HI AND METAL ABSORPTION LINES DURING THE EPOCH OF REIONIZATION

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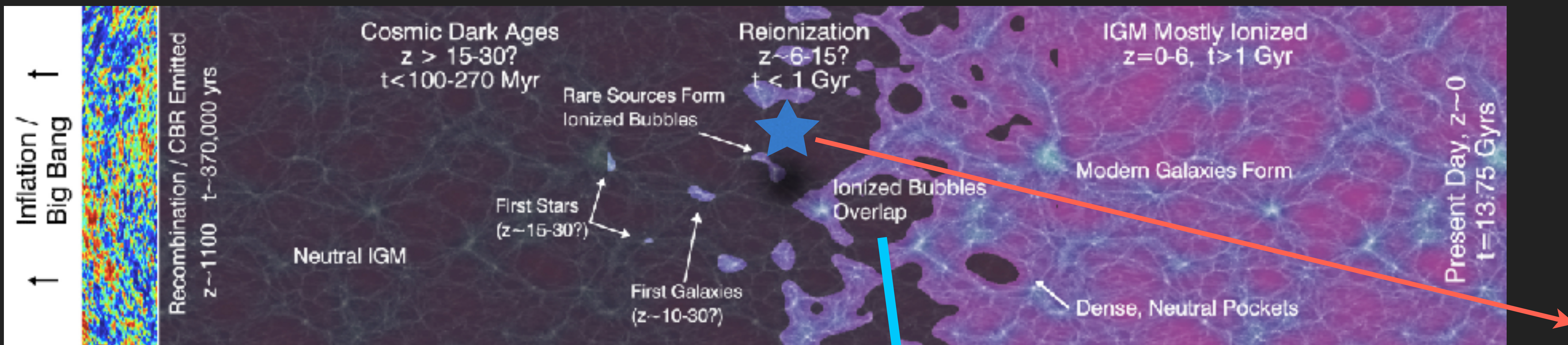
ASTRO COLLOQUIUM UNI MELBOURNE, OCTOBER 4TH, 2017

IMPRINTS ON SPECTRA OF HIGH REDSHIFT QUASARS

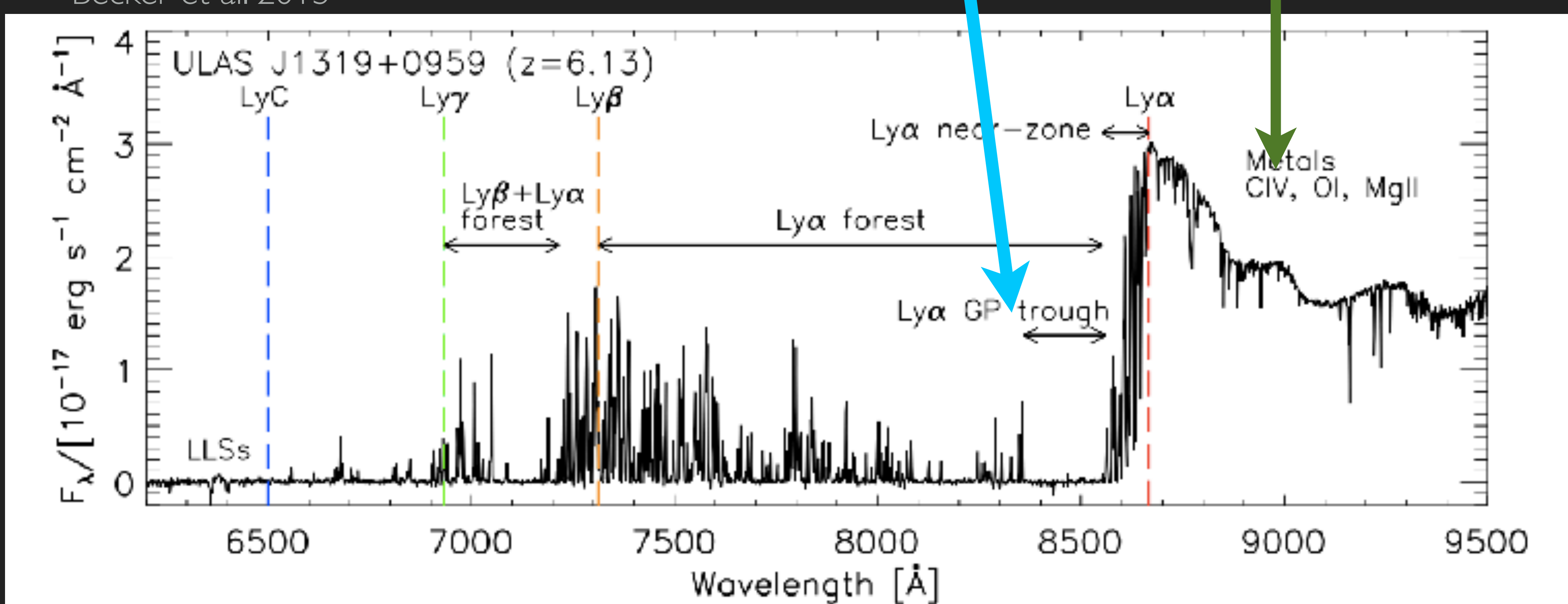


Robertson et al. 2010

GP troughs at high z in QSOs spectra

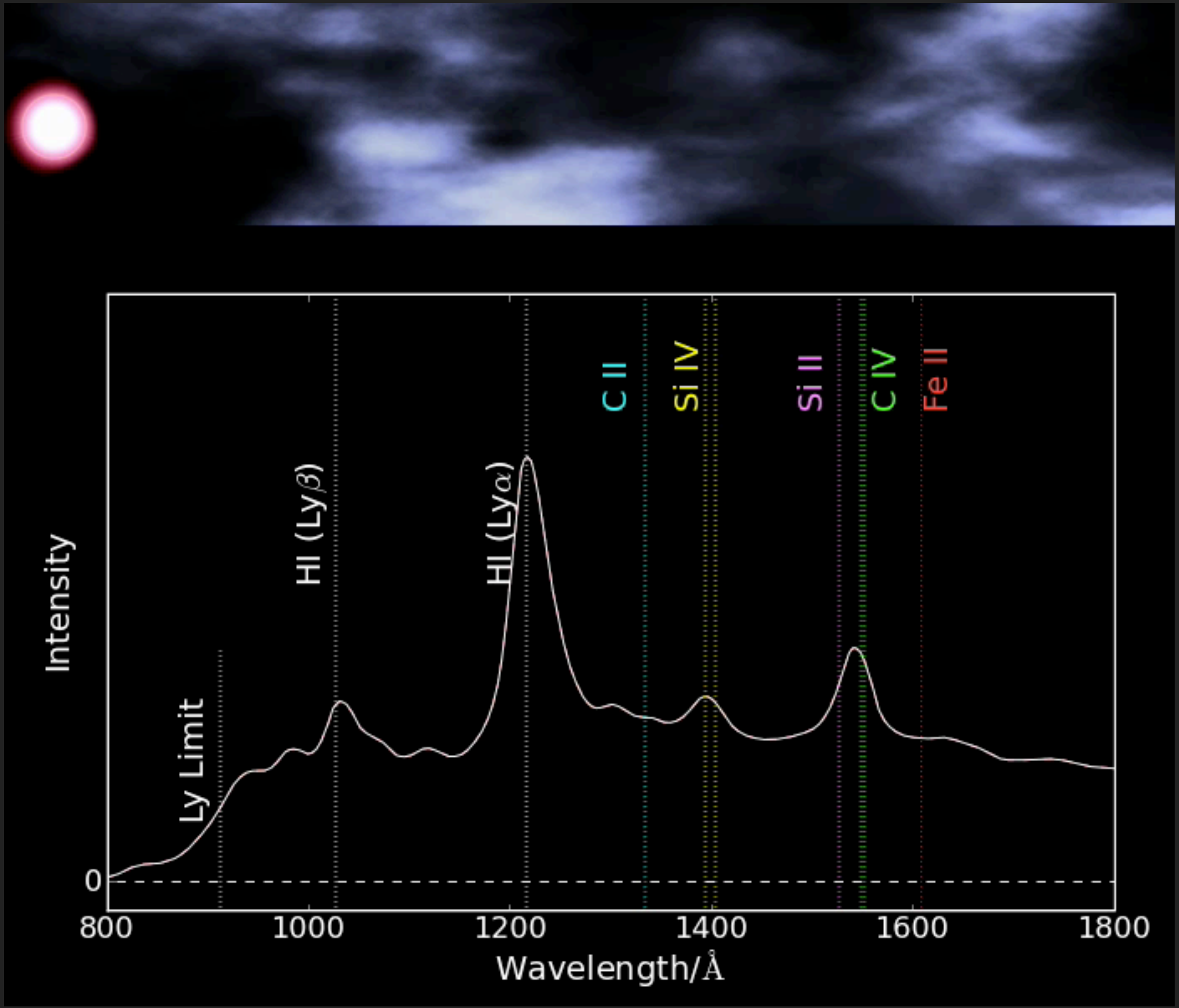
Metal absorption lines

Becker et al. 2015

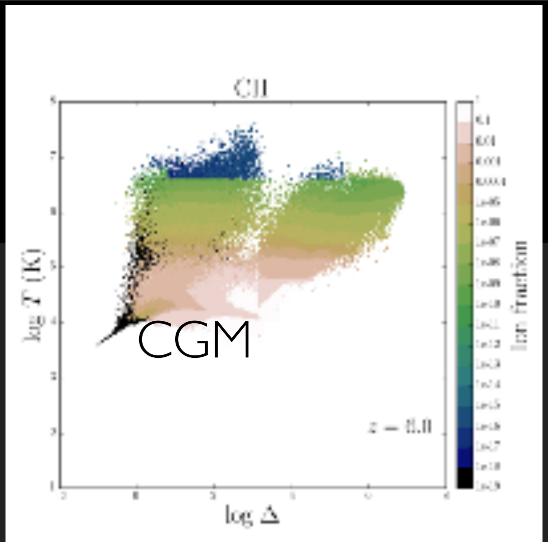
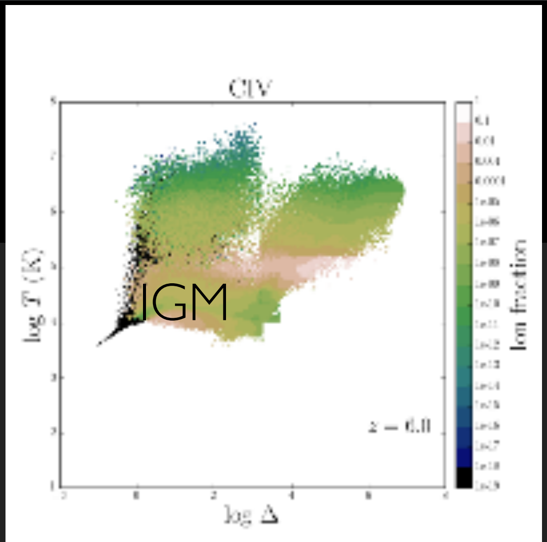


IMPRINTS ON SPECTRA OF HIGH REDSHIFT QUASARS

Credit: Andrew Pontzen



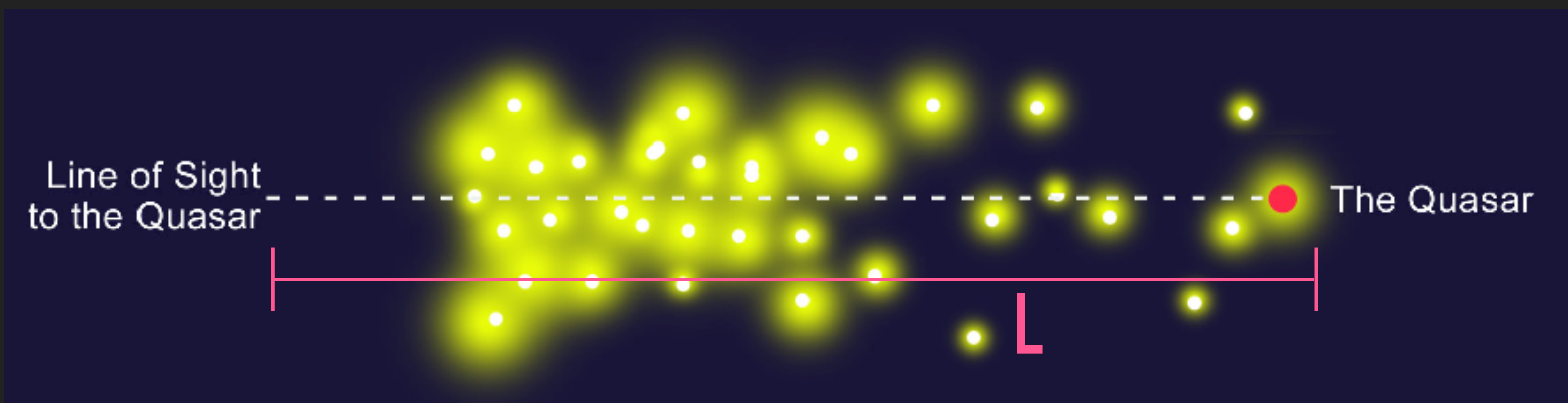
IONIZATION STATES

Low ionization	High ionization
e.g. CII, SiII, OI, etc.	e.g. CIV, SiIV, OVI, etc.
Ionization potential energy ~ H	Much larger ionization potential energy than H
Expectation to find them in the CGM and regions nearby galaxies.	They are detected in the IGM and shock heated gas.
	

