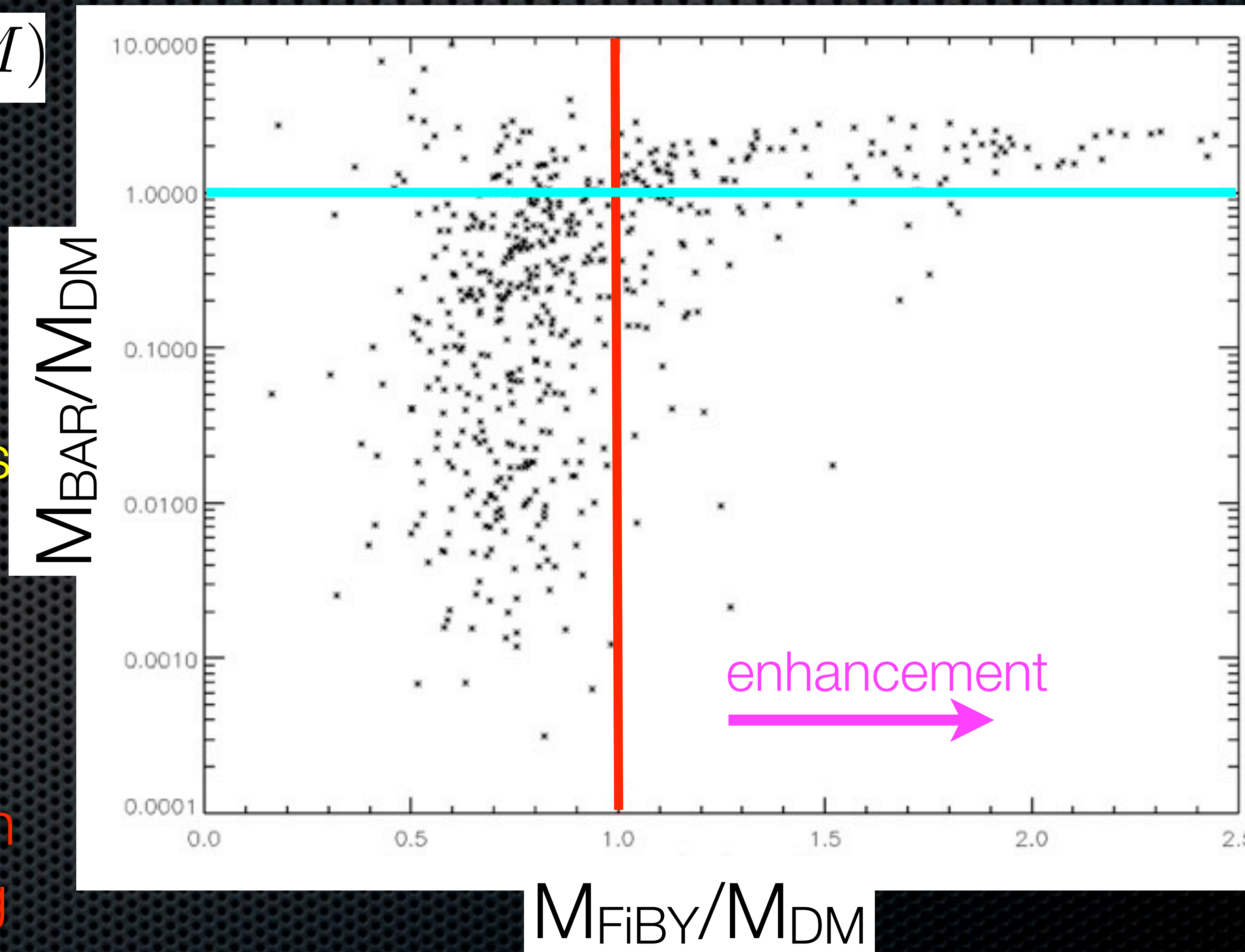
Davis, SK 2012

Baryon-DM connection

Adiabatic contraction:

