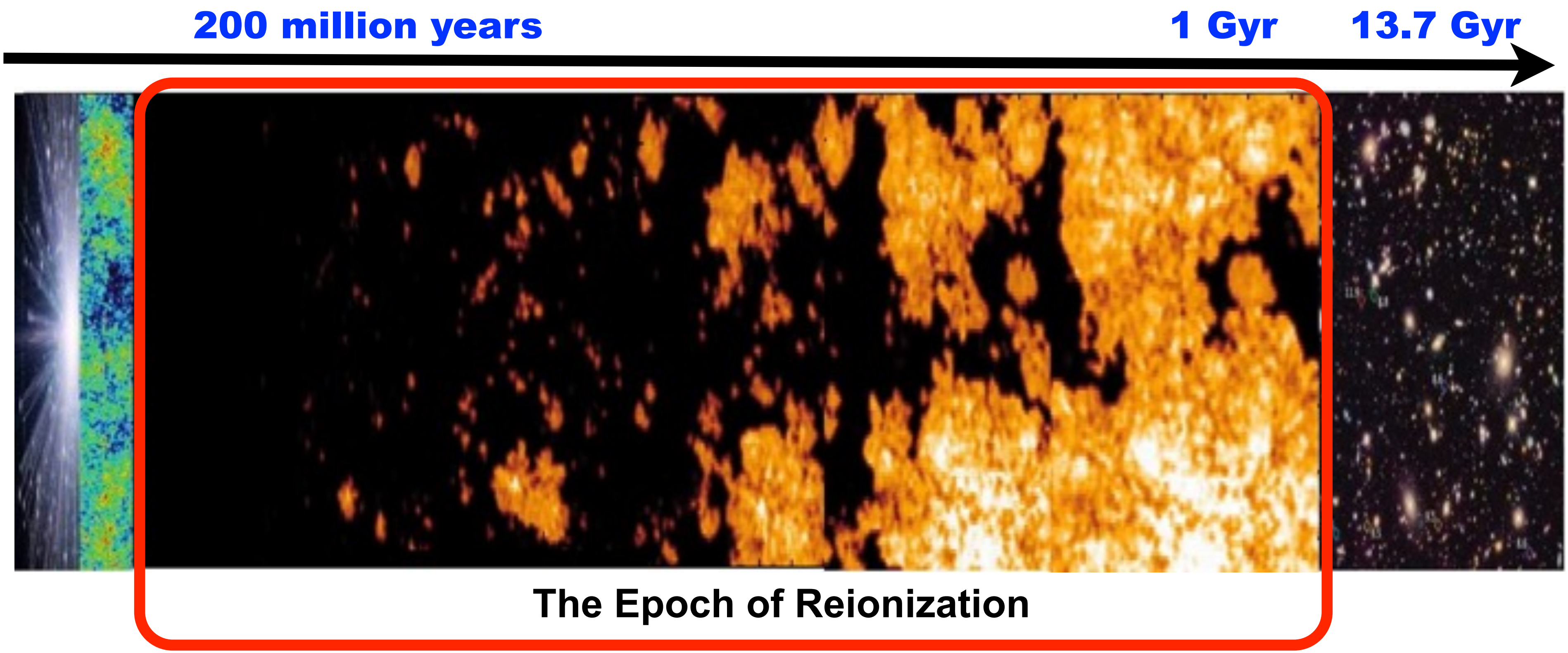
The first billion years of galaxy formation

Pratika Dayal



With: Volker Bromm, Tirth Choudhury, James Dunlop, Andrea Ferrara, Anne Hutter, Andrei Mesinger & Fabio Pacucci

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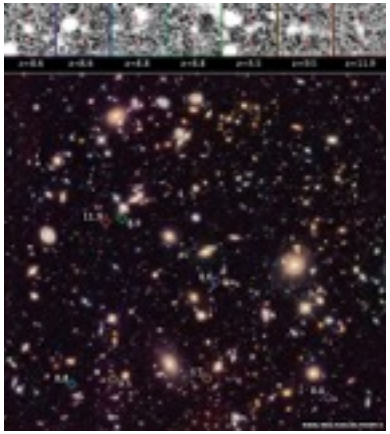
rijksuniversiteit groningen

The main questions

- **What is the fundamental physics driving the evolution of early galaxies?**

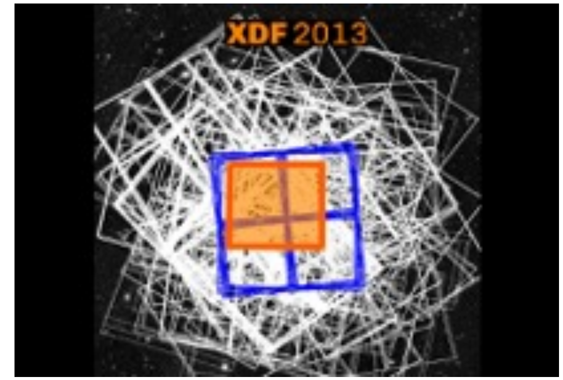
- **What constraints do early galaxies yield on the nature of Dark Matter?**

Observational status of Lyman break galaxies



HUDF

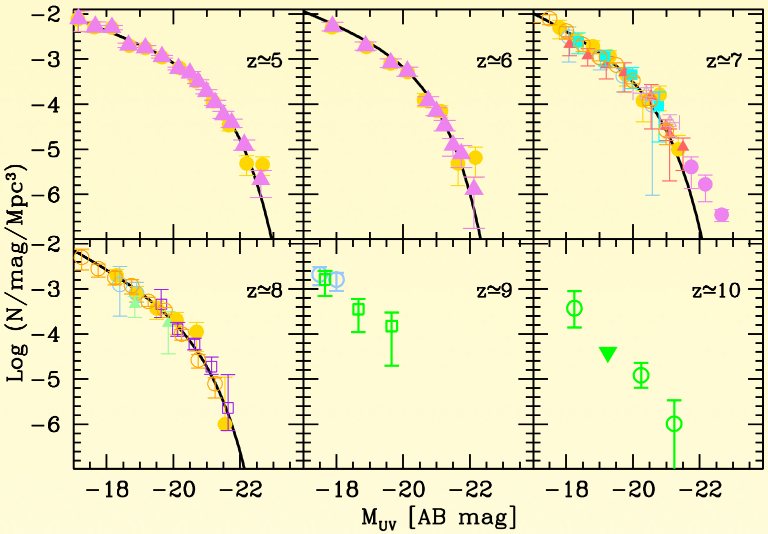
z	Number of galaxies
5	3391
6	940
7	598
8	225
9	~4-6
10	~6



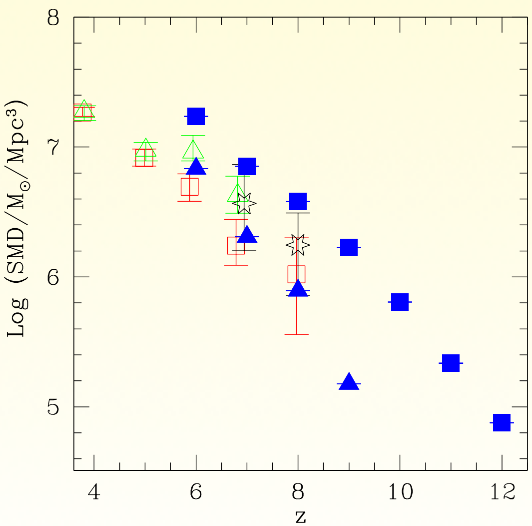
Atek+2015
Bouwens+2007, 2011, 2014
Bowler+2014, 2015
Bradley+2013
Castellano+2010, 2016
Ellis+2013
Finkelstein+2012, 2013
Livermore+2016
McLeod+2015, 2016
McLure+2009, 2013
Oesch+2010, 2014, 2016
Stanway+2010...

What can we learn from all this data?

Global quantities

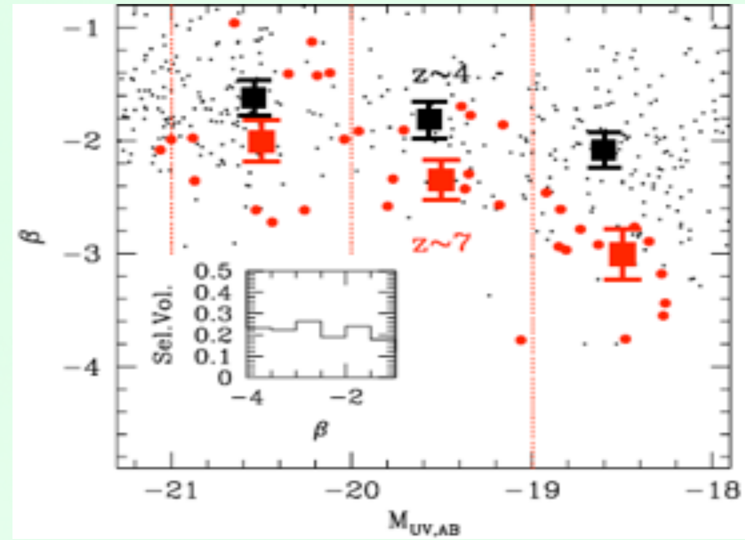


Ultraviolet luminosity functions (UV LF)

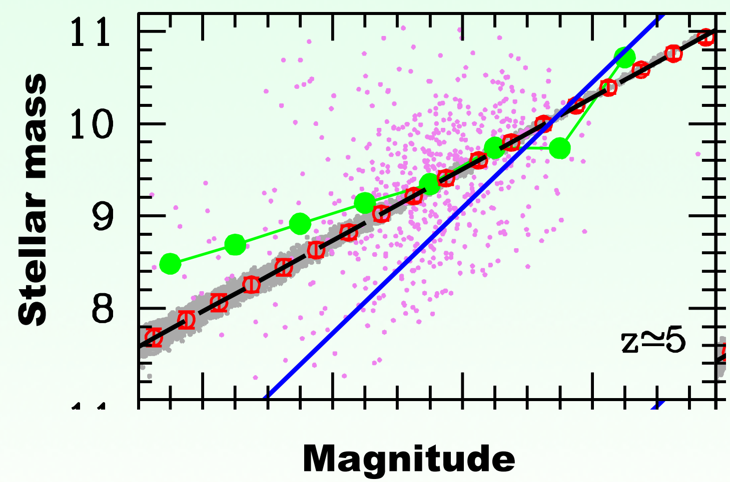


Stellar Mass Density (SMD)