COLUMN DENSITY & ABSORPTION PATH

Number of atoms / cm^2

Total survey path length.



$$N = \int_0^L n(l)\, dl$$

$$\frac{dX}{dz} = (1+z)^2 \frac{H_0}{H(z)}$$

SOME STATISTICS: COLUMN DENSITY DISTRIBUTION FUNCTION

What is the distribution of the column density values for a given system ?

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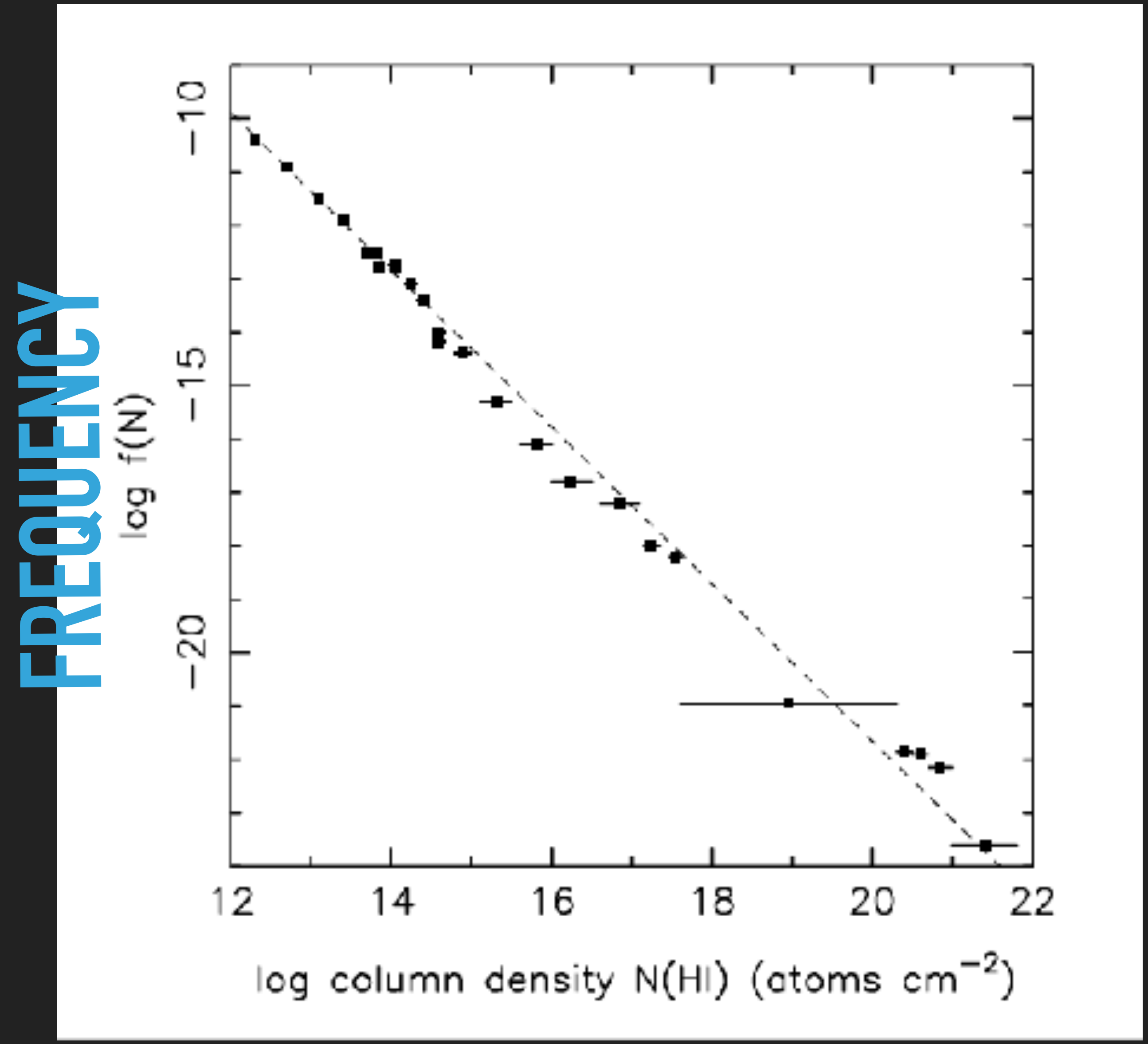
Frequency of absorbers per column density bin.



Adapted from Max Pettini's lectures

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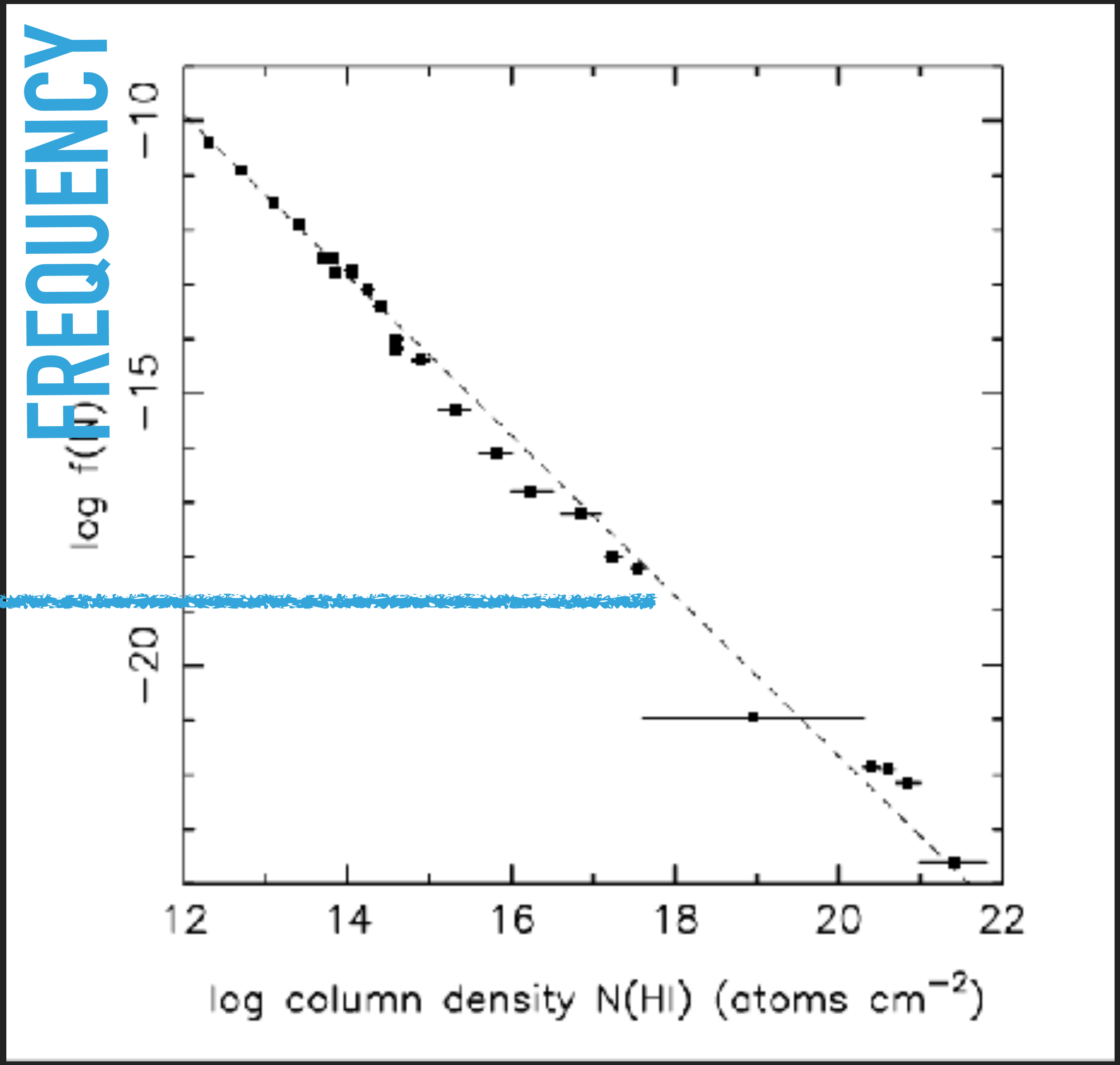


First approximation: a single power law !

$$f(N) = B \cdot N^{-\beta}$$

Adapted from Max Pettini's lectures

METAL ABSORPTION LINES

Some of these transitions occur redward of Lyα emission (1215 Å).

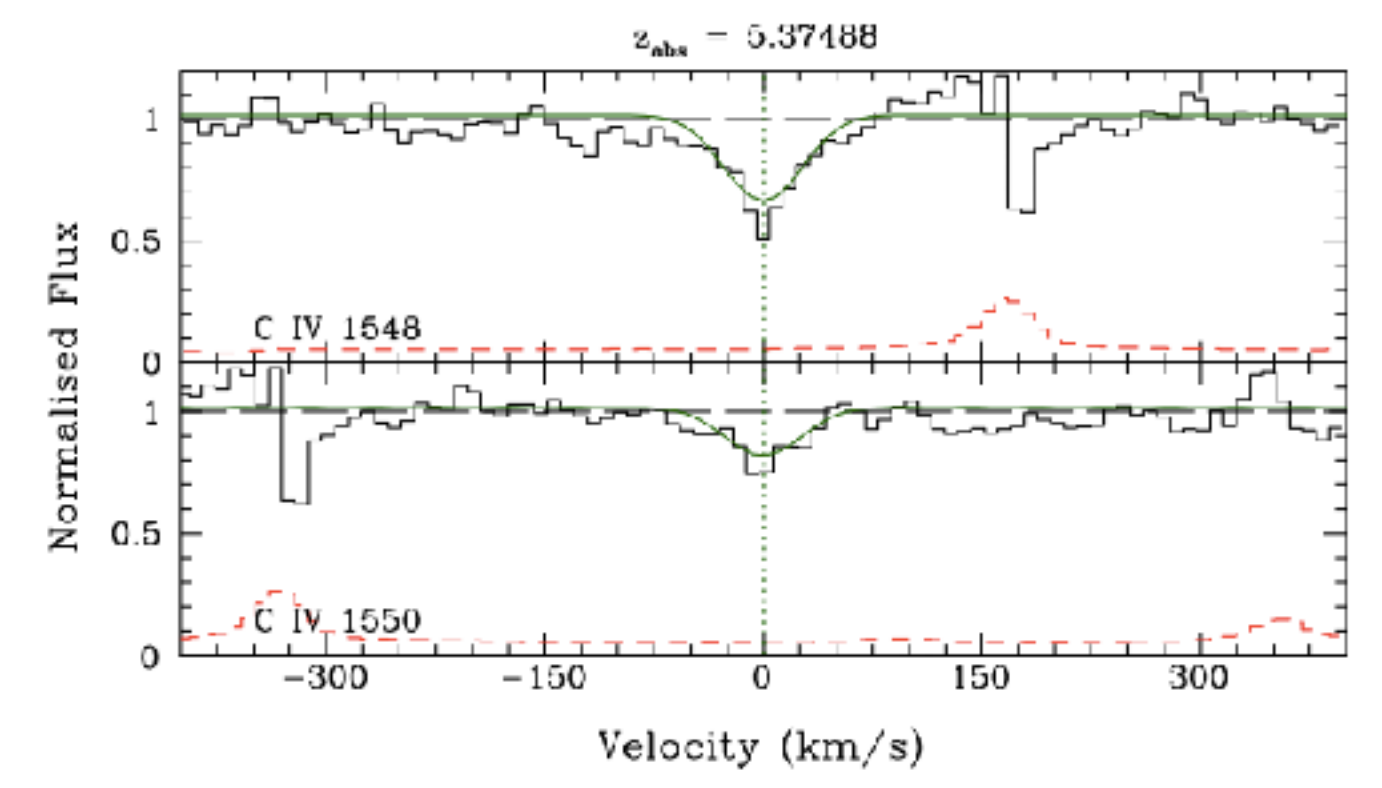
There are many different absorptions $\rightarrow$ the likelihood to be observed increases.

