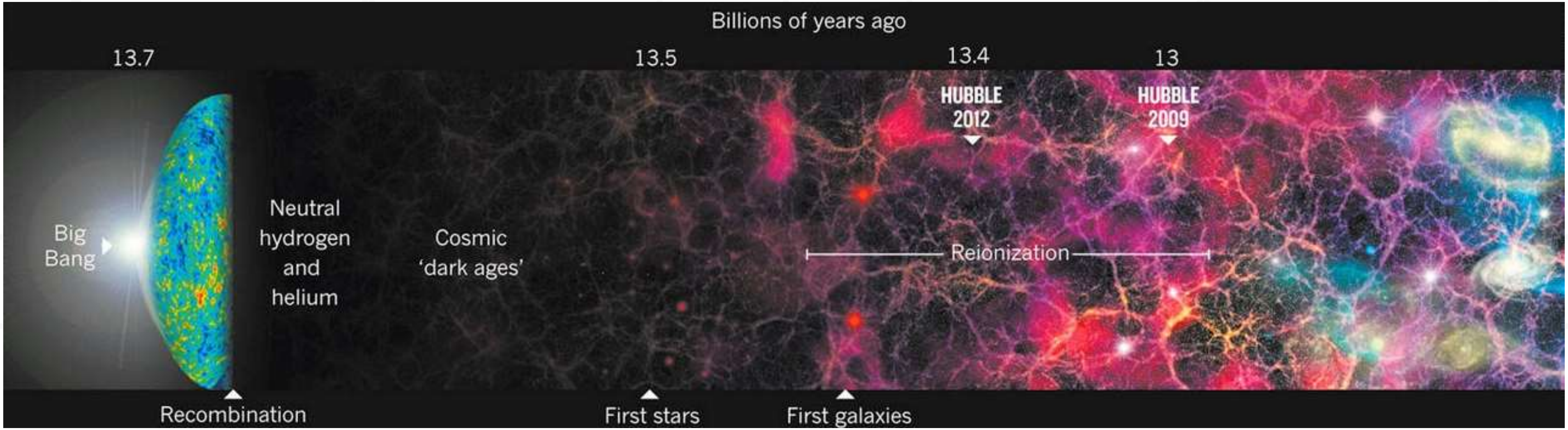
The epoch of Reionization in Warm Dark Matter scenarios

M. Romanello, N. Menci, M. Castellano

keV Warm Dark Matter in Agreement with Observations in Tribute to Héctor J. De Vega

10/11/2021

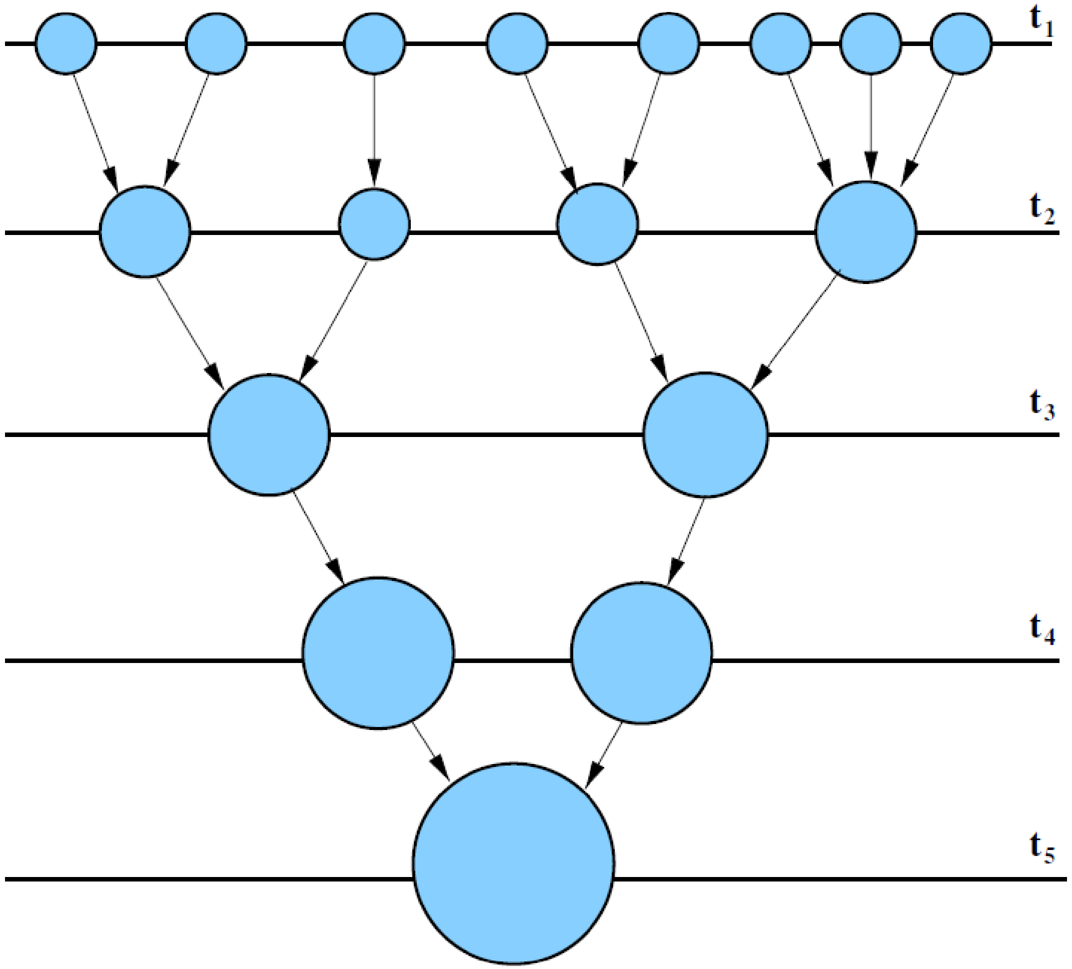


PART I

Dark Matter

ΛCDM model

- 69% contribution of cosmological constant
- 26% CDM (e.g. WIMPS, m_X>1 GeV)
- 5% baryonic matter

