جامعة نيويورك أبوظبي

NYU | ABU DHABI

Clues to dark matter from galaxies

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working with B. Stoychev, A. Macciò, A. Dutton, M. Blank

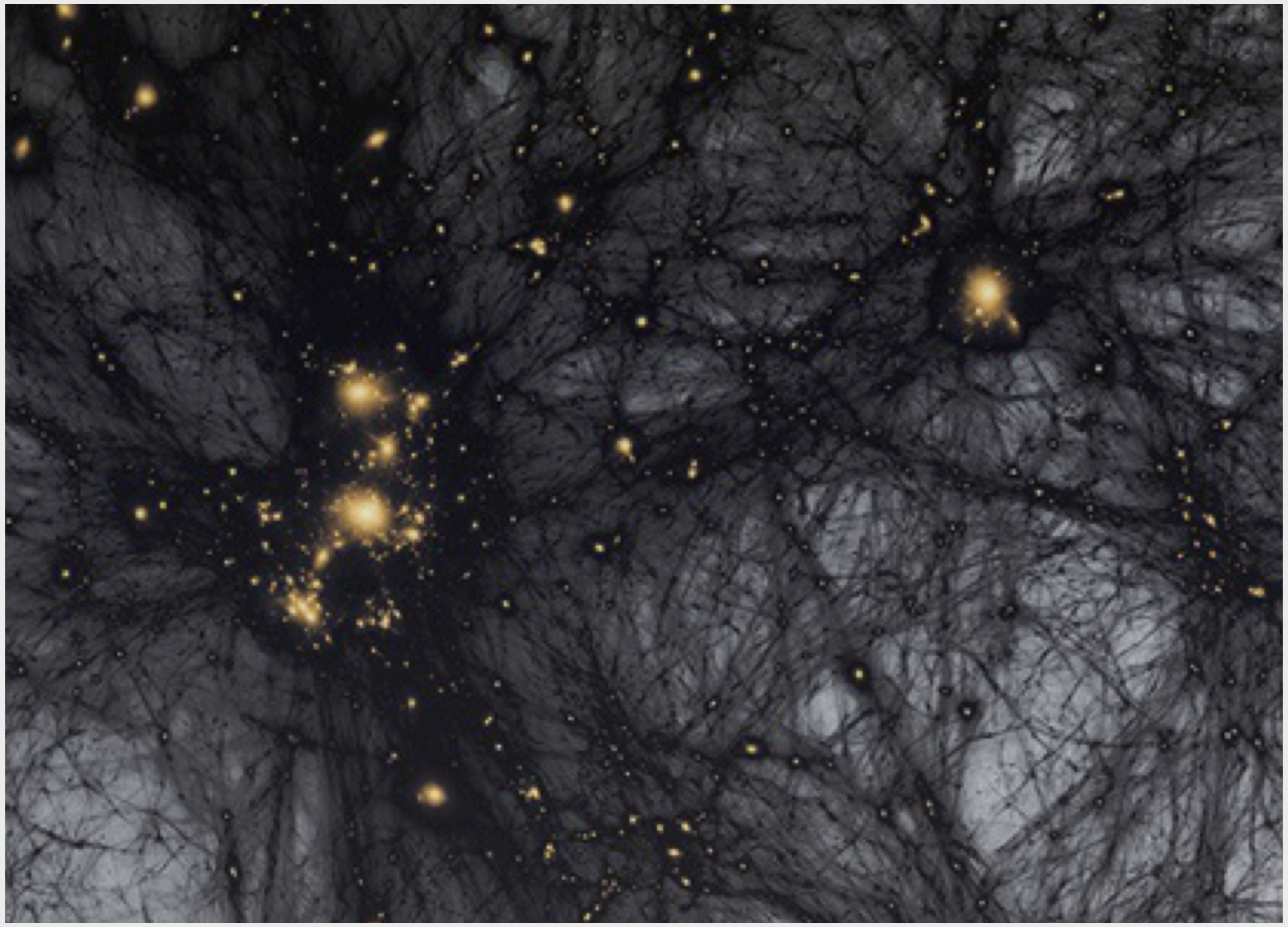
Shanghai meeting 2019

2019MNRAS.489..487S

Premise:

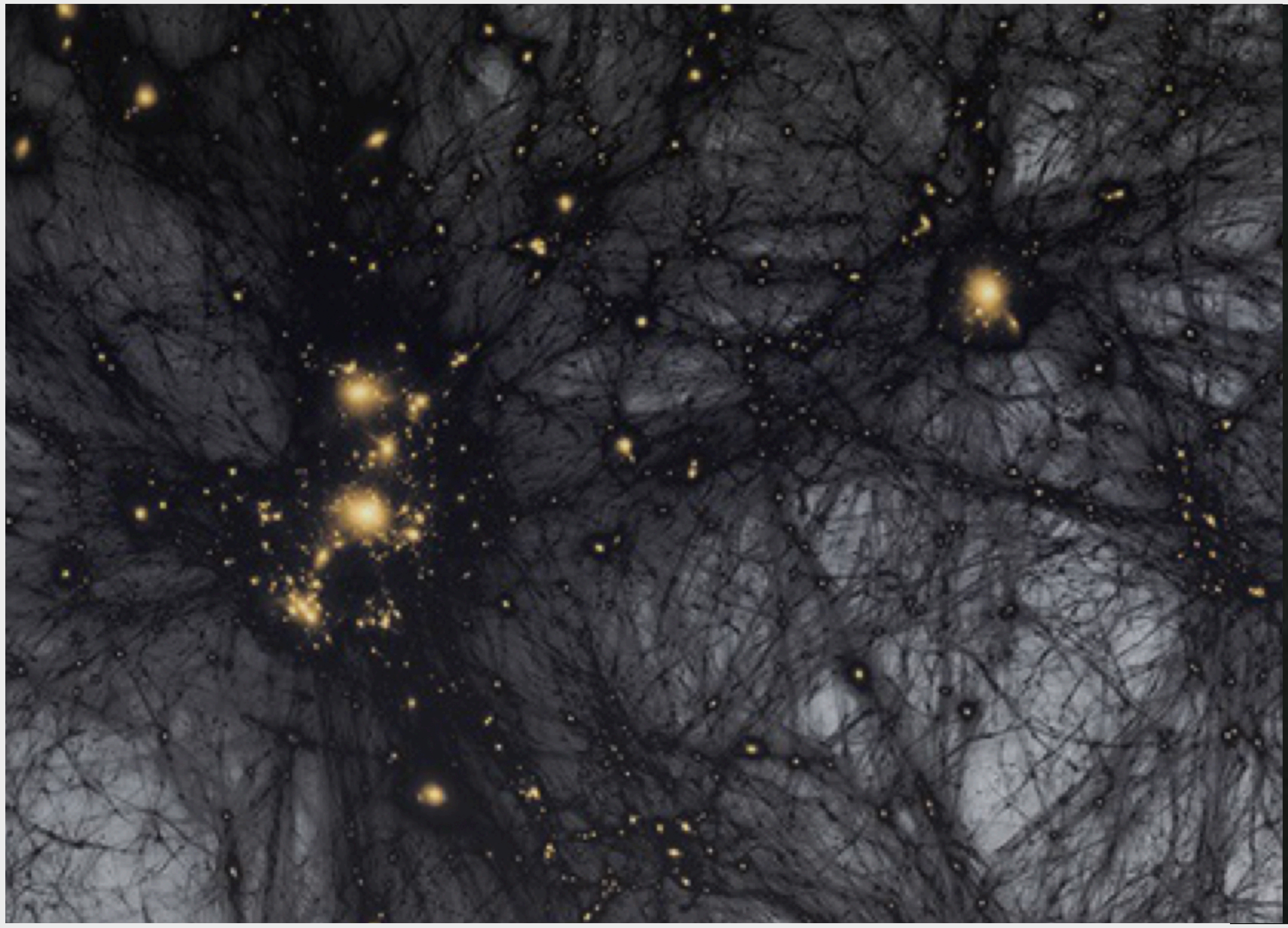
Cosmology and stars are linked

Start with dark matter and form halos



Credit: **Tom Abel & Ralf Kaehler**

Galaxies live there and can impact those halos



Credit: Tom Abel & Ralf Kaehler

Credit: NASA / ESA / Hubble / L. Ho

Cold

Warm

Fuzzy

Self-interacting

∞

Cold

Warm

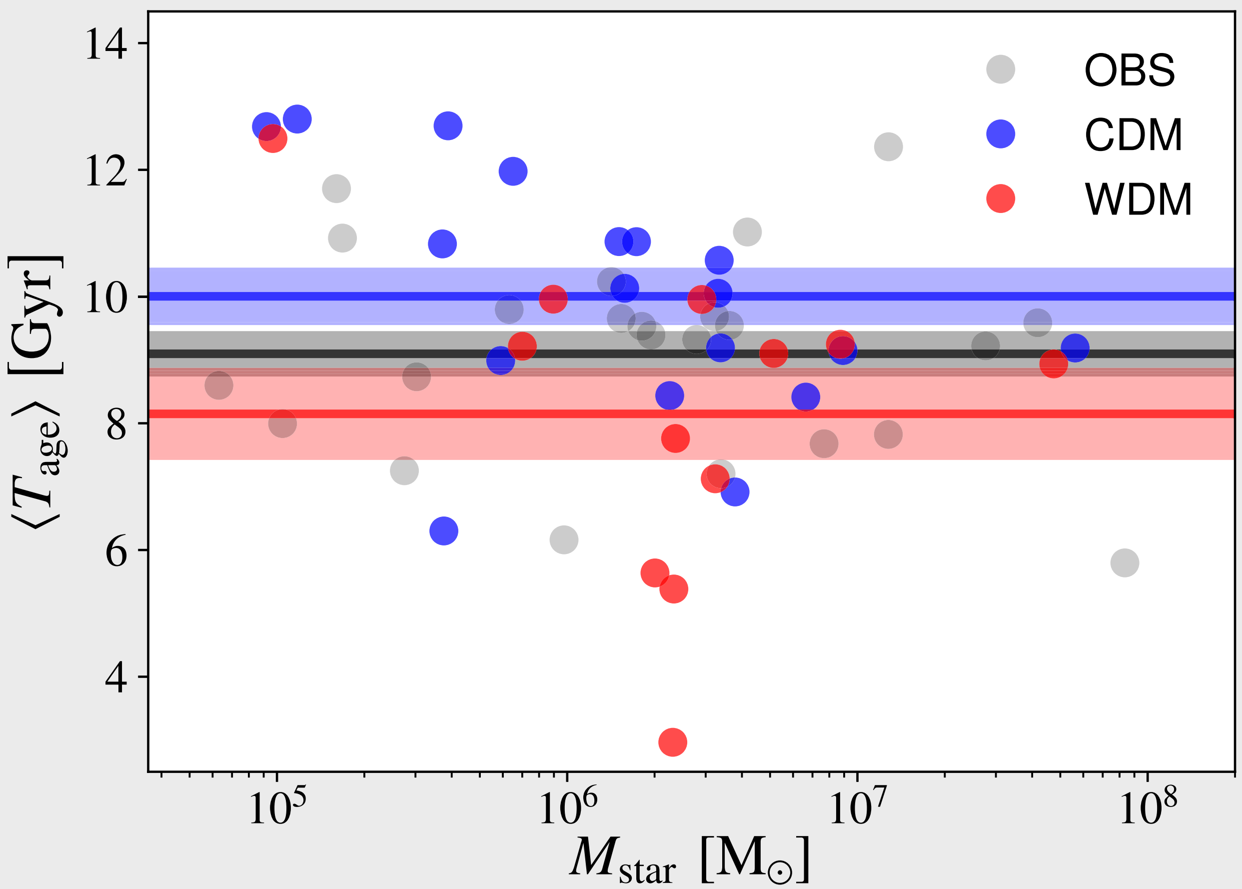
Fuzzy

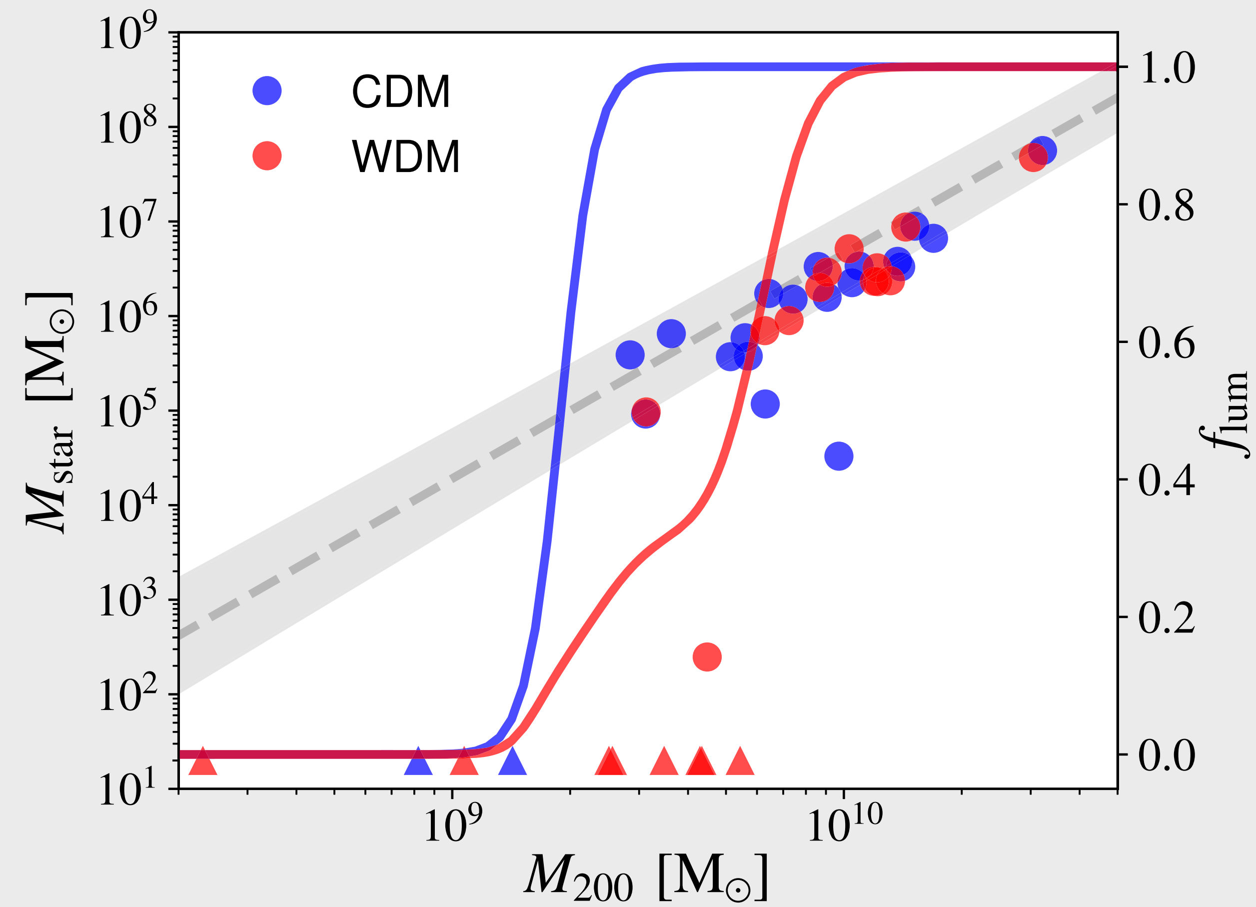
Self-interacting

∞


g1536 CDM 0.000 Gyr
g1536 5keV 0.000 Gyr
g1536 2keV 0.000 Gyr
g1536 1keV 0.000 Gyr

Tweeze out some differences





…even at z = 0 (Macciò, KLD, et al. 2019)

The **NIHAO** project

Numerical
Investigation (of)
Hundred
Astrophysical
Objects

你好

PI: A.V. Macciò (NYUAD)

Co-PI: A.A. Dutton, X. Kang

NIHAO members:
M. Blank (NYUAD),T. Buck (MPIA),
K.Dixon (NYUAD), A. Obreja(USM),
J.Chang (PMO), L. Wang (UWA),
J. Frings (MPIA), A. Di Cintio (AIP),
C. Brook (IAC)

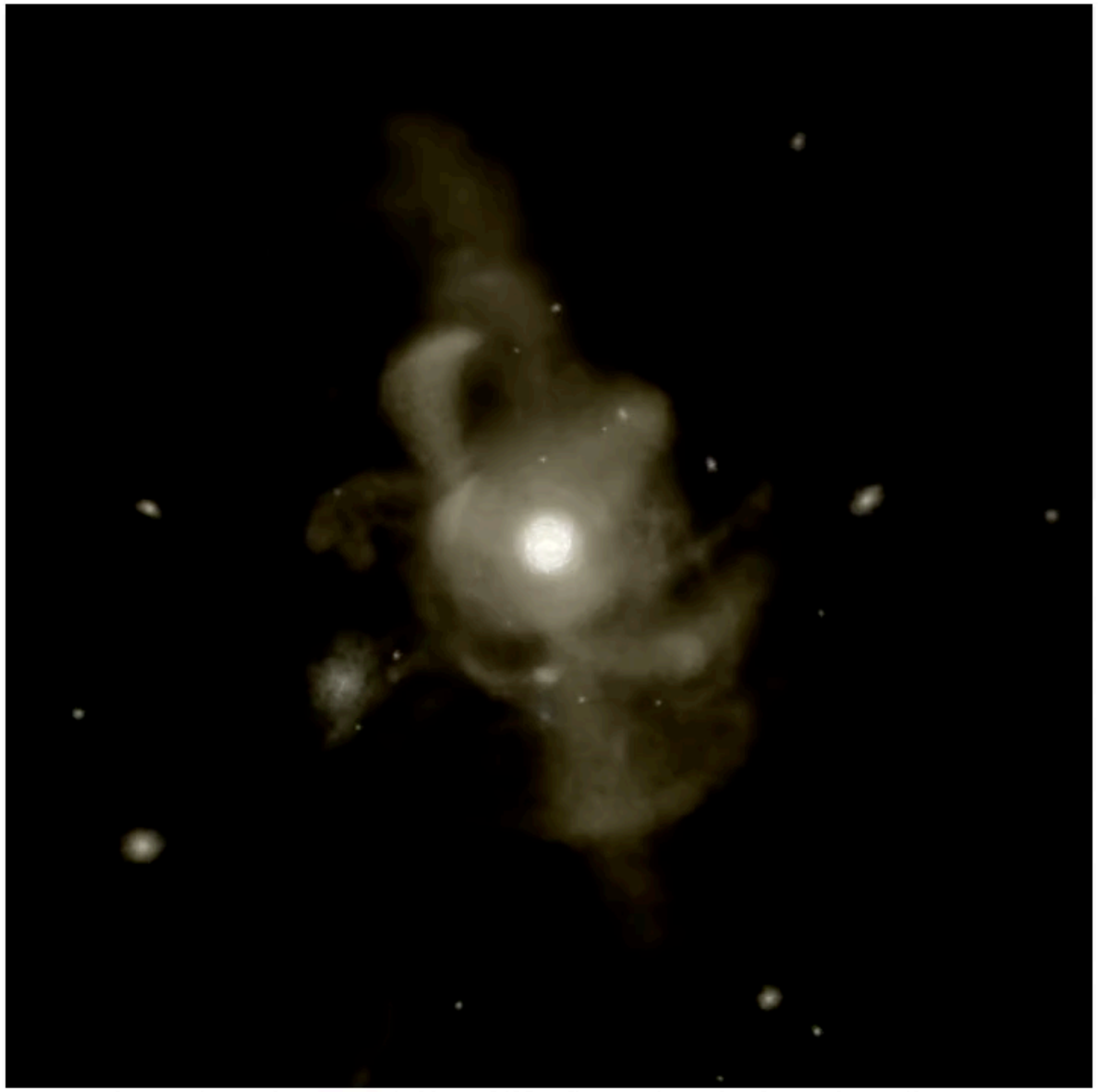
The NIHAO project

Largest database of high-res galaxies (172)
From tiny MW satellites to massive ellipticals

One million elements per galaxy
Able to resolve the galaxies internal regions

Code Gasoline2.0

- Cooling and star formation
- heavy elements production and enrichment
- SN feedback
- Massive stars feedback
- BH creation and accretion
- AGN feedback
- Local Photoionization feedback



Animation by T. Buck (MPIA, NYUAD) based on NIHAO simulations

Stoychev, KLD, et al. 2019

Use 19 zoom simulations in both CDM and 3 keV WDM

Include any galaxy with greater than 10,000 particles

Level	$m_{\rm DM}$	$m_{\rm gas}$	$\epsilon_{\rm DM}$	$\epsilon_{\rm gas}$
	$M_\odot$	$M_\odot$	pc	pc
1	1.95×10^3	3.56×10^2	63	27