Individual galaxy properties

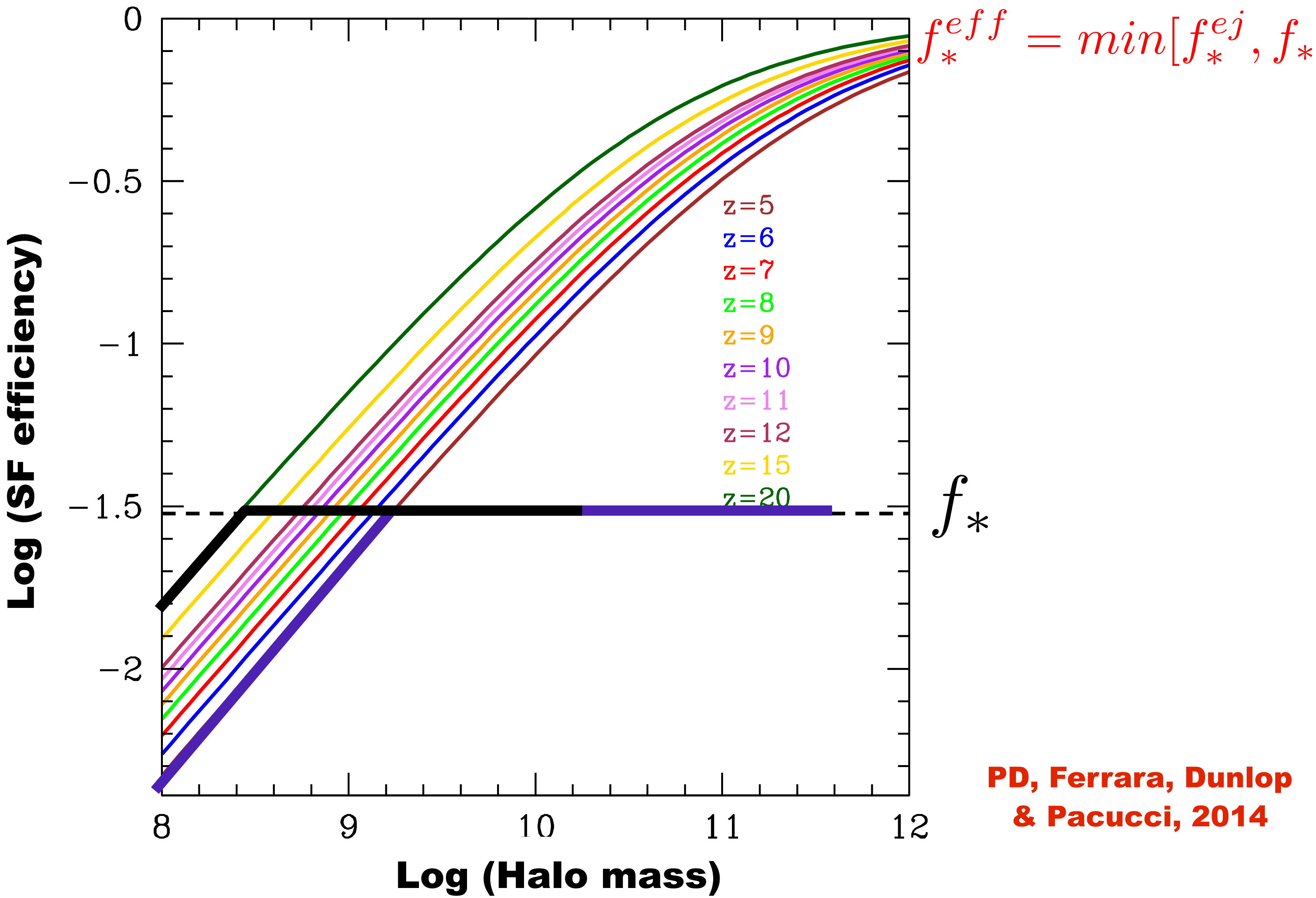


UV spectral slopes



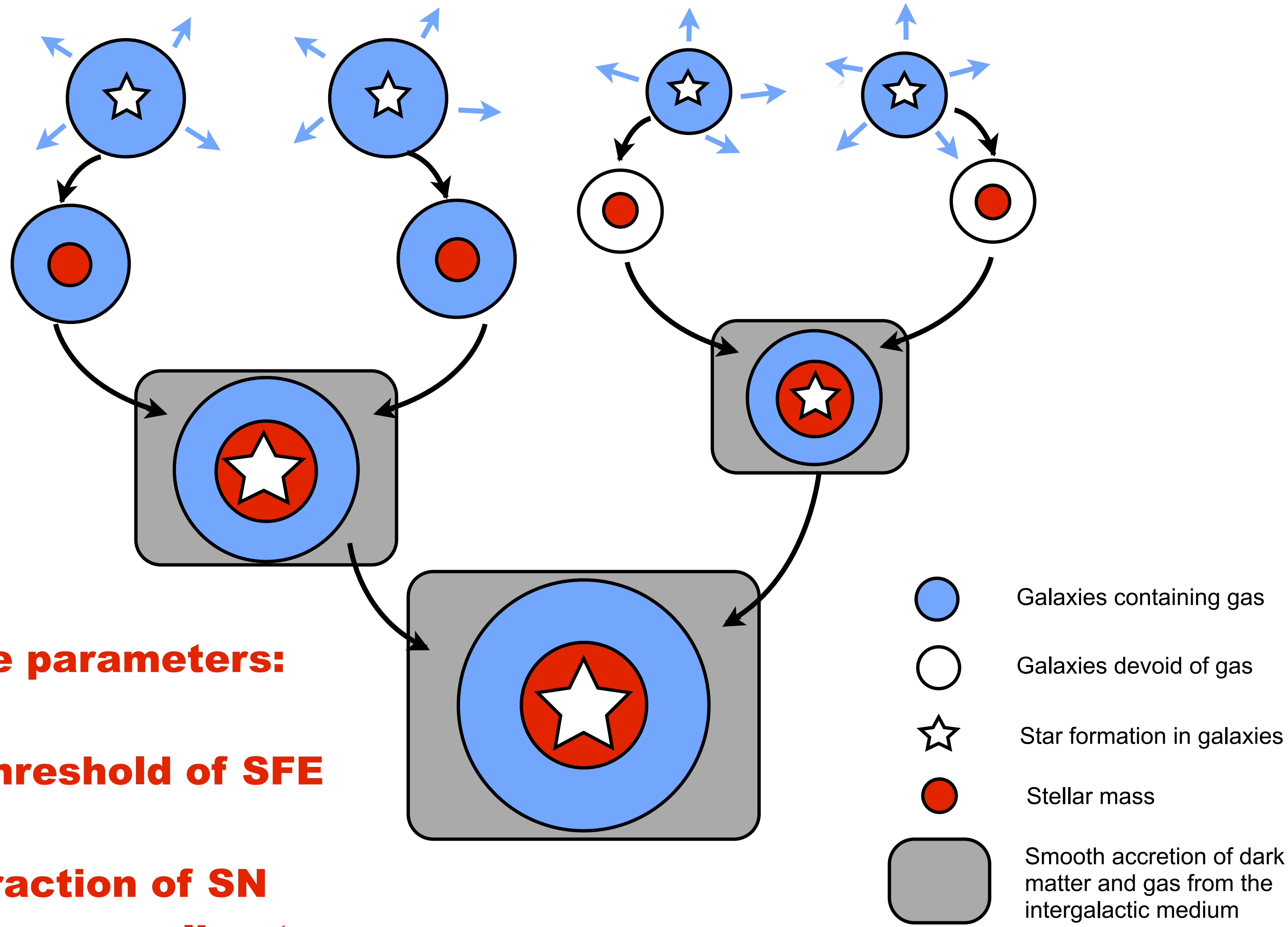
Mass-to-light ratios

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



PD, Ferrara, Dunlop & Pacucci, 2014

A semi-analytic model implemented with this simple idea



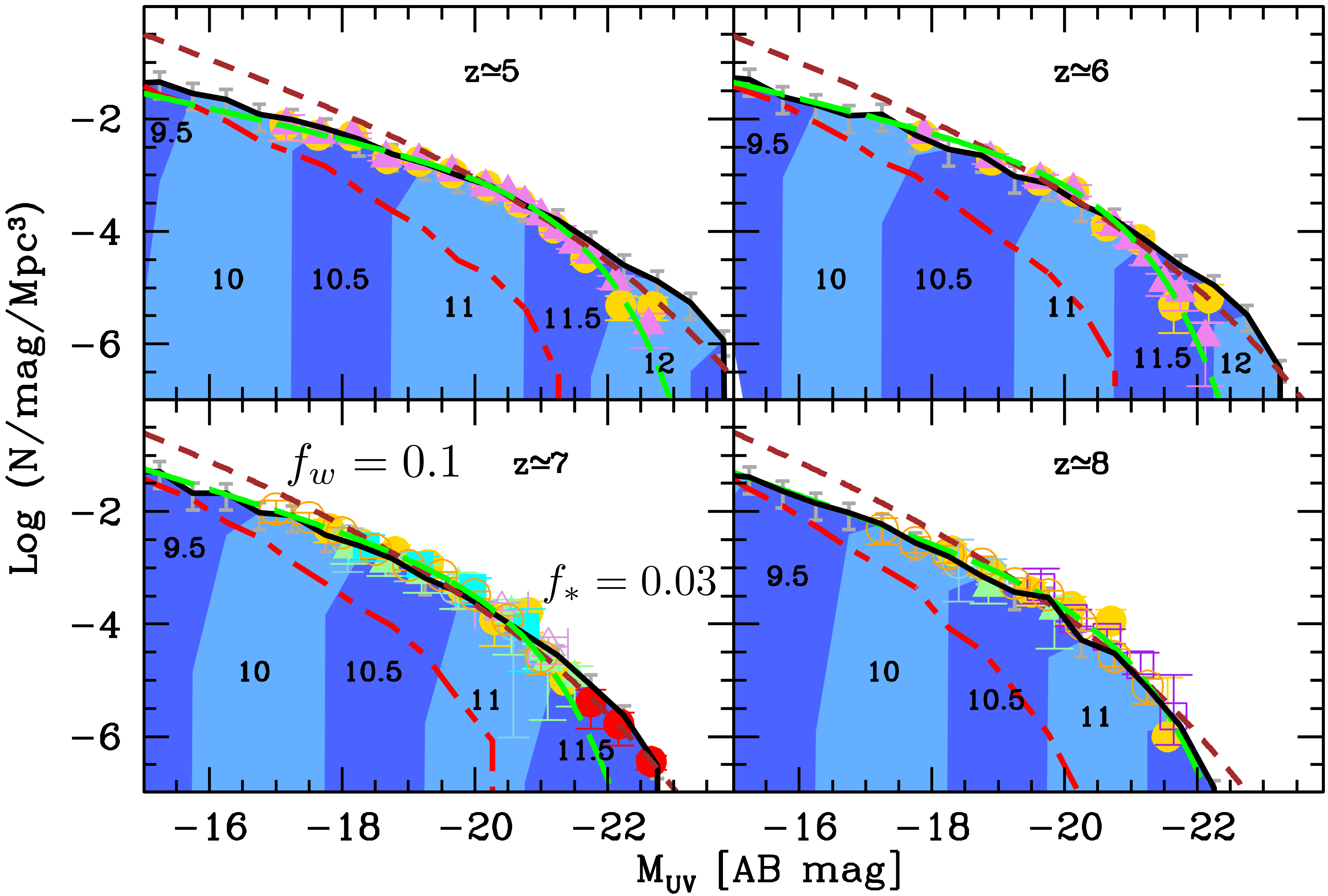
Free parameters:

f_* **1. threshold of SFE**

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

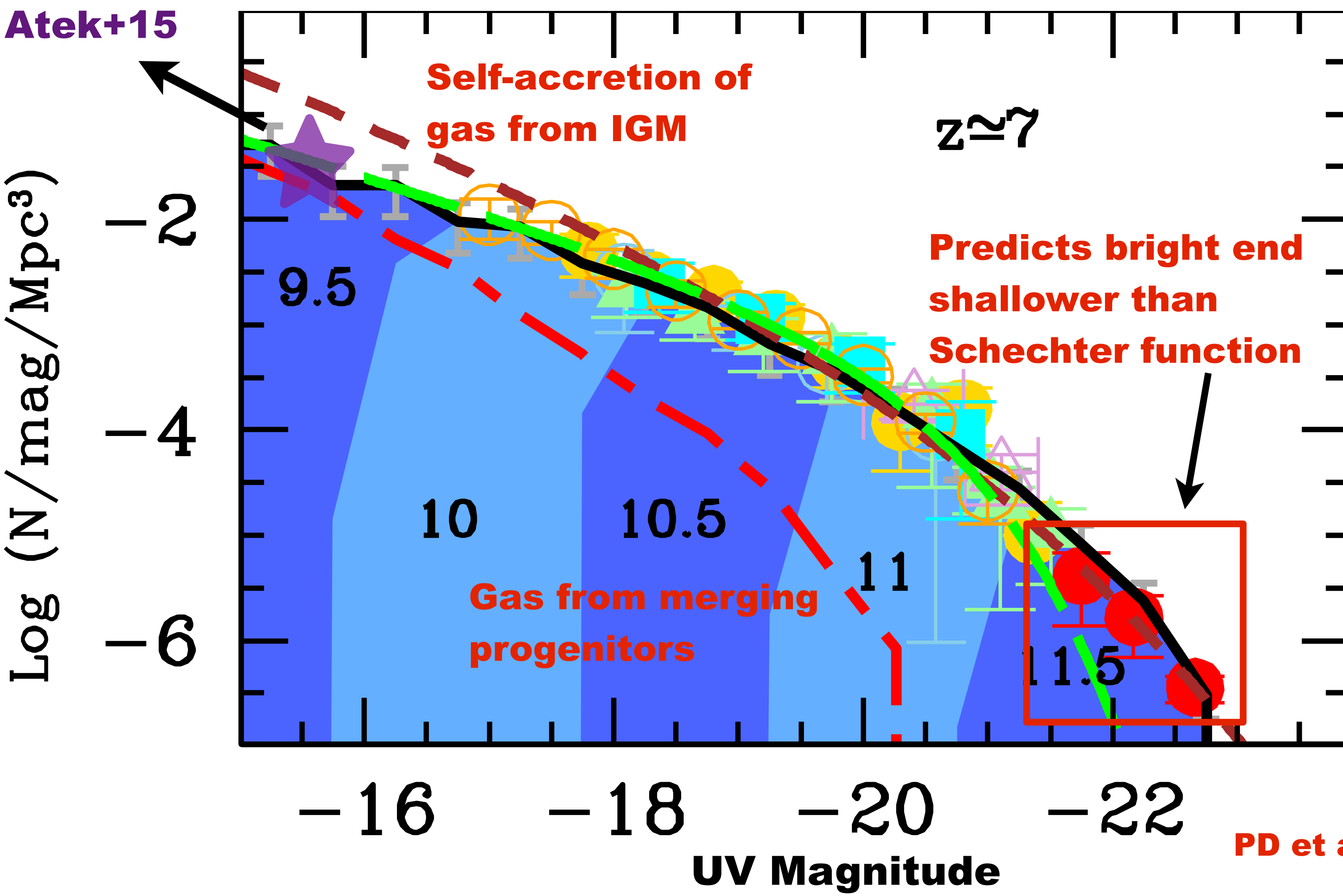
PD, Ferrara, Dunlop & Pacucci, 2014

The number counts of early LBGs (the UV LF)



PD, Ferrara, Dunlop & Pacucci, MNRAS, 2014

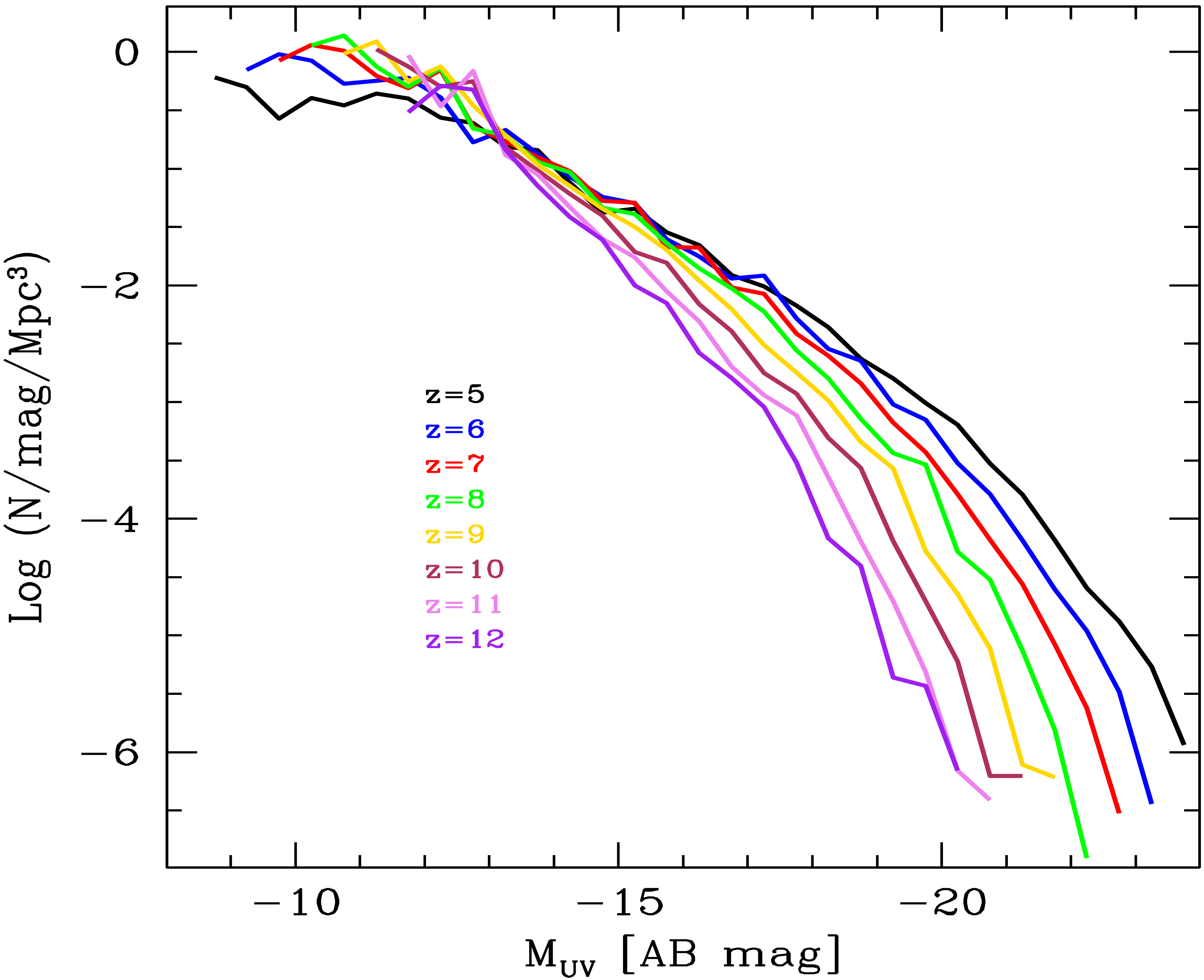
The gastrophysics of early LBGs



PD et al. 2014

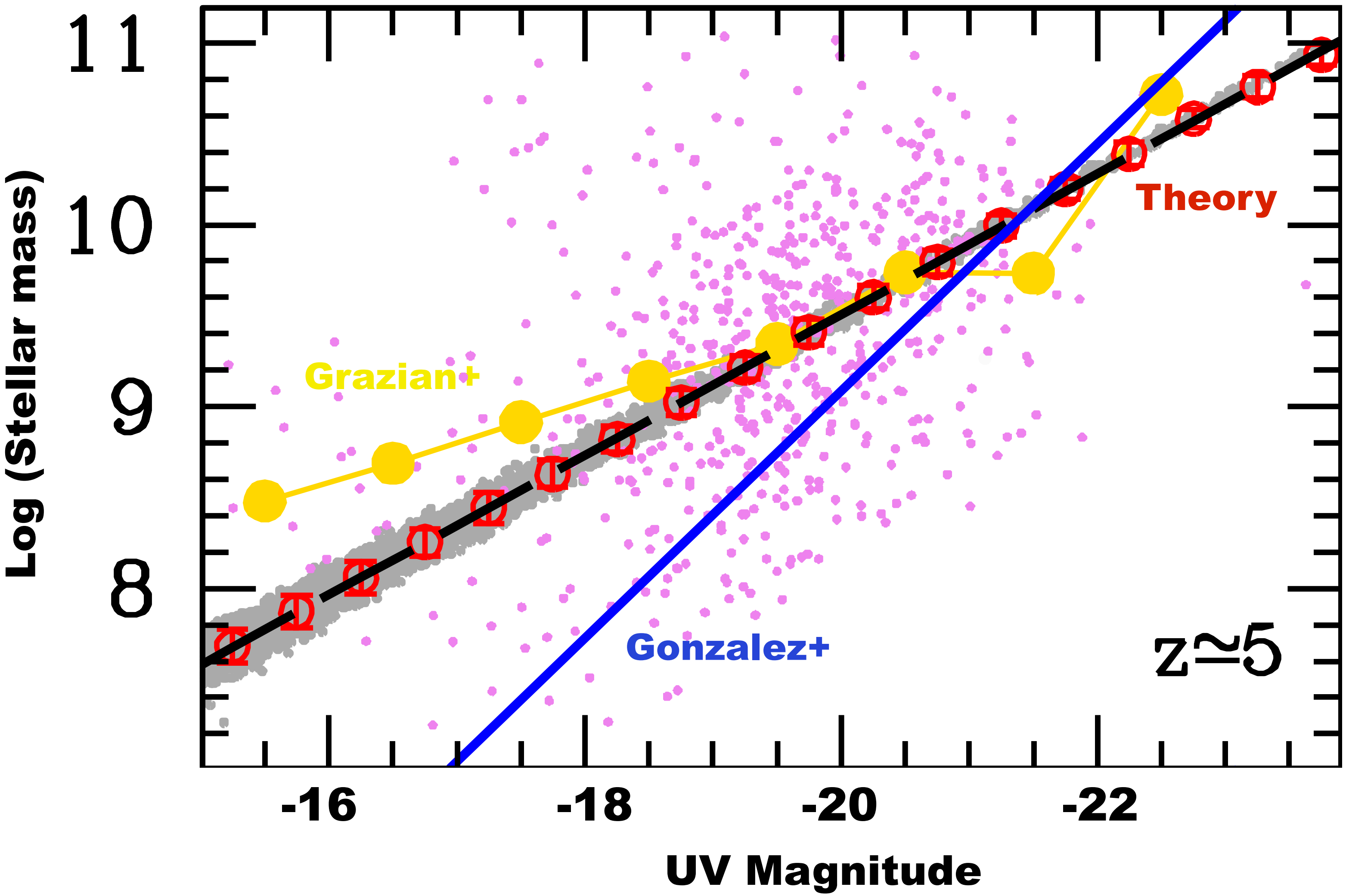
Prediction for the frontier Fields and JWST: $\alpha = -1.75 \log z - 0.52$

How far down do the LFs extend?



