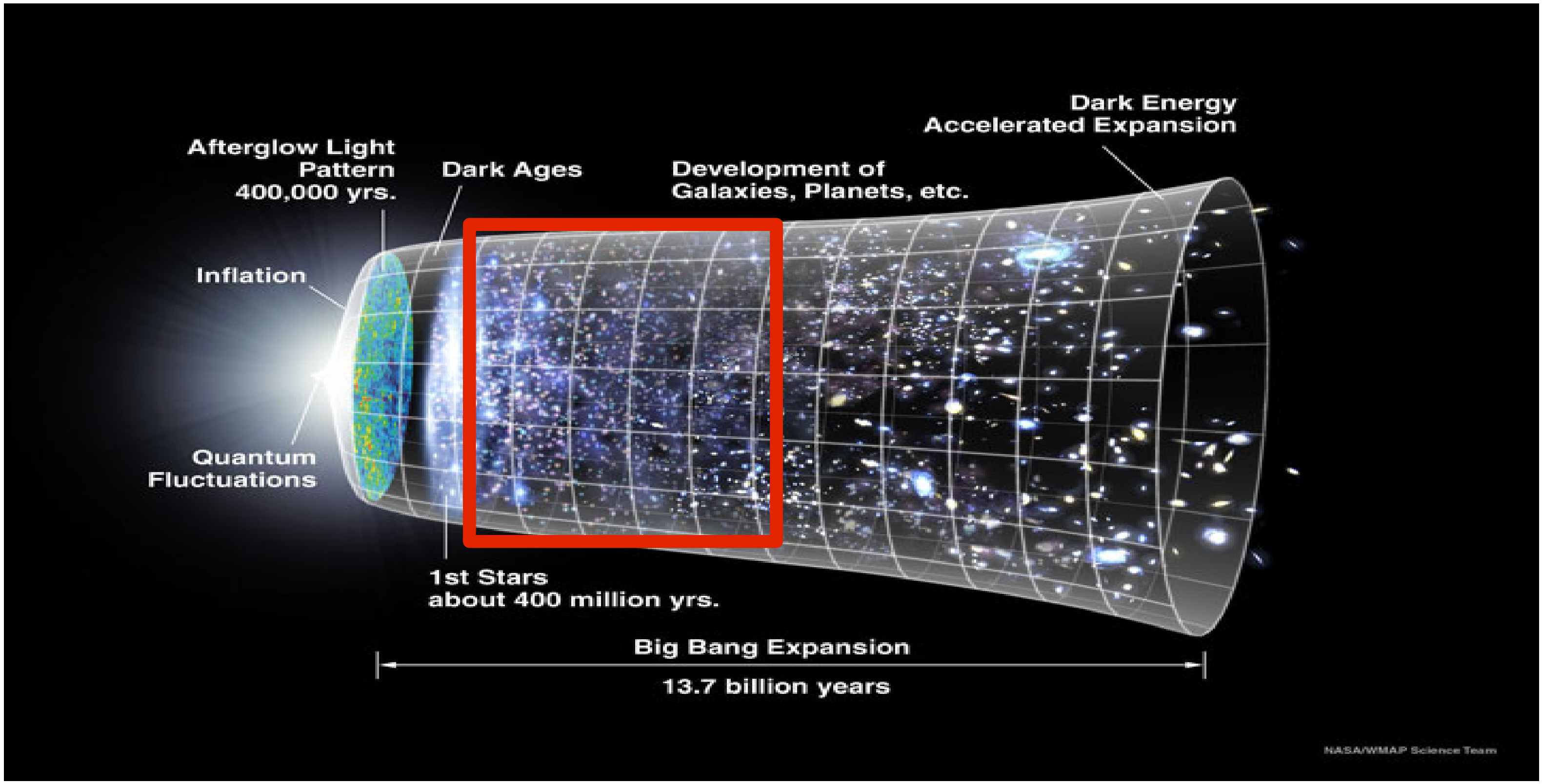
The first billion years of galaxy formation

Pratika Dayal



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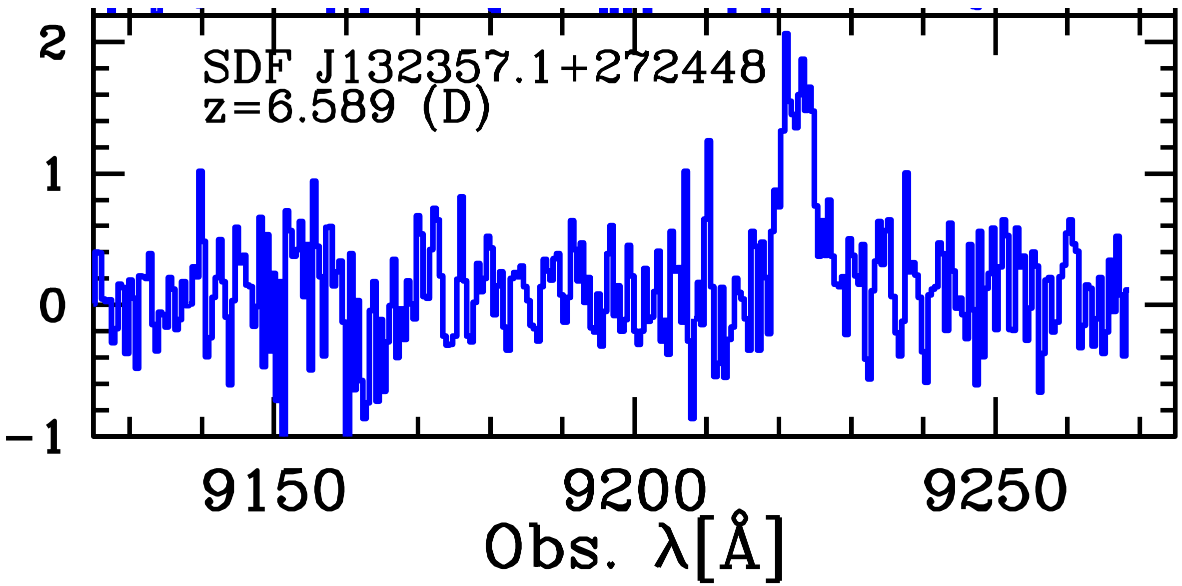
Institute of Advanced Study

Durham University

The main questions

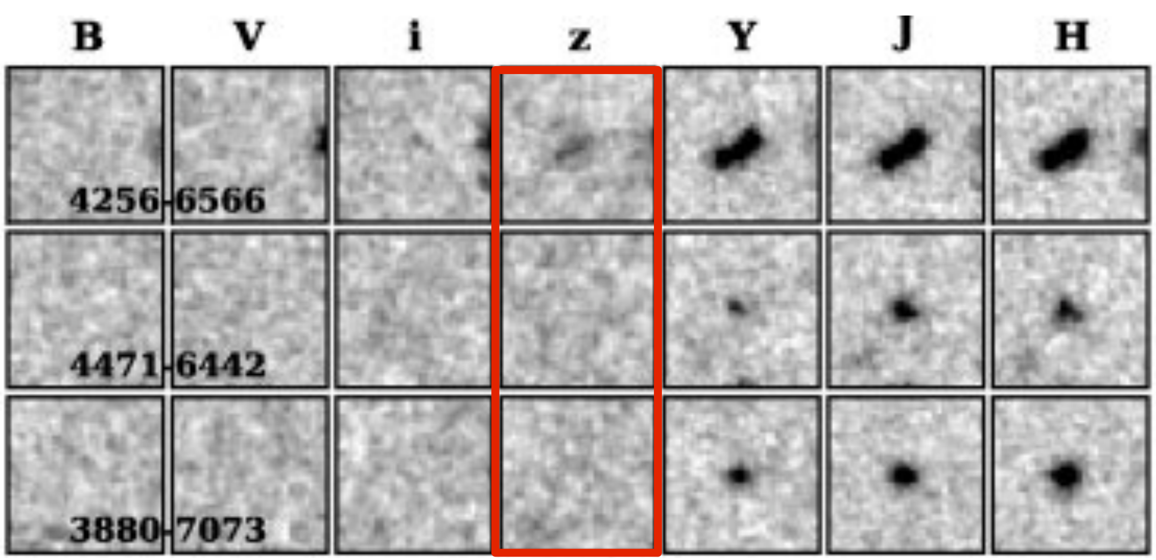
- **What is the fundamental physics driving the evolution of early galaxies?**
- **How does galaxy formation (and reionization) proceed in different Dark Matter cosmologies?**

The two main classes of high-z galaxies



Lyman Alpha Emitters (LAEs) - Narrow Band Spectroscopy to observe very strong and narrow Lya emission line to get exact source redshift.

Kashikawa+2006 - z~6.6 LAE



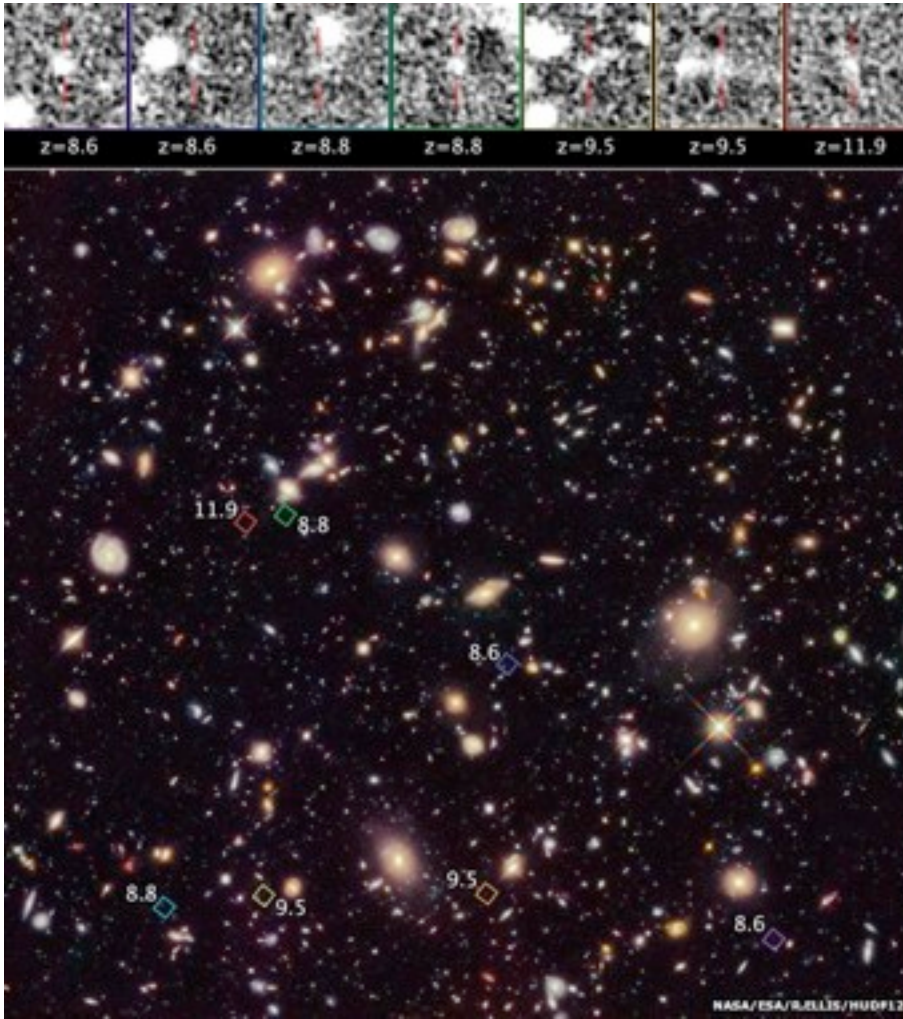
Lyman Break Galaxies (LBGs) - Broad Band photometric band in which galaxy drops-out used to obtain redshift.