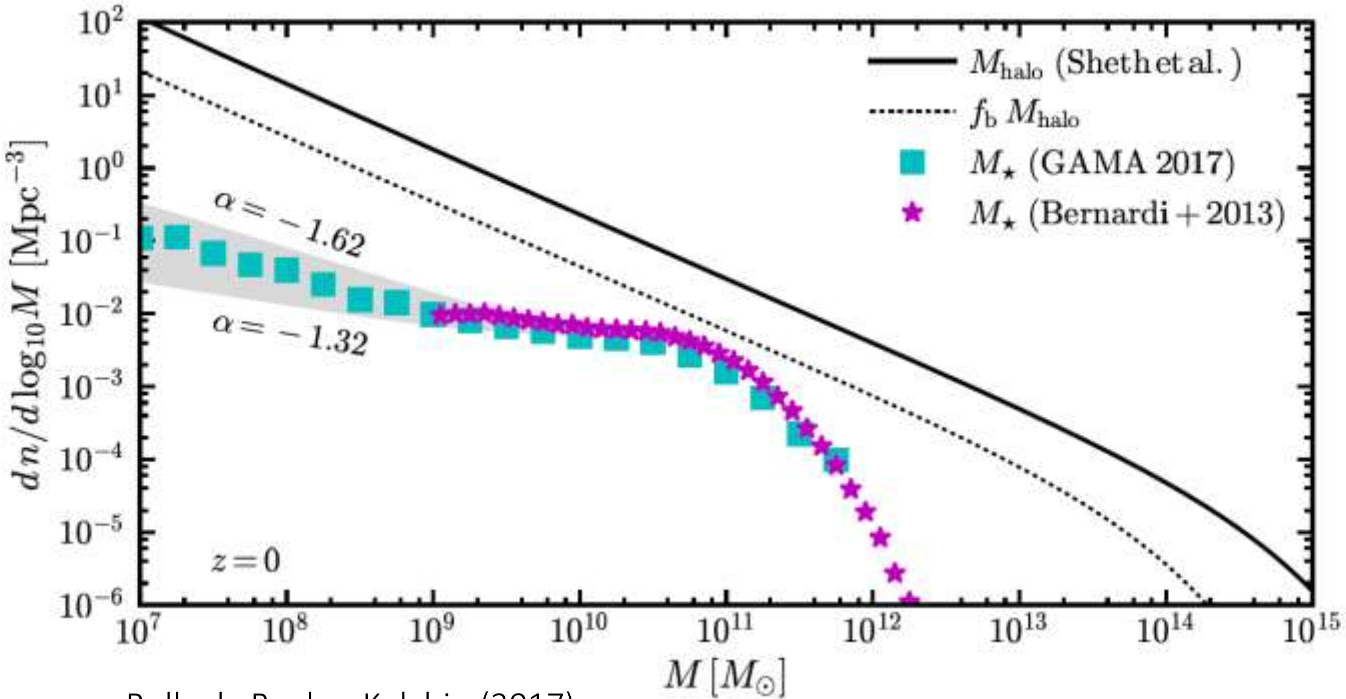


Initial power spectrum yields to a hierarchical growth of matter perturbation

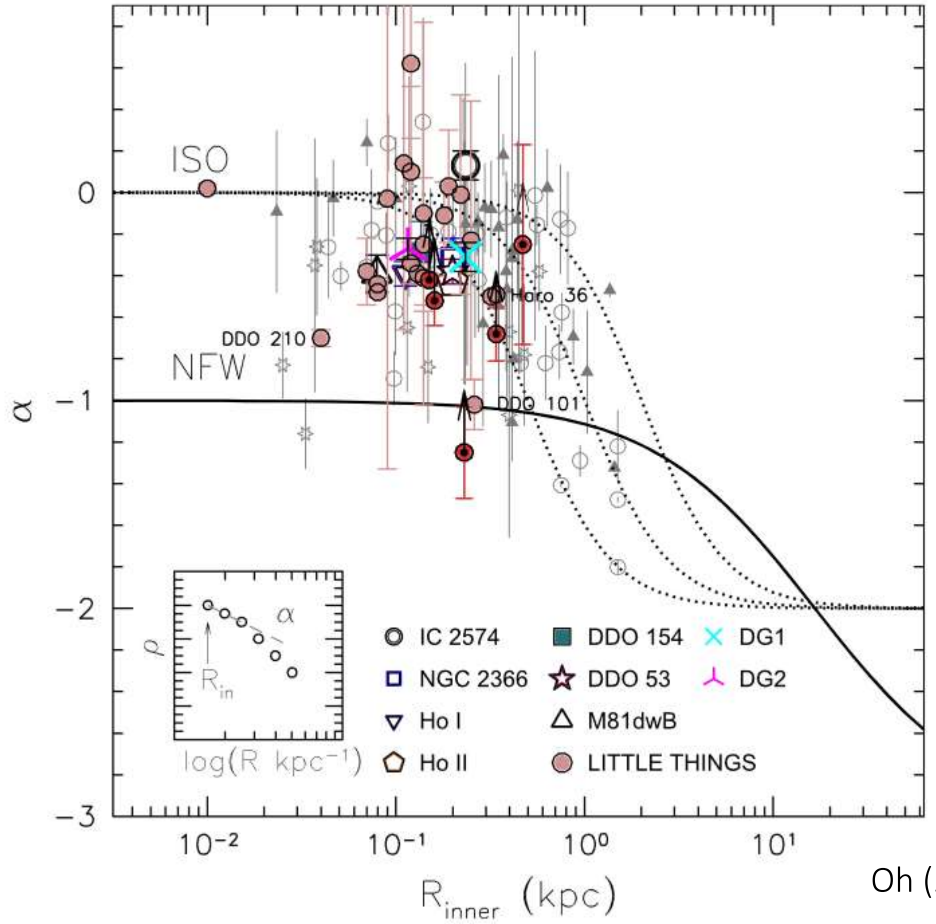
ΛCDM model limits

Missing satellites problem

Cusp/core problem



Bullock, Boylan-Kolchin (2017)



Oh (2015)

Possible solutions: WDM cosmologies

Warm Dark Matter

Thermal WDM

Sterile Neutrinos

Free-streaming of DM particles determines a suppression in low mass halos.