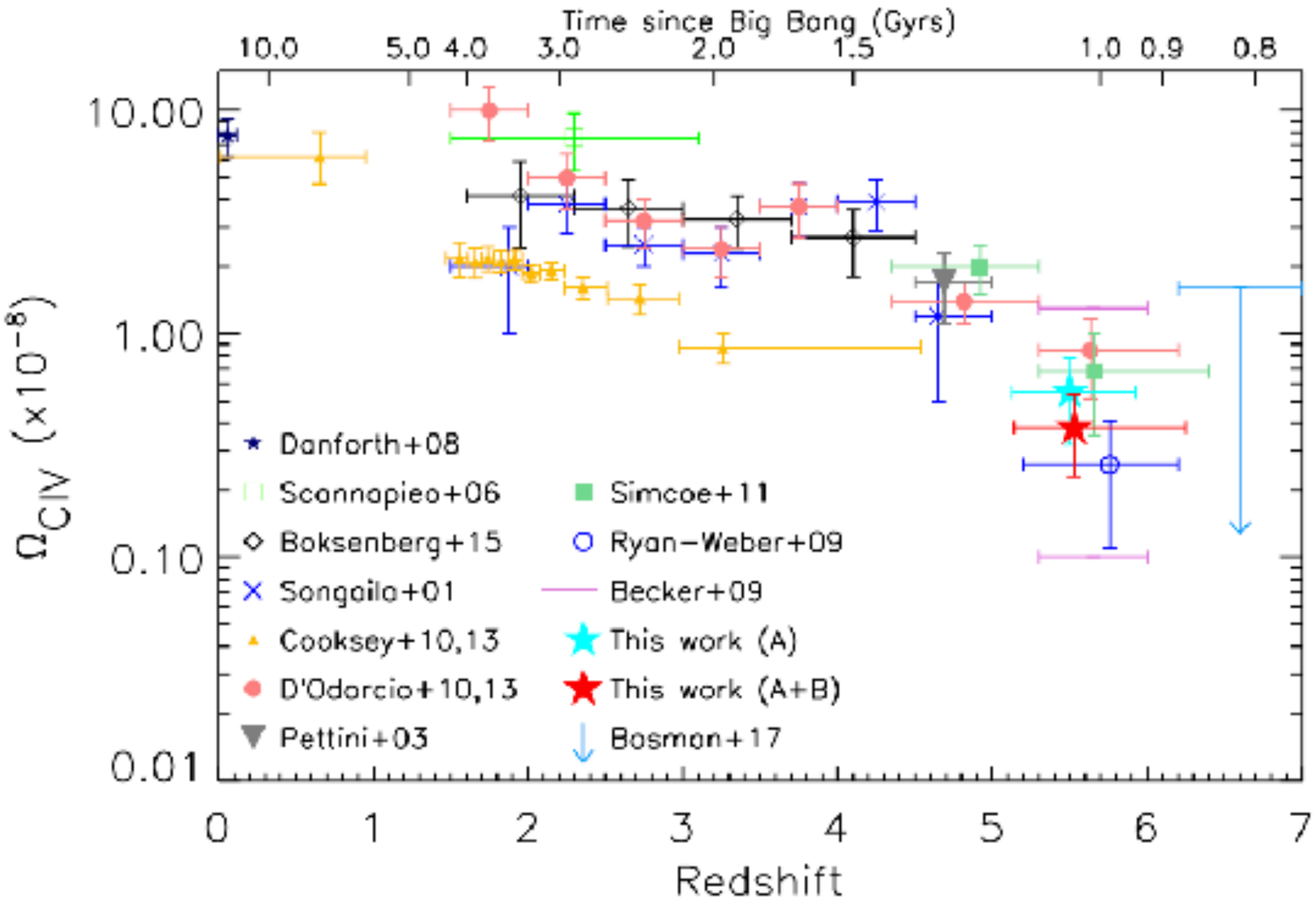
The ionic ratios can give us additional information on the conditions of the gas independent from HI.

An alternative proxy to study the ionization state of the IGM at high z.

METAL ABSORPTION LINES - CIV

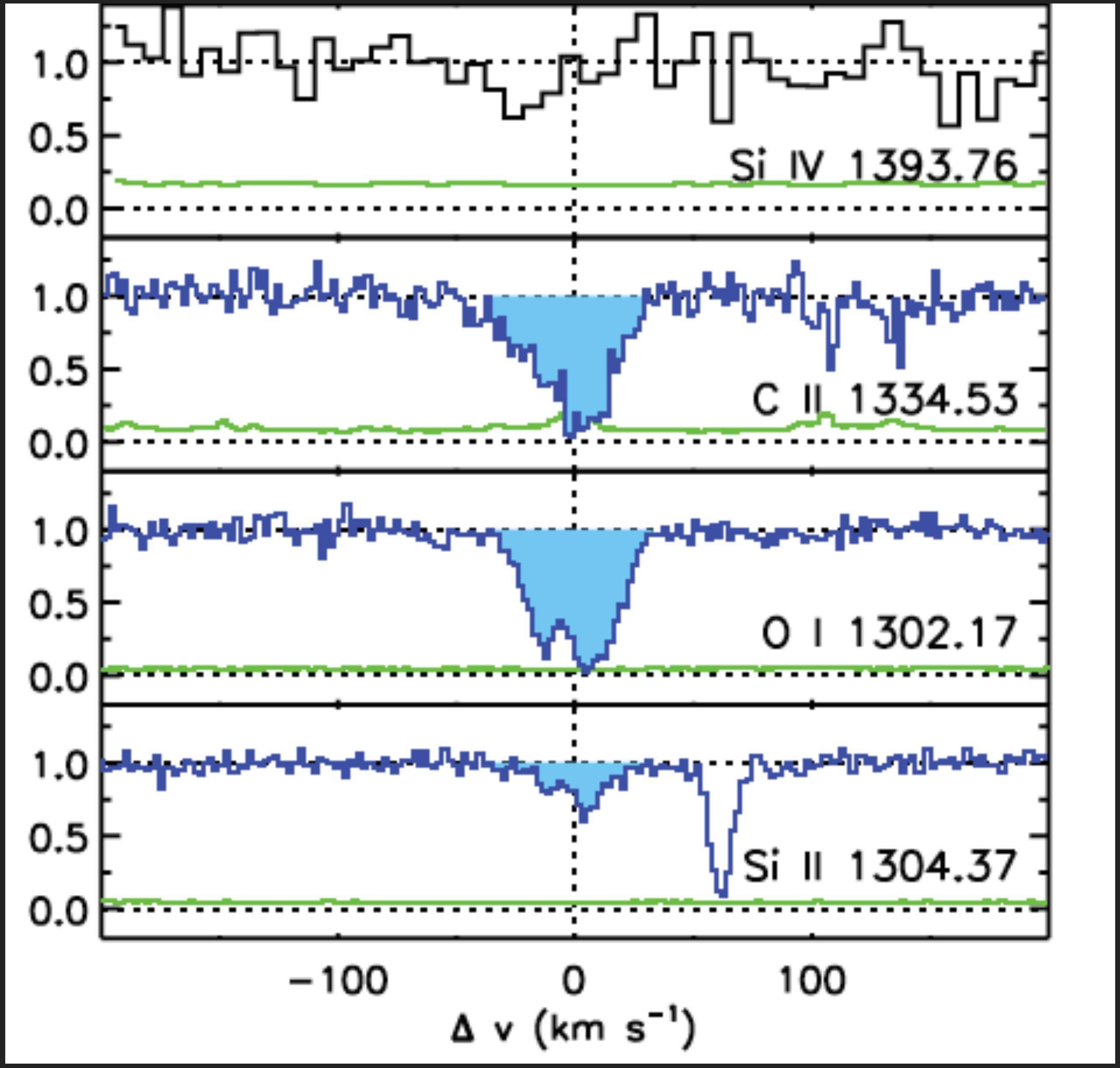
Díaz et al. in prep.



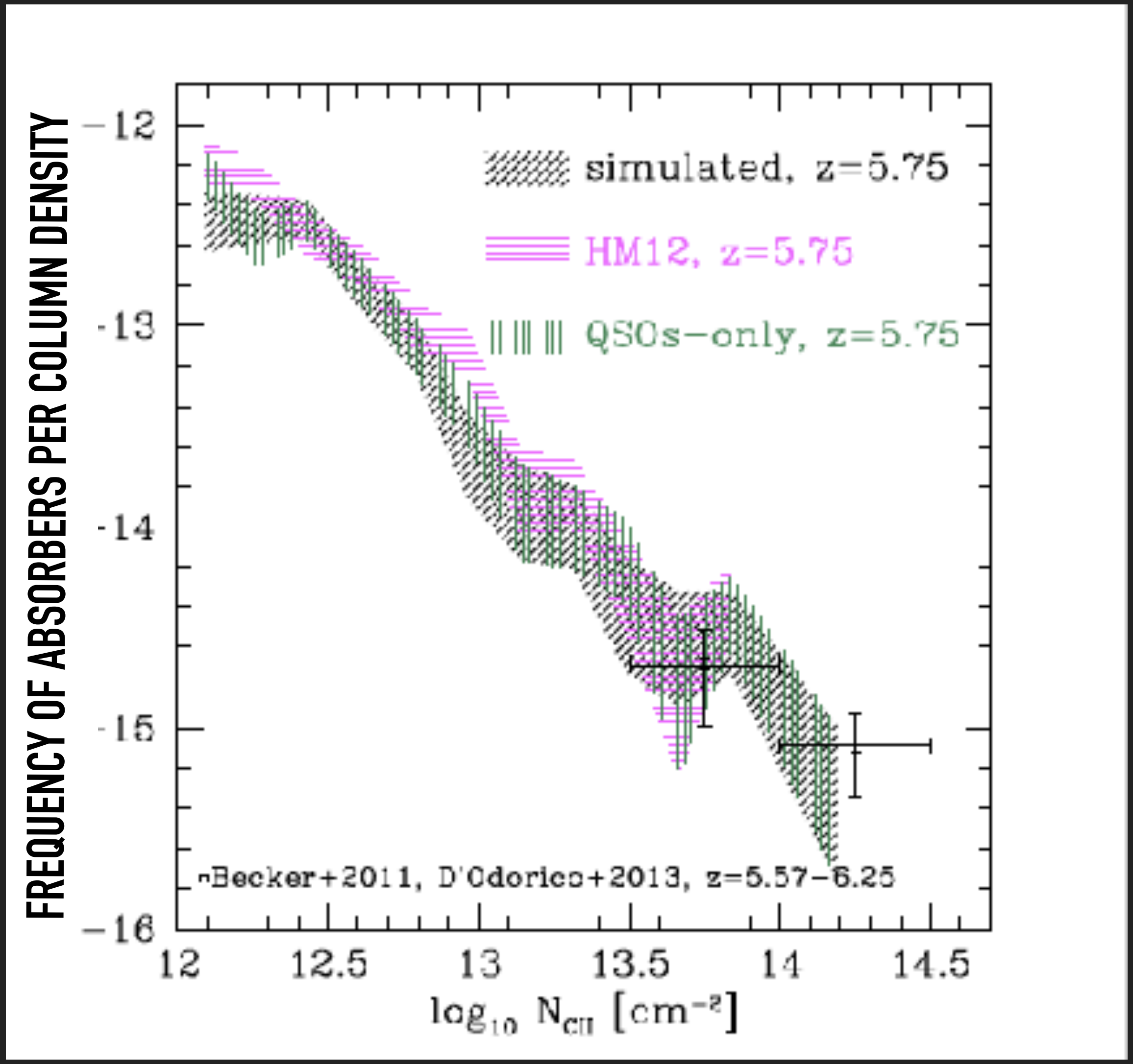


D'Odorico et al. 2013

METAL ABSORPTION LINES – CII



Becker et al. 2011



Finlator et al. 2016

NUMERICAL APPROACH:

* INCREASES THE SAMPLE OF ABSORBERS.

* TRACES DIFFERENT PHASES OF THE GAS.

* REACHES REDSHIFT THAT ARE NOT DETECTED YET WITH OBSERVATIONS.

* SPATIAL DISTRIBUTION OF THE ABSORBERS WITH RESPECT TO OTHER OBJECTS.

NUMERICAL APPROACH:

1. RUN HIGH-RESOLUTION SIMS

Simulation	Box size (cMpc/h)	Comoving softening (ckpc/h)	Δz	Molecular cooling
Ch 18 512 MDW	**18**	**1.5**	**4.0 – 8.0**	
Ch 18 512 MDW mol	18	1.5	4.0 – 8.0	✓
Ch 18 512 EDW	18	1.5	4.0 – 8.0	
Ch 18 512 EDW mol	18	1.5	4.0 – 8.0	✓
Ch 12 512 MDW mol	12	1.0	2.2 – 8.0	✓
Ch 25 512 MDW mol	25	2.0	3.6 – 8.0	✓

P-GADGET3 (XXL) that includes self-consistent **star formation** and **metal enrichment**.

Flat Λ-CDM model is assumed with cosmological parameters from **Planck 2015**.