Oesch+2010 - z~7 dropouts

LBG Observational status

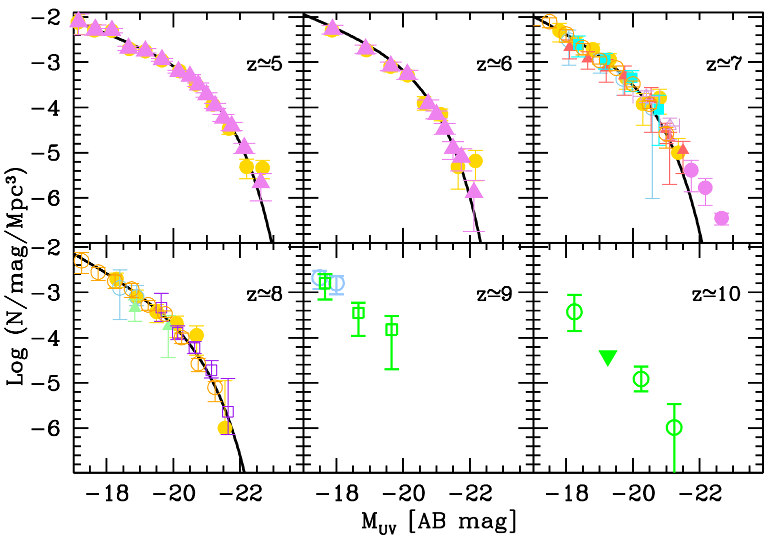
Pre-2009 (WFC3 era): 1 convincing z>7 candidate (Bouwens et al. 2004)

Status after the installation of the WFC3 (2009)

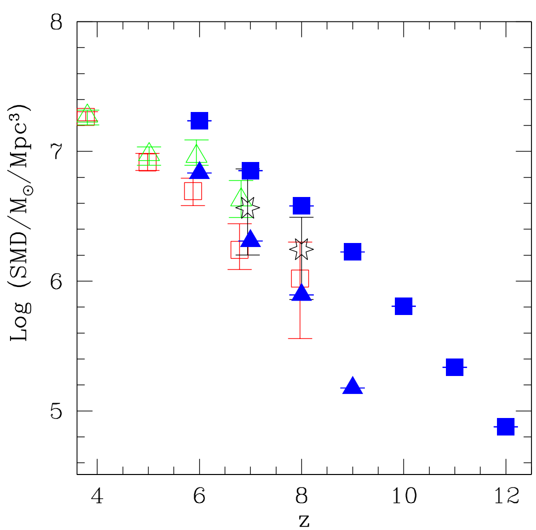


What can we learn from all this data?

Global quantities

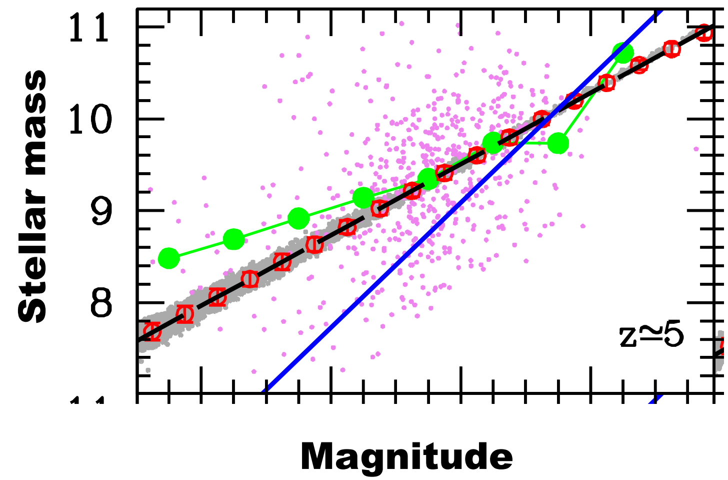


Ultraviolet luminosity functions (UV LF)

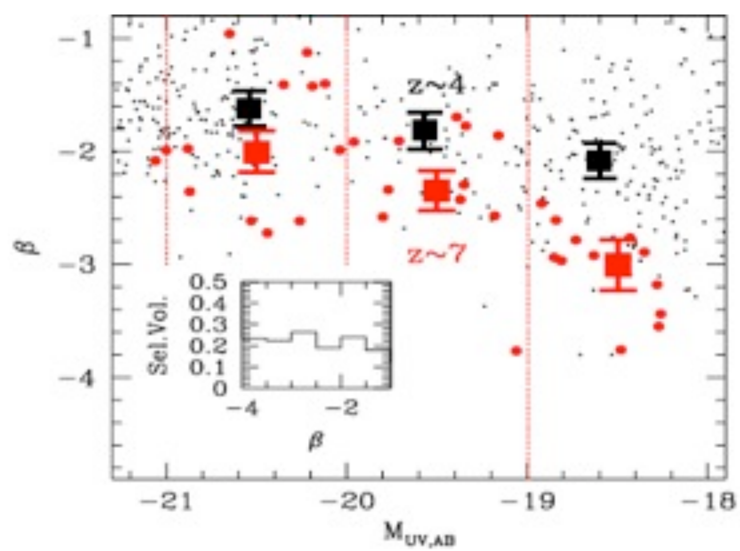


Stellar Mass Density (SMD)

Individual galaxy properties

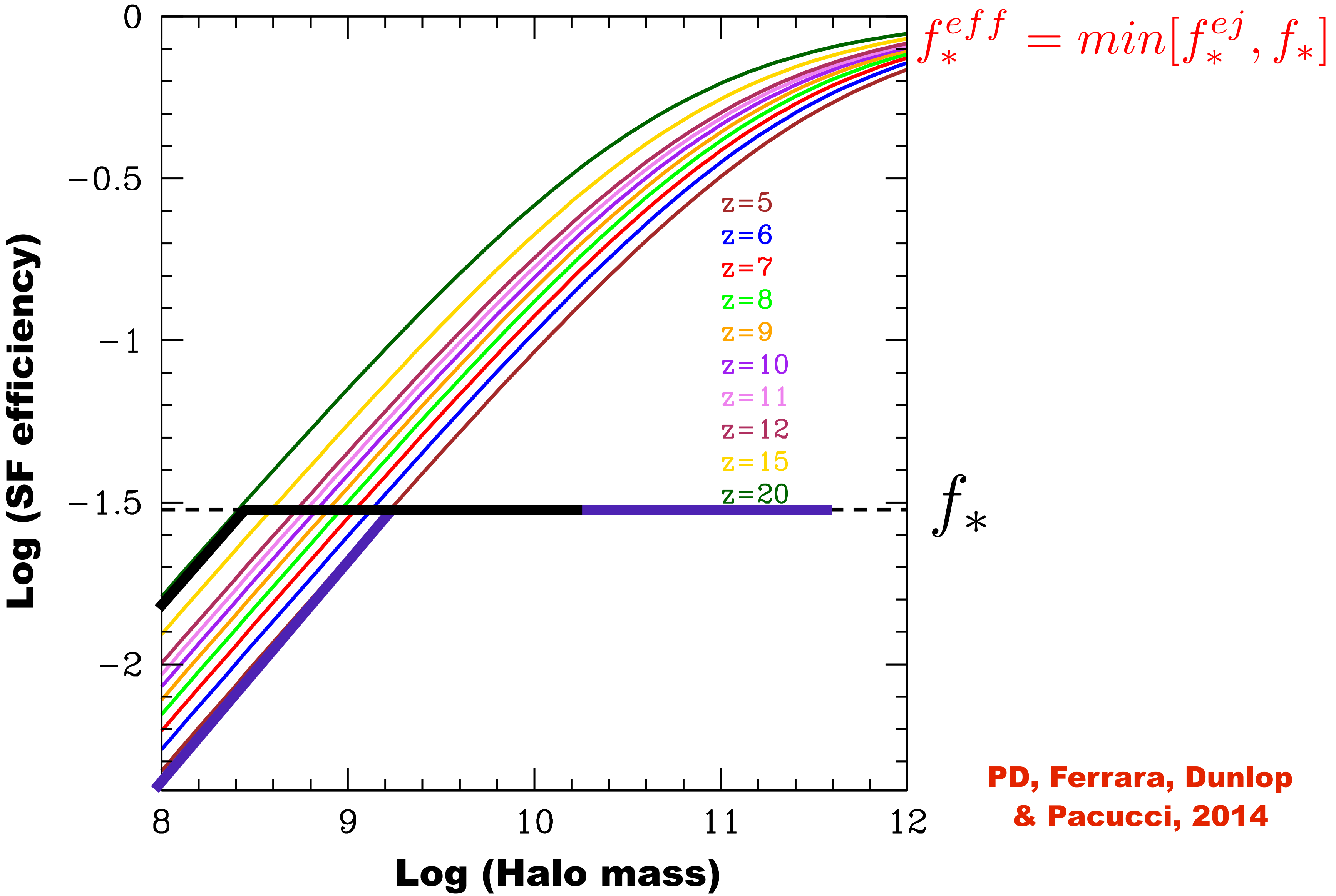


Mass-to-light ratios



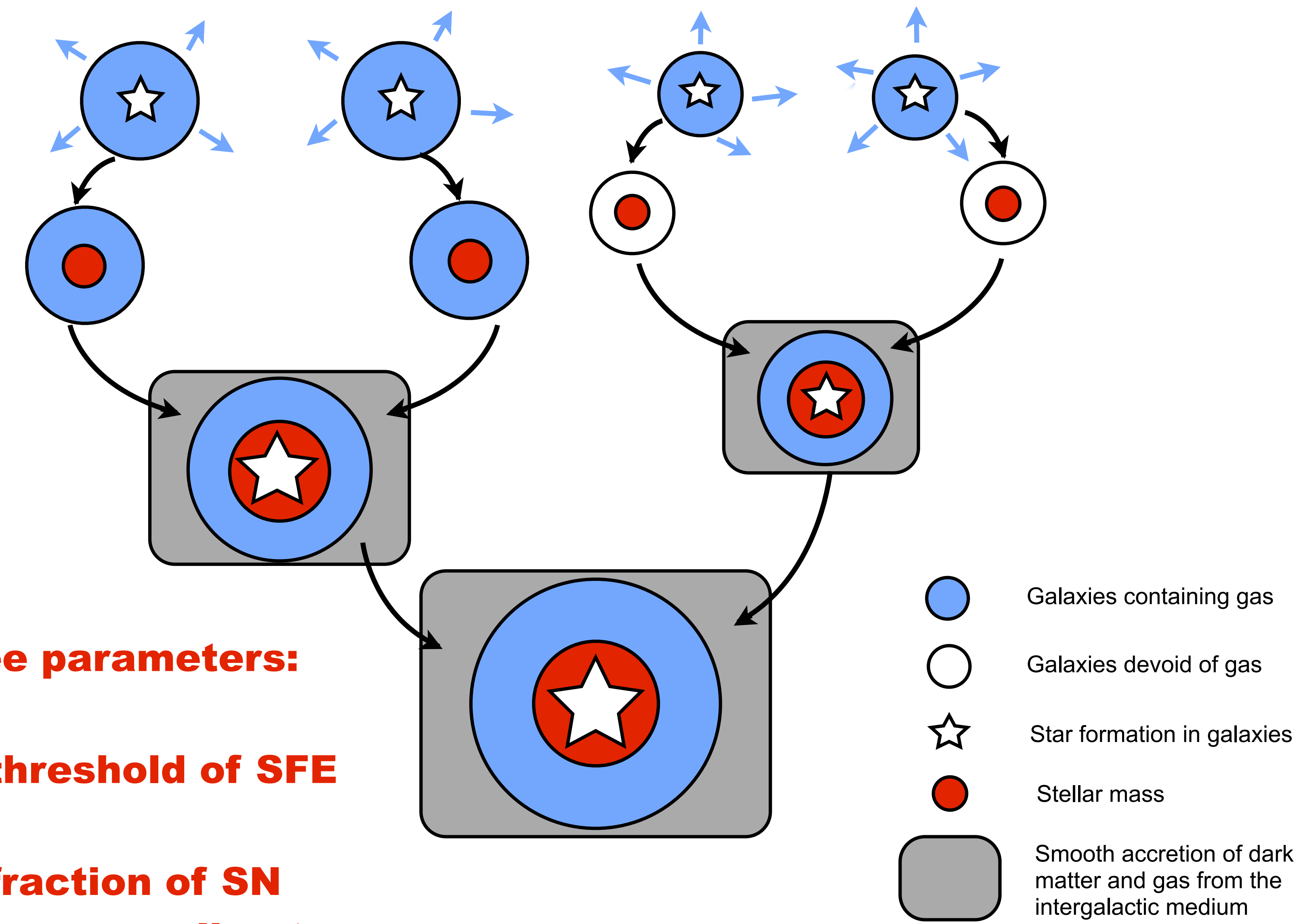
UV spectral slopes

The premise: maximum SFE limited by energy required to unbind rest of the gas and quench star formation - up to a certain maximum threshold