$$\lambda_{FS} = a(t) \int_0^t \frac{v(t')}{a(t')} \mathrm{d}t'$$

$$T_{WDM}(k) = \left[\frac{P_{WDM}}{P_{CDM}} \right]^{1/2}$$

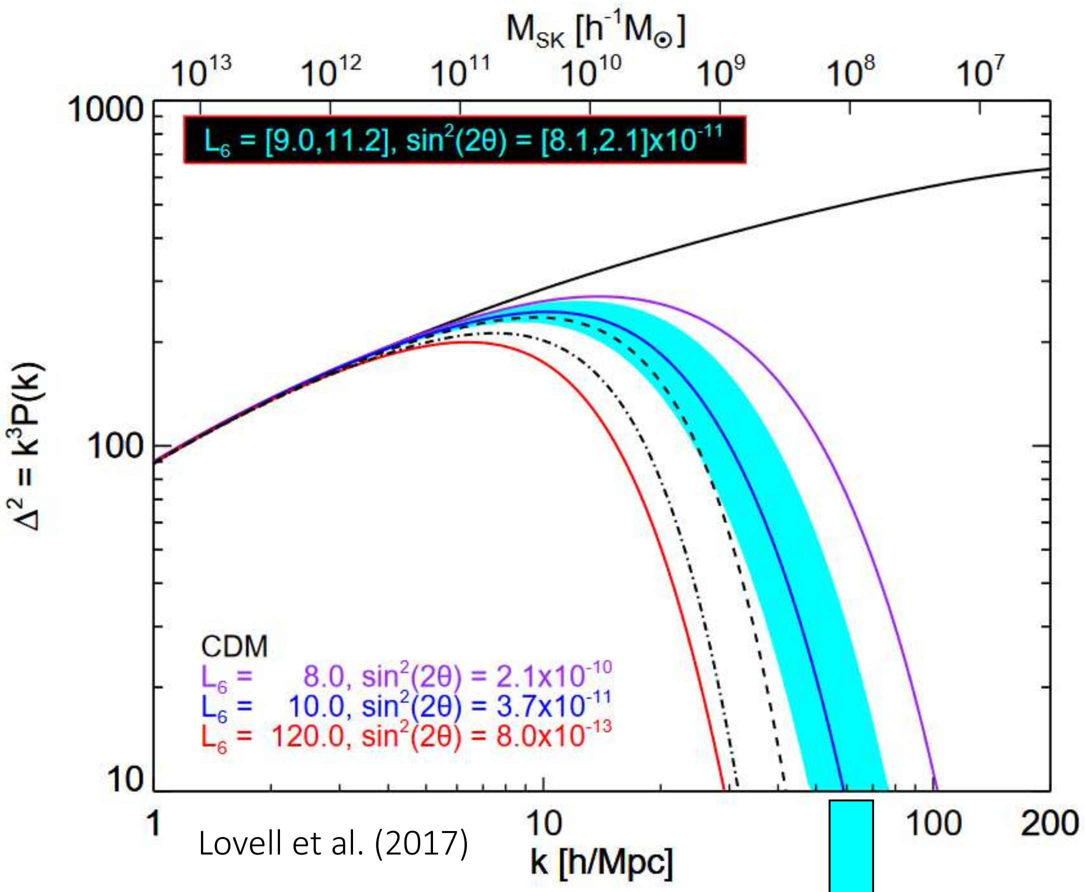
In thermal WDM case the half-mode mass:

$$M_{hm} \approx 3 \times 10^8 \left(\frac{m_X}{3.3\mathrm{keV}} \right)^{-3.33} \mathrm{M}_\odot$$

WDM power spectrum

DM model	M_{hm} ($M_{\odot}$)
LA8	1.3×10^8
LA9	2.6×10^8
LA10	5.3×10^8
LA11	9.2×10^8
LA120	3.1×10^9
WDM 2	1.6×10^9
WDM 3	4.1×10^8
WDM 4	1.6×10^8

From Lovell et al. (2020)



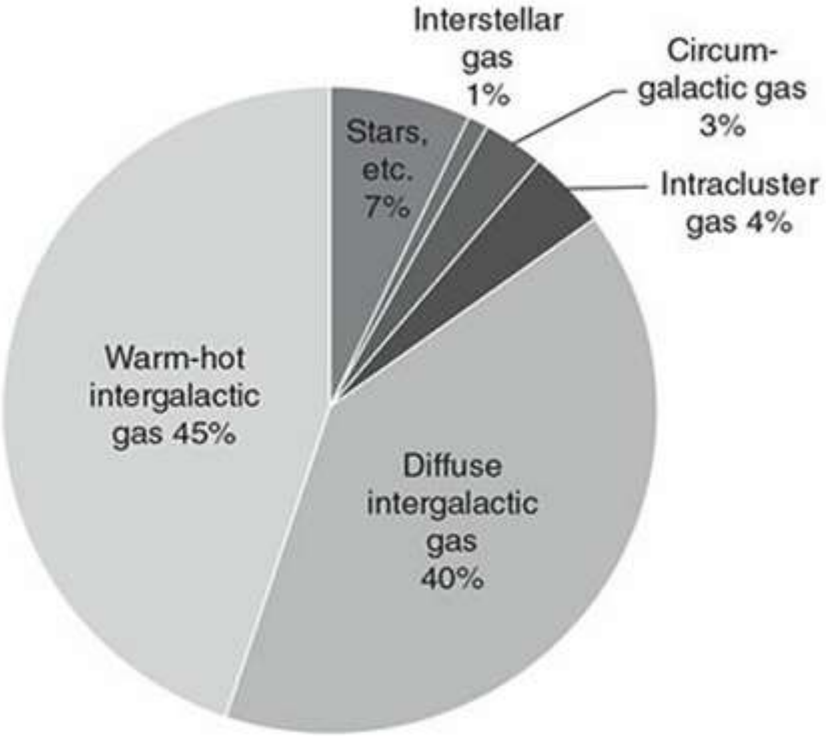
Lovell et al. (2017)

LA9-LA10-LA11 are compatible with 3.5 keV emission line observed towards galaxy-clusters.