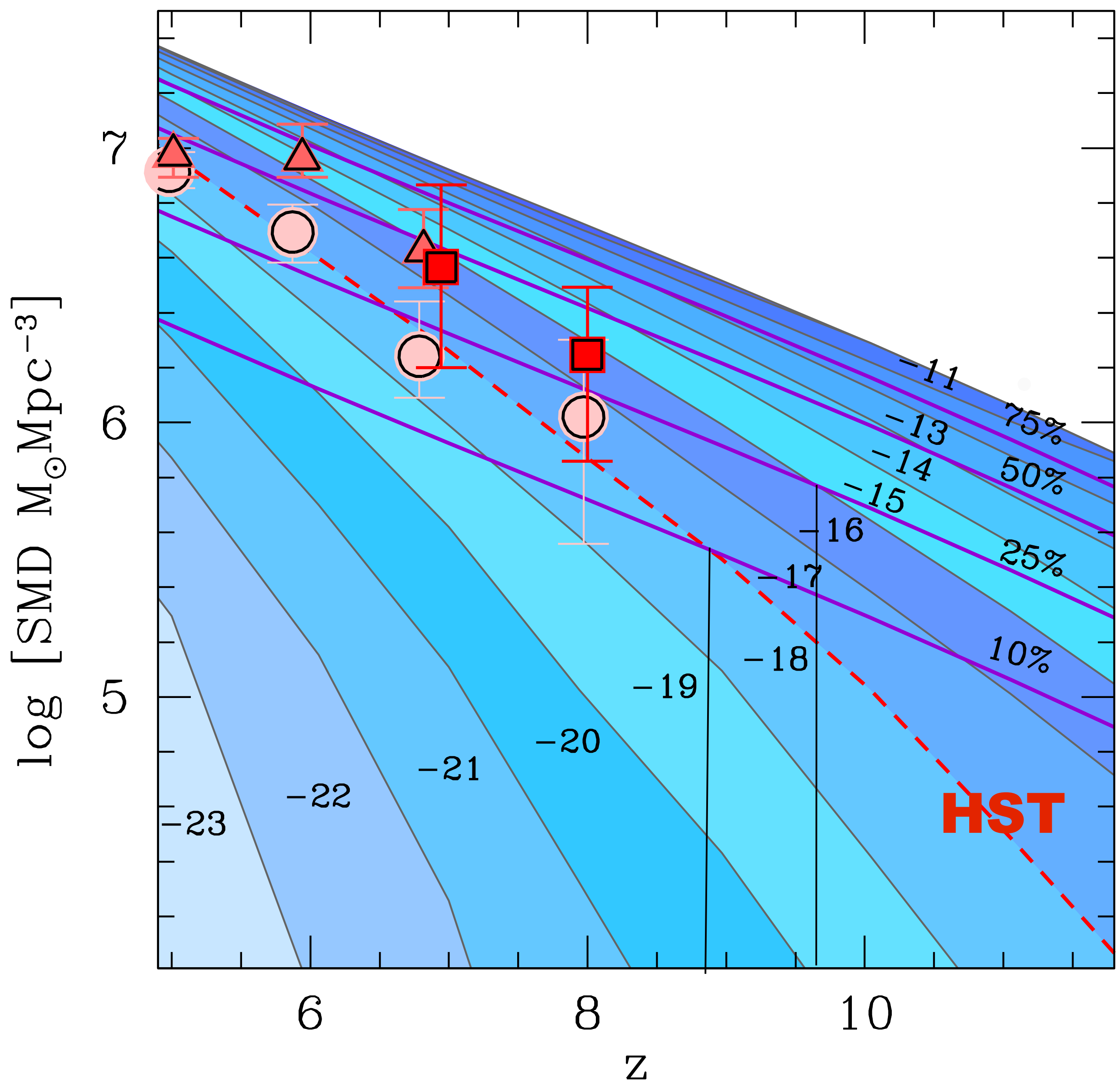
Light scales linearly with mass - but slope debated

PD, Ferrara, Dunlop & Pacucci, 2014



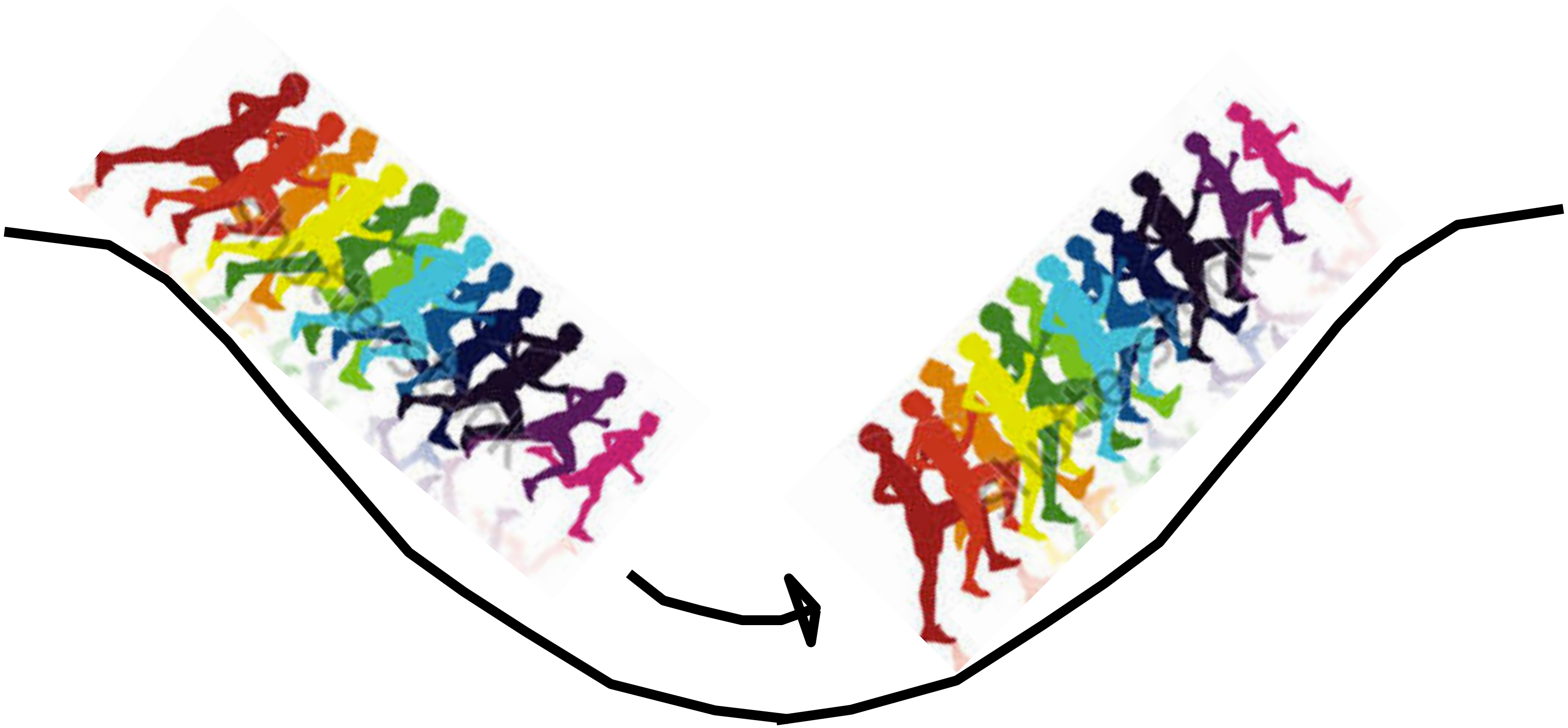
Testable prediction: $\log M_* \propto -0.38 M_{UV}$

Stellar mass census: detected, detectable and hidden

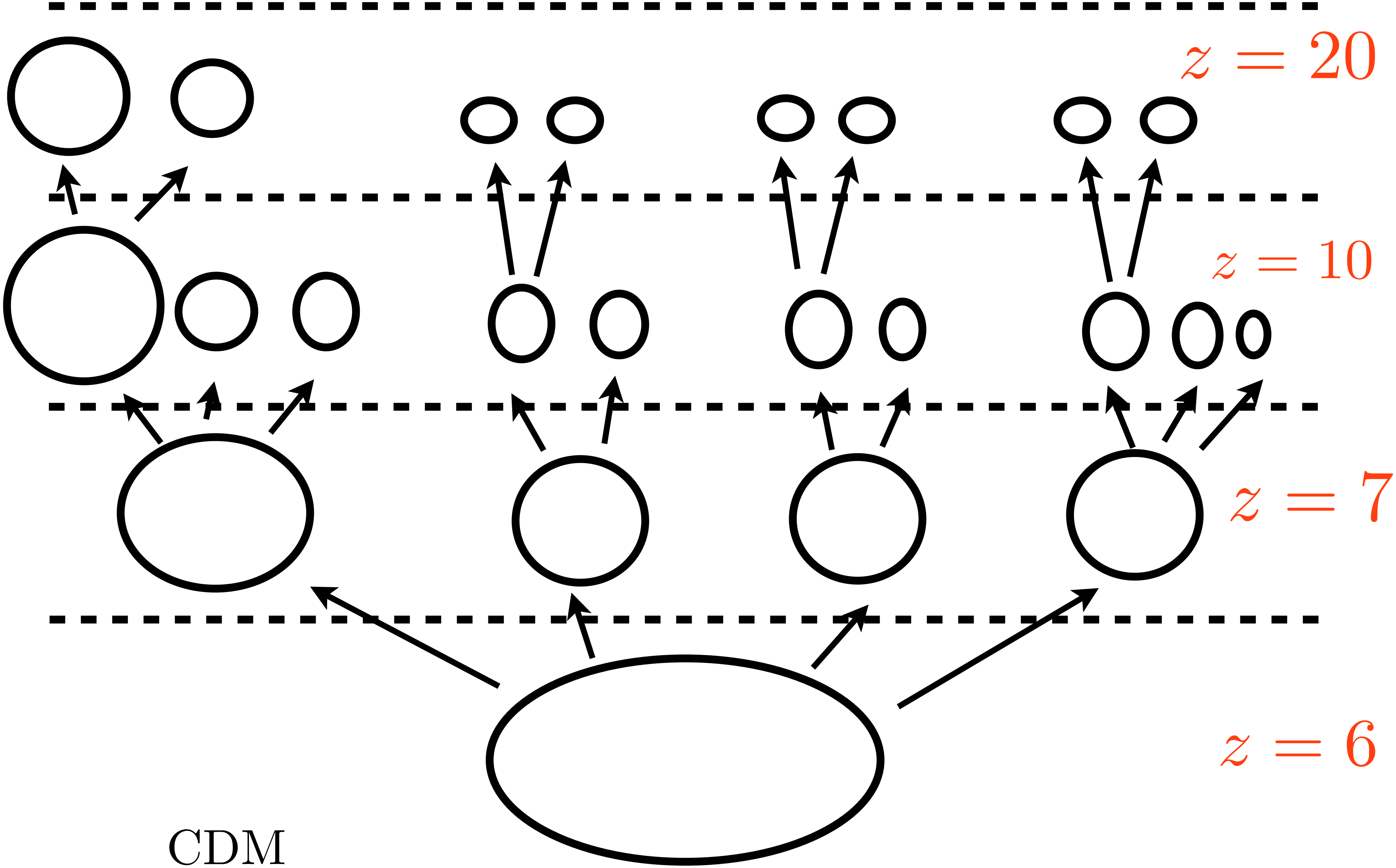


- Currently detected LBGs contain 50% (10%) of total SMD at z~5 (9).
- JWST will detect upto half (a fourth) of the total SMD up to z~ (7) 9.5.