Code Gasoline2.0

- Cooling and star formation
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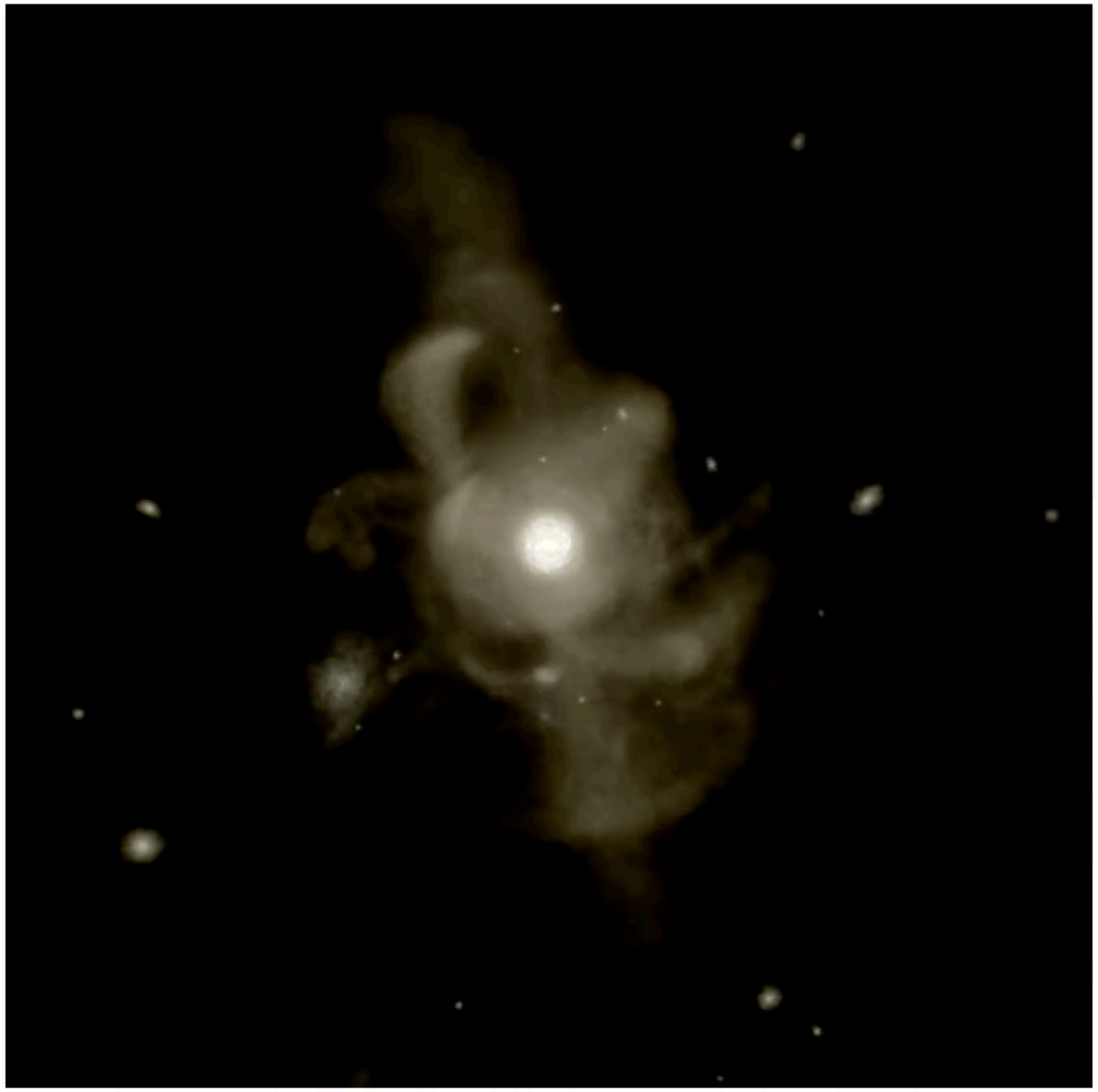
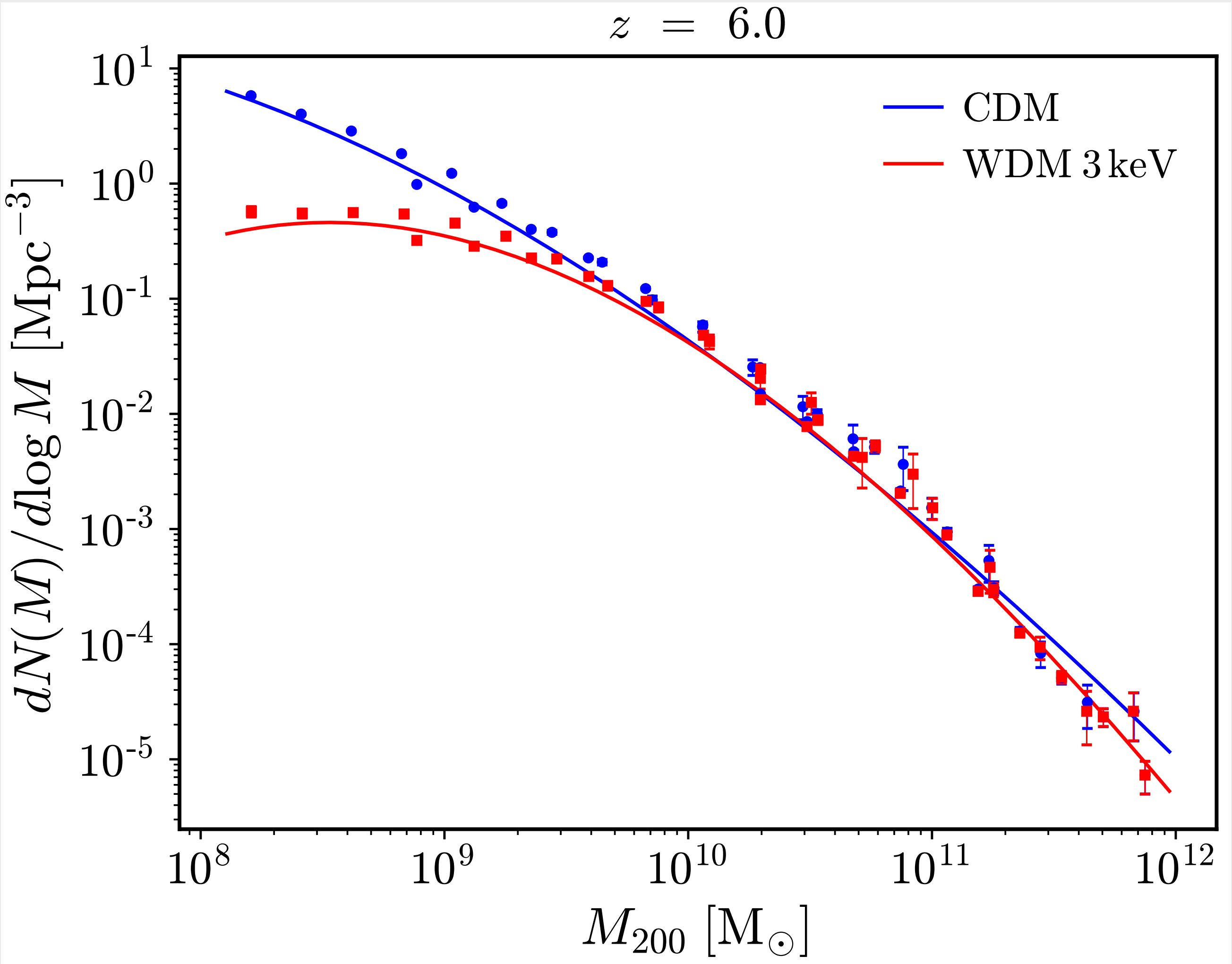

Animation by T. Buck (MPIA, NYUAD) based on NIHAO simulations

Using NIHAO to get the Universe:

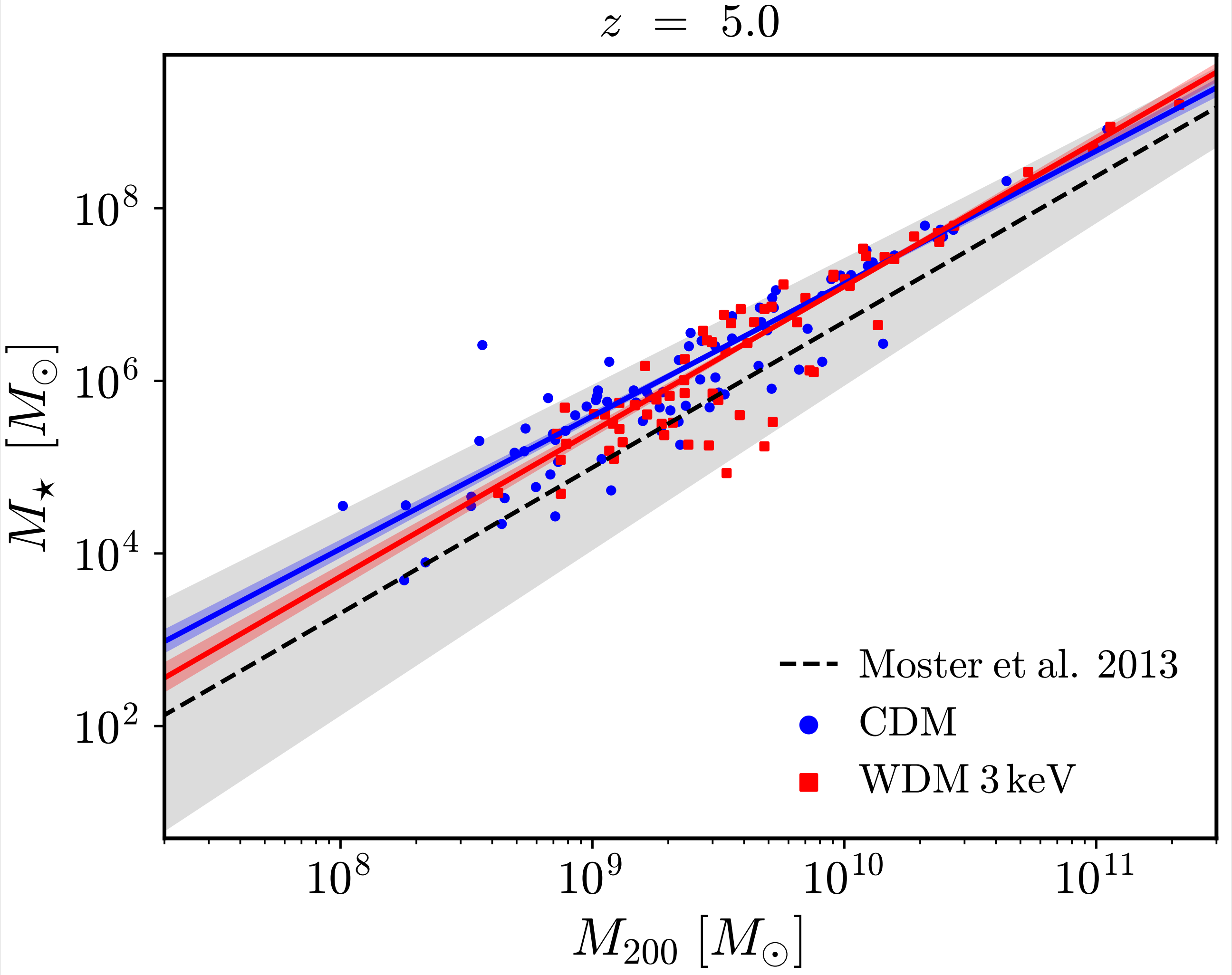
From DM to observed SFR

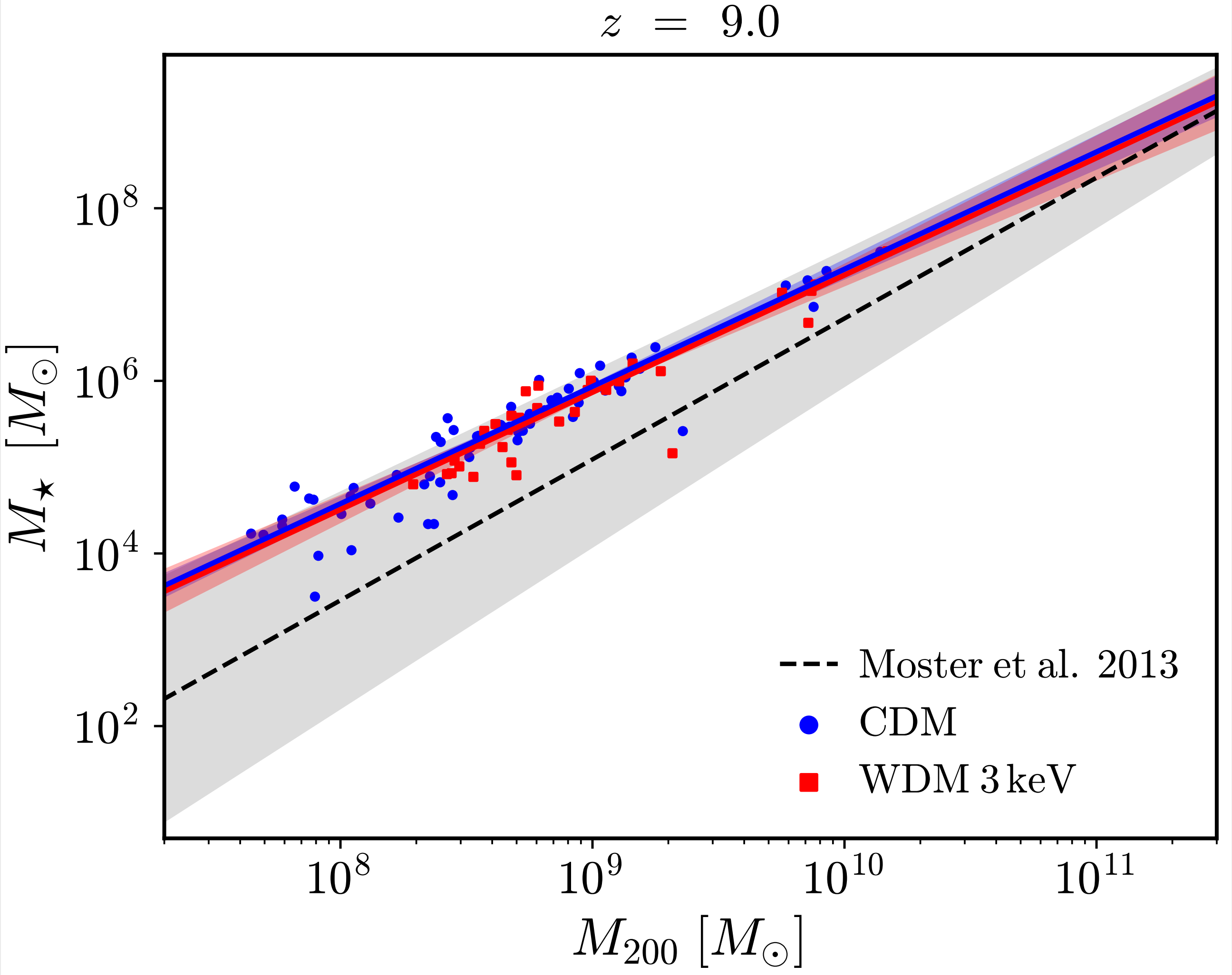
Halo mass functions from N-body



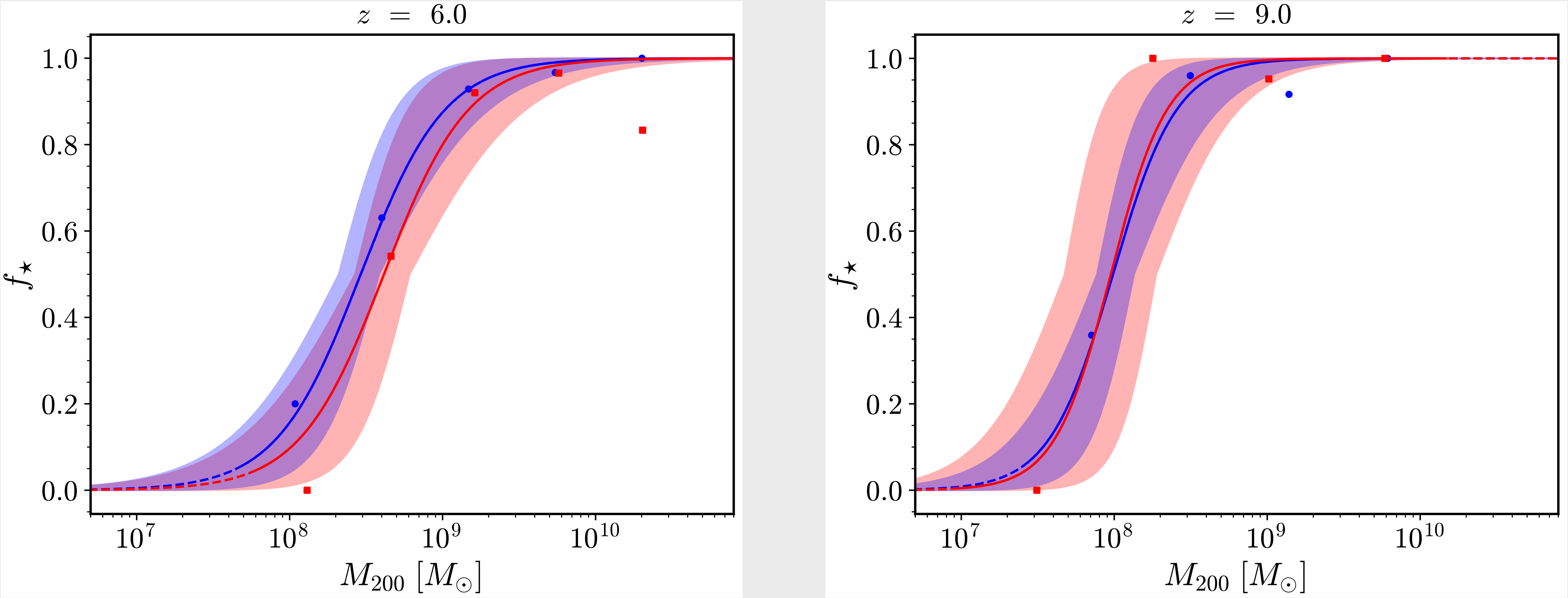
$$\log\left(\frac{dN}{d\log M}\right) = A - B\log M - C\mathrm{e}^{(M_0 - \log M)^{\alpha}}$$