PD, Ferrara, Dunlop & Pacucci, 2014

A semi-analytic model implemented with this simple idea



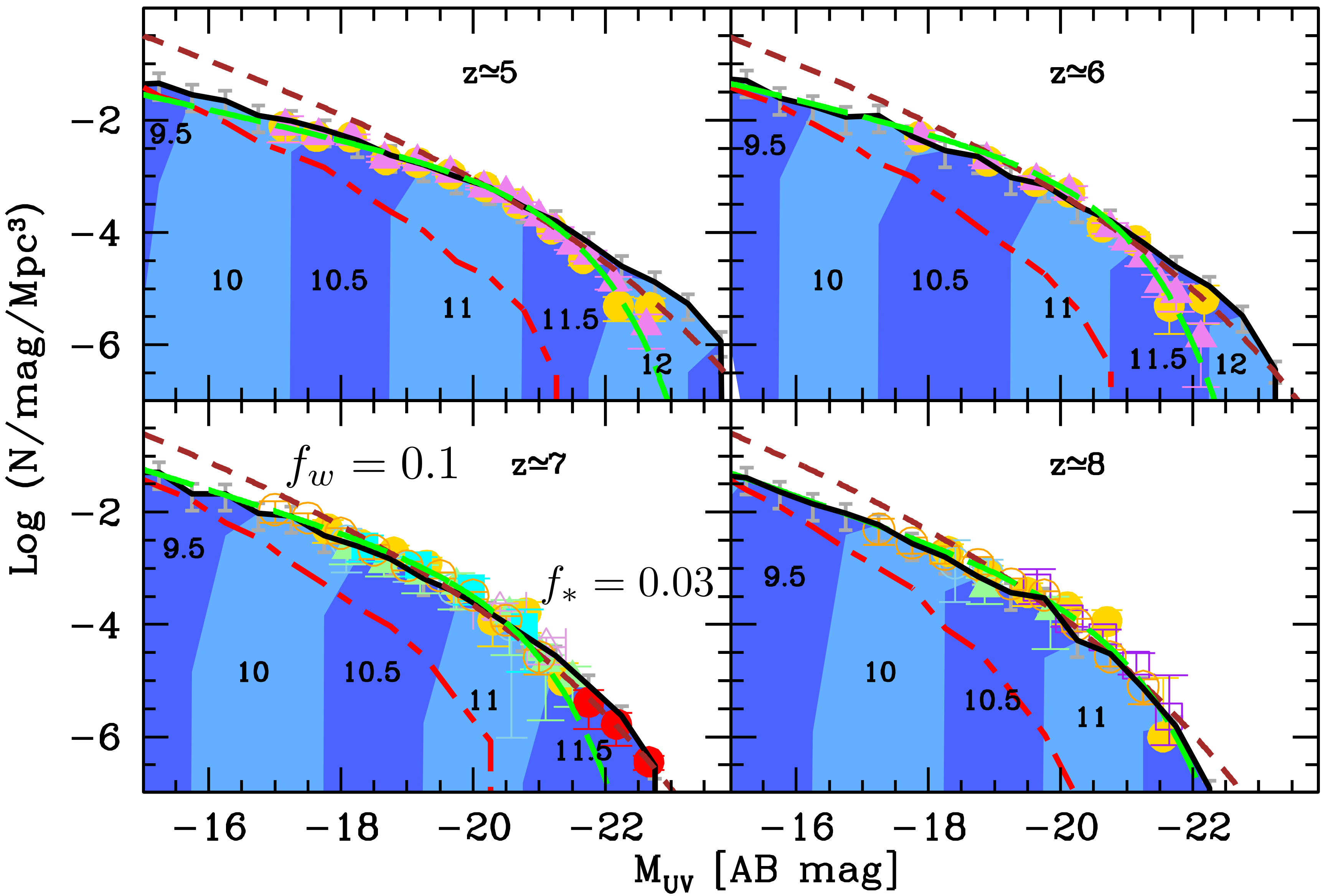
Free parameters:

f_* **1. threshold of SFE**

f_w **2. fraction of SN energy coupling to gas**

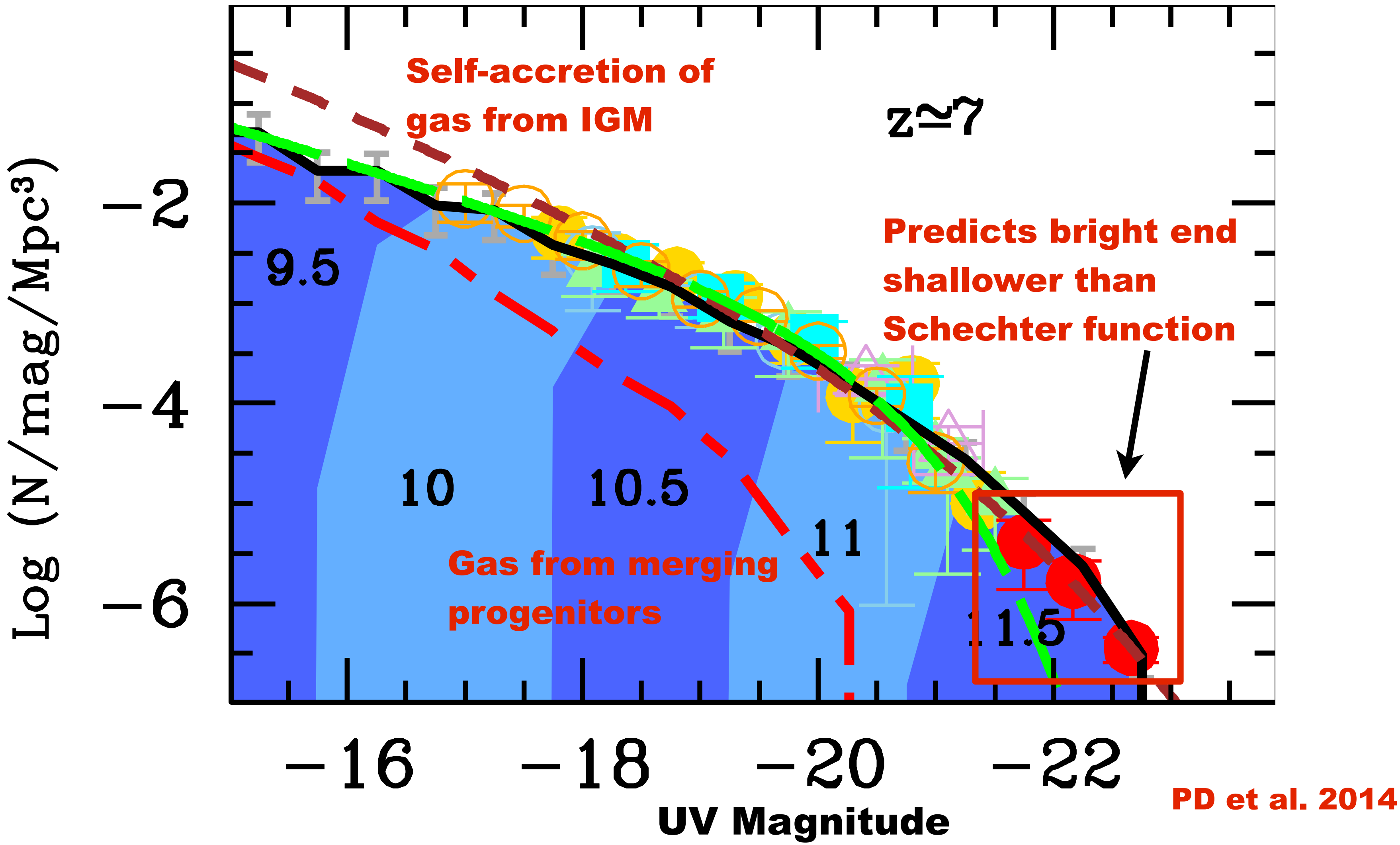
PD, Ferrara, Dunlop & Pacucci, 2014

The number counts of early LBGs (the UV LF)