Extending this framework to Warm Dark Matter Cosmologies

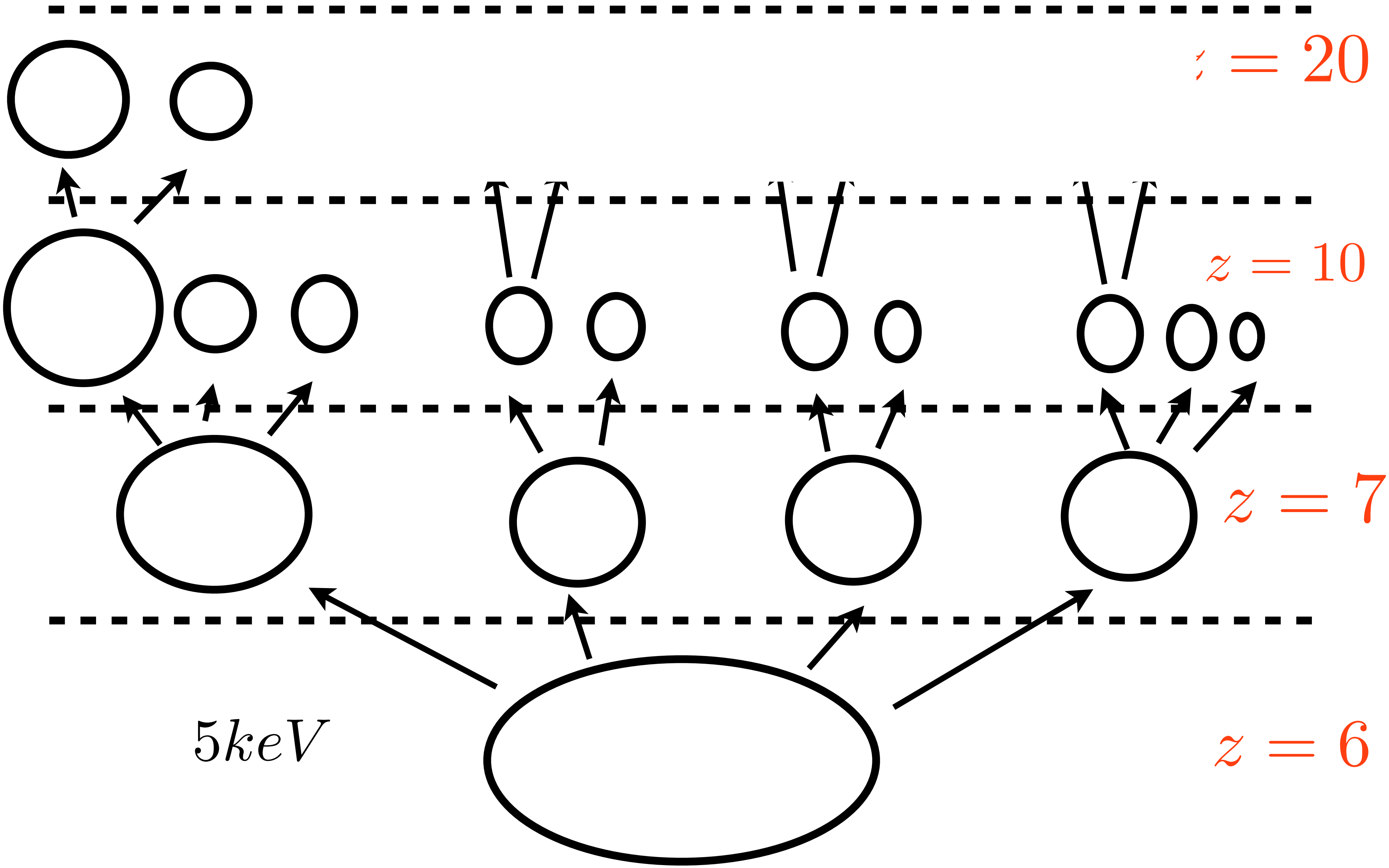


Hierarchical structure formation in CDM



Mass roughly 100 GeV

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



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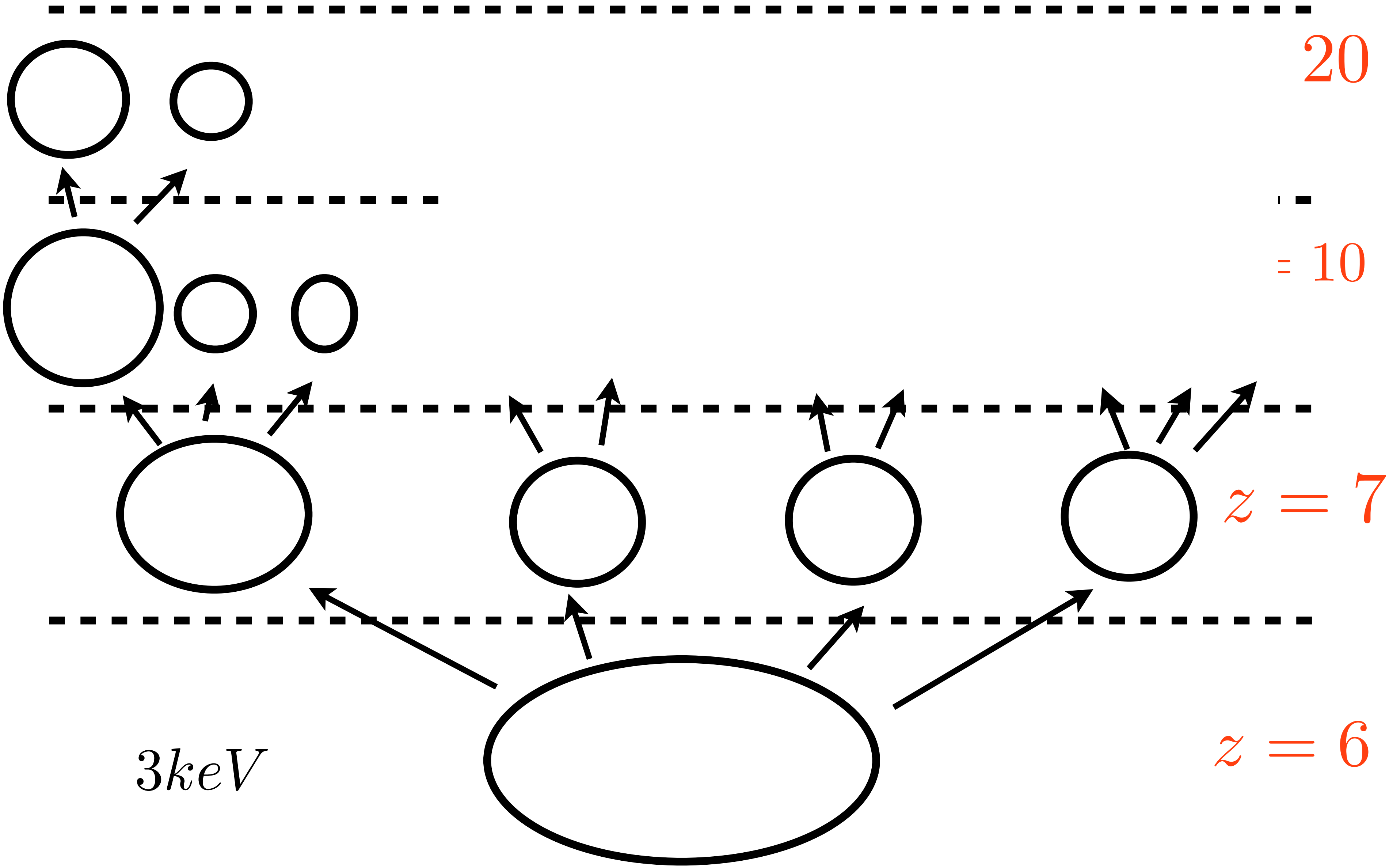