M_*-$M_{\rm halo}$: by construction at z=0



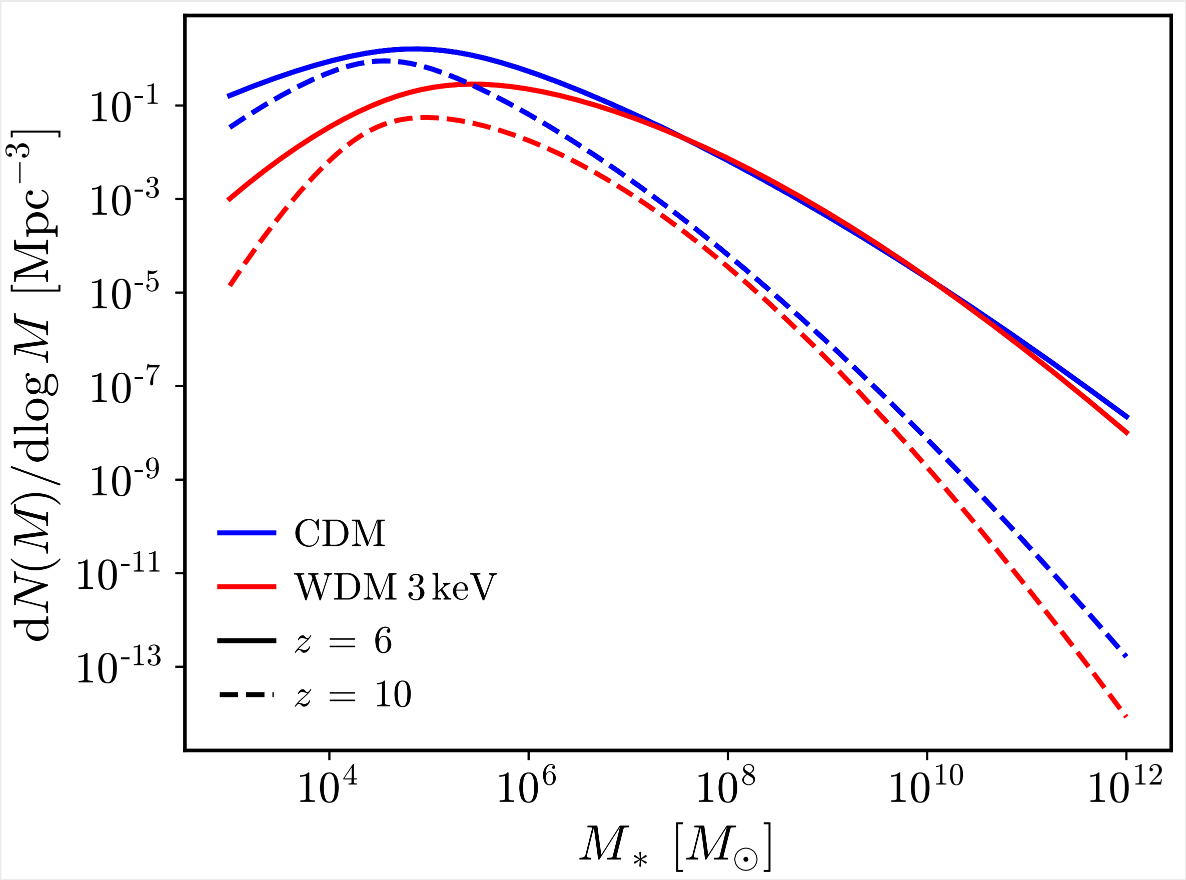


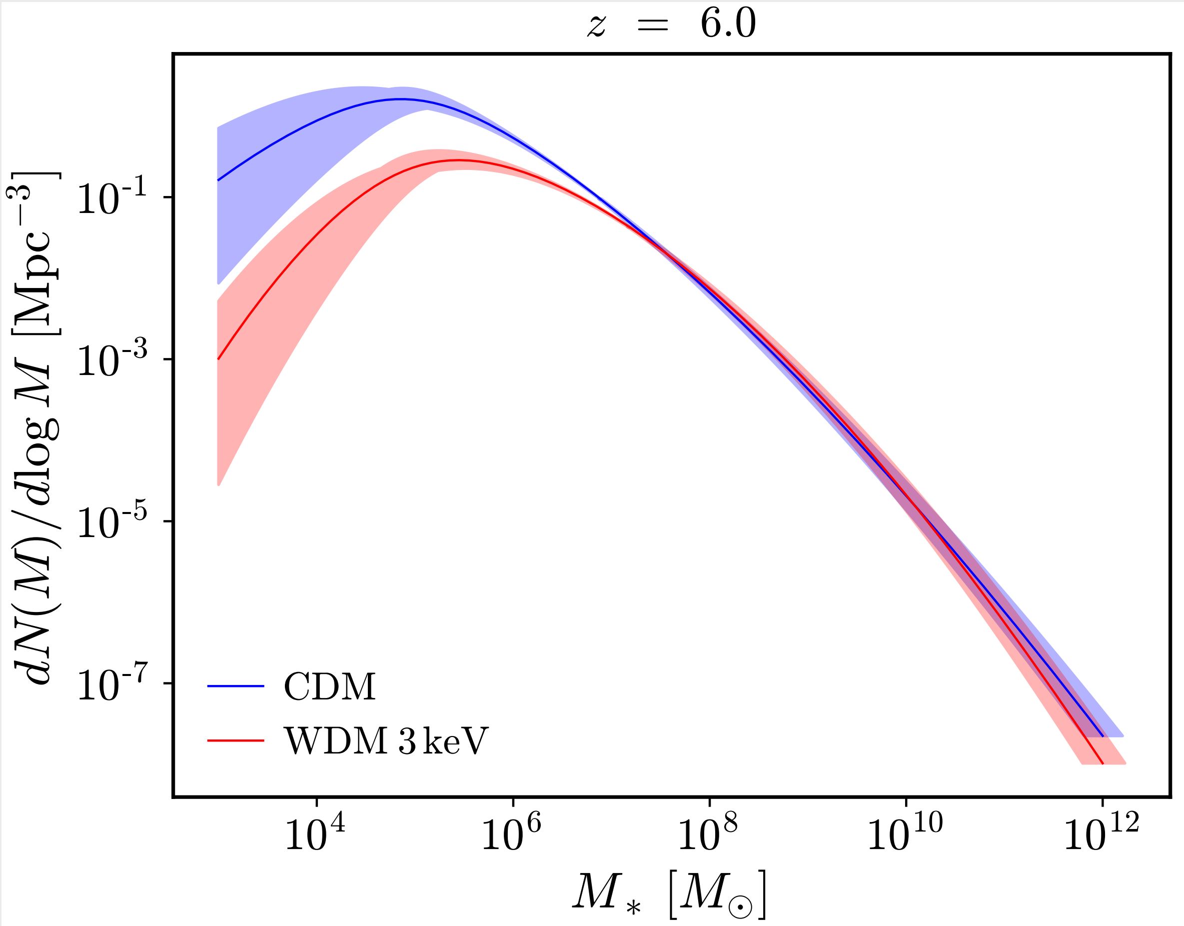
Dark fraction



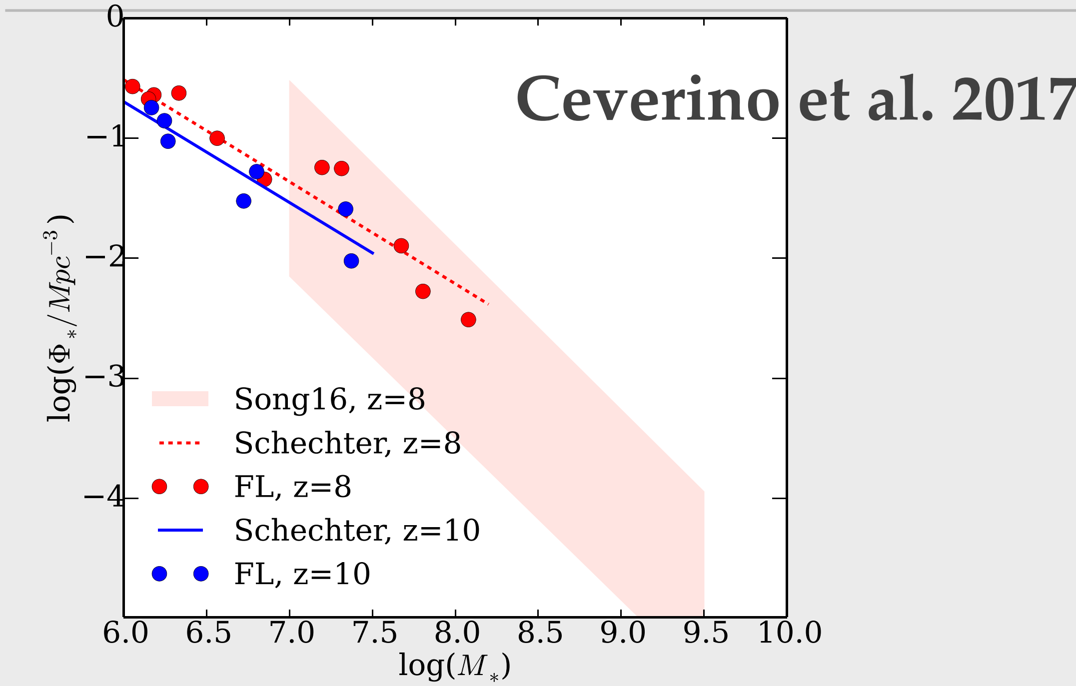
$$f_\star = \frac{1 + \tanh\left[\,\beta(\log M - M_1)\right]}{2}$$