PD, Ferrara, Dunlop & Pacucci, MNRAS, 2014

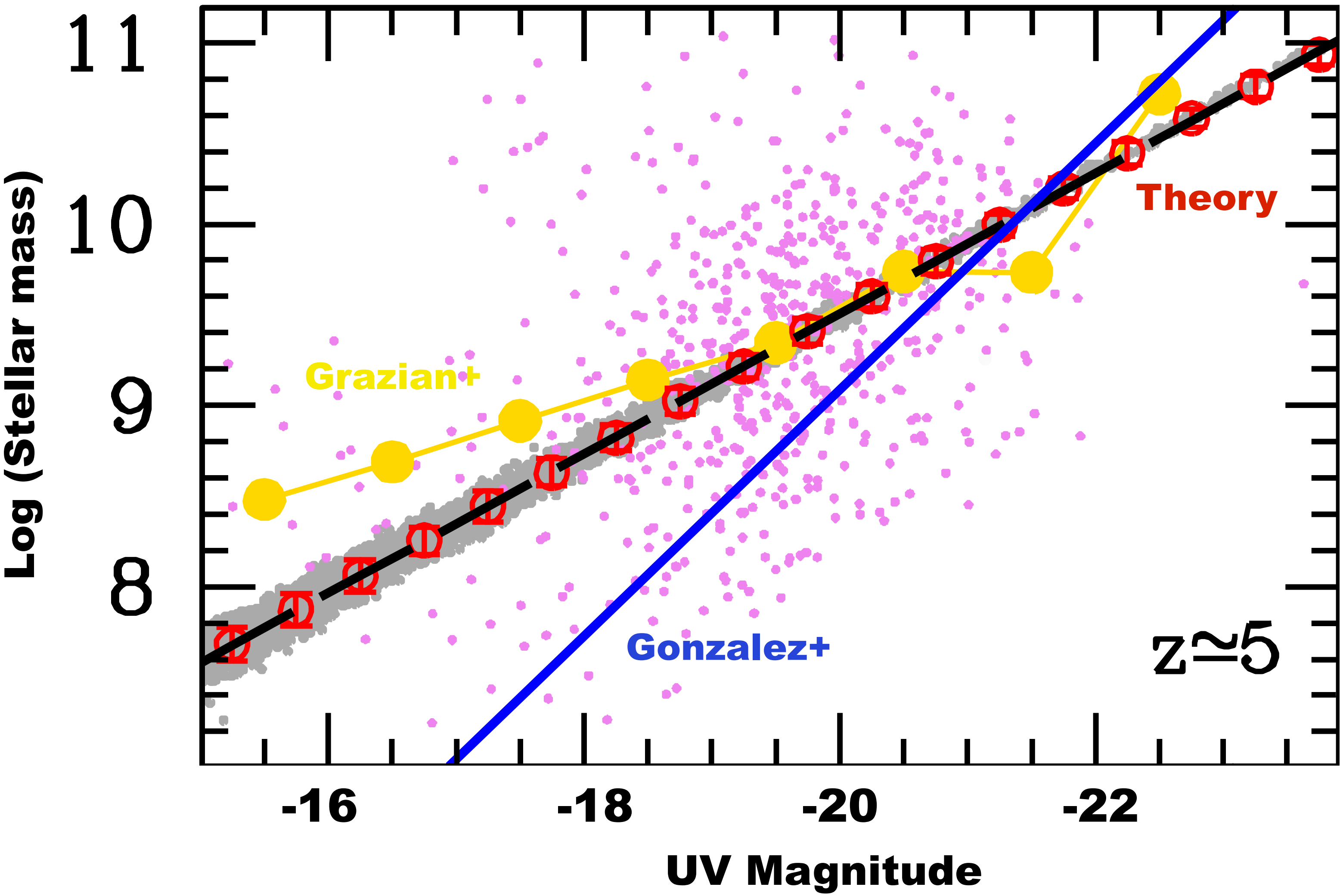
The gastrophysics of early LBGs



Prediction for the frontier Fields and JWST: $\alpha = -1.75\log z - 0.52$

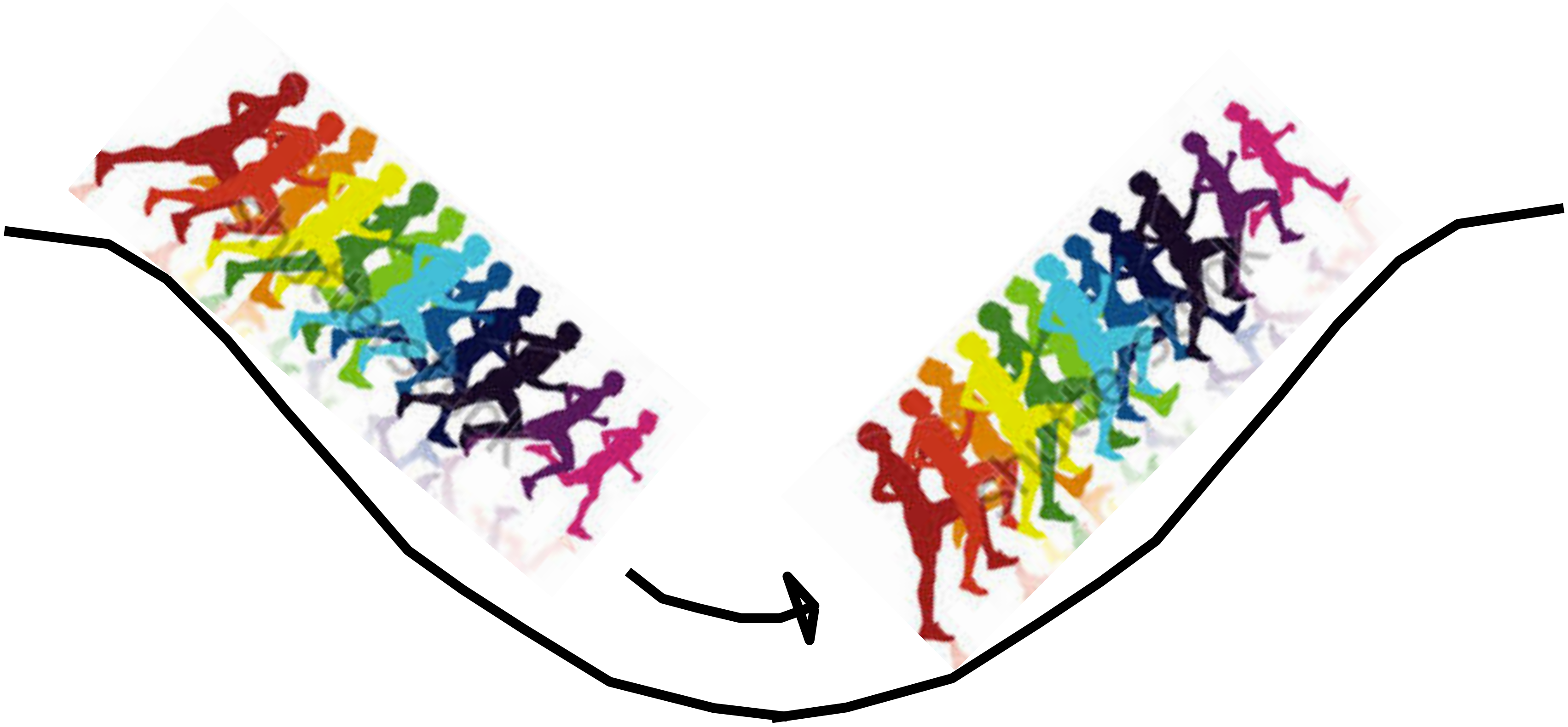
Light scales linearly with mass - but slope debated