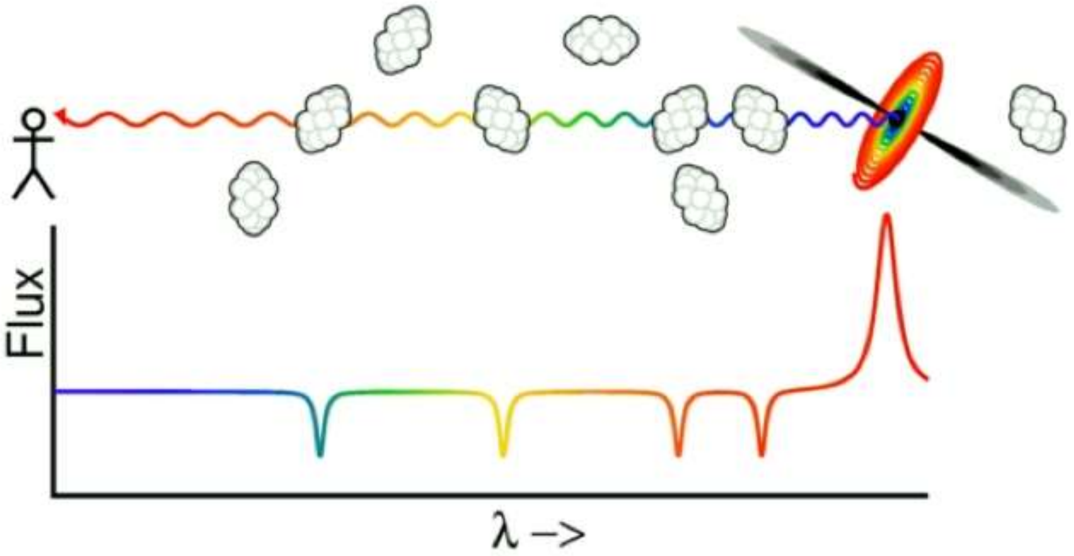
PART II

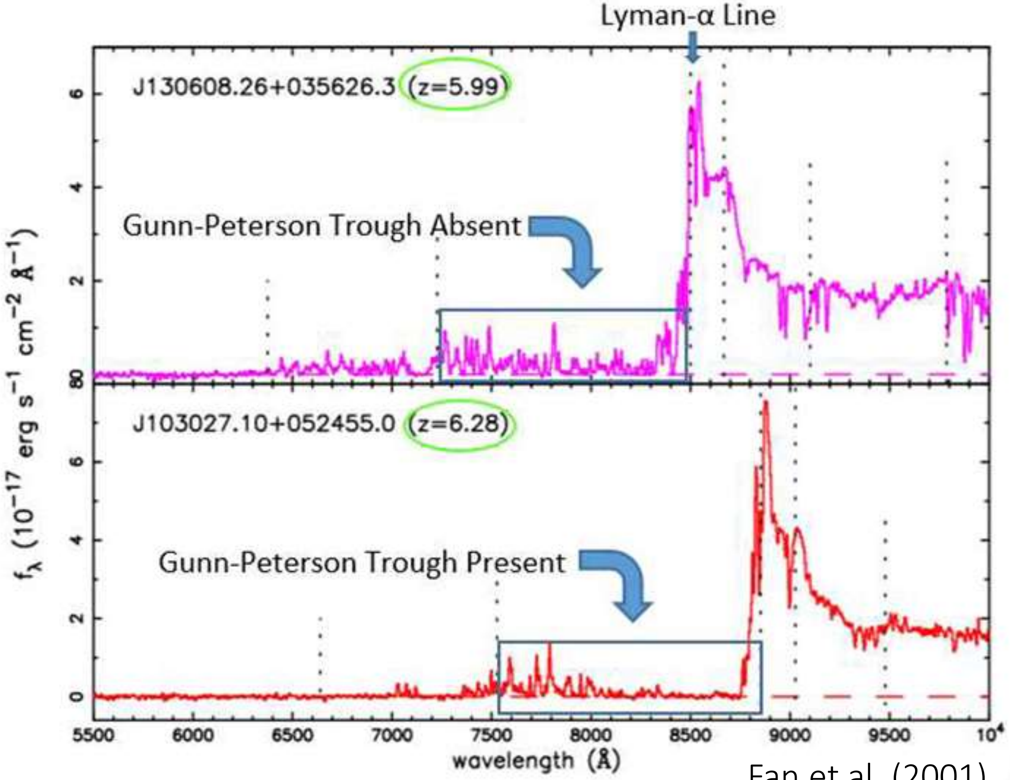
Baryonic Matter

The Intergalactic medium (IGM) and the Gunn Peterson Test



Ryden (2017)

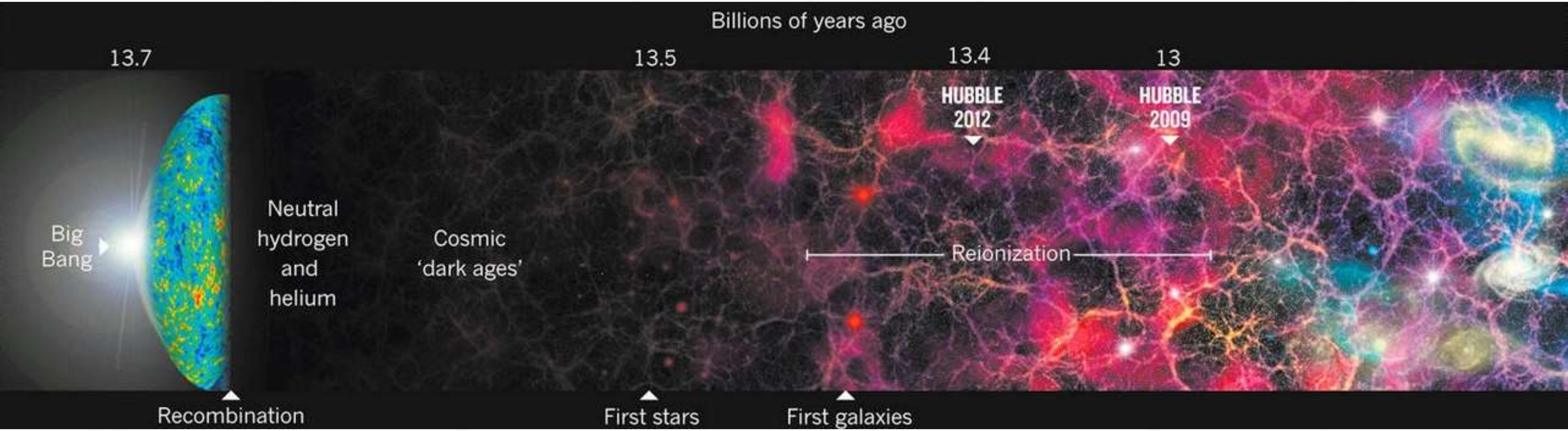




Fan et al. (2001)

Reionization

The Epoch of Reionization (EoR) marked a fundamental phase transition in the history of the Universe, during which the Intergalactic Medium (IGM) became transparent to UV photons.