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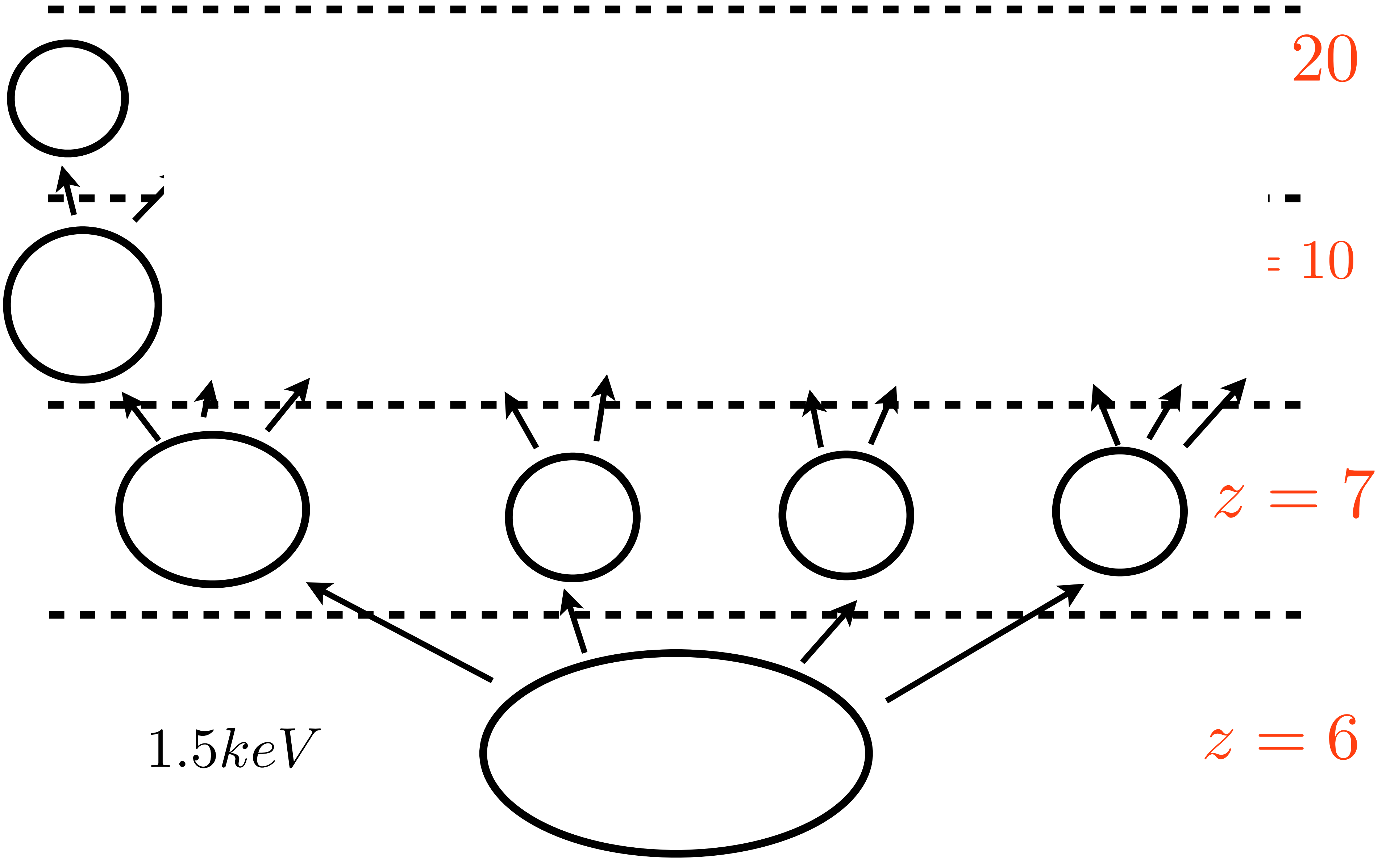
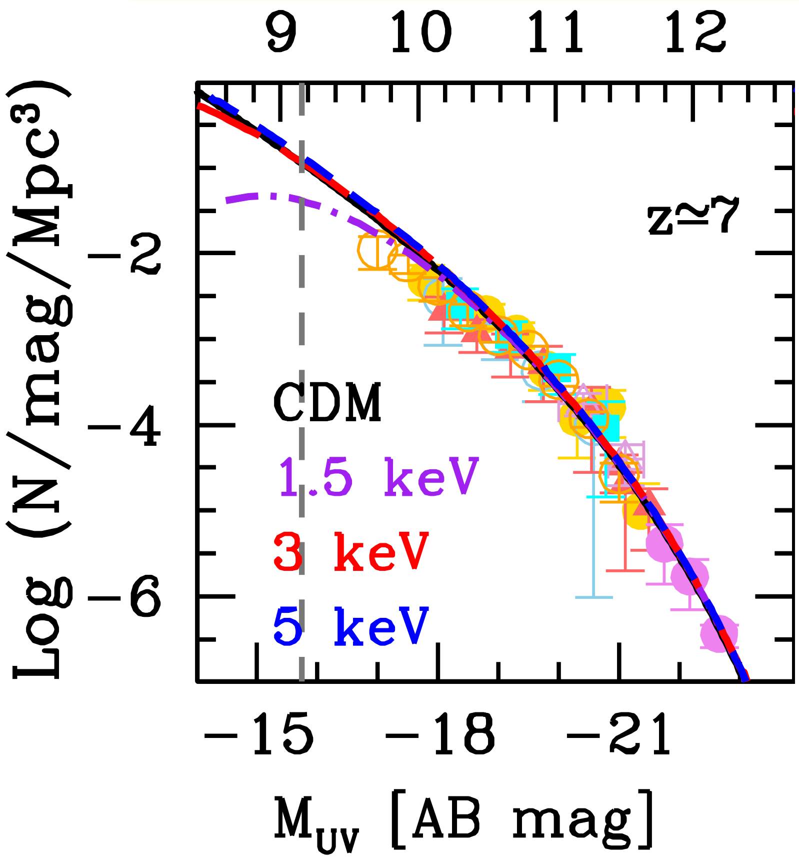
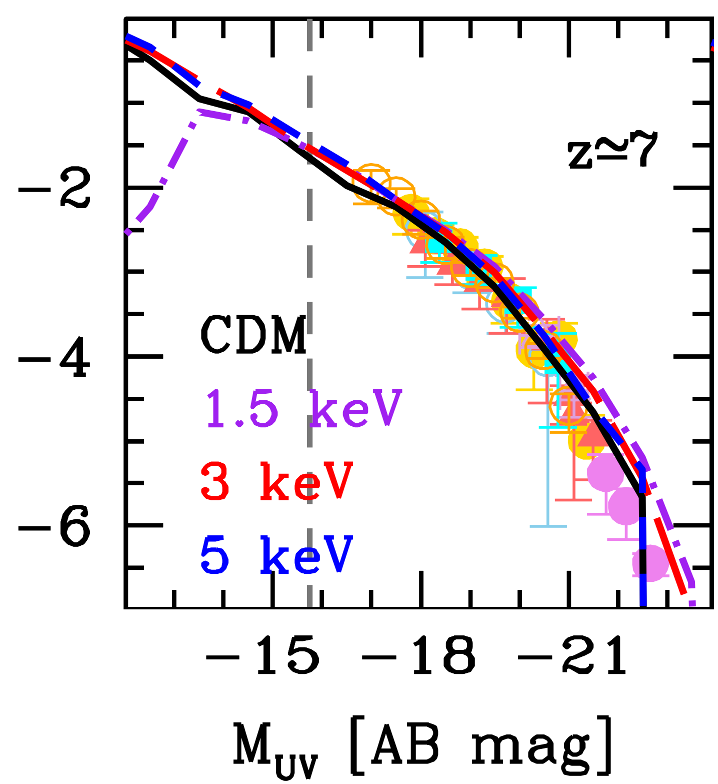


UV LFs in WDM

Scaling Halo mass function



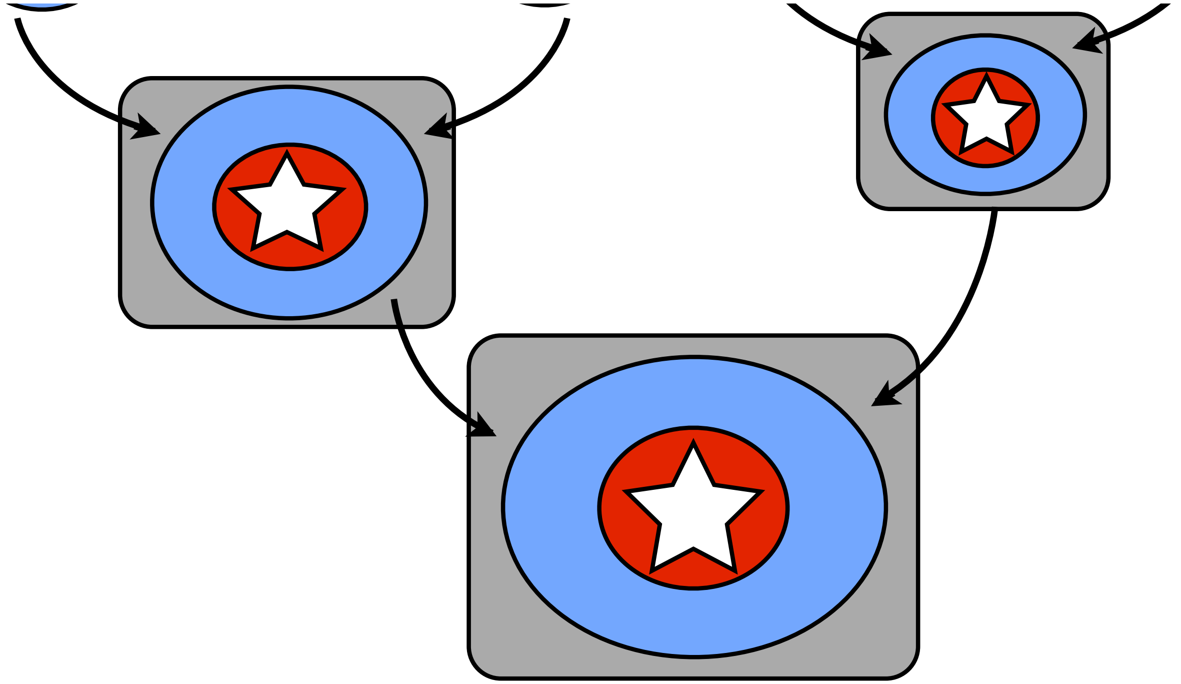
Fiducial model



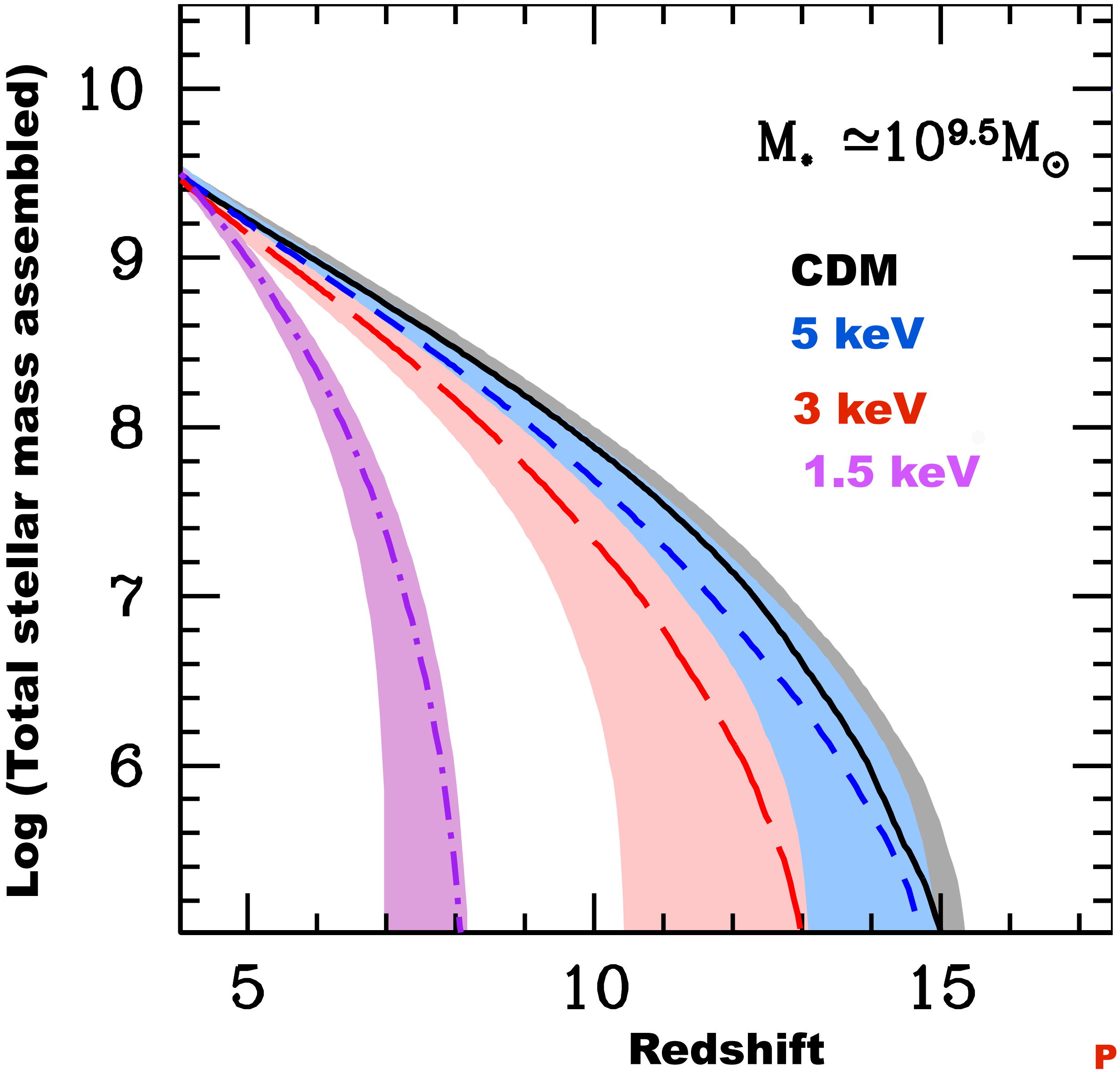
Including baryons (and SF) decreases the difference between CDM and 1.5 keV WDM models