PD, Ferrara, Dunlop & Pacucci, 2014

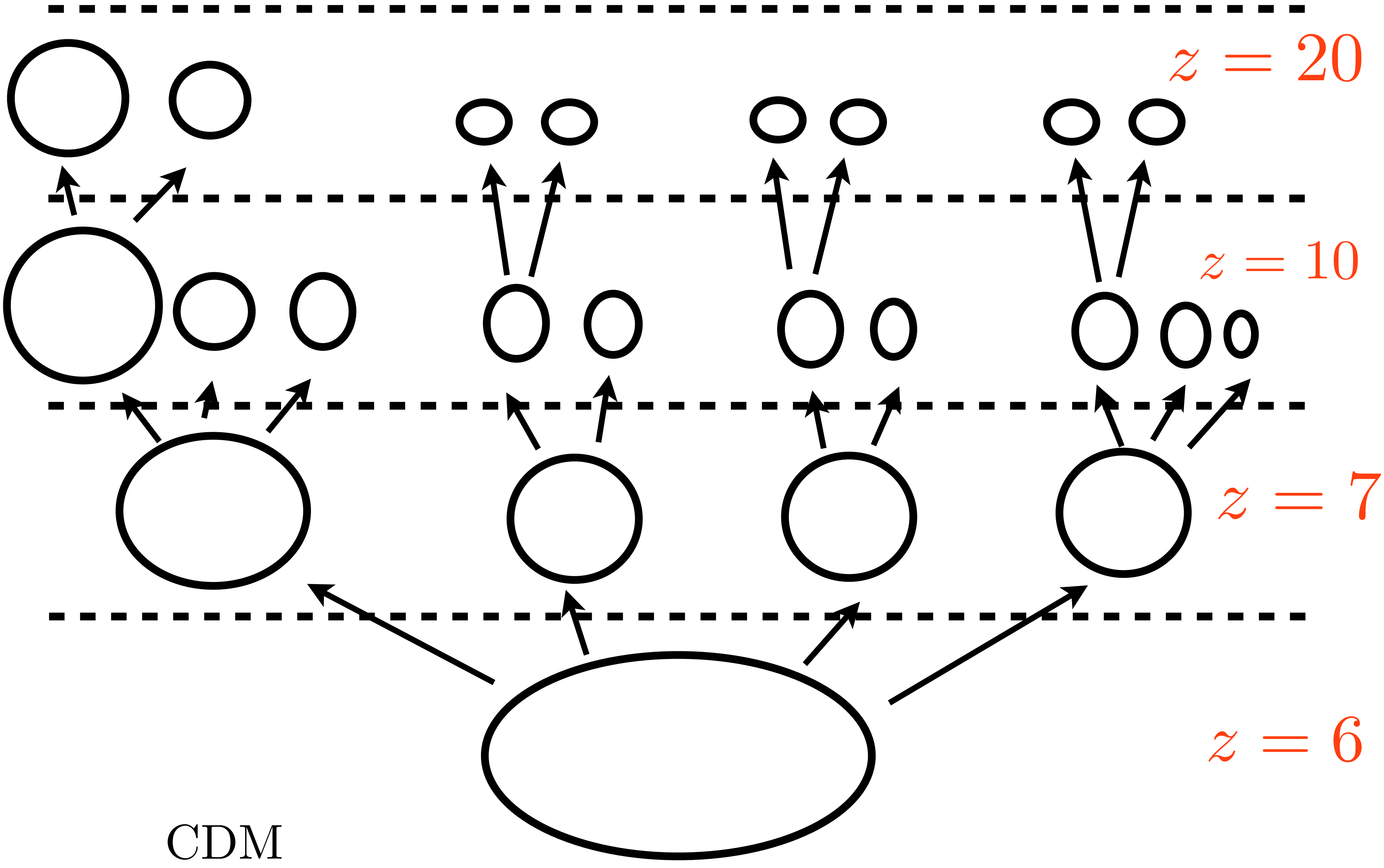


Testable prediction: $\log M_{*} \propto -0.38 M_{UV}$

Extending this framework to Warm Dark Matter Cosmologies

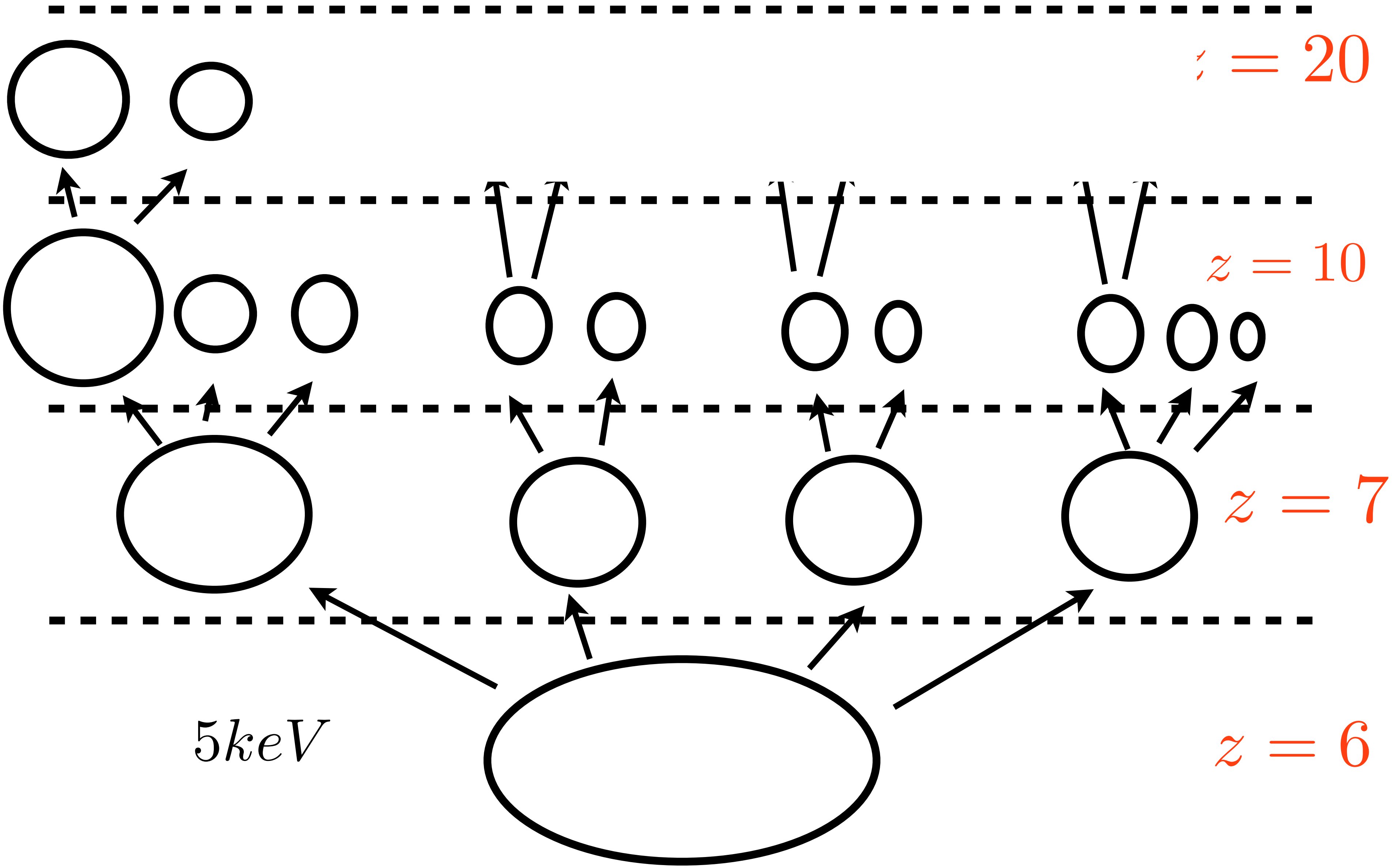


Hierarchical structure formation in CDM



Mass roughly 100 GeV

Lighter the WDM particle, more is the suppression of small scale structures



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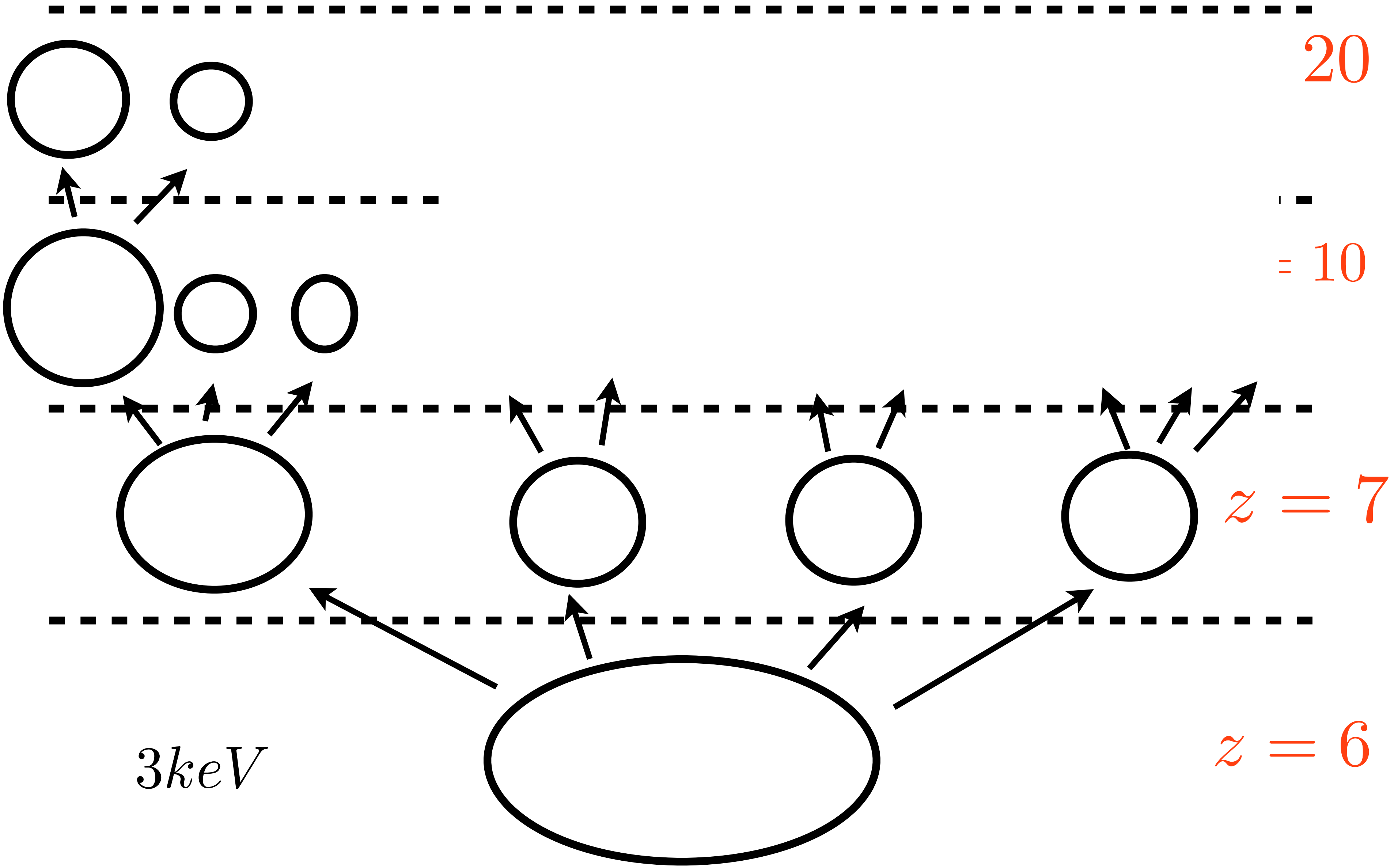

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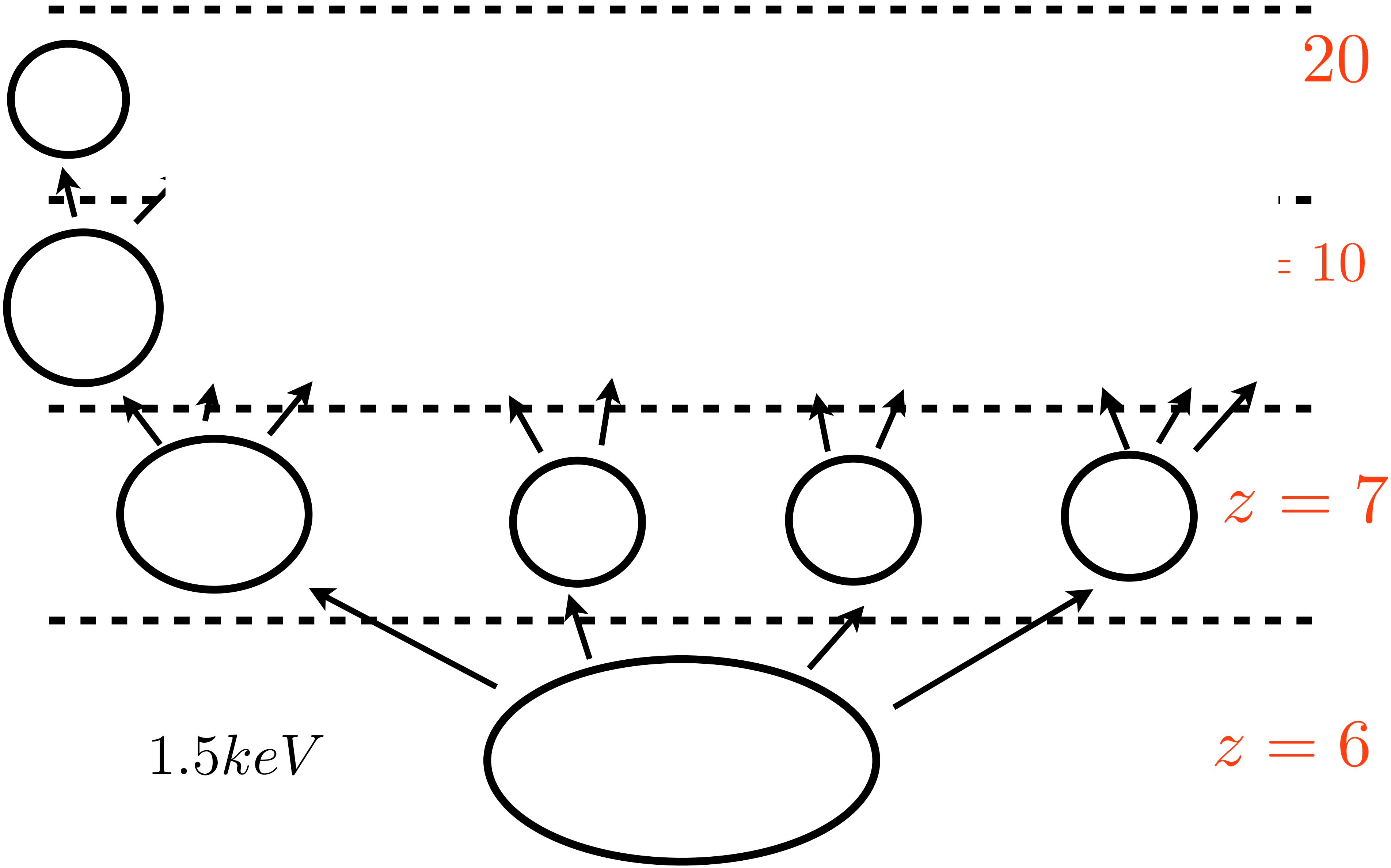
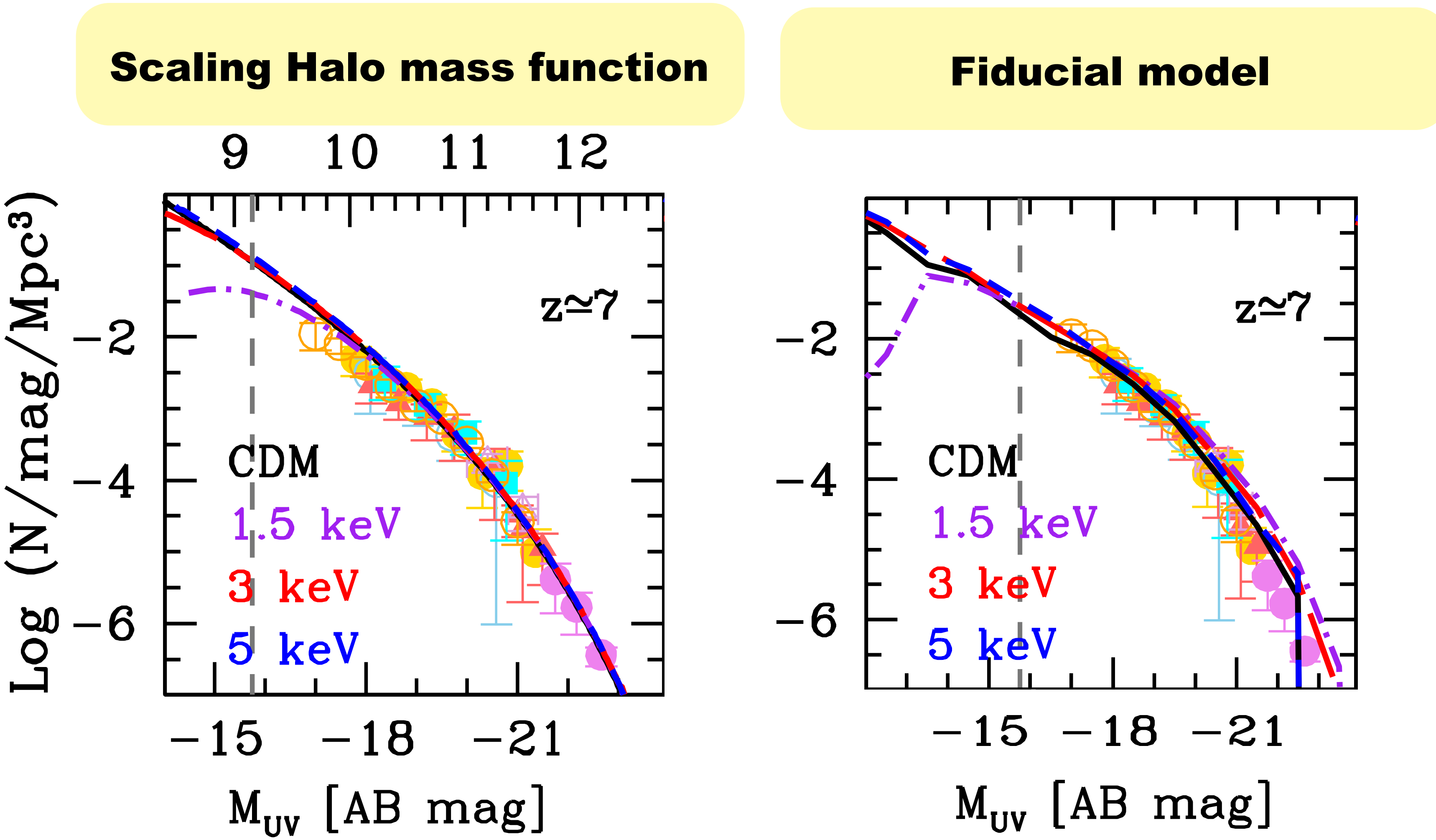