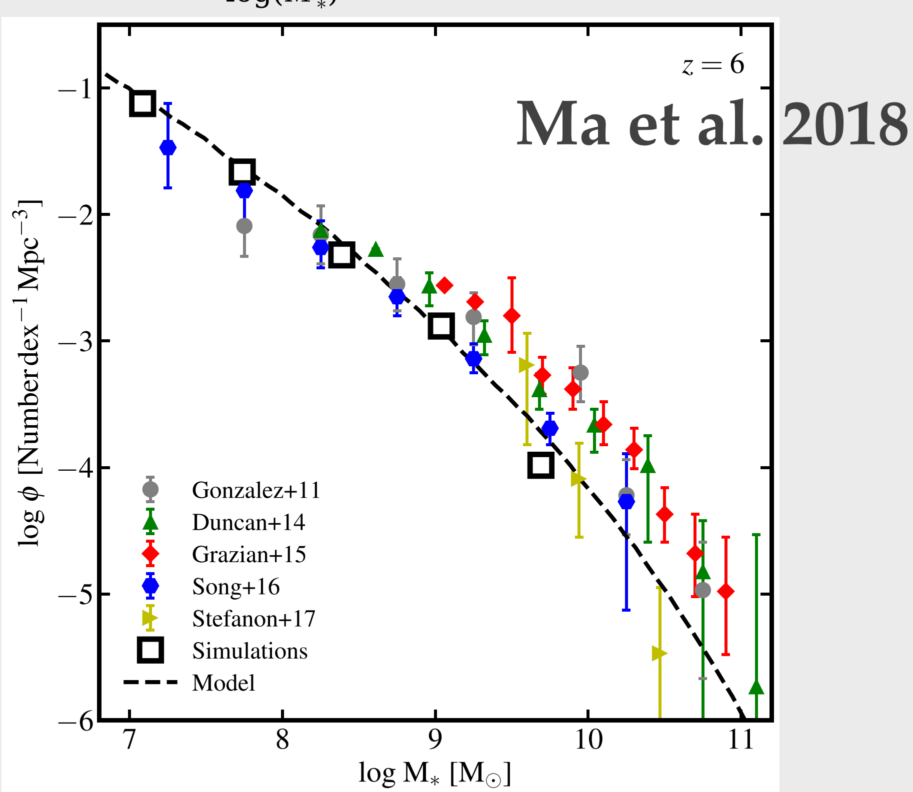
Stellar mass functions

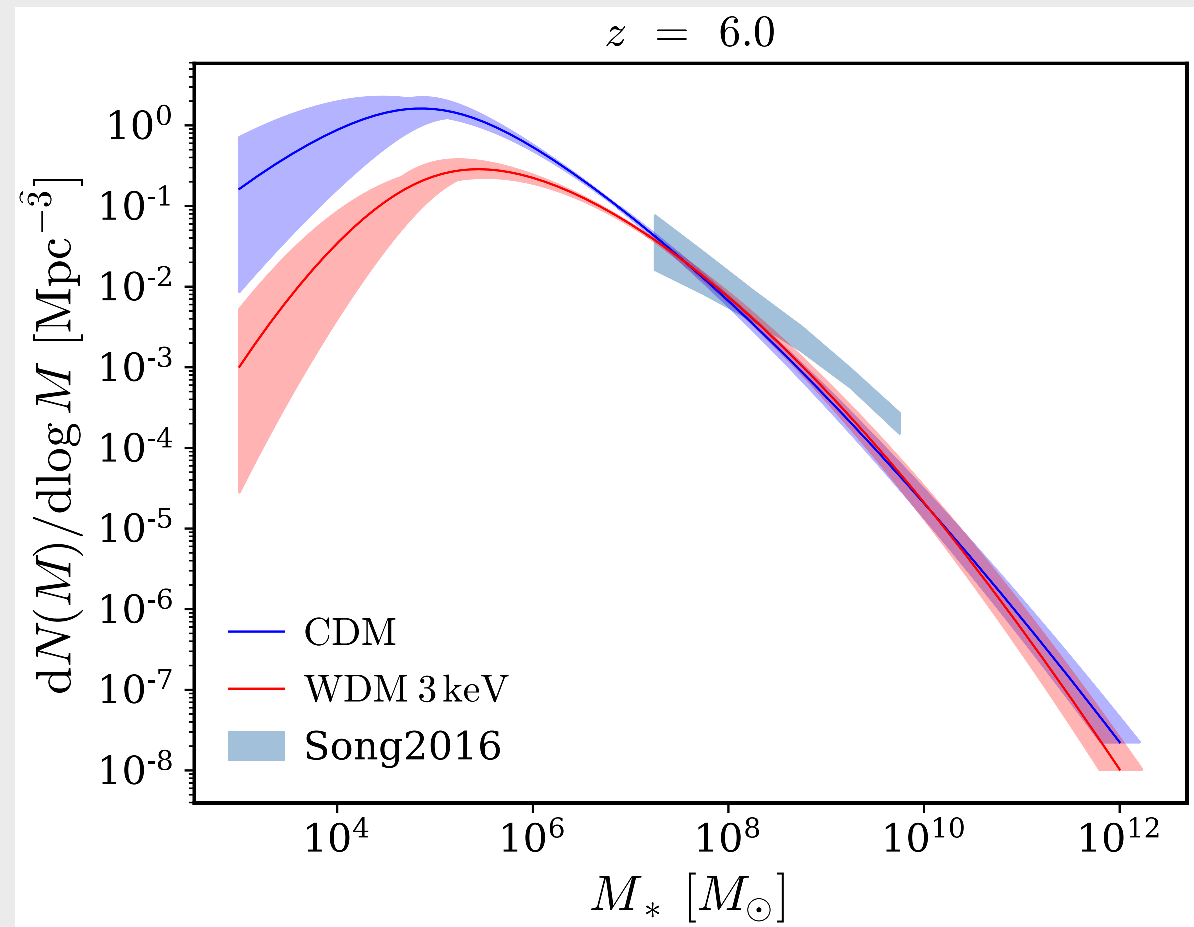




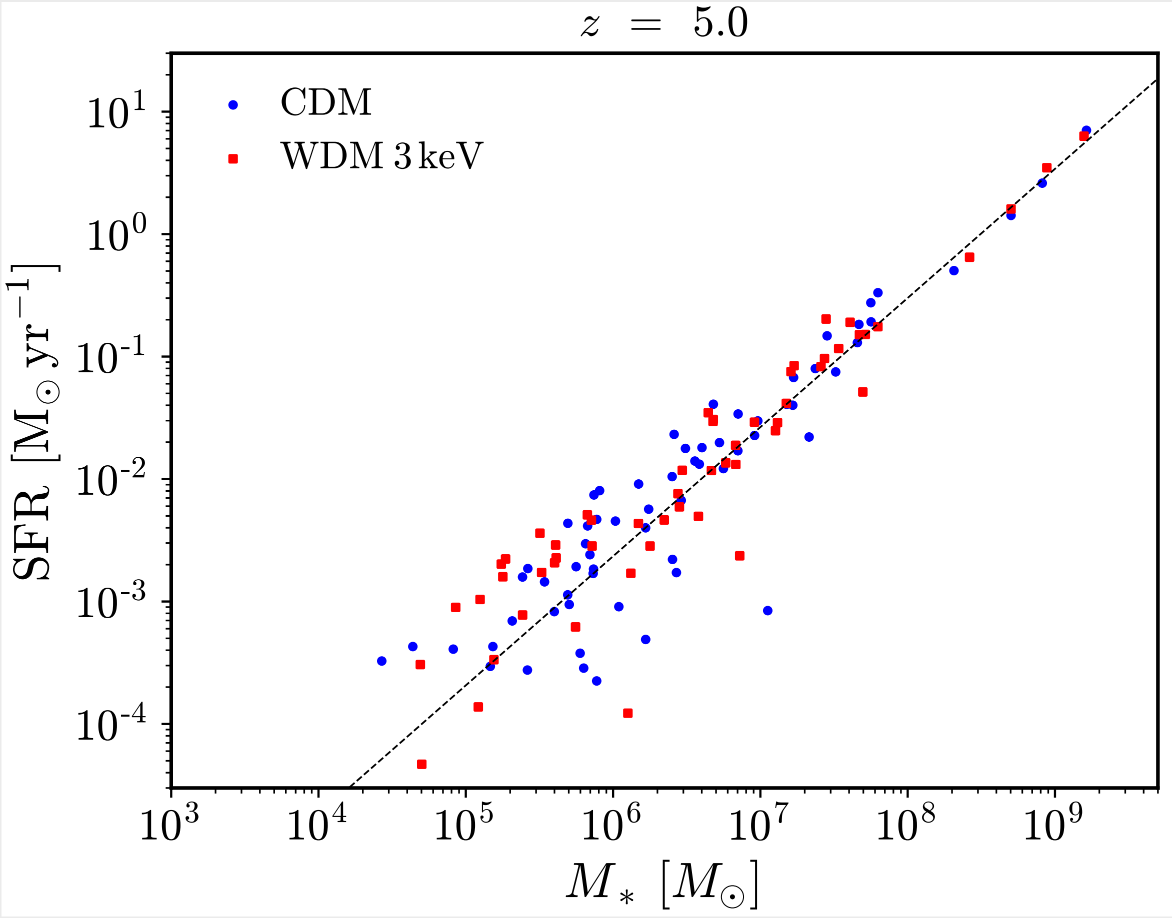
Stellar mass functions

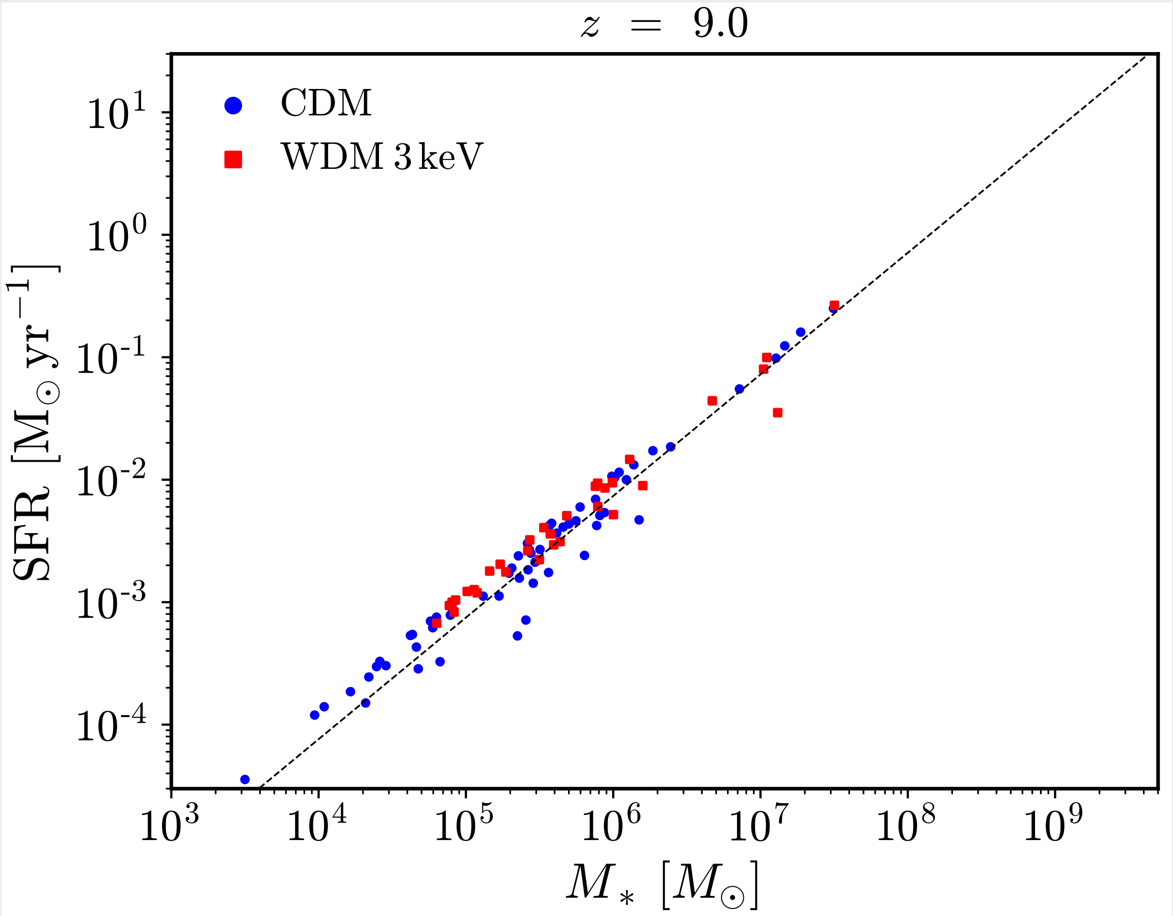






SFR-M* relation





Find some redshift dependence in the intercept, but not the slope

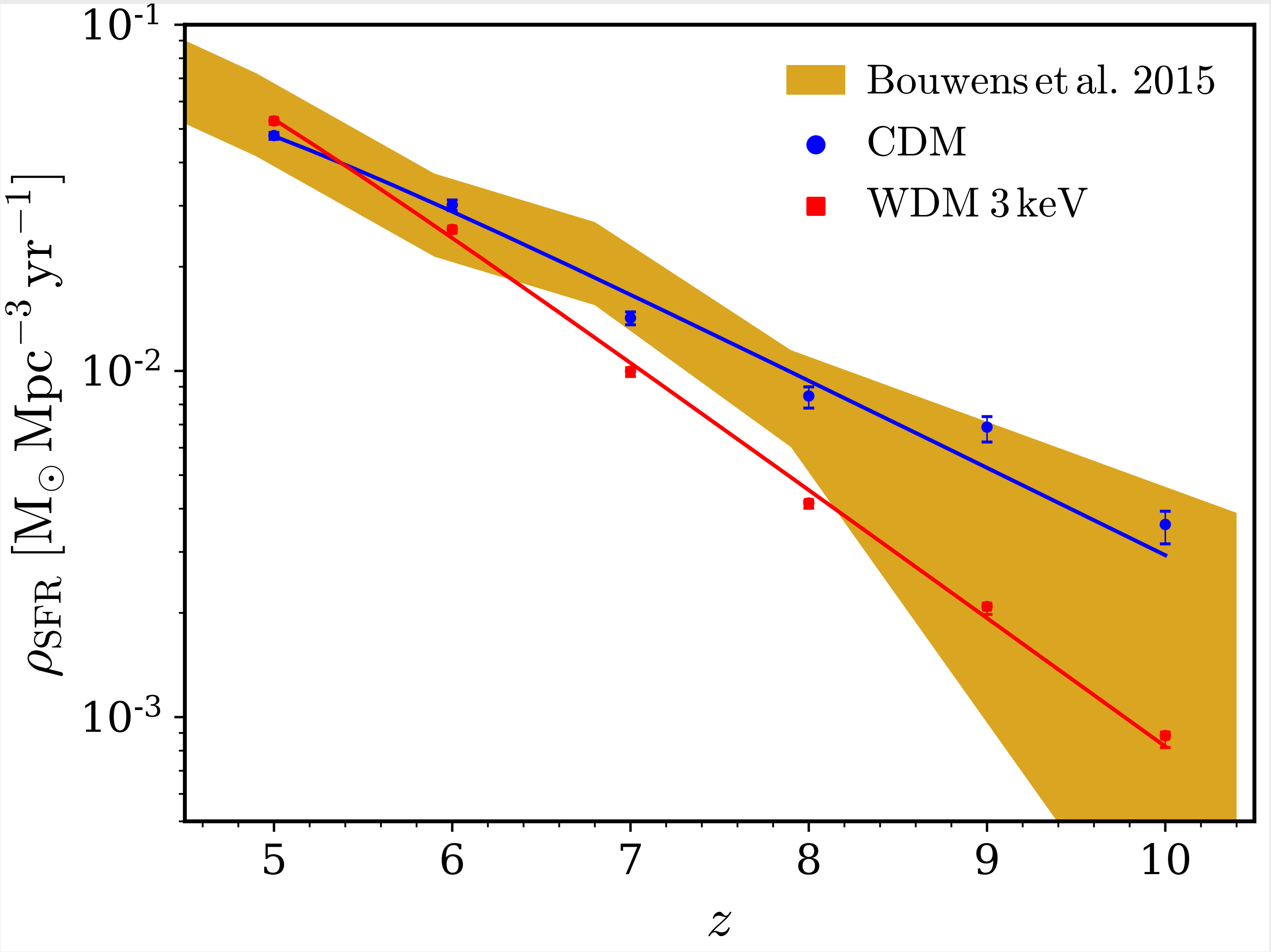
…though see Ma et al. 2018

Convolve everything together:

Plus some reionization

Star formation rate density

$$\log\left(\frac{\rho_{\rm SFR}(z)}{\mathrm{M_\odot\,Mpc^{-3}\,yr^{-1}}}\right) = \kappa - \lambda z - \mu e^{z_0 - z}$$