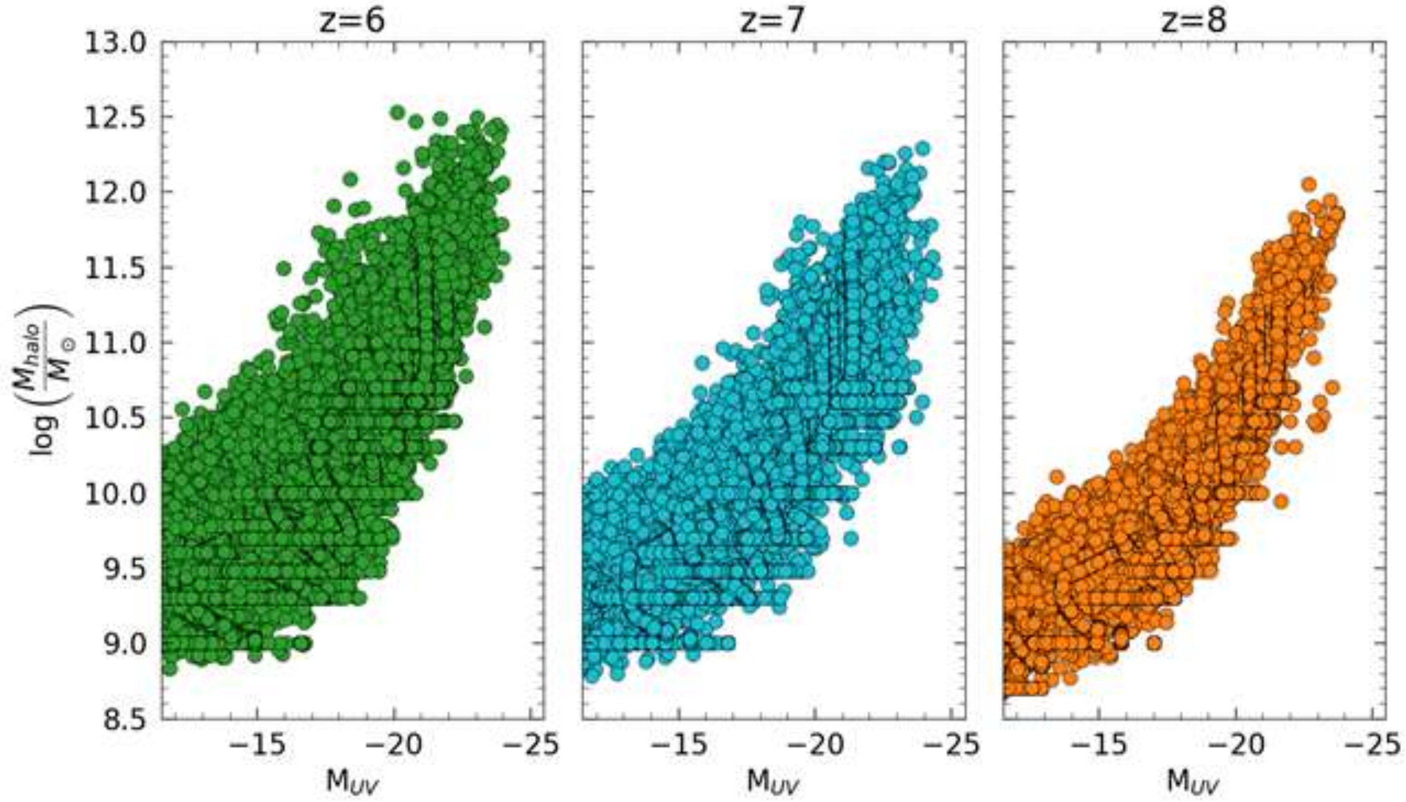
PART III

Properties of ionizing sources

Galaxy evolution

(more massive)

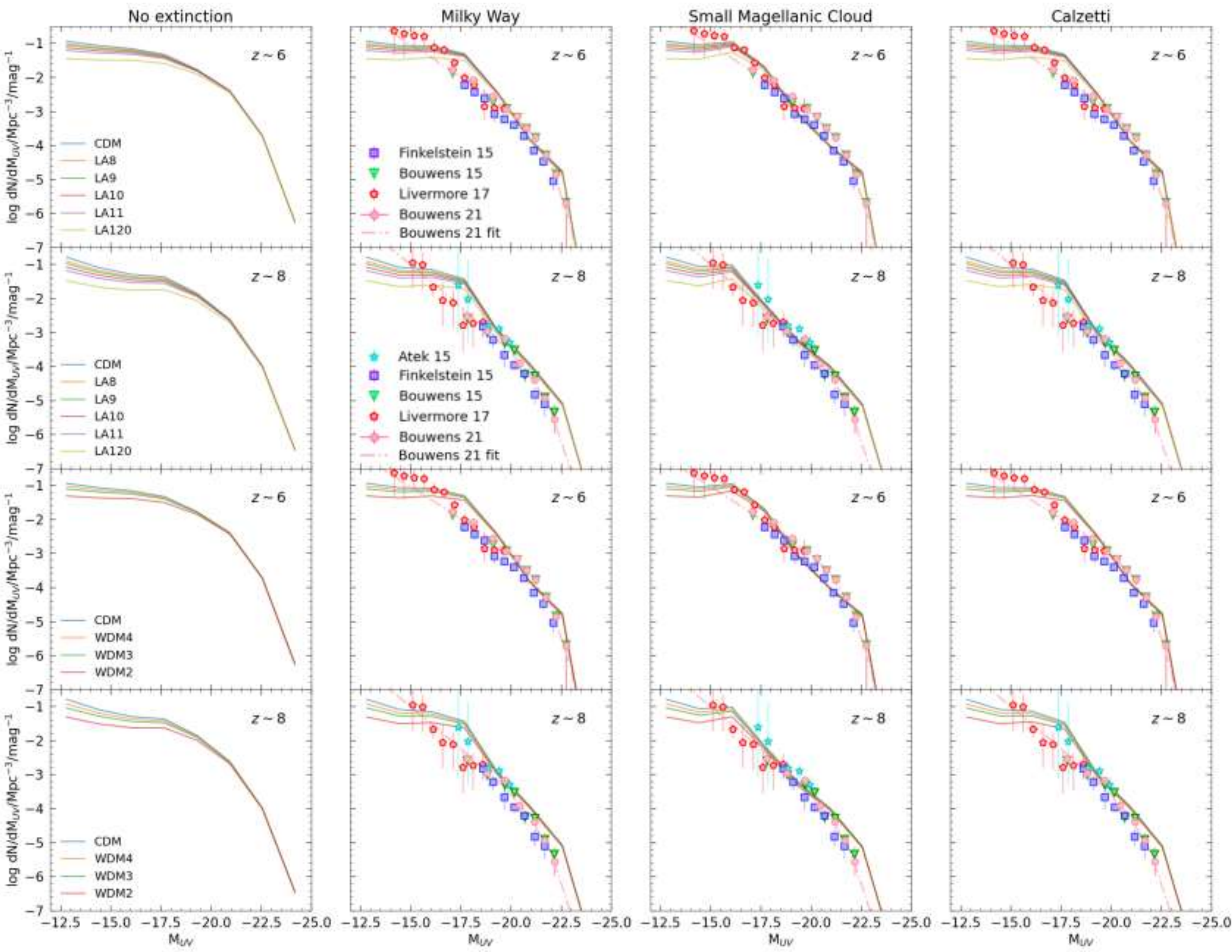
(more luminous)



The semi-analytic model by Menci et al. (2018) retraces the collapse of dark matter halos and includes baryonic processes (i.e., cooling, star formation, feedbacks)