MDW / EDW: momentum / energy driven **winds.**

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Initial conditions at $z = 125$

Feedback prescriptions

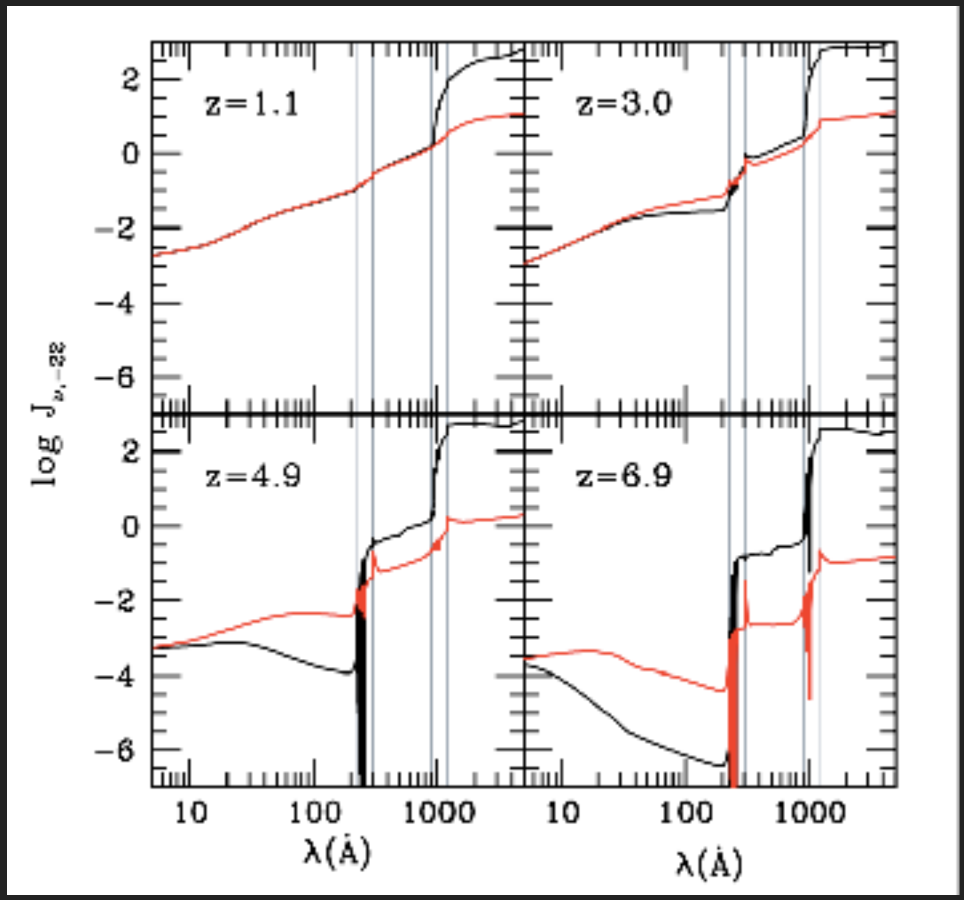
Metal enrichment

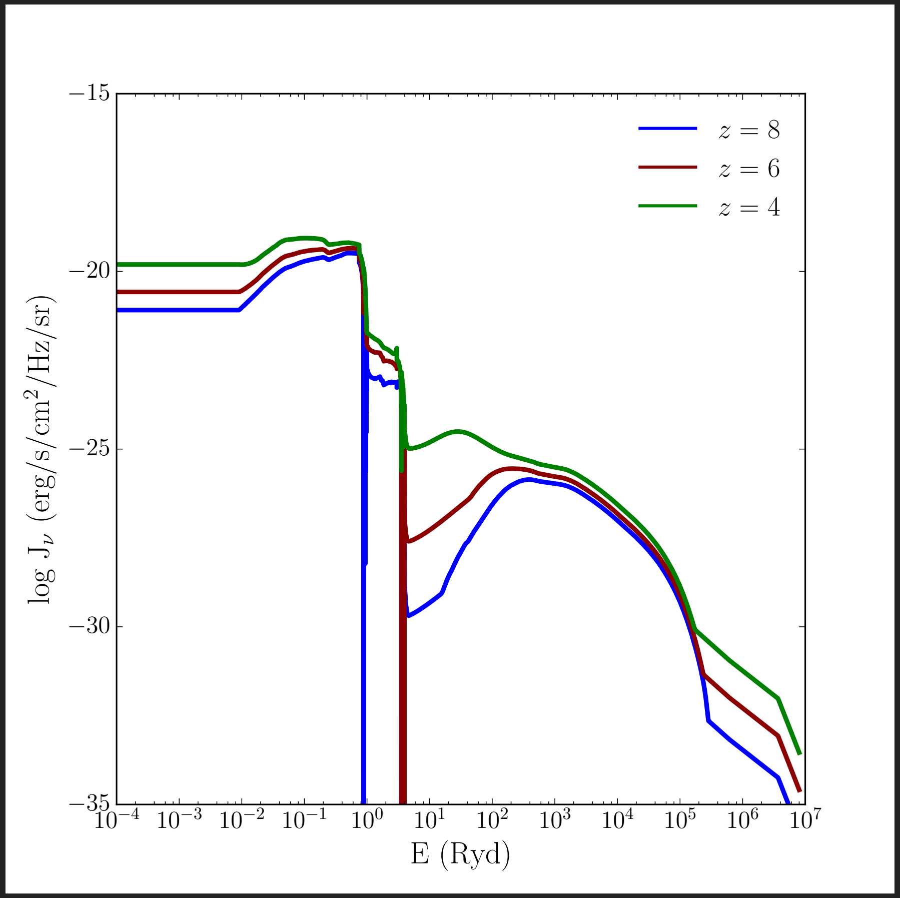
Molecular cooling

NUMERICAL APPROACH:

2. ASSUME A UV BACKGROUND CONSISTENT AT HIGH REDSHIFT

Uniform UV ionizing field: radiation background due to the CMB + ultraviolet/X-ray photons from quasars and galaxies with saw-tooth attenuation (Haardt & Madau 2012).





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$$\Gamma(z) = \int_{\nu_{\rm th}}^{\infty} \frac{4\pi J(\nu, z)}{h\nu}\, \sigma(\nu)\, d\nu$$

Grand sum of ionizing flux from quasars and galaxies

NUMERICAL APPROACH:

3. METAL IONS COMPUTED WITH CLOUDY PHOTO-IONIZATION CODE V8.1 FOR OPTICALLY THIN GAS IN IONIZATION EQUILIBRIUM (FERLAND 2013).

NUMERICAL APPROACH:

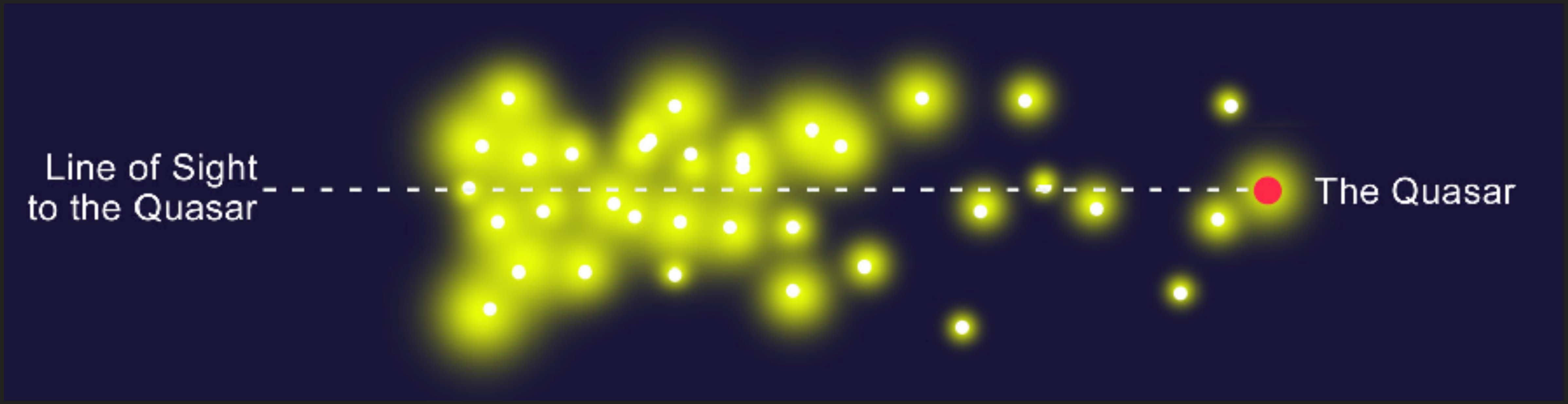
4. IMPLEMENT A PRESCRIPTION HI SELF-SHIELDING TO ACCURATELY DESCRIBE THE REGIONS INSIDE THE MASSIVE DARK MATTER HALOS (RAHMATI ET AL. 2013)

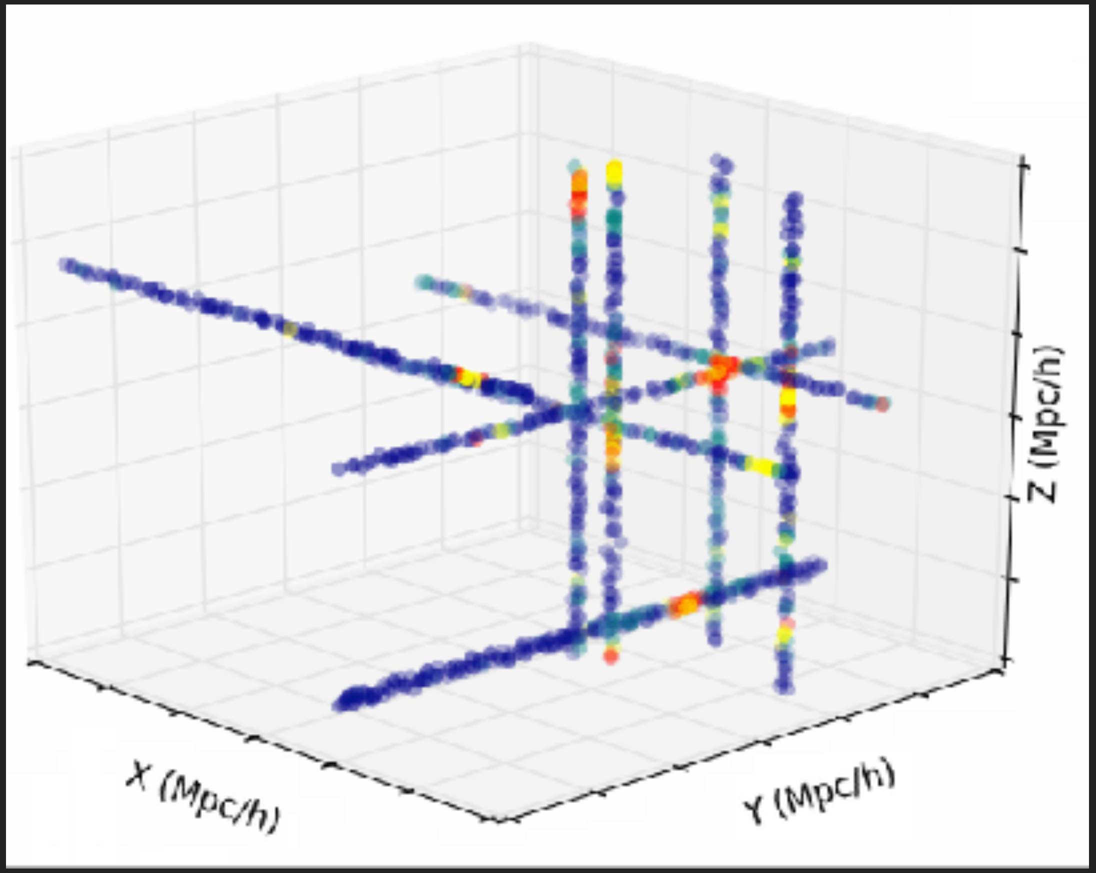
$$\frac{\Gamma_{\rm phot}}{\Gamma_{\rm UVB}} = (1-f)\left[1+\left(\frac{n_H}{n_0}\right)^{\beta}\right]^{\alpha_1} + f\left[1+\frac{n_H}{n_0}\right]^{\alpha_2}$$

NUMERICAL APPROACH:

5. GENERATE 1000 RANDOM LINES OF SIGHT INSIDE THE BOX.

NUMERICAL APPROACH:



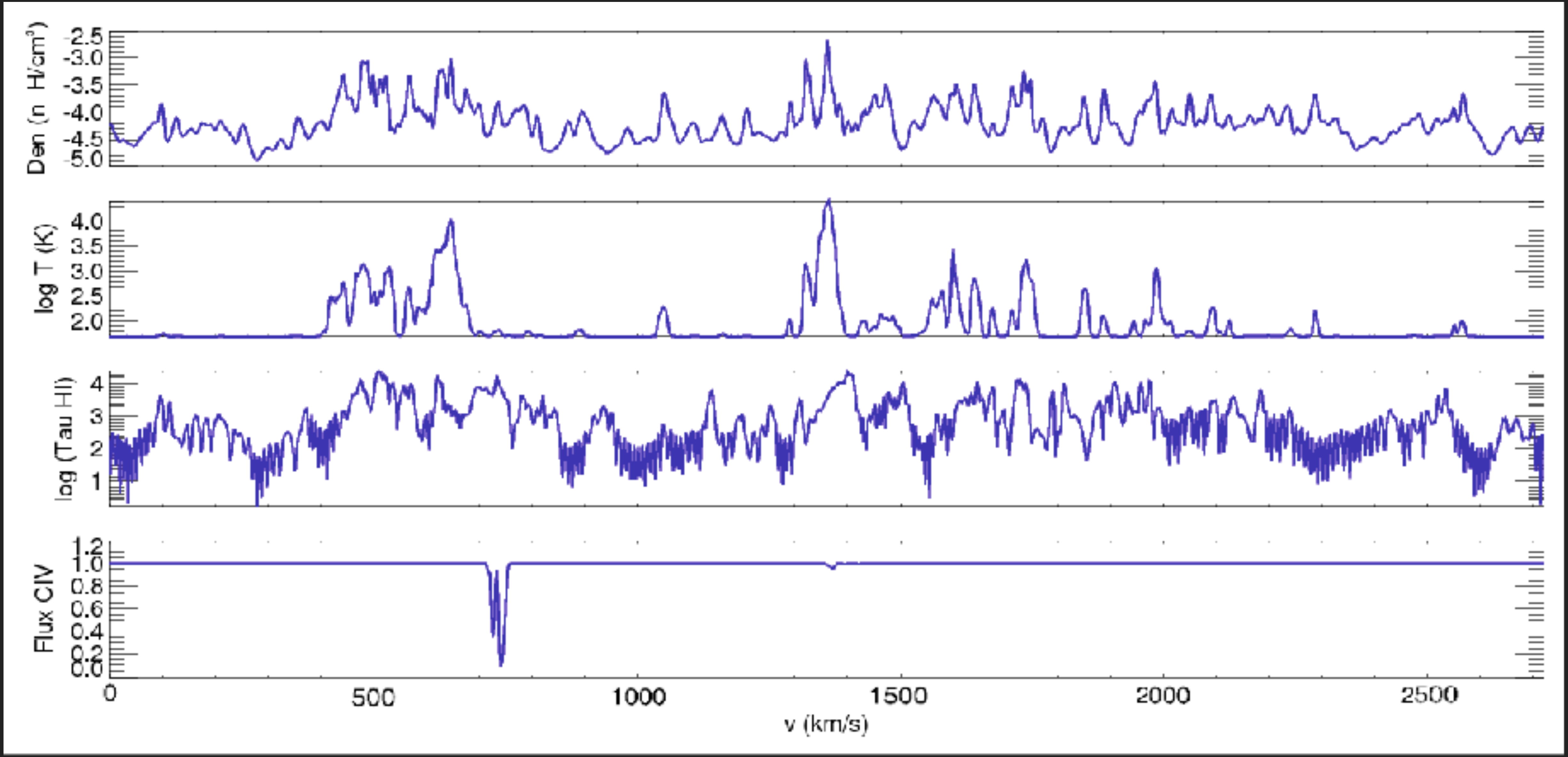


5. GENERATE 1000 RANDOM LINES OF SIGHT INSIDE THE BOX.

NUMERICAL APPROACH:

6. RECOVER THE SPECTRA OF EACH ION IN EACH LINE OF SIGHT

(C II, C IV, SI II, SI IV, O I).



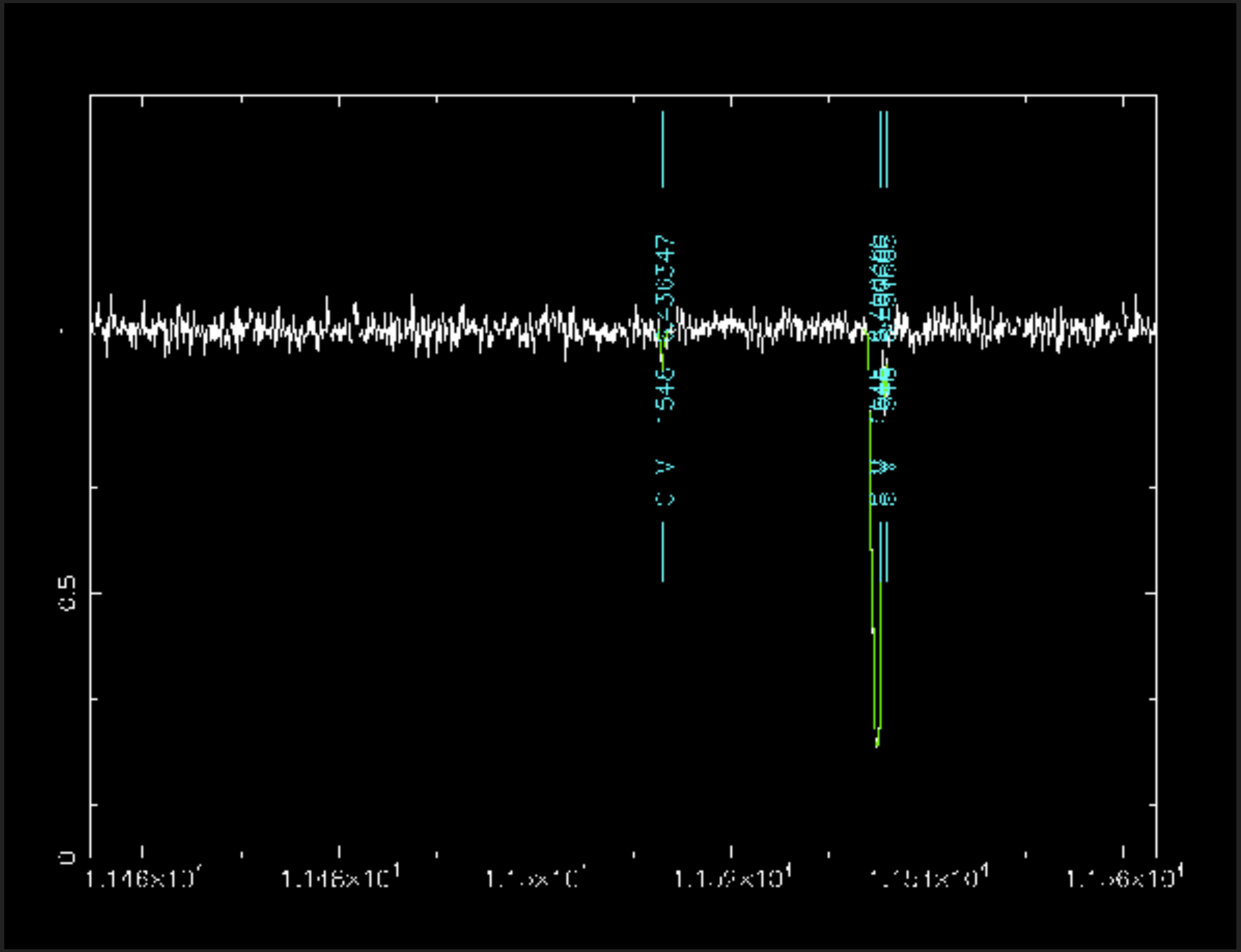
NUMERICAL APPROACH:

7. CONVOLVE SYNTHETIC SPECTRA WITH GAUSSIAN NOISE.

NUMERICAL APPROACH:

8. USE VOIGT PROFILES TO FIT THE ABSORPTION FEATURES AUTOMATICALLY WITH THE CODE VPFIT 10.2.

NUMERICAL APPROACH:



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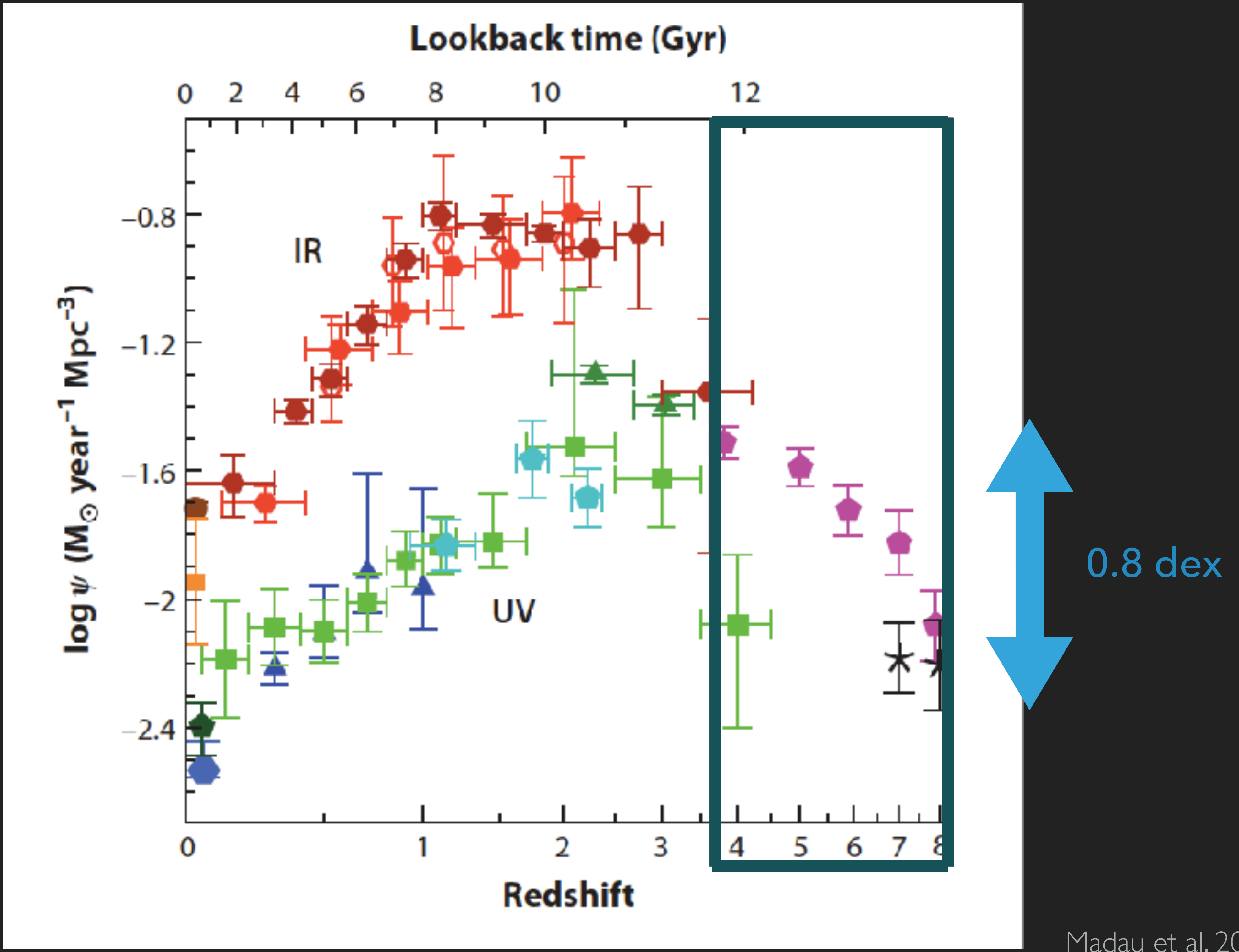
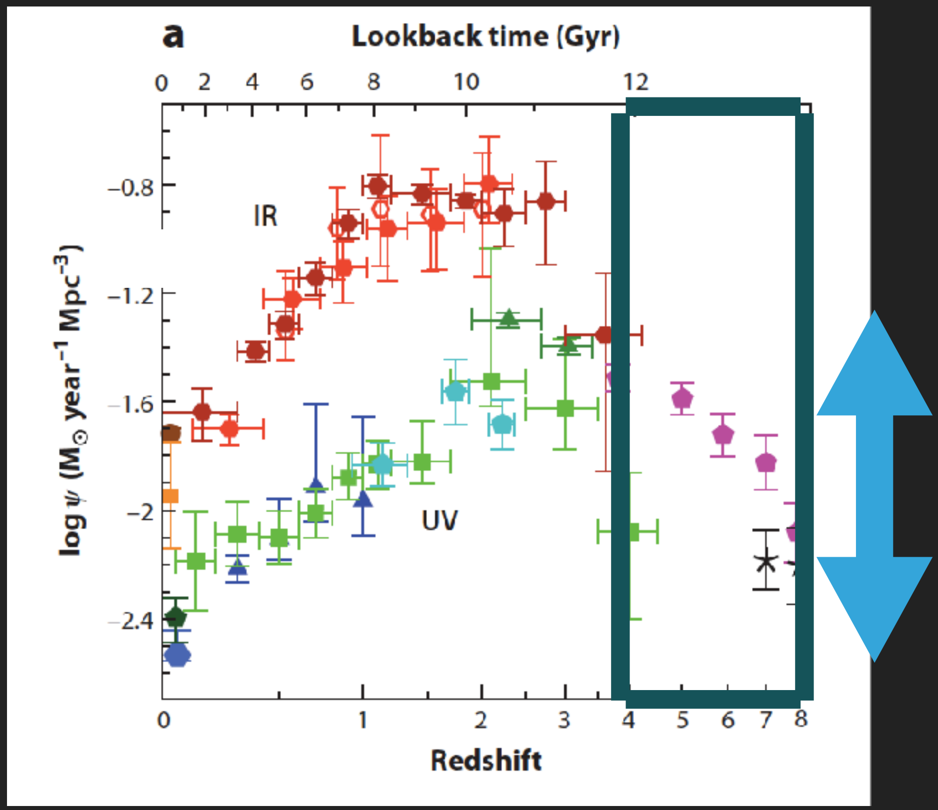
STAR FORMATION RATE DENSITY