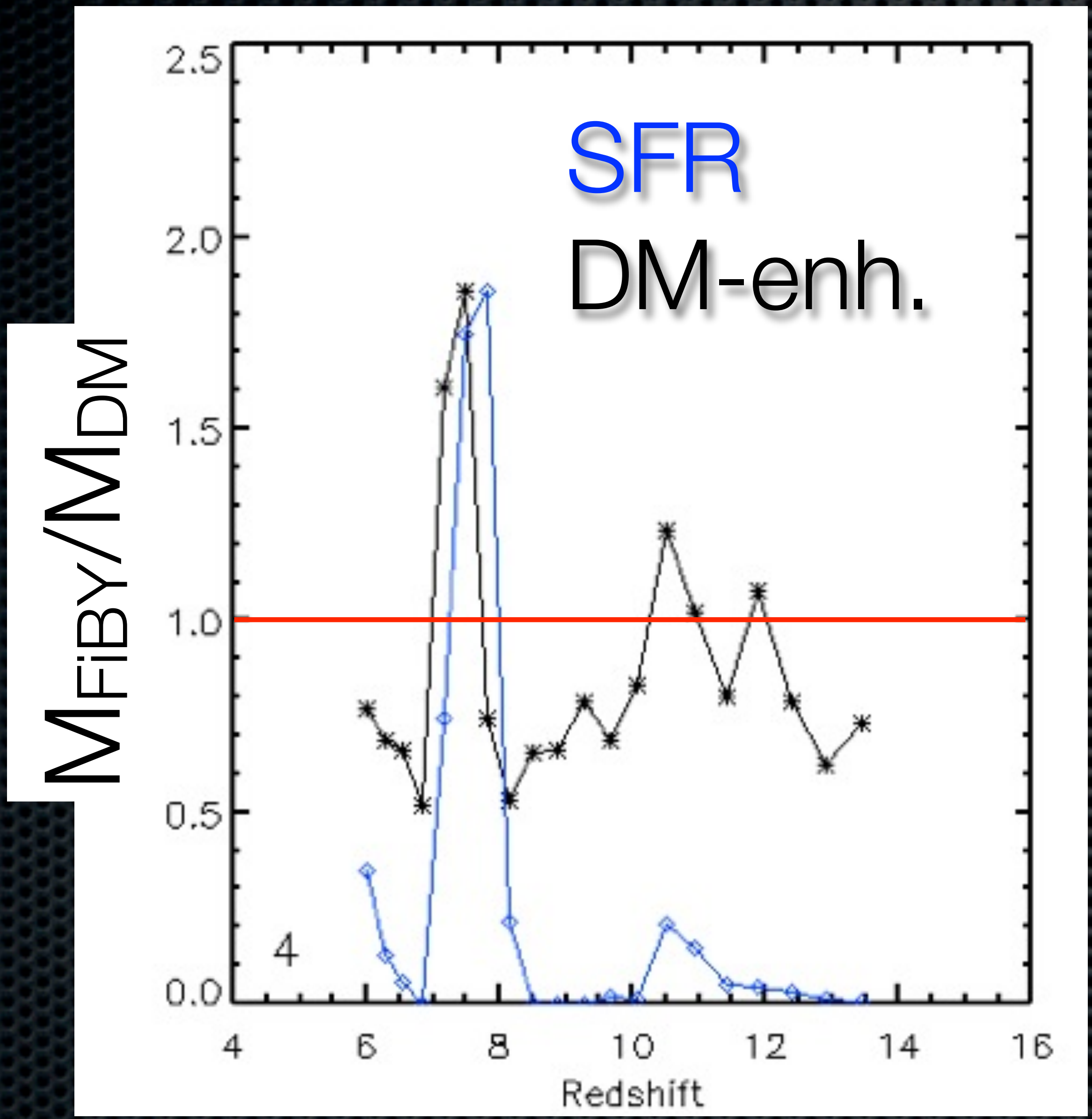
$$r_i M_i = r_f (M_i + \Delta M)$$

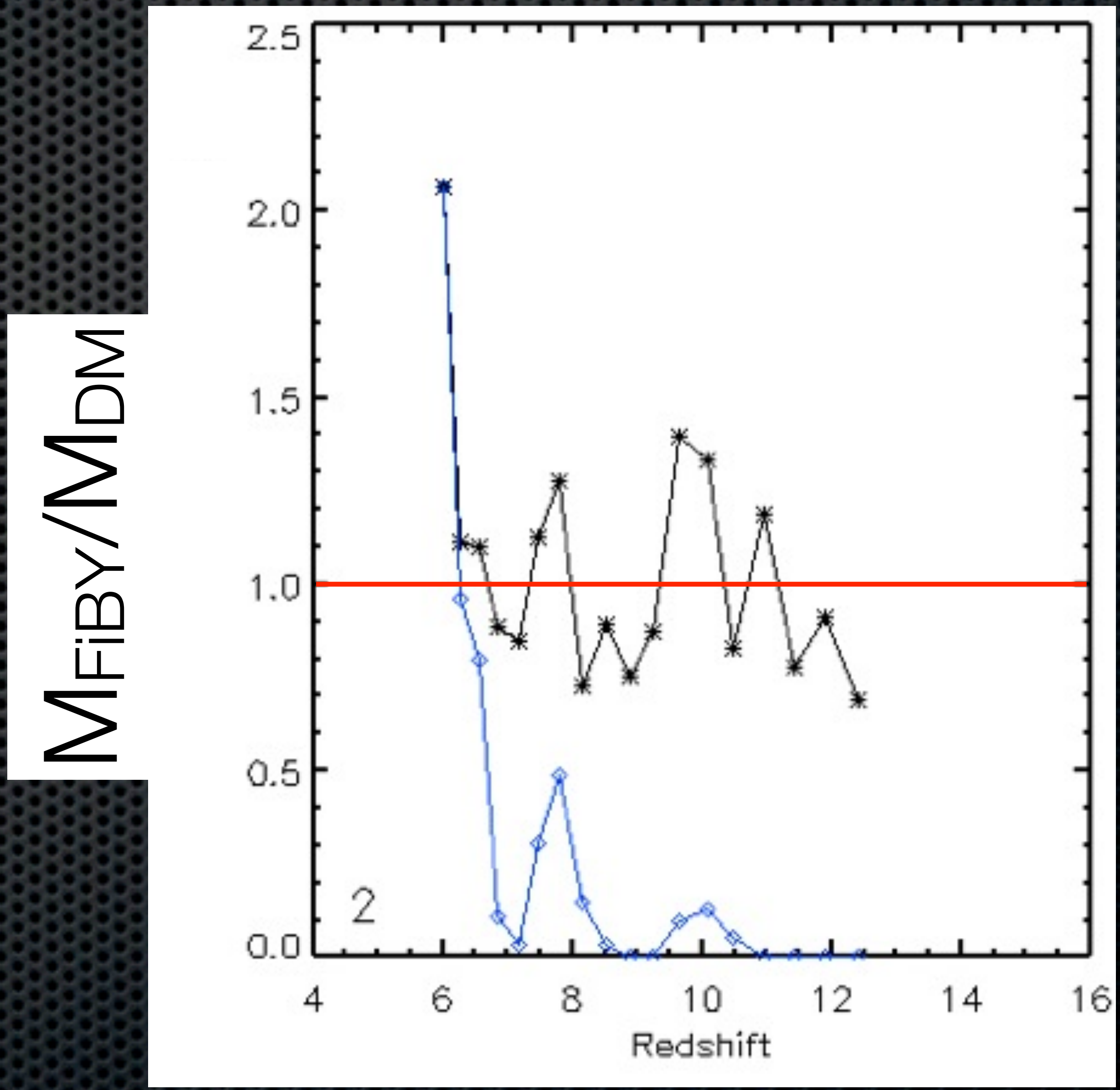
- Enhancement of baryons leads to dark matter response, but not always! Some haloes have less dark matter in them even if the baryon fraction is increased. Adiabatic contraction is clearly not working in those cases.