PD, Mesinger & Pacucci, 2015

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



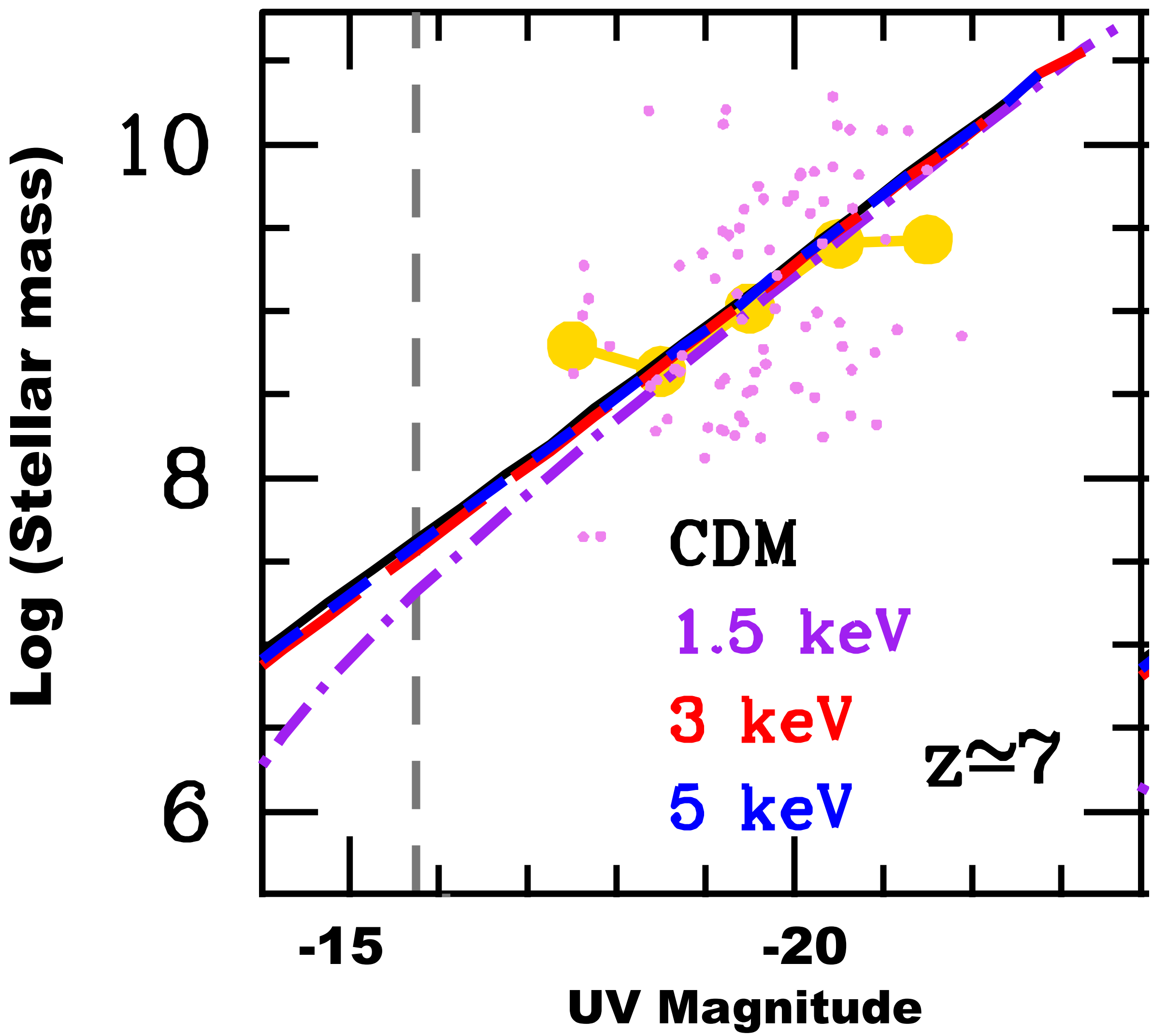
it leads to a delayed assembly of the stellar mass



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

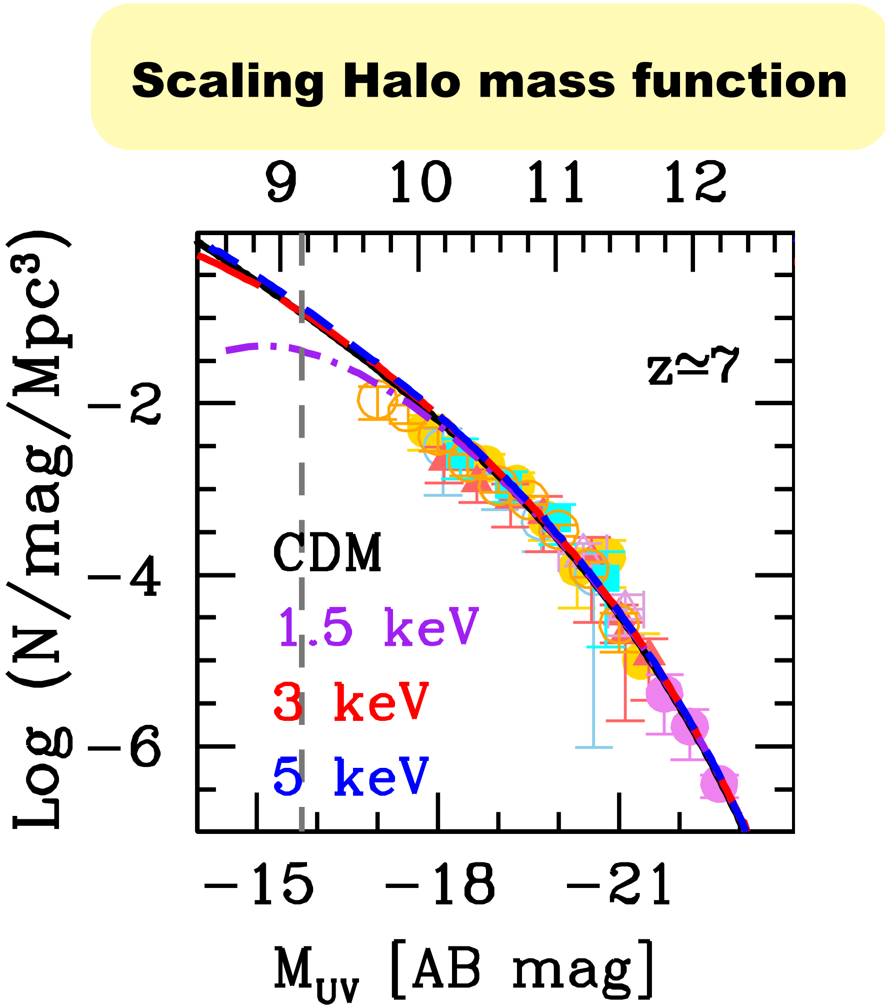
Mass-to-light ratios depend on cosmology!