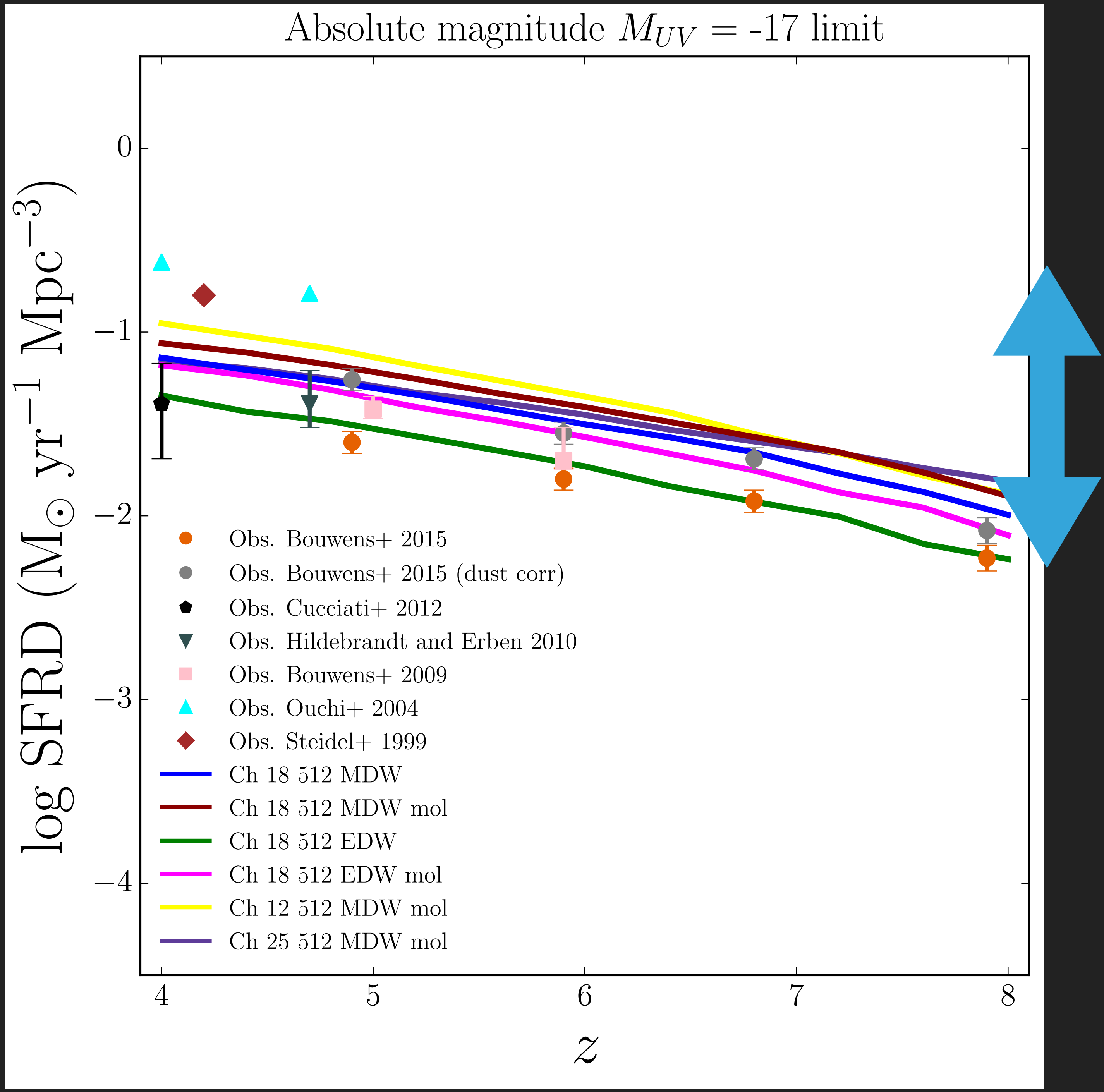


Madau et al. 2014

STAR FORMATION RATE DENSITY

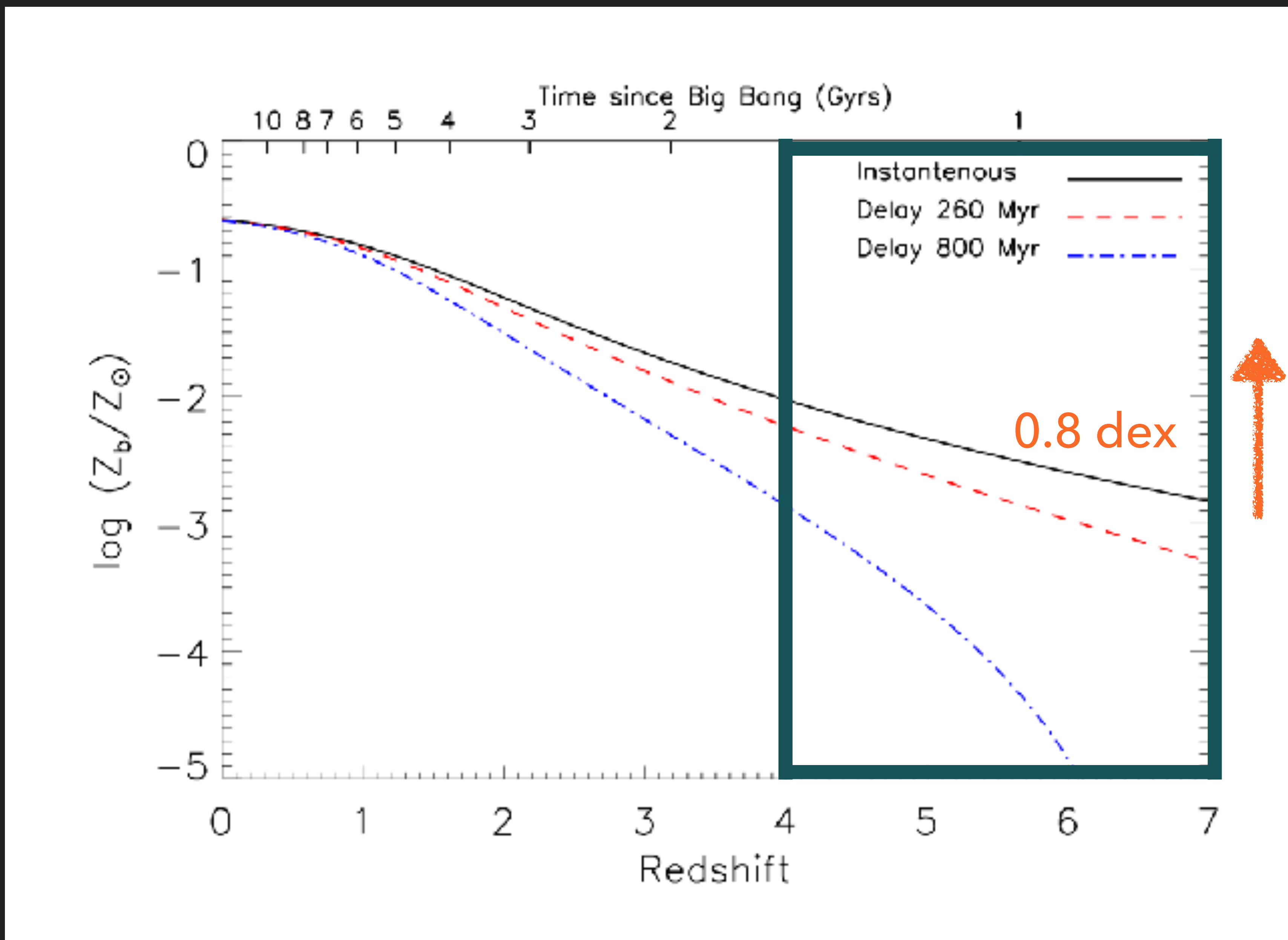


Madau et al. 2014



García et al. 2017a

CHEMICAL ENRICHMENT



Díaz et al. in prep

$$Z_b(z) \equiv \frac{y\rho_*(z)}{\rho_b}$$

Mean metallicity of the Universe:

y: amount of heavy metals

$\rho_*(z)$

model SFR

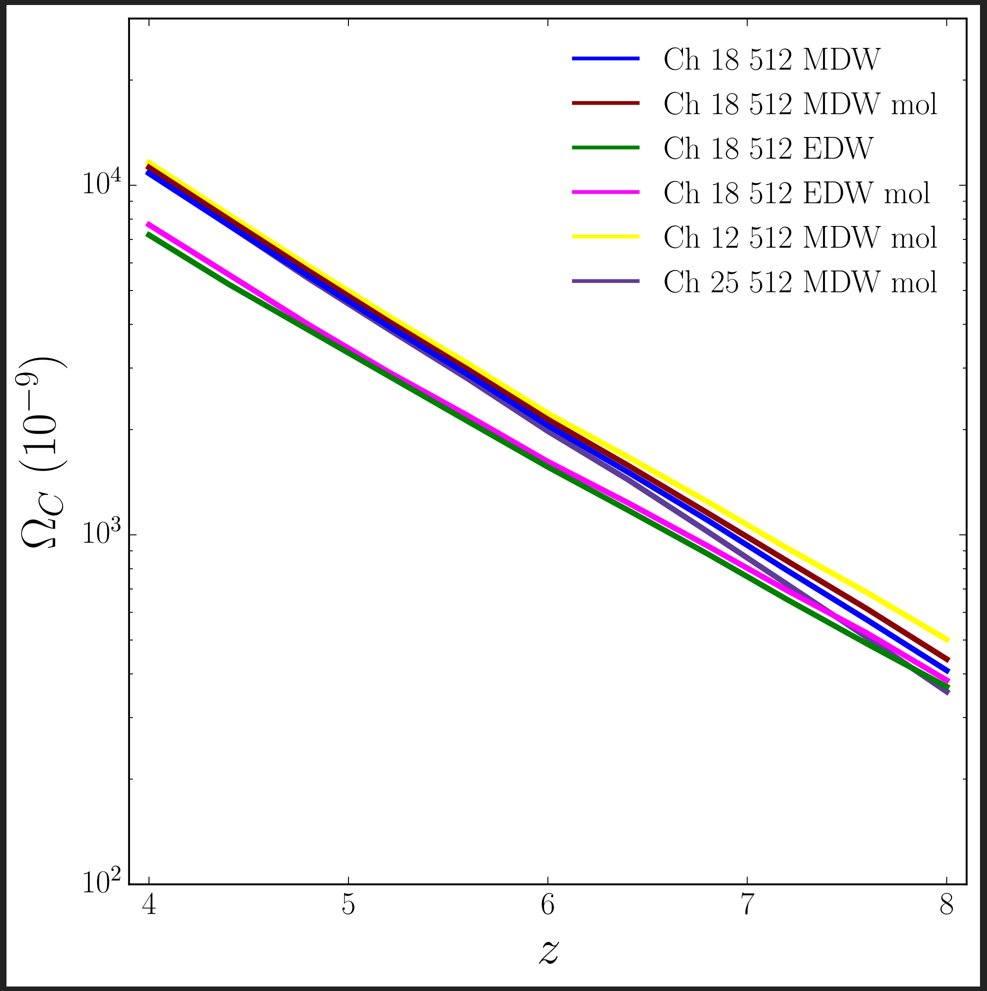
IMF

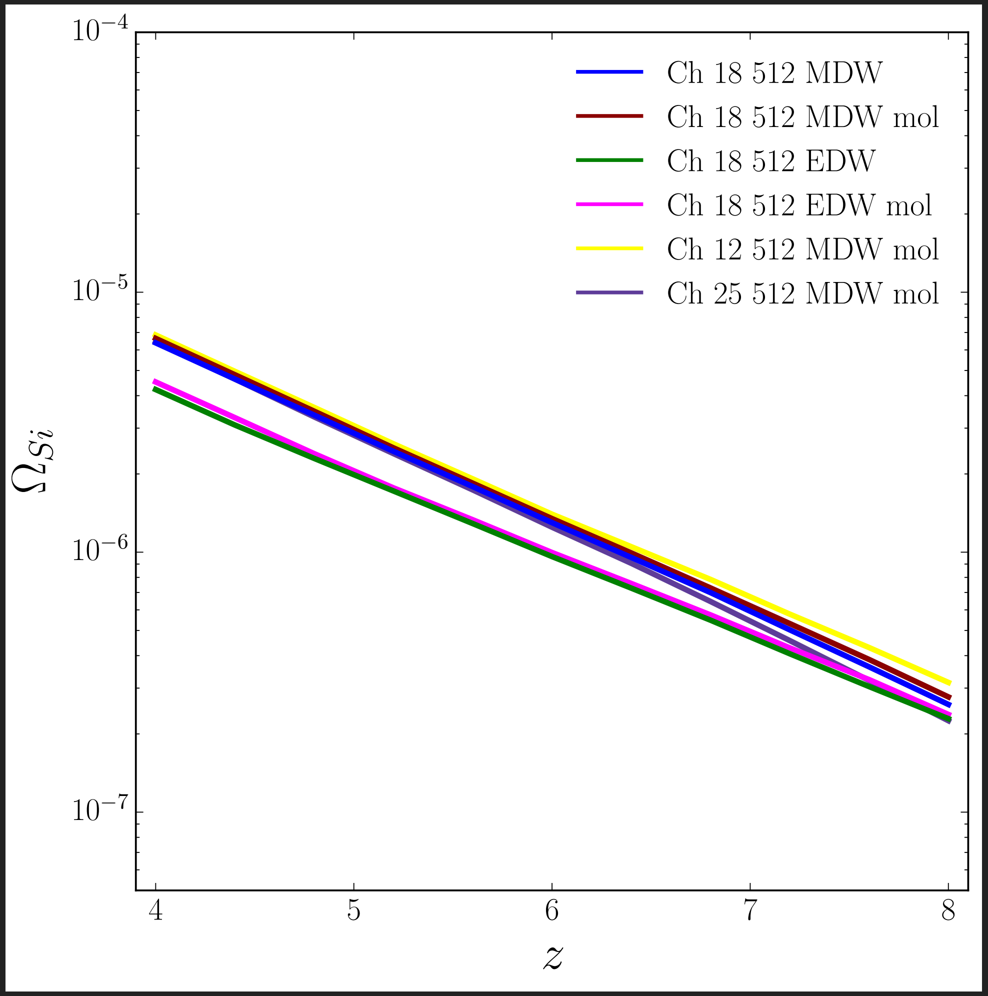
stellar yields

CHEMICAL ENRICHMENT

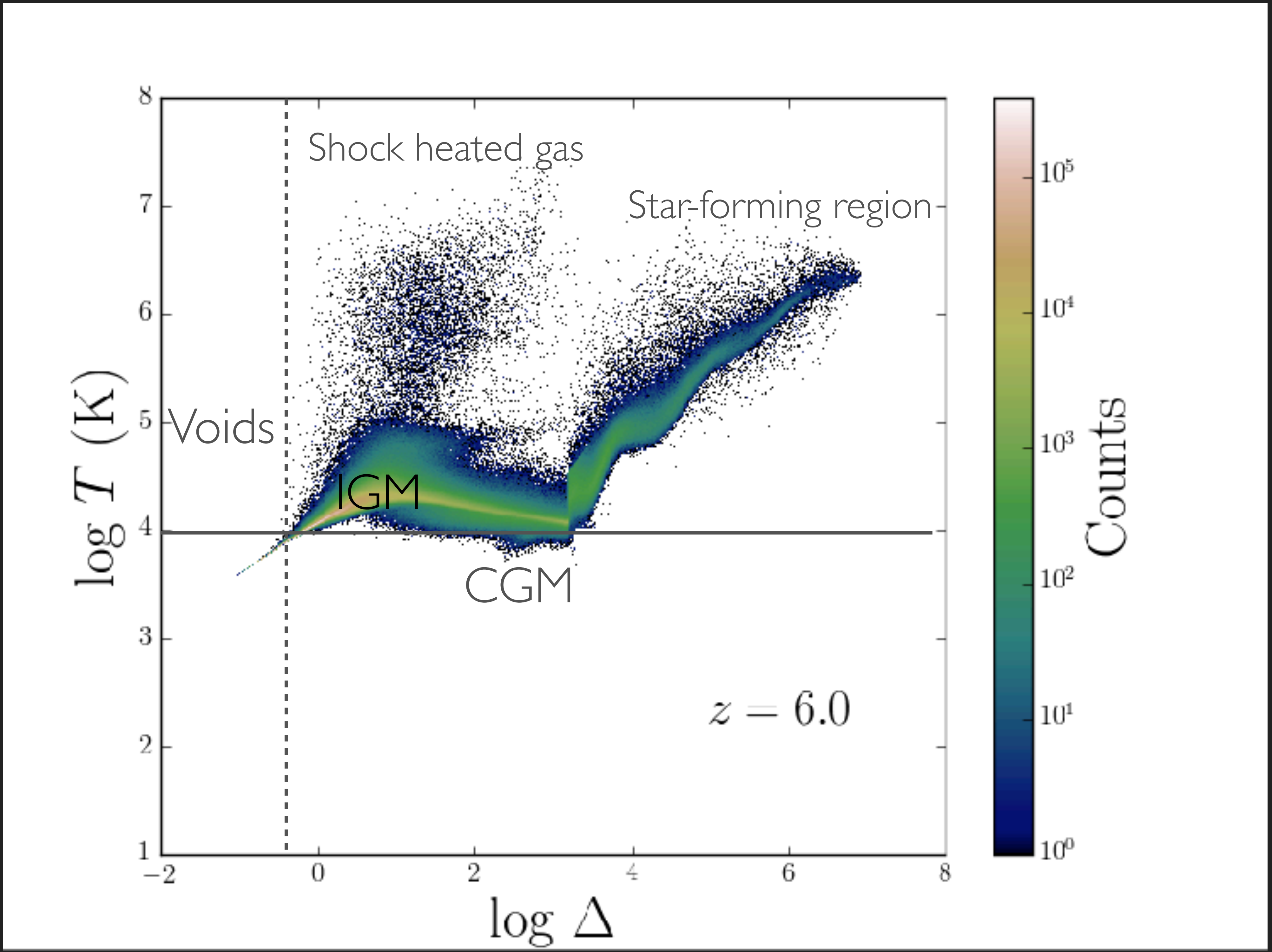
* Difference between EDW / MDW feedback models.

* Consistent with observational constraints at high z.