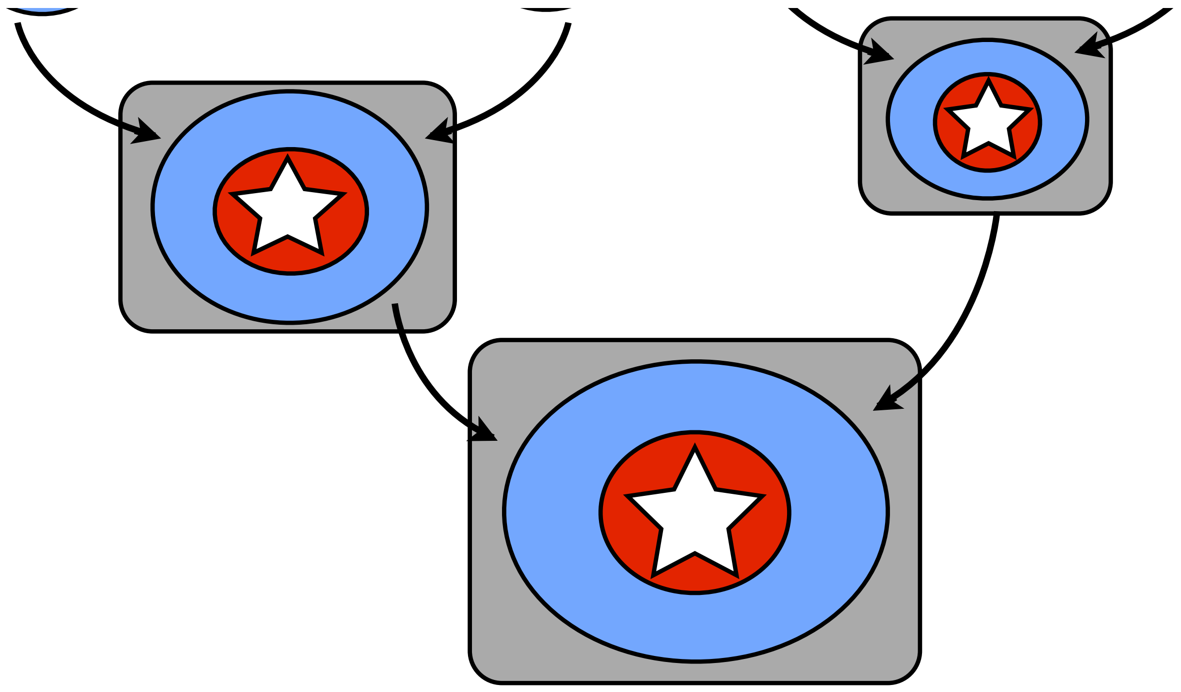
UV LFs in WDM



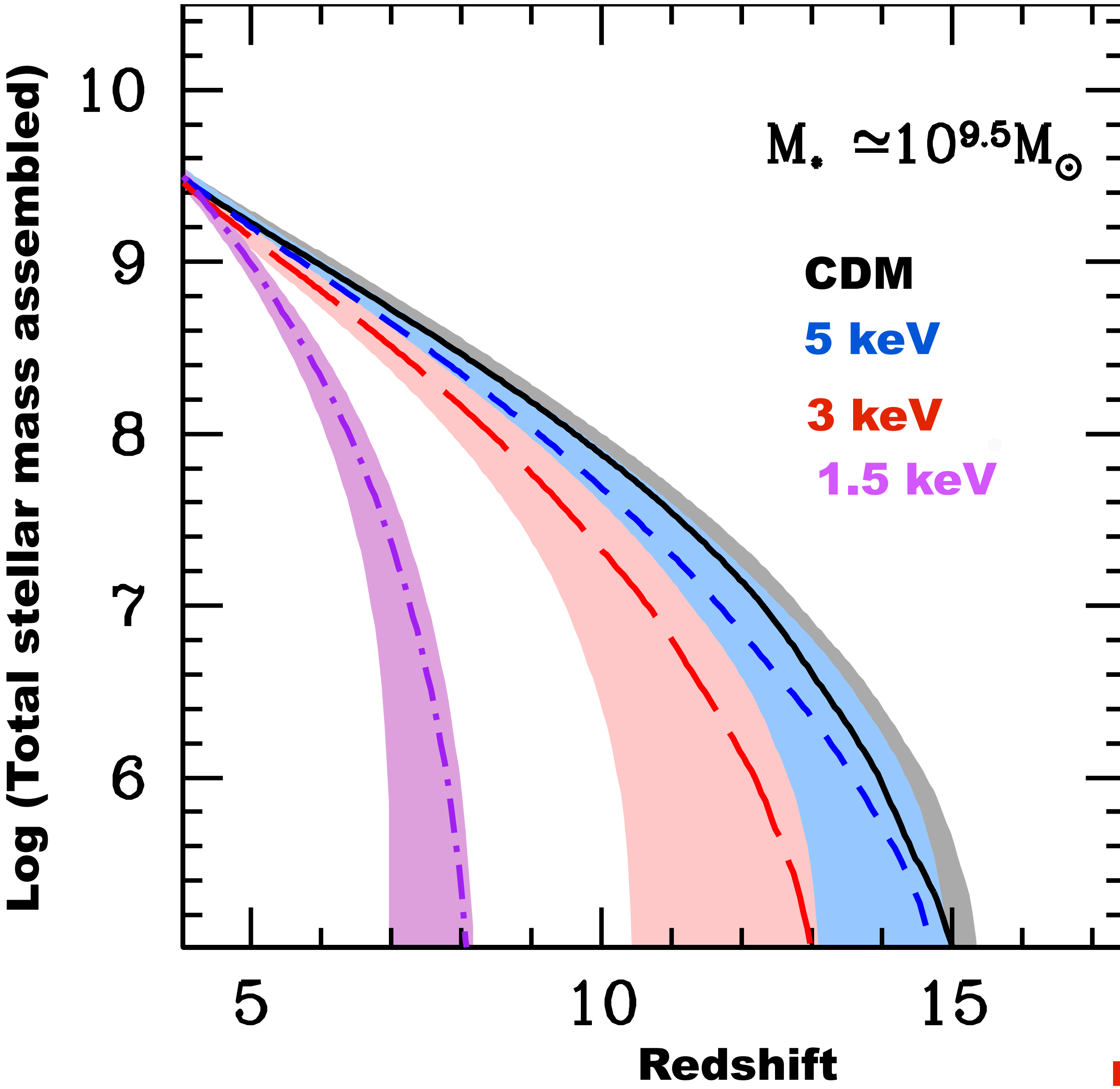
Including baryons (and SF) decreases the difference between CDM and 1.5 keV WDM models

PD, Mesinger & Pacucci, 2015

Since the merger tree starts building up later in WDM models..



it leads to a delayed assembly of the stellar mass

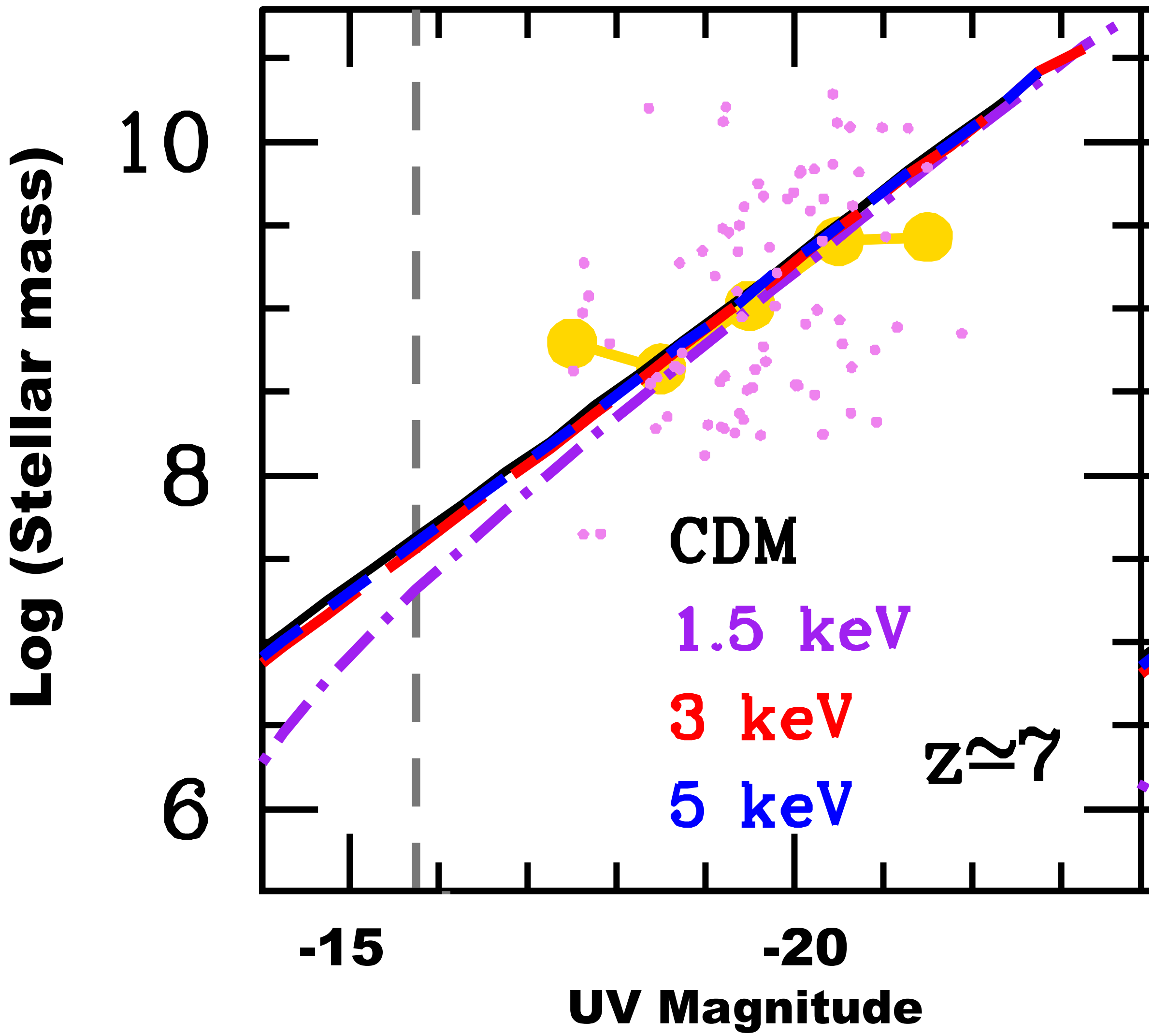


Galaxies assemble faster in 1.5 keV WDM models compared to CDM. This is because they start off bigger and are less feedback limited as a consequence.

PD, Mesinger & Pacucci, 2015

Mass-to-light ratios depend on cosmology!