Davis, SK 2012

Feedback impact on the halo

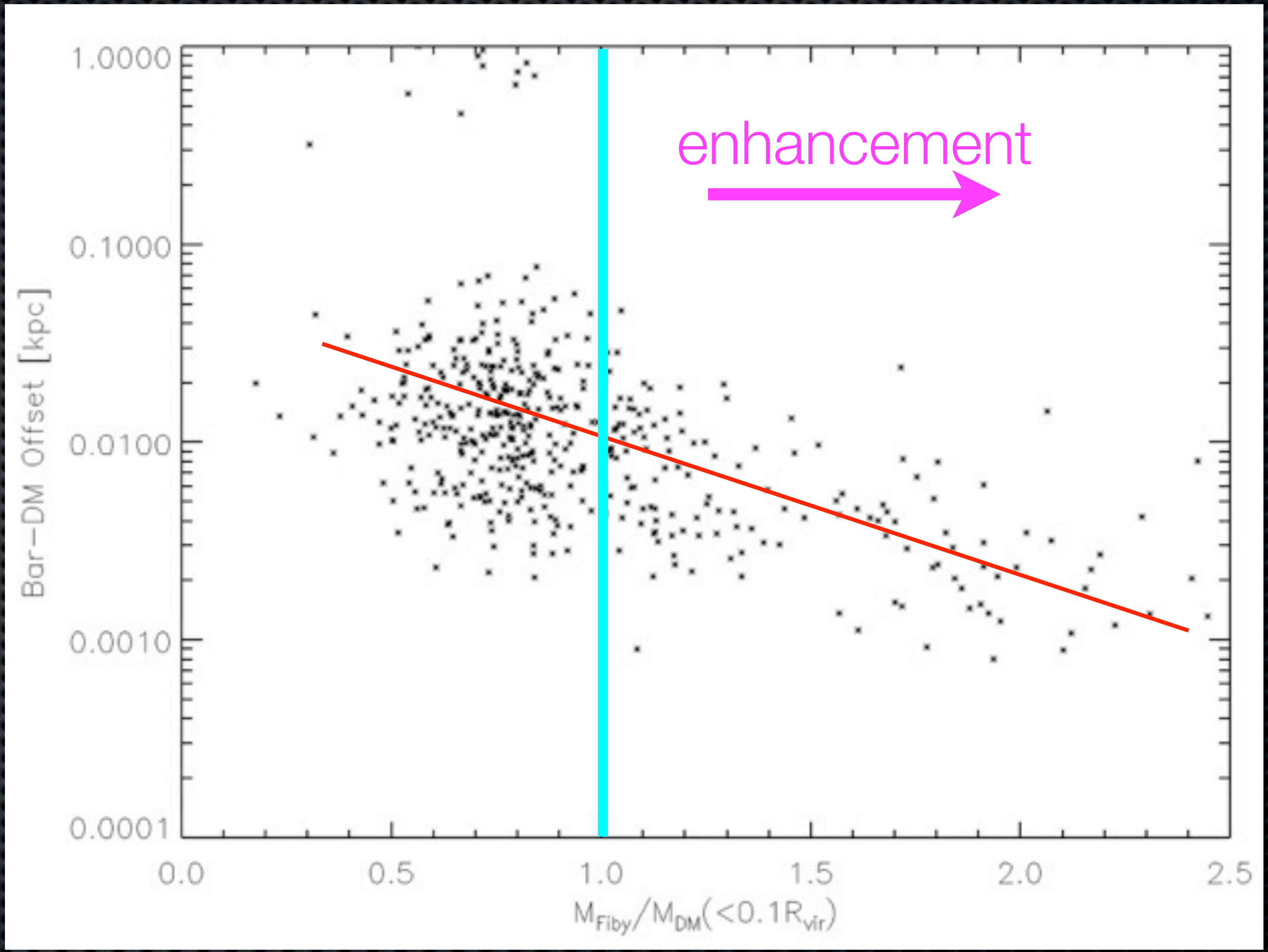




Davis, SK et al 2012

Off-set galaxies

- Galaxies show an off-set with respect to the DM potential minimum. Systematic larger off-set in haloes with reduced dark matter fraction.
- Galaxies could heat dark matter halo via dynamical friction



Davis, SK 2012

Conclusions

- The Universe is initially reionized by baby galaxies and kept ionized by massive galaxies.
- Baby galaxies with $M_* < 10^6$ M_{sun} can reionize the Universe due to higher escape fraction then massive galaxies
- SN-feedback drives the escape fractions
- Dark matter haloes can contract due to the presence of baryons consistent with AC
- ‘Offset’ galaxies can create cores in DM haloes due to the exchange of angular momentum
- Inner dark matter profiles have transient feature