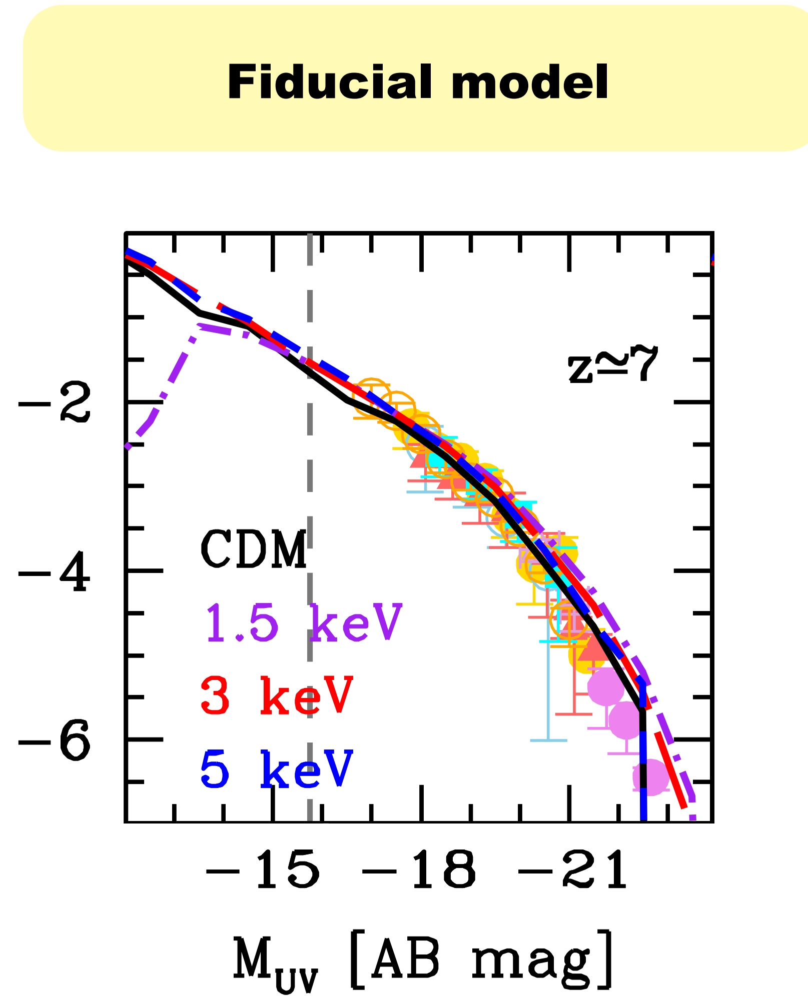


PD, Mesinger & Pacucci, 2015

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

UV LFs in WDM

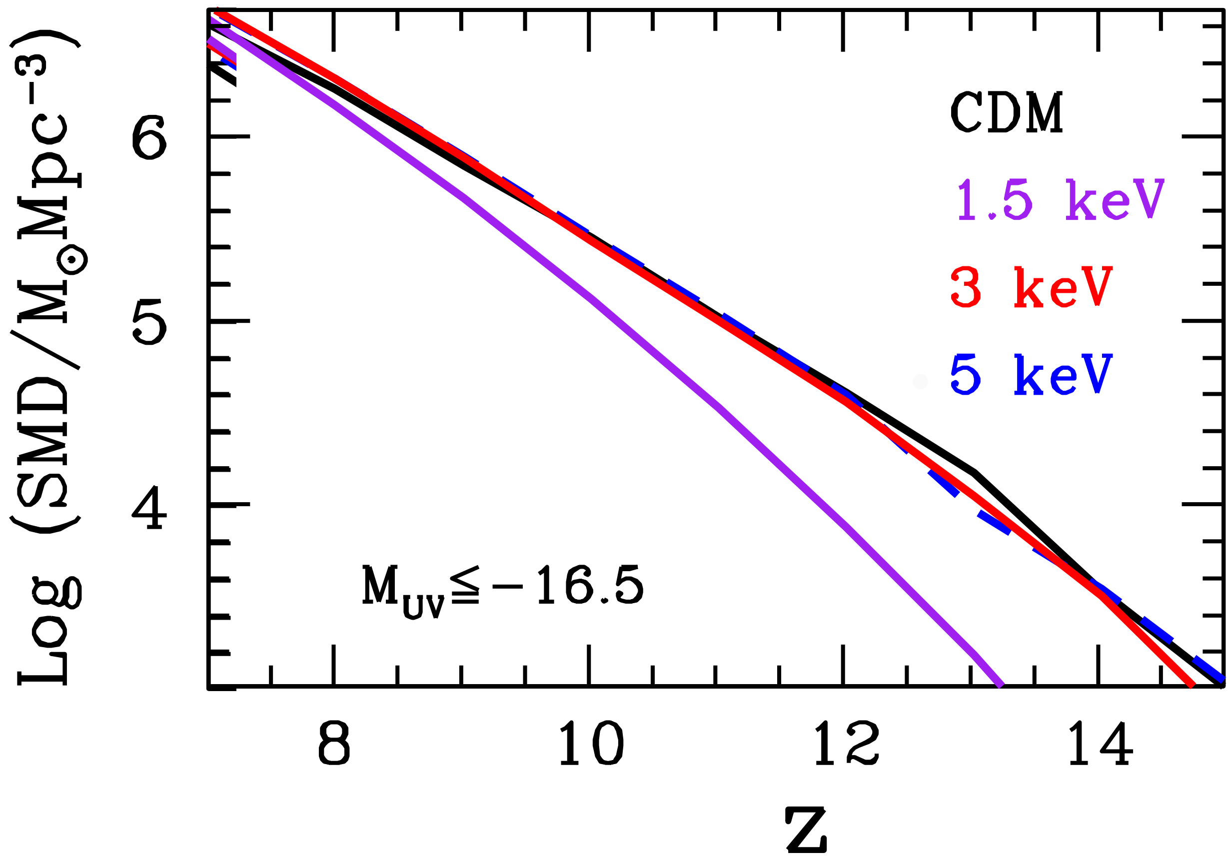




Including baryons (and SF) decreases the difference between CDM and 1.5 keV WDM models

PD, Mesinger & Pacucci, 2015

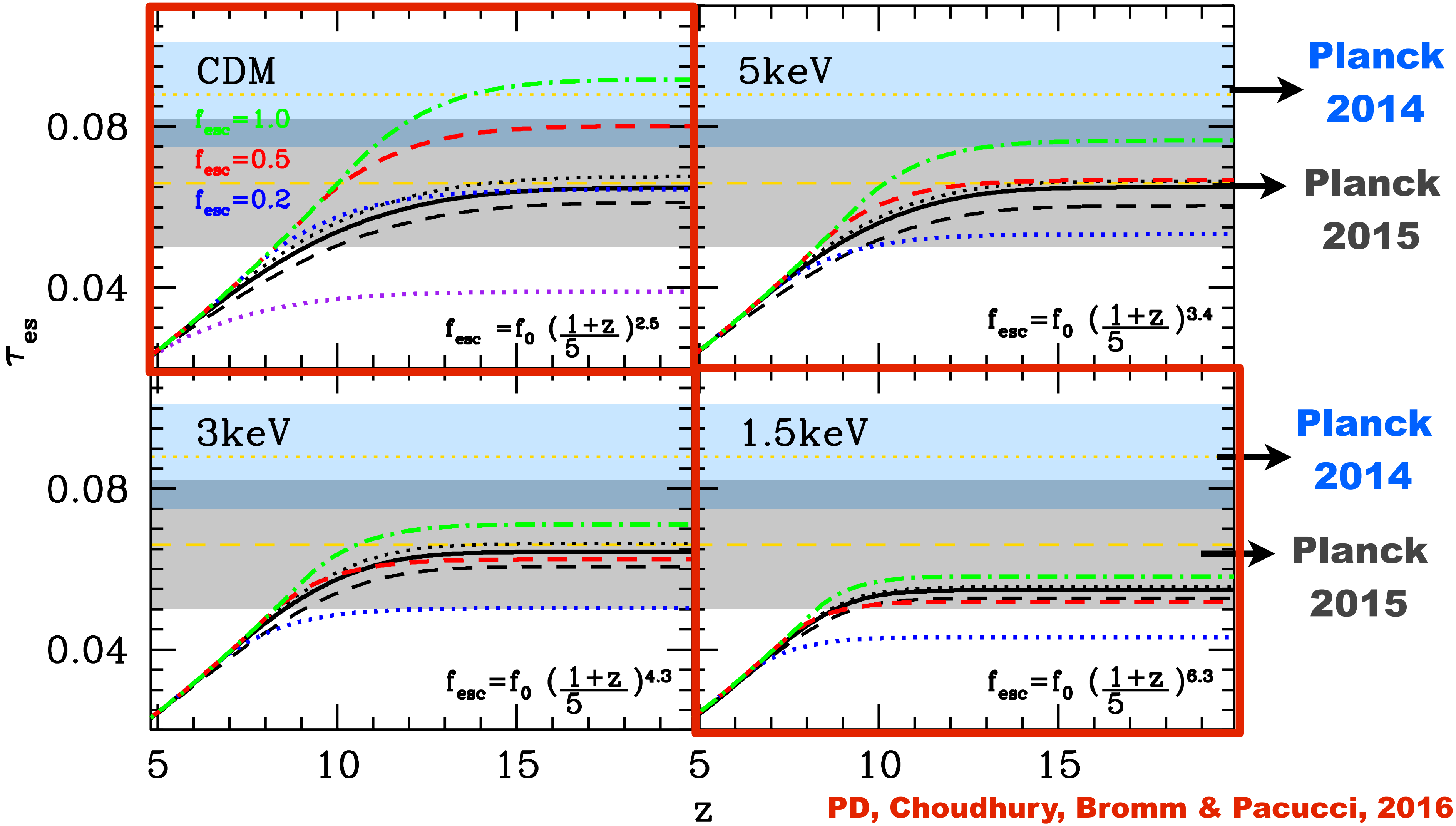
Observational imprints of light WDM particles: buildup of the cosmic stellar mass density



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

PD, Mesinger & Pacucci, 2015

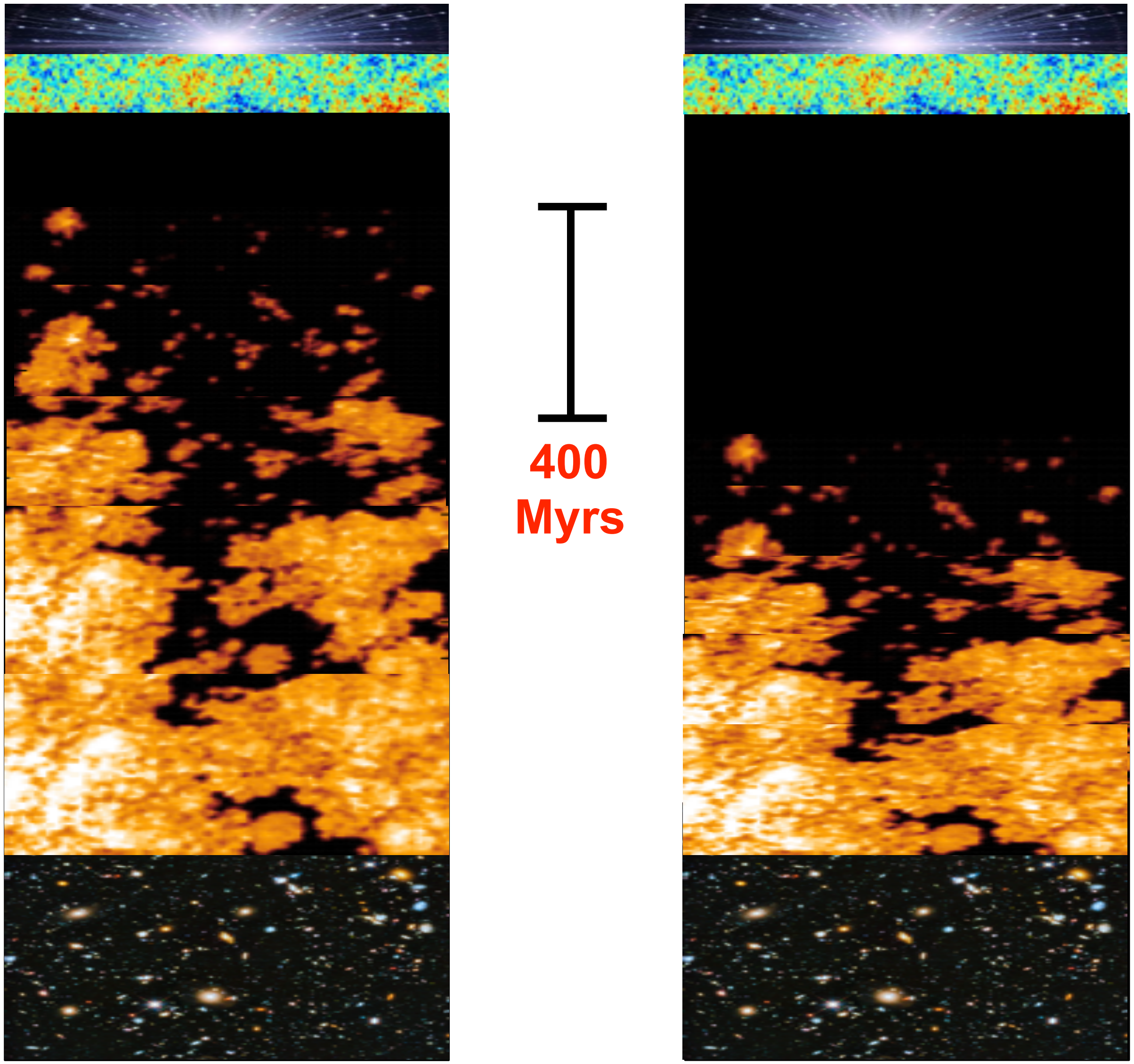
Reionization in different DM cosmologies



PD, Choudhury, Bromm & Pacucci, 2016

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

The future: 21cm emission in different cosmologies



Cold Dark Matter

Warm Dark Matter

The emerging picture..

- Huge increase in high-z LBG data has led to statistically robust evolving UV LF (slope steepens with redshift), mass to light ratios (slope of -0.38) and estimates of stellar mass density (currently detected LBGs only contain 10% of total).

- Gastrophysics depends on halo mass - self accretion (mergers) build up the gas mass for low mass (high mass) galaxies.

- Implementing the same baryonic physics, we find CDM and >3 keV WDM models to be indistinguishable. But the JWST can be used as a “DM-machine” - stellar mass density buildup with time can help distinguish lower mass (~1.5 keV) WDM.