The UV Luminosity Function

We use the semi-analytic model to compute UV LF with CDM and WDM power spectra

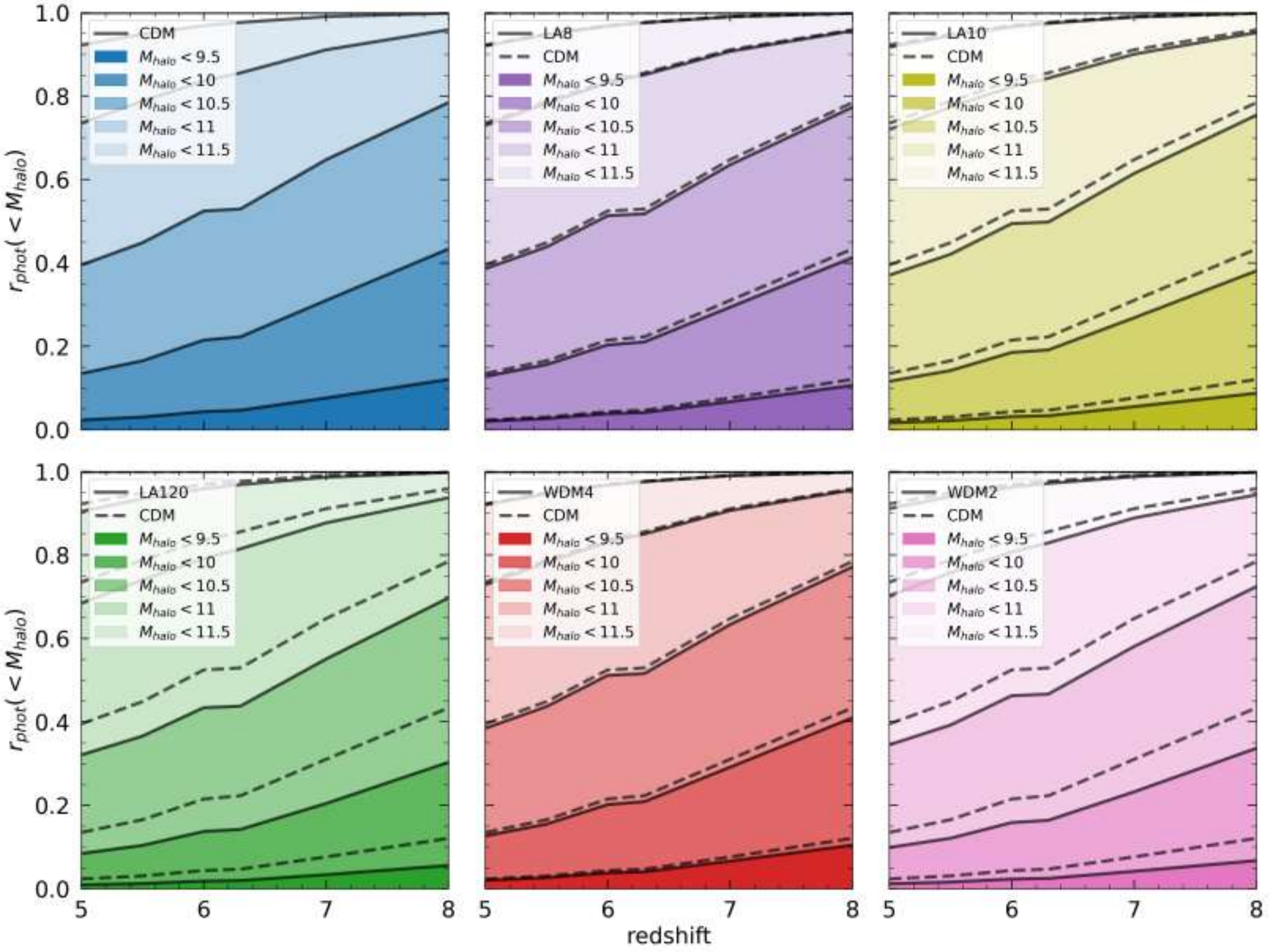


Reionization and halo mass

$$r_{phot}(< M_{lim}^{halo}) = \frac{\dot{N}_{ion}(M_{halo} < M_{halo}^{lim})}{\dot{N}_{ion,tot}}$$

1. Role of massive halos increases with time.

2. The contribution of low mass halos is suppressed in WDM cosmologies.



PART IV

The epoch of Reionization in WDM cosmologies

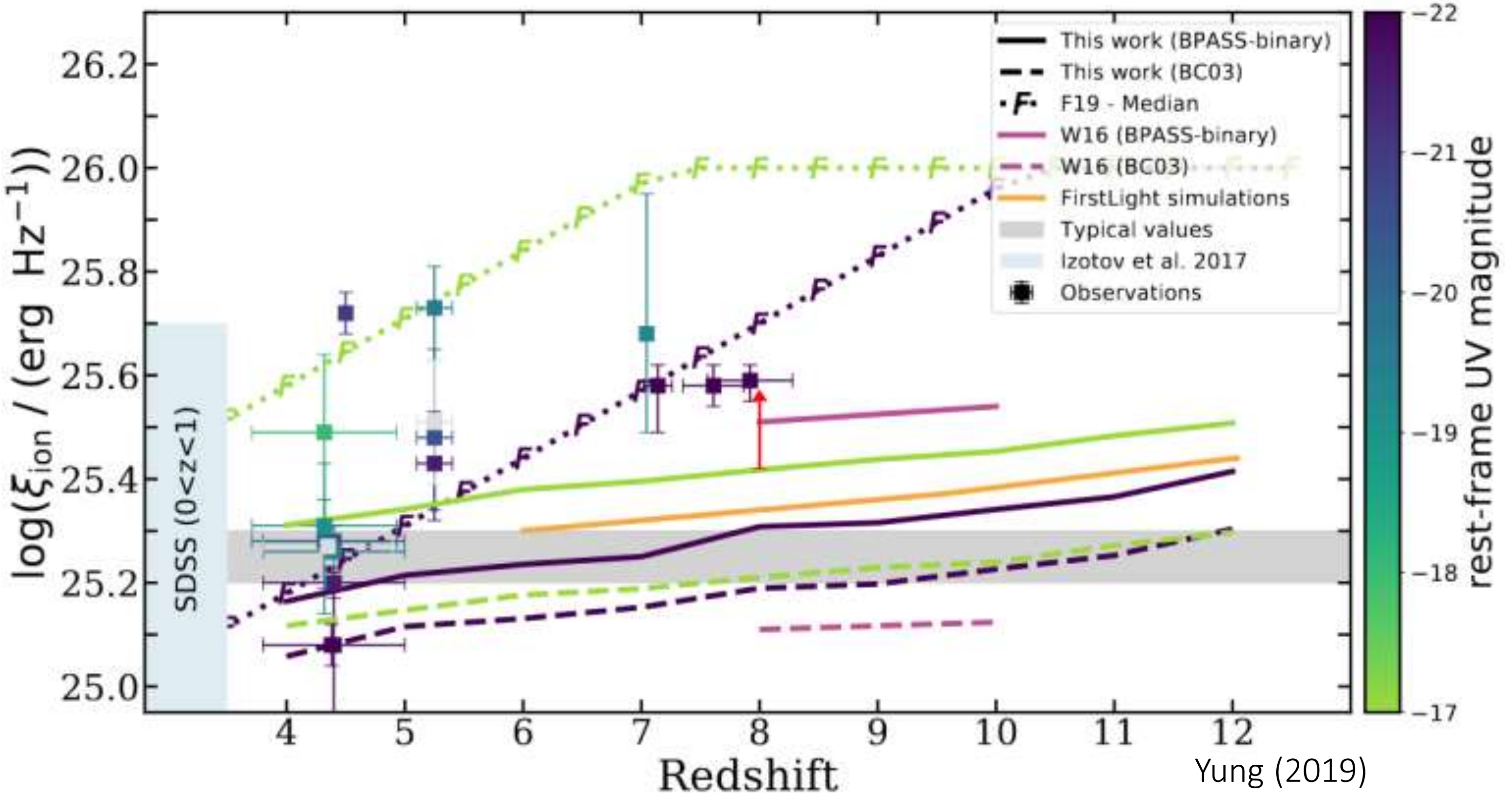
Ionizing photons

$$\rho_{UV} = \int^{M_{UV}^{lim}} \mathrm{d}M_{UV} \frac{\mathrm{d}N}{\mathrm{d}M_{UV}} L_{UV}$$

$$\dot{N}_{ion} = f_{esc} \xi_{ion} \rho_{UV}$$

Ionizing photons production efficiency ($10^{25.2}$ Hz/erg)