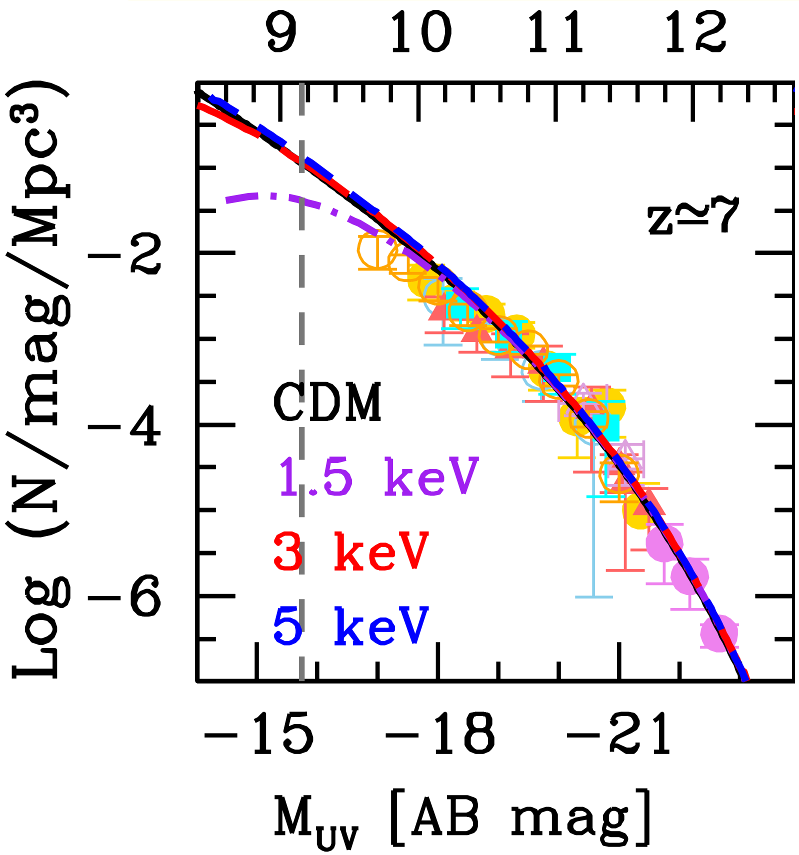
PD, Mesinger & Pacucci, 2015



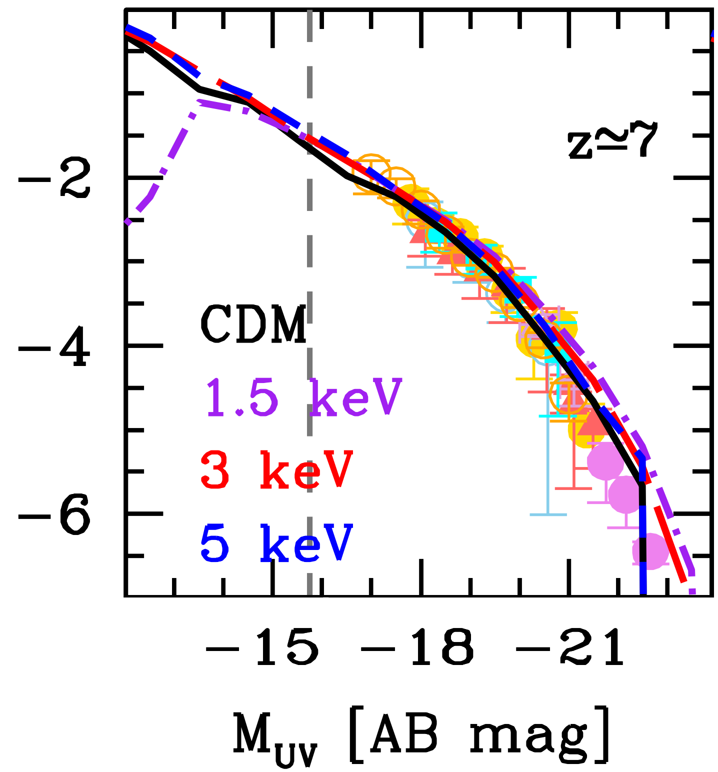
Light WDM models show lower M/L ratios (i.e. more luminosity per unit stellar mass) compared to CDM

UV LFs in WDM

Scaling Halo mass function



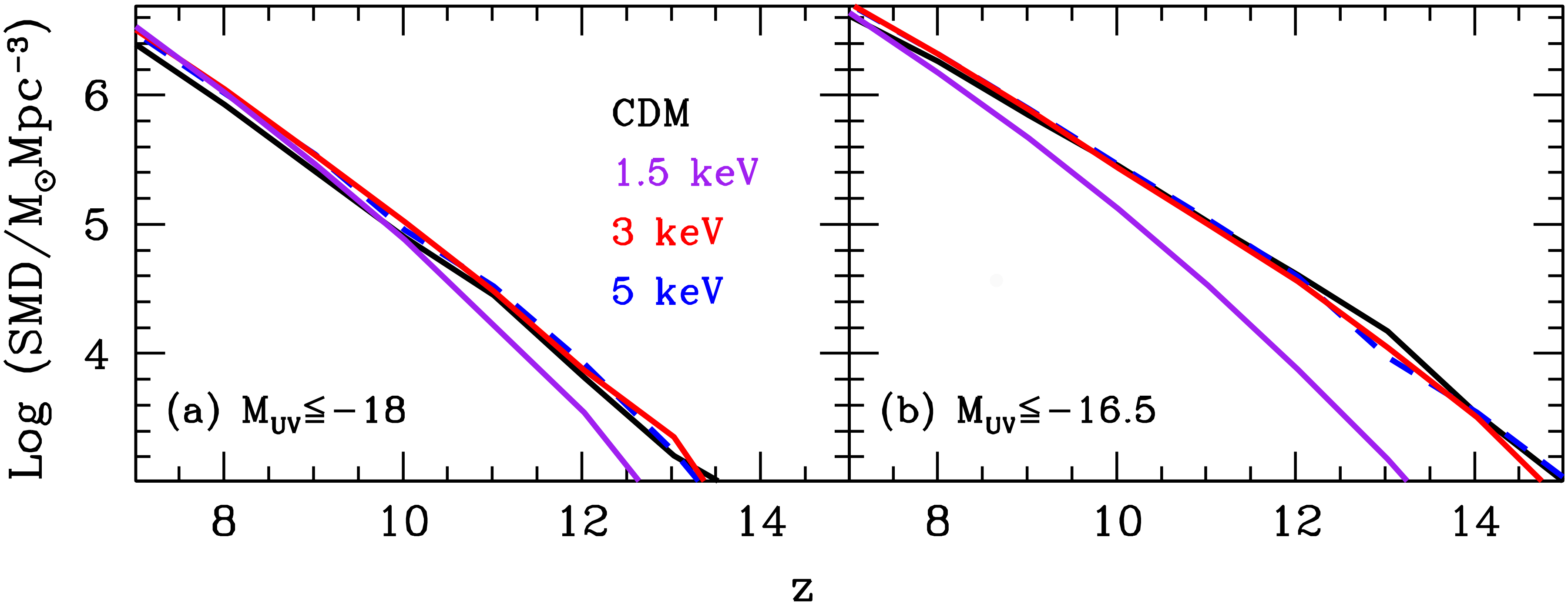
Fiducial model



Including baryons (and SF) decreases the difference between CDM and 1.5 keV WDM models

PD, Mesinger & Pacucci, 2015

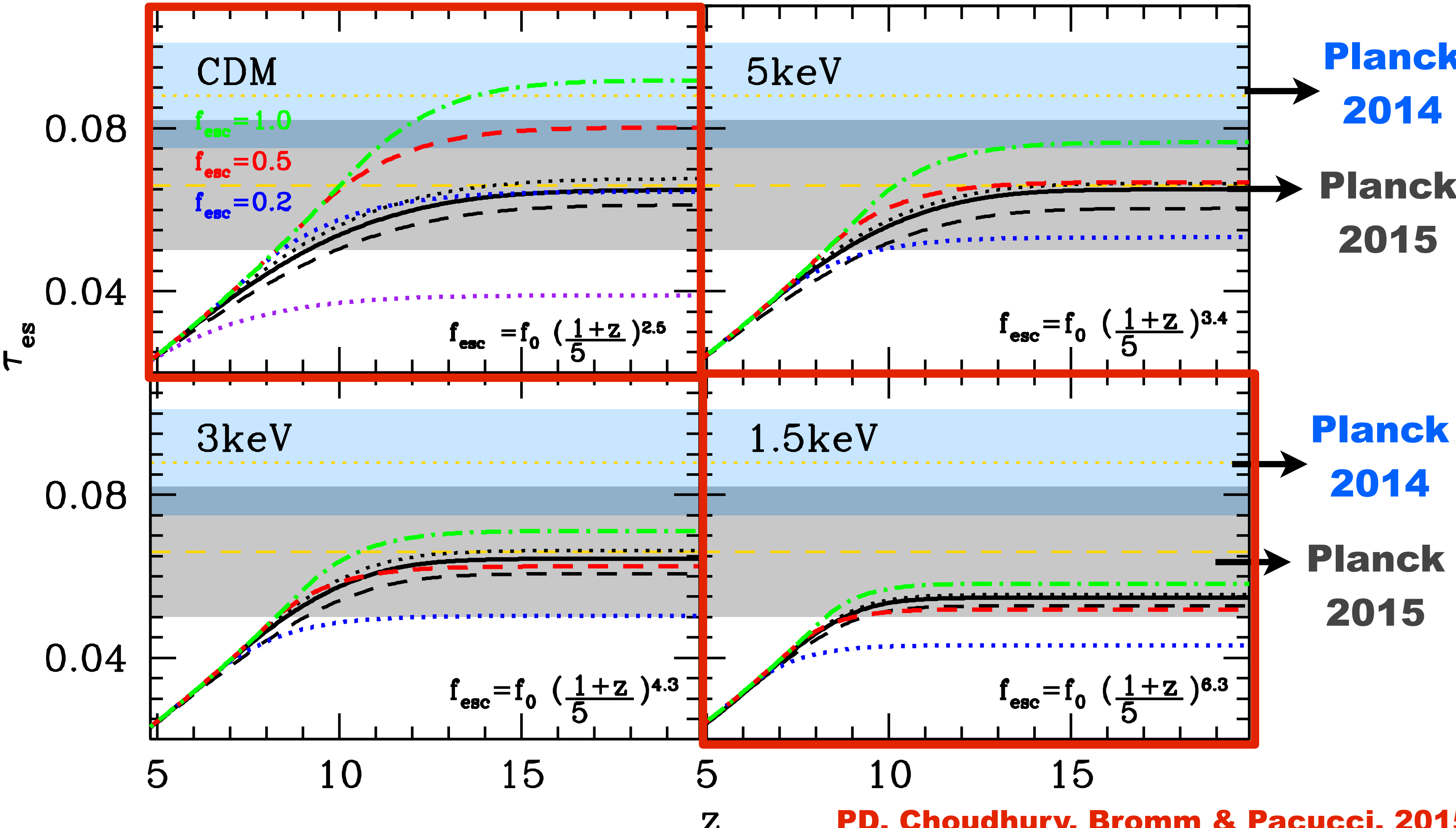
Observational imprints of light WDM particles: buildup of the cosmic stellar mass density



Redshift evolution of stellar mass density with JWST-detectable galaxies can allow constraints on WDM mass of about 2keV!