WDM and CDM converge at $z = 5$

CDM arguably performs better

First-order reionization

Boundary conditions:

Fully ionized at $z = 6$
10% ionized at $z = 10$

$$\dot{Q}_{\rm H\,II} = \frac{\dot{n}_{\rm ion}}{\langle n_{\rm H} \rangle} - \frac{Q_{\rm H\,II}}{t_{\rm rec}}$$

Assumptions:

Consistent ionizing efficiency
Clumping factor of 3
Halo-independent escape fraction

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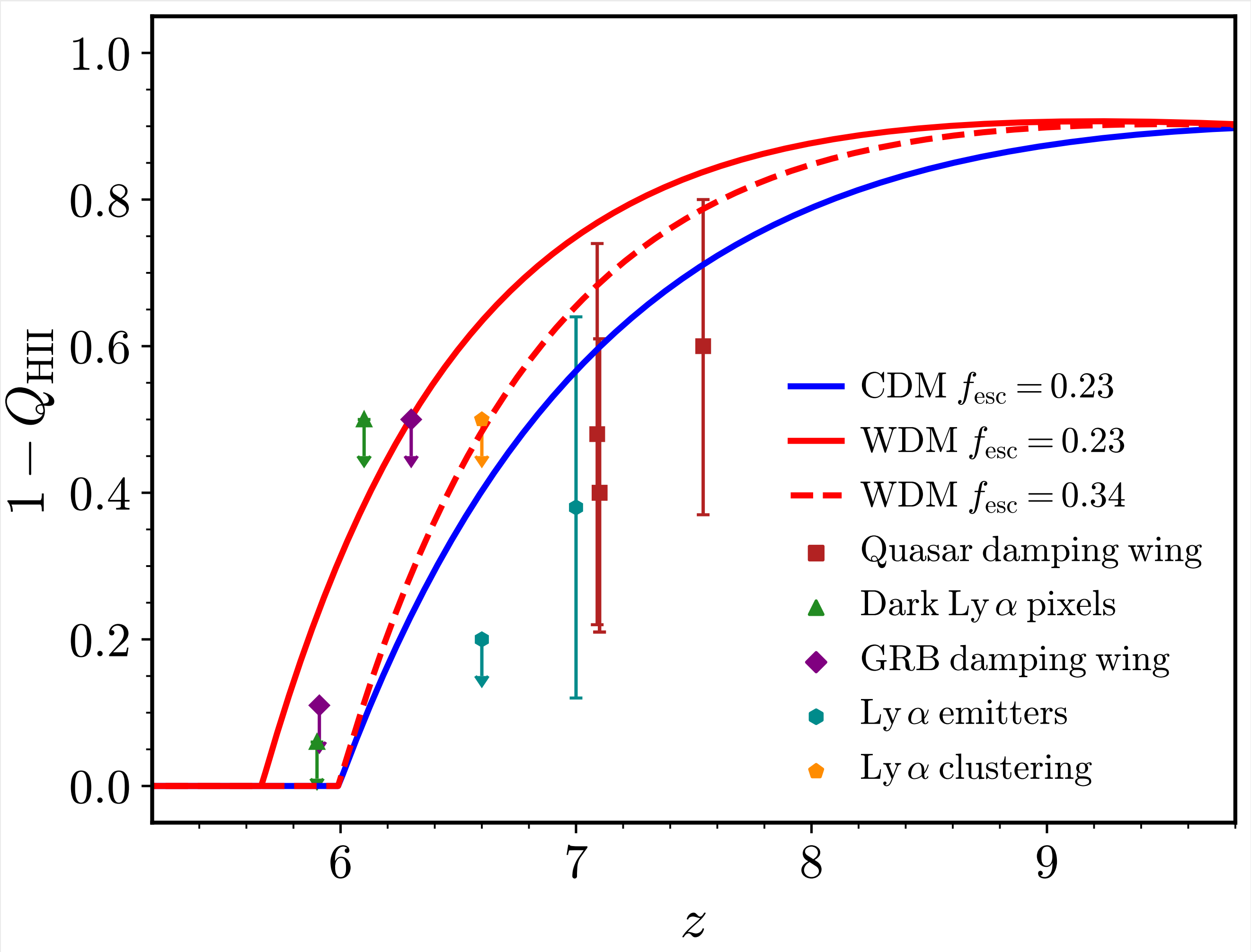
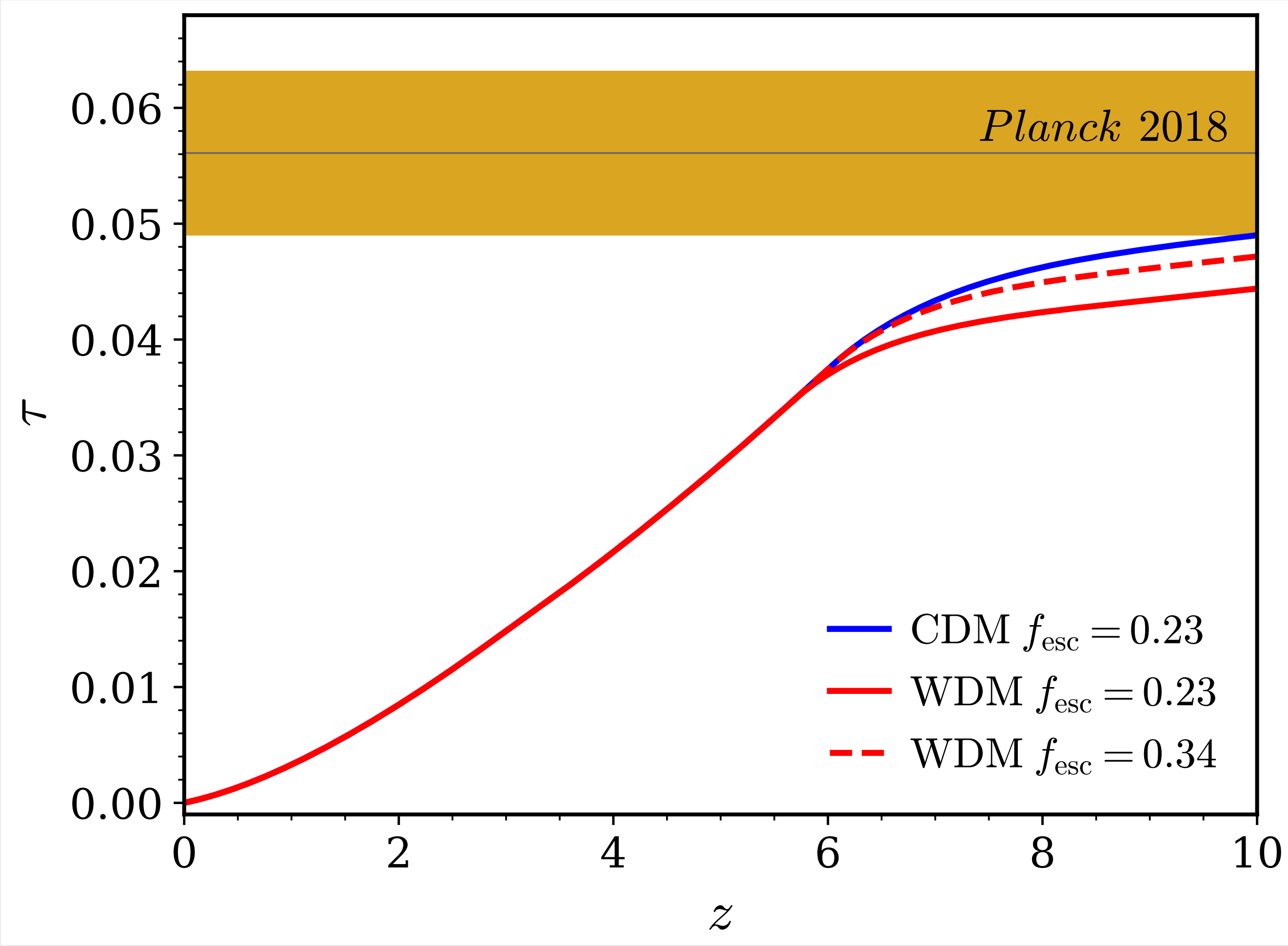
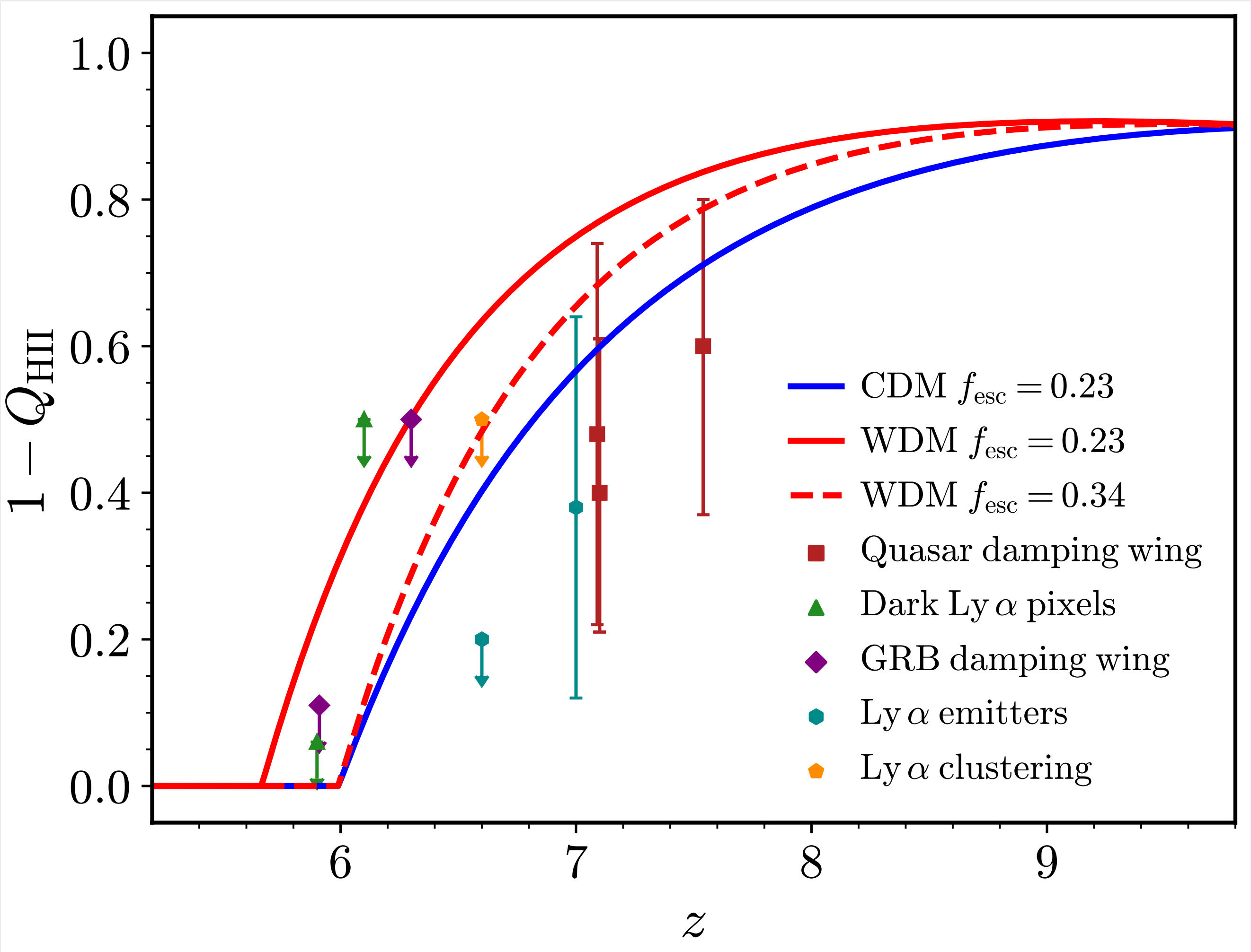