The escape fraction represents the fraction of ionizing photons that can escape from the source galaxy and summarizes most of our uncertainties about the EoR



Yung (2019)

Evolution of the filling fraction

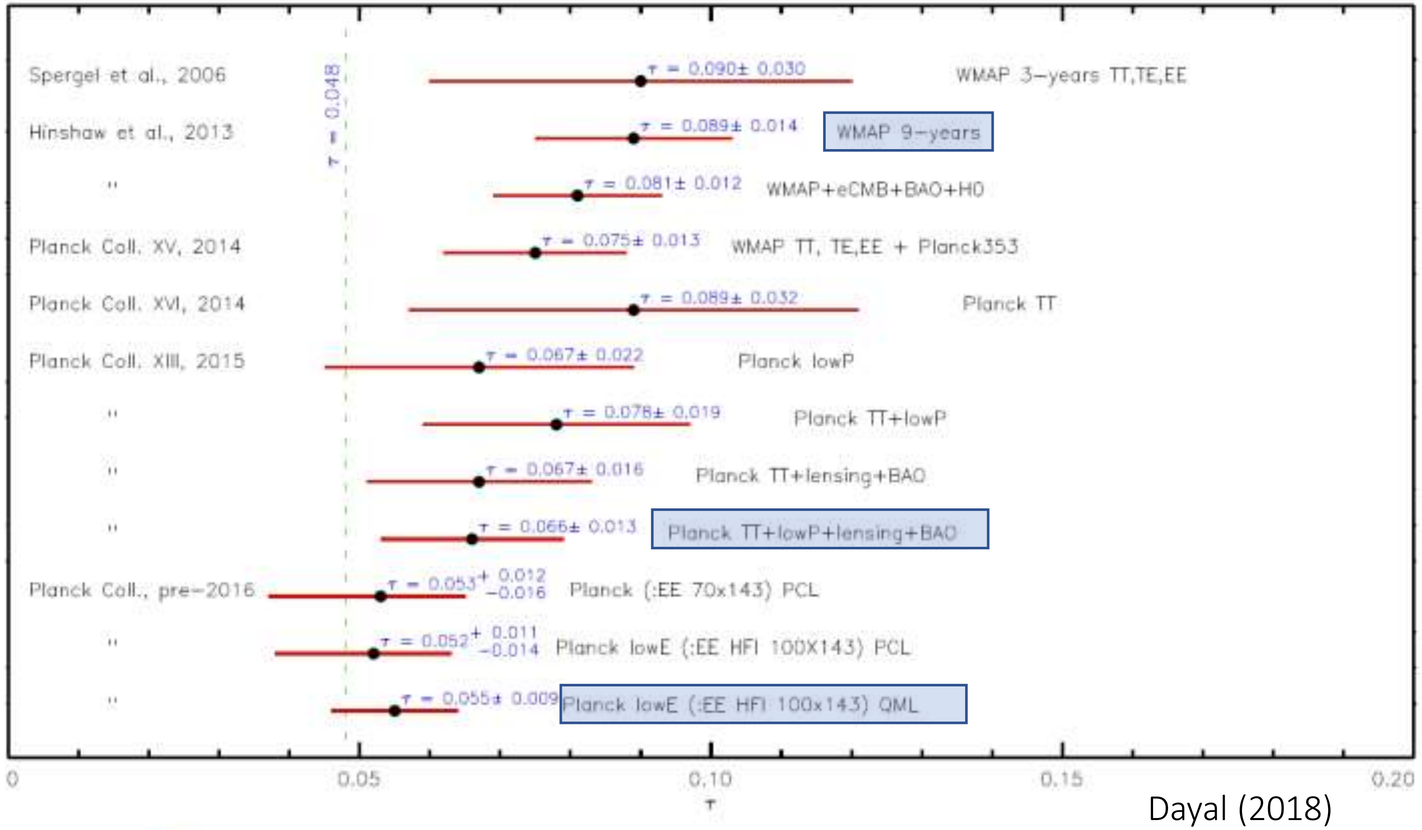
Evolution of ionized hydrogen filling fraction:

$$\dot{Q}_{HII} = \frac{\dot{N}_{ion}}{\bar{n}_H} - \frac{Q_{HII}}{t_{rec}}$$

$$\bar{n}_H \approx 2 \times 10^{-7} (\Omega_b h^2 / 0.022)\ \mathrm{cm}^{-3}$$

$$t_{rec} \approx 3.2\ \mathrm{Gyr}\ [(1+z)/7]^{-3} C_{HII}^{-1}$$

Electron scattering optical depth:

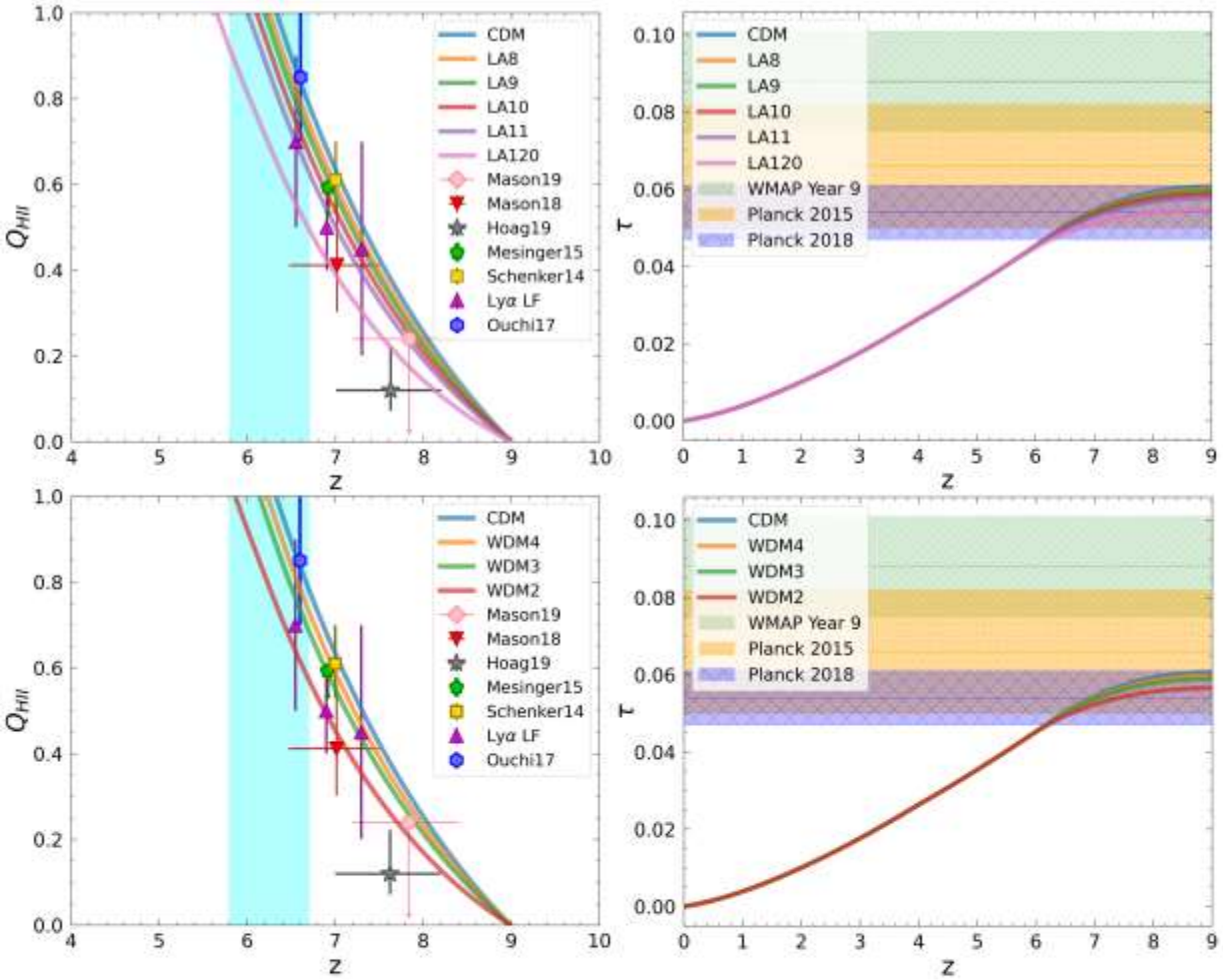


Dayal (2018)

$$\tau_{es}(z) = c\sigma_T \bar{n}_H \int_0^z Q_{HII}(z')(1+z')^2 \left(1 + \frac{\eta Y}{4X}\right) H^{-1}(z')\mathrm{d}z'$$

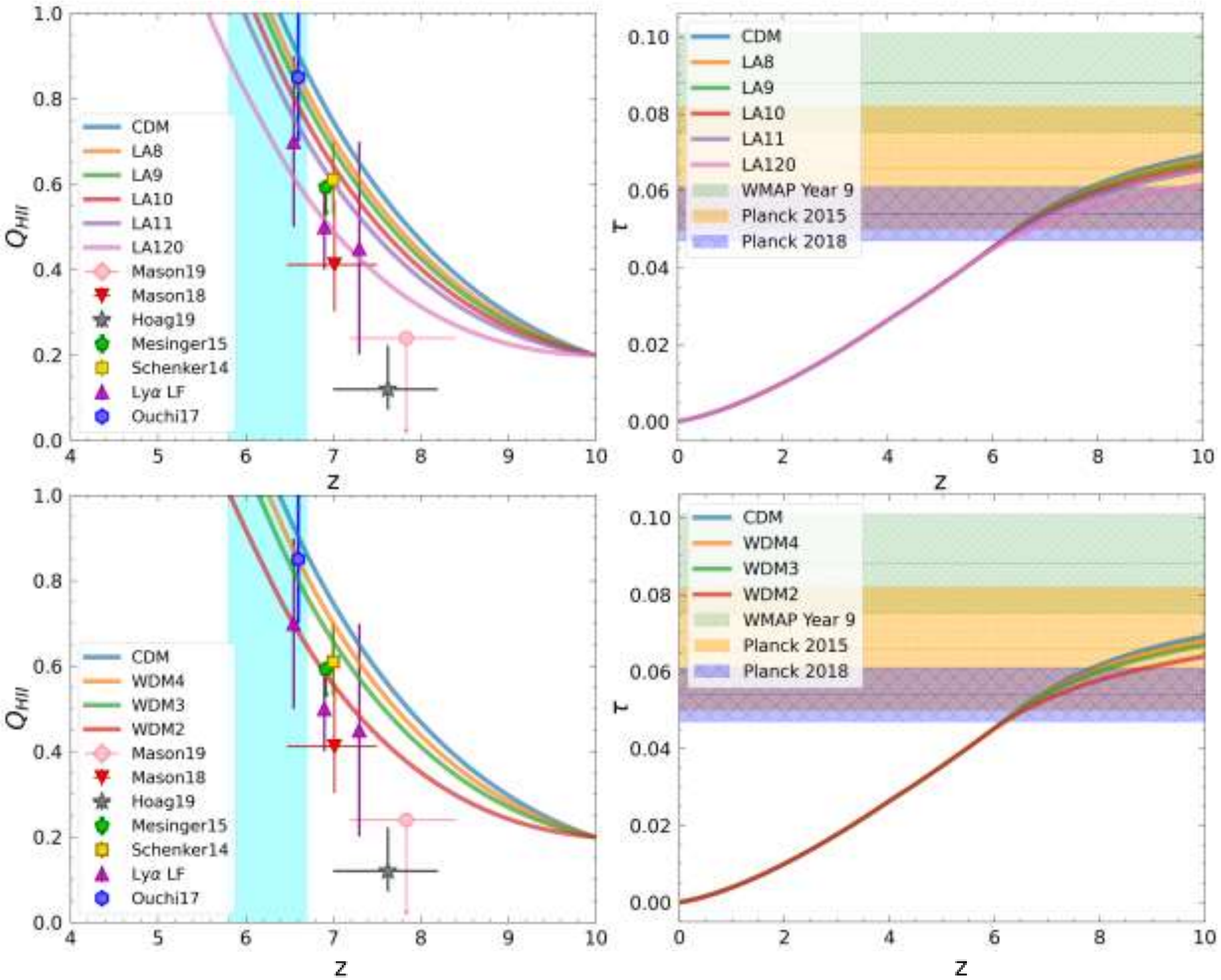
$$Q_{HII}(z = 9) = 0.0$$

f_{esc} = 6%



$$Q_{HII}(z = 10) = 0.2$$

f_{esc} = 5%



Constraints on fixed escape fraction

Reionization at z<6.7 requires an upper limit to f_{esc}

Fixed escape fraction is useful to broadly characterize the Reionization history

A universal value for f_{esc} is highly unrealistic (different mass, gas and dust content, age and metallicity)

Name	$M_{hm}(M_\odot)$	f_{esc}^{sup}
CDM	-	0.07
LA8	1.3×10^8	0.08
LA9	2.6×10^8	0.08
LA10	5.3×10^8	0.09
LA11	9.2×10^8	0.09
LA120	3.1×10^9	0.12
WDM 2	1.6×10^9	0.10
WDM 3	4.1×10^8	0.08
WDM 4	1.6×10^8	0.08

universe

MDPI

Article

The Epoch of Reionization in Warm Dark Matter Scenarios

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Summary and conclusion

The impact of faint-galaxies (M_{UV} > -20 or M_{halo} <$10^{10.5} M_{sun}$) is dominant during the EoR

Merging phenomena between halos increase the relative contribution of bright systems

WDM scenarios yield to an overall reduction of the ionizing photons and to a delay in Reionization process with respect to CDM