PD, Mesinger & Pacucci, 2015

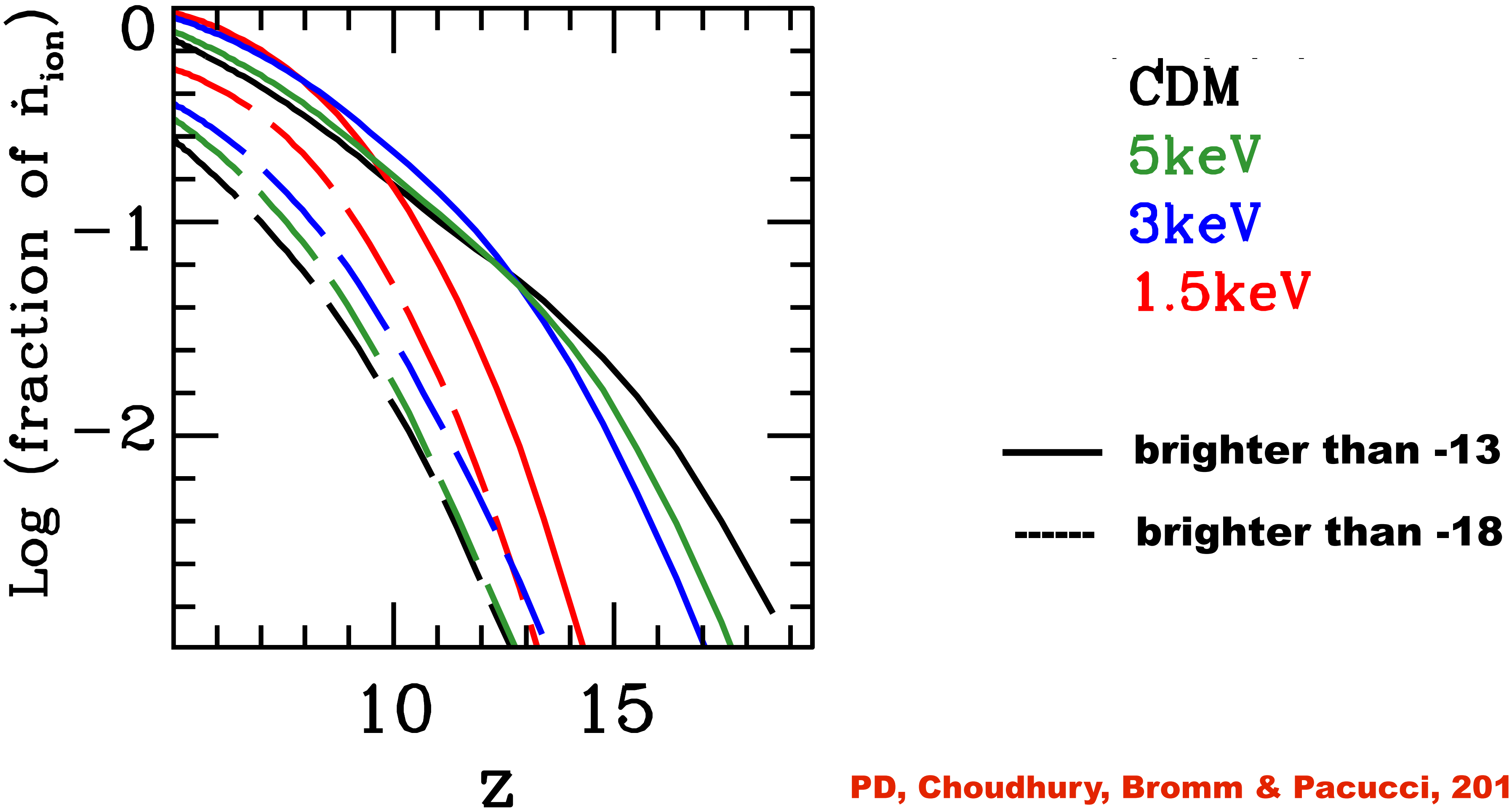
Reionization in different DM cosmologies



PD, Choudhury, Bromm & Pacucci, 2015

While old Planck optical depths rules out <2 keV WDM, the newer lower measurements are consistent with such light masses.

Reionization sources in different DM cosmologies



PD, Choudhury, Bromm & Pacucci, 2015

Currently detected galaxies contribute ~25% (~50%) of ionizing photons in CDM (1.5 keV WDM). Need to go as faint as UV magnitude of -13 to get 65% (100%) ionizing photons in CDM (1.5 keV WDM).

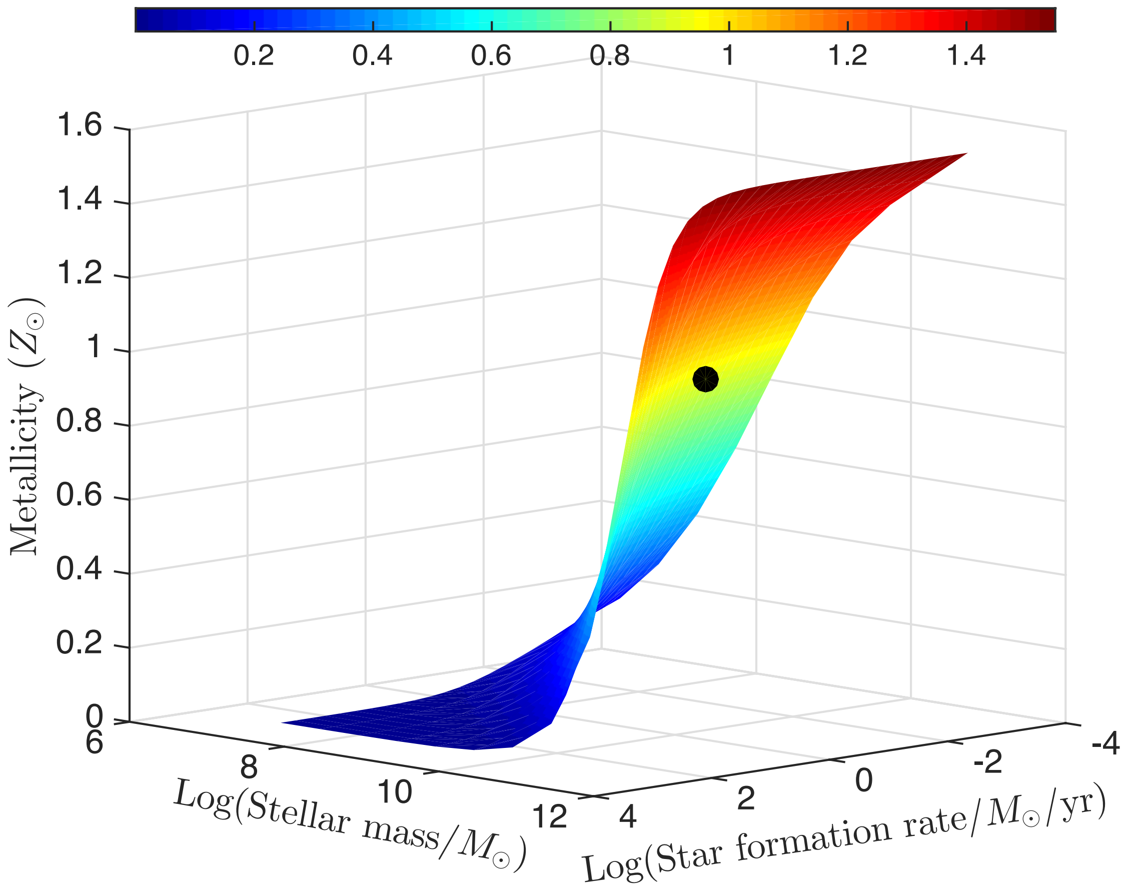
The emerging picture

- Observables like M/L are cosmology dependent!

- JWST SMD measurements may help distinguish between ~2 keV WDM and CDM (heavier WDM indistinguishable from CDM).

- New Planck reionization limits consistent with WDM as light as 1.5 keV with most (all) reionizing photons coming from MUV ~-13 galaxies in CDM (1.5 keV) WDM.

The cradles of life: which galaxy type is most habitable?



Stellar mass

Gas-phase metallicity

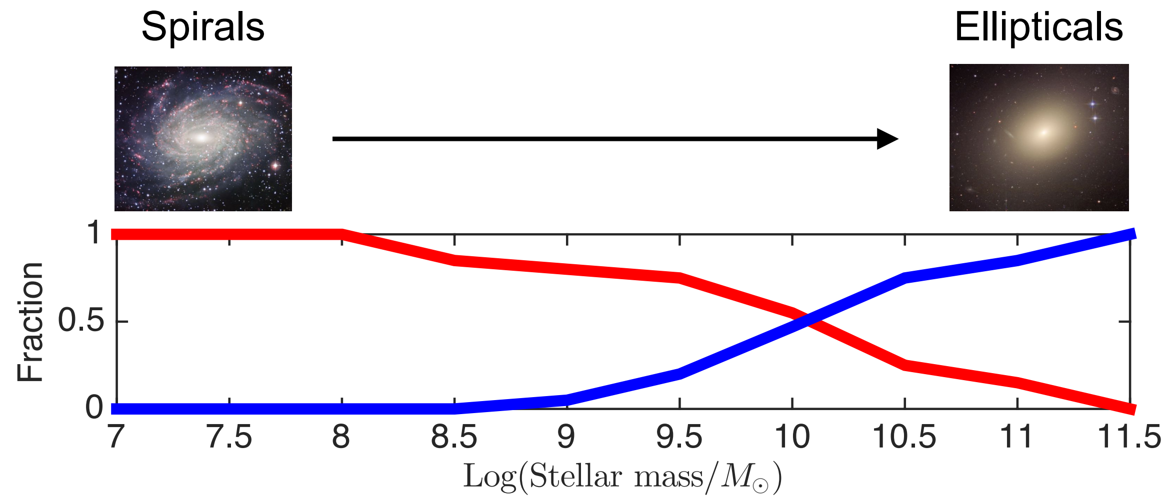
Ongoing SFR

$$N_t \propto N_{tot} P_t P_{cl} \propto \frac{N_{tot} Z_g^\alpha}{f_{irr}}$$

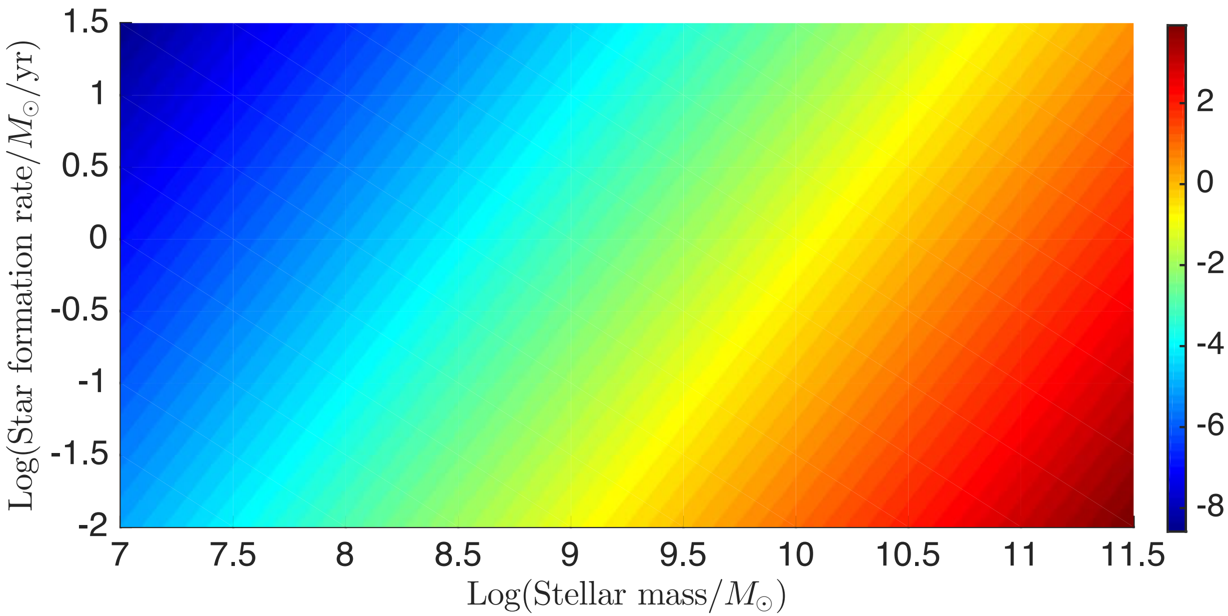
$$N_t \propto \frac{M_*^2 Z_g^\alpha}{\psi}.$$

PD, Cockell, Rice & Mazumdar, arXiv:1507.04346

Spirals or ellipticals?



PD, Cockell, Rice & Mazumdar, arXiv: 1507.04346



Giant ellipticals roughly twice as massive as MW, with a tenth of its SFR best places for habitability