First-order reionization





Bonus info for homework!

z	Cosmology	A	B	C	M_0	α
5	CDM	52.93	3.641	15.31	11.05	0.1315
	WDM	48.99	3.863	16.06	8.574	0.2371
6	CDM	53.23	3.851	17.12	9.568	0.1462
	WDM	53.60	4.331	14.72	9.092	0.2569
7	CDM	47.86	3.819	14.86	8.572	0.1862
	WDM	62.80	5.0117	17.48	9.201	0.2411
8	CDM	54.53	4.338	16.04	8.975	0.1837
	WDM	60.06	4.987	14.13	9.495	0.2628
9	CDM	51.62	4.274	15.18	8.557	0.1963
	WDM	58.73	4.960	15.83	8.878	0.2616
10	CDM	54.11	4.652	11.09	9.837	0.2199
	WDM	65.11	5.537	21.02	8.175	0.2643

Table A1. Best-fitting parameter values for halo mass functions.

z	Cosmology	slope	intercept
5	CDM	$1.536^{+0.049}_{-0.051}$	$-8.24^{+0.50}_{-0.47}$
	WDM	$1.683^{+0.058}_{-0.062}$	$-9.73^{+0.61}_{-0.58}$
6	CDM	$1.490^{+0.050}_{-0.052}$	$-7.67^{+0.50}_{-0.47}$
	WDM	$1.621^{+0.065}_{-0.070}$	$-9.01^{+0.67}_{-0.63}$
7	CDM	$1.448^{+0.056}_{-0.060}$	$-7.25^{+0.56}_{-0.51}$
	WDM	$1.483^{+0.078}_{-0.082}$	$-7.61^{+0.78}_{-0.74}$
8	CDM	$1.358^{+0.064}_{-0.069}$	$-6.37^{+0.62}_{-0.58}$
	WDM	$1.444^{+0.094}_{-0.100}$	$-7.23^{+0.93}_{-0.87}$
9	CDM	$1.354^{+0.078}_{-0.083}$	$-6.25^{+0.73}_{-0.96}$
	WDM	$1.350^{+0.13}_{-0.13}$	$-6.28^{+1.21}_{-1.16}$
10	CDM	$1.43^{+0.11}_{-0.12}$	$-6.96^{+1.06}_{-0.99}$
	WDM	$1.41^{+0.19}_{-0.20}$	$-6.89^{+1.81}_{-1.71}$

Table A2. The median parameter values, including the 1σ uncertainties, derived from the MCMC sample for the $M_\star$-M_{200} relation in log-log space.

z	Cosmology	β	M_1
5	CDM	$1.45^{+0.63}_{-0.32}$	$-8.73^{+0.16}_{-0.17}$
	WDM	$1.64^{+1.04}_{-0.47}$	$-8.96^{+0.19}_{-0.17}$
6	CDM	$1.82^{+0.88}_{-0.42}$	$-8.46^{+0.15}_{-0.12}$
	WDM	$1.82^{+1.05}_{-0.50}$	$-8.62^{+0.19}_{-0.16}$
7	CDM	$2.02^{+0.96}_{-0.48}$	$-8.35^{+0.14}_{-0.12}$
	WDM	$2.08^{+1.22}_{-0.62}$	$-8.59^{+0.22}_{-0.16}$
8	CDM	$2.43^{+1.15}_{-0.63}$	$-8.15^{+0.13}_{-0.13}$
	WDM	$2.50^{+1.31}_{-0.76}$	$-8.20^{+0.27}_{-0.22}$
9	CDM	$2.36^{+1.11}_{-0.58}$	$-7.99^{+0.10}_{-0.14}$
	WDM	$2.74^{+1.30}_{-0.88}$	$-7.99^{+0.30}_{-0.30}$
10	CDM	$2.55^{+1.19}_{-0.69}$	$-8.03^{+0.12}_{-0.15}$
	WDM	$2.78^{+1.29}_{-0.94}$	$-7.97^{+0.37}_{-0.38}$

Table A3. The median parameter values, including the 1σ uncertainties, resulting from the MCMC procedure for $f_\star$, which follows the functional form of equation (5).

z	slope	intercept
5	0.999	−8.947
6	1.019	−8.493
7	1.070	−8.802
8	1.030	−8.408
9	0.9930	−8.053
10	0.9994	−8.026

Table A4. The best-fitting parameters derived from the MCMC procedure for the SFR-$M_\star$ relation, which is linear in log-log space.

Looking forward to more high-z data

We can use galaxy formation as insight to cosmology

Results comparable, not identical to other groups
(e.g. Ma et al. 2018, Rosdahl et al. 2018, Ceverino et al. 2017)

High redshift and integrated quantities promising
(Lovell et al. 2018, Villaneuva-Domingo et al. 2018, Crosianti et al. 2017)

Need more careful astrophysics for reionization

Overall, Cold Dark Matter is favored

2019MNRAS.489..487S