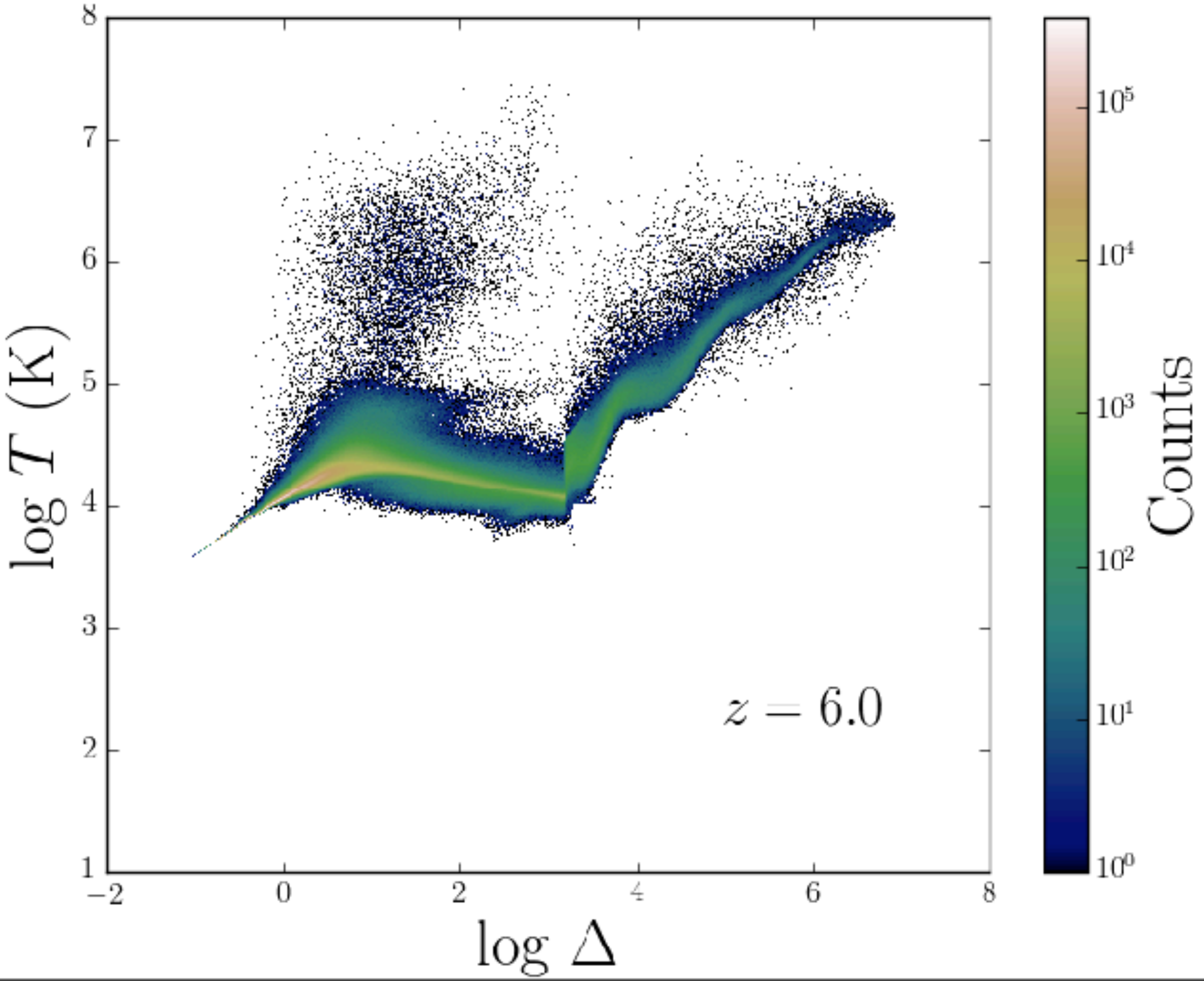


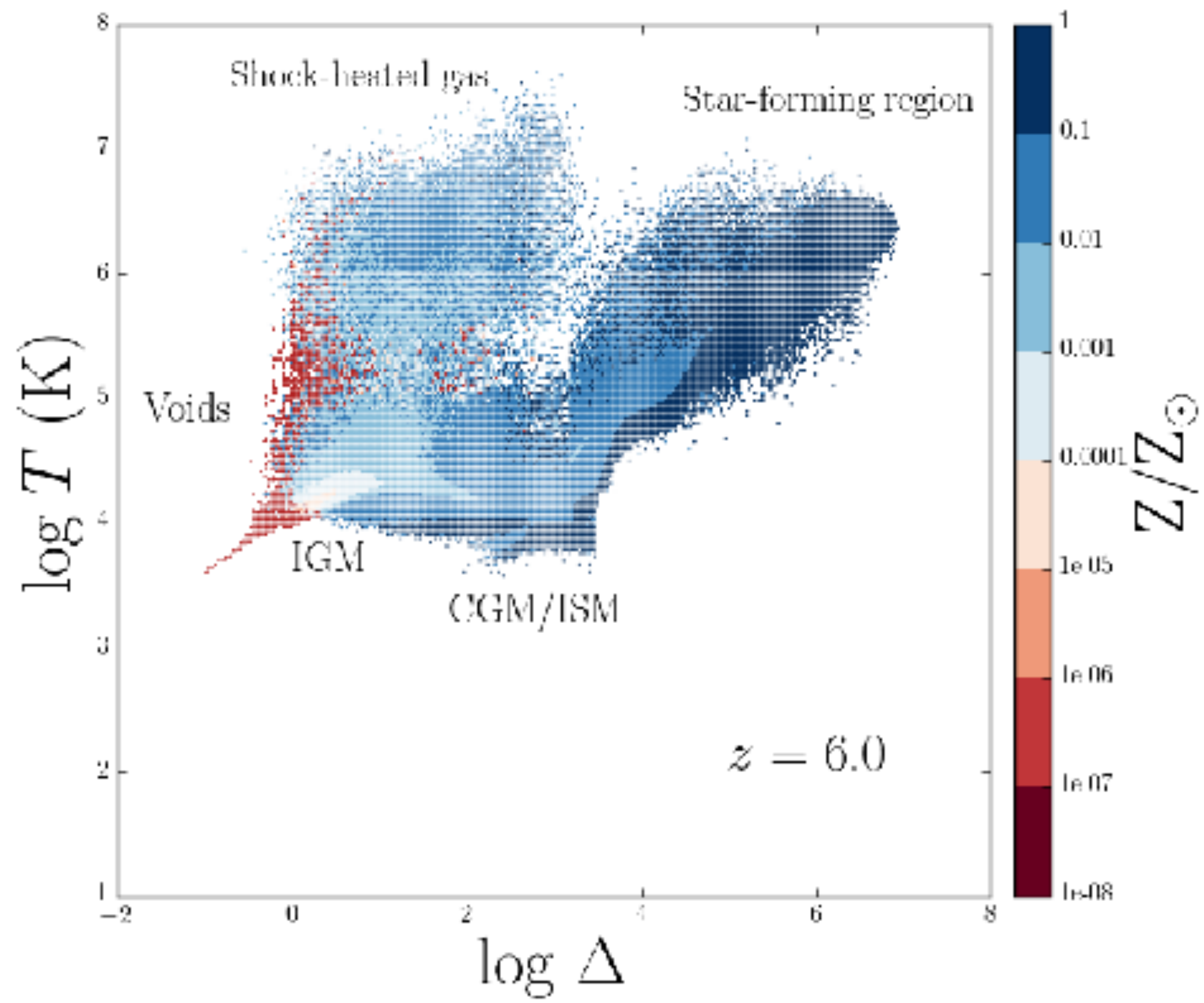


MULTIPHASE GAS

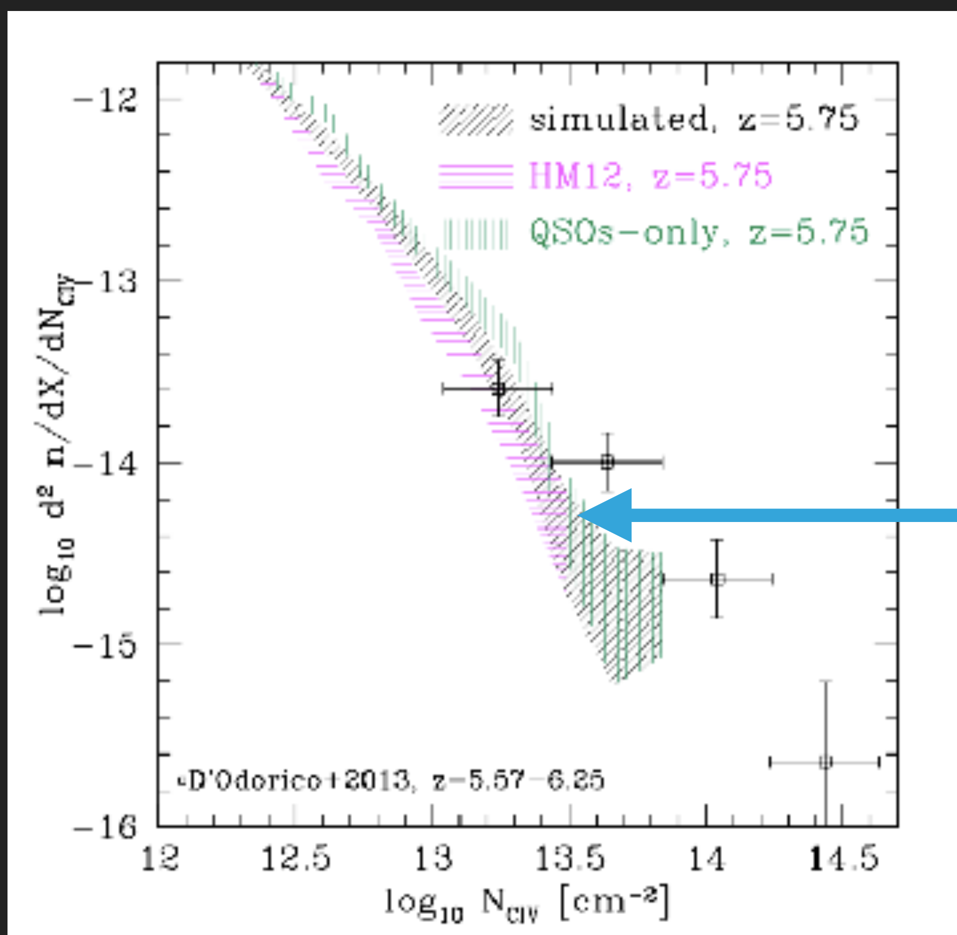


MULTIPHASE GAS – METALLICITY

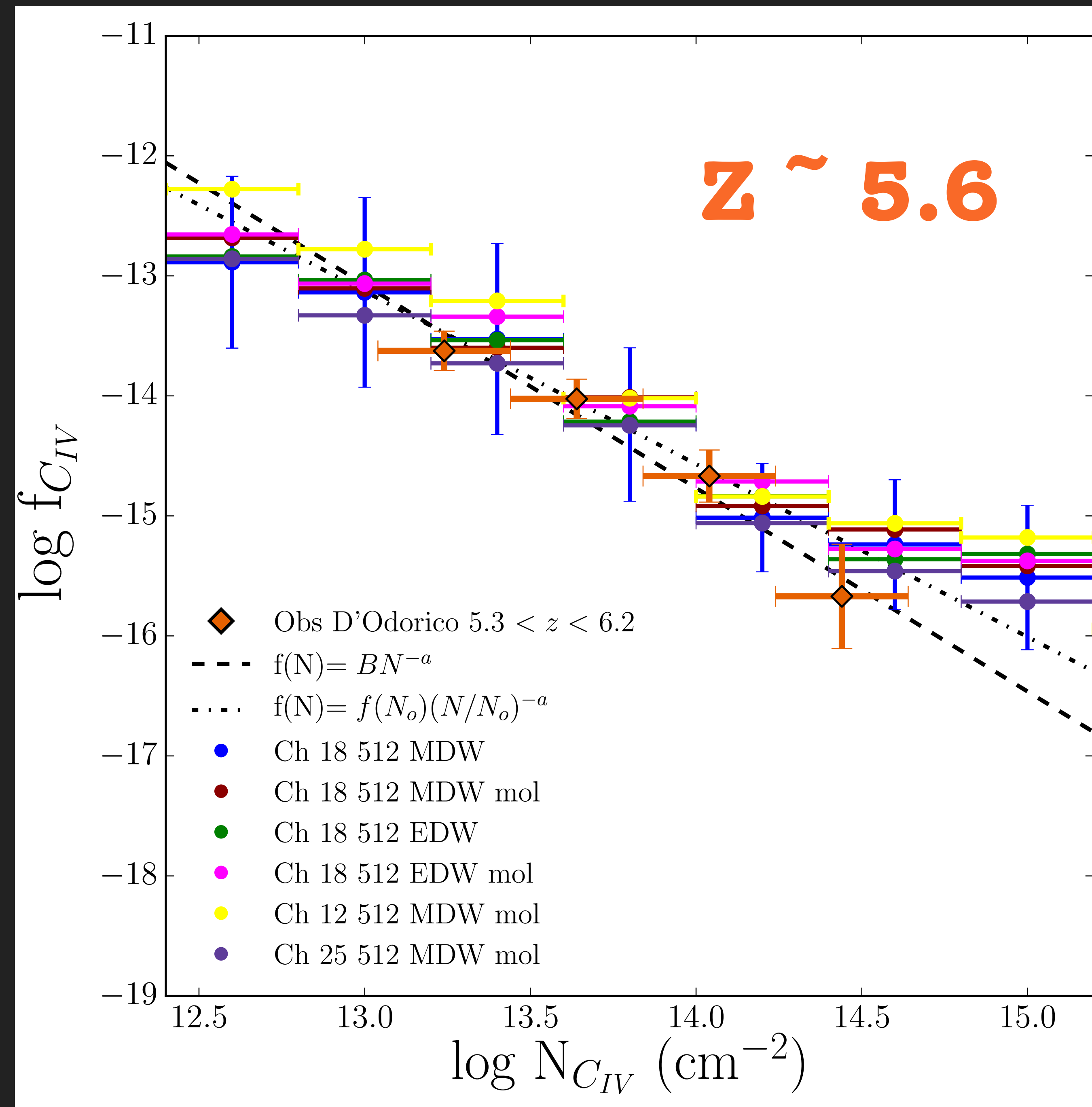




CIV – CDDF CALIBRATION



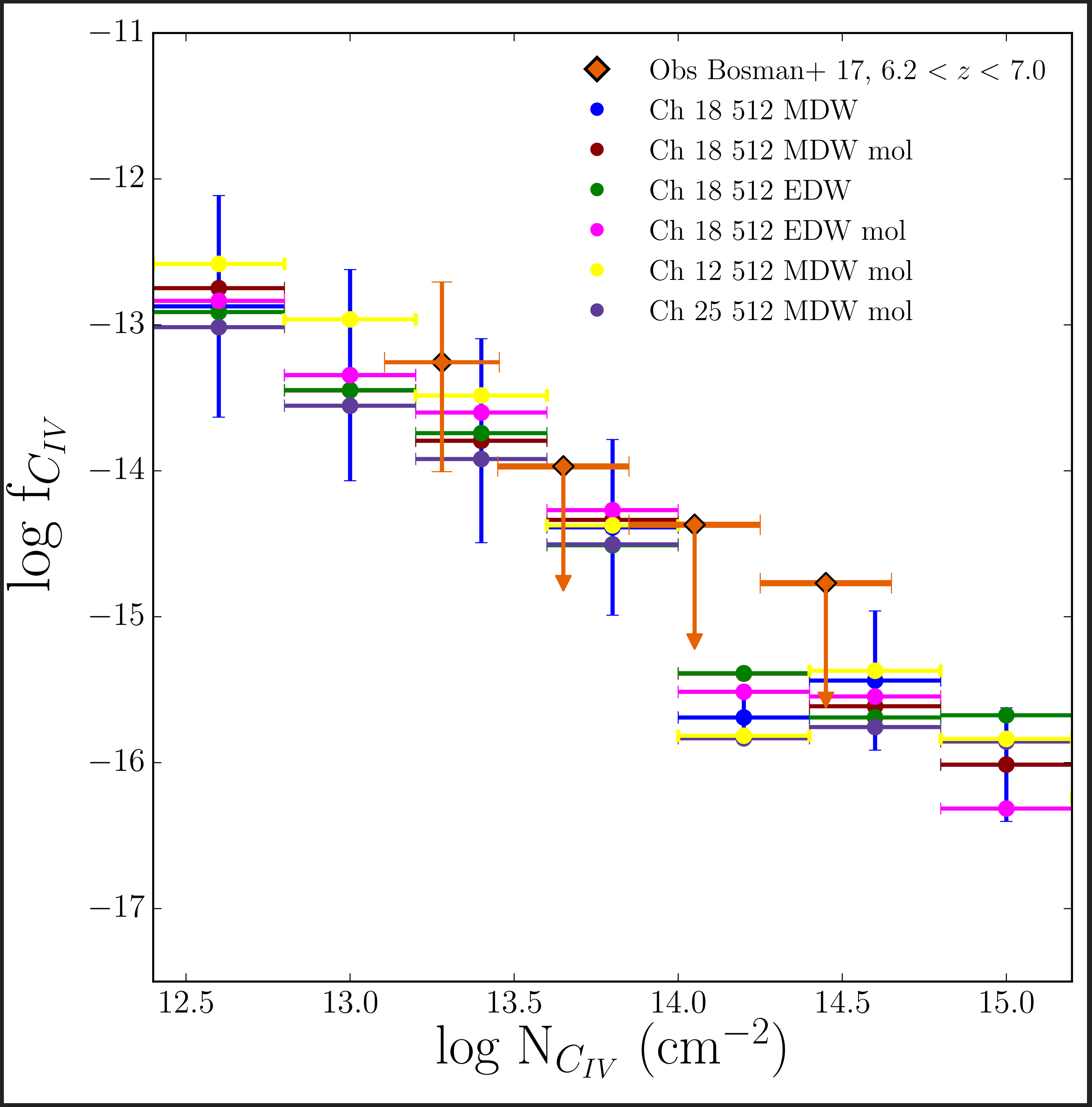
Finlator et al. 2016



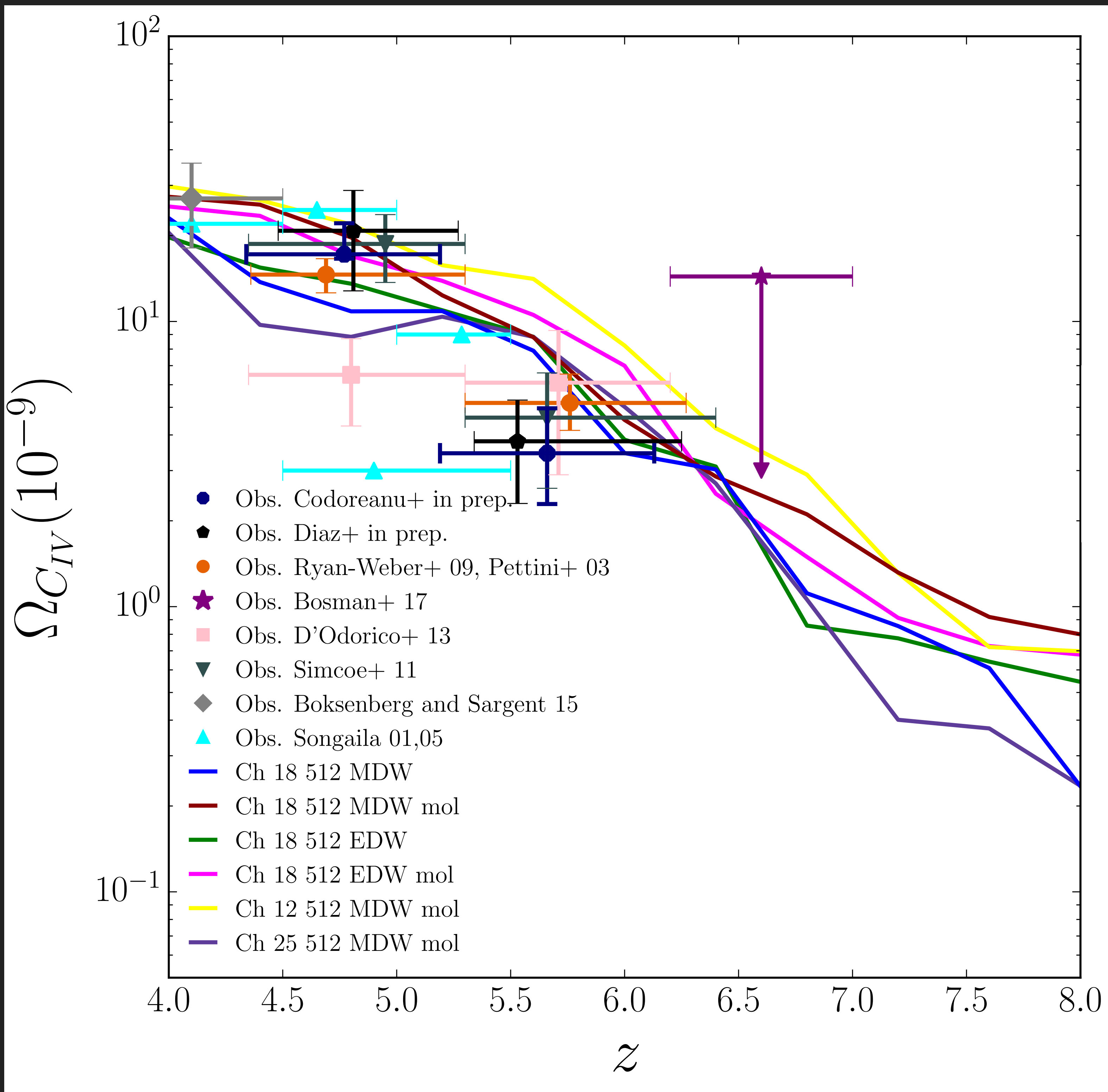
García et al. 2017a

In most works, strong CIV absorbers are quite rare!

CIV - CDDF AT $z \sim 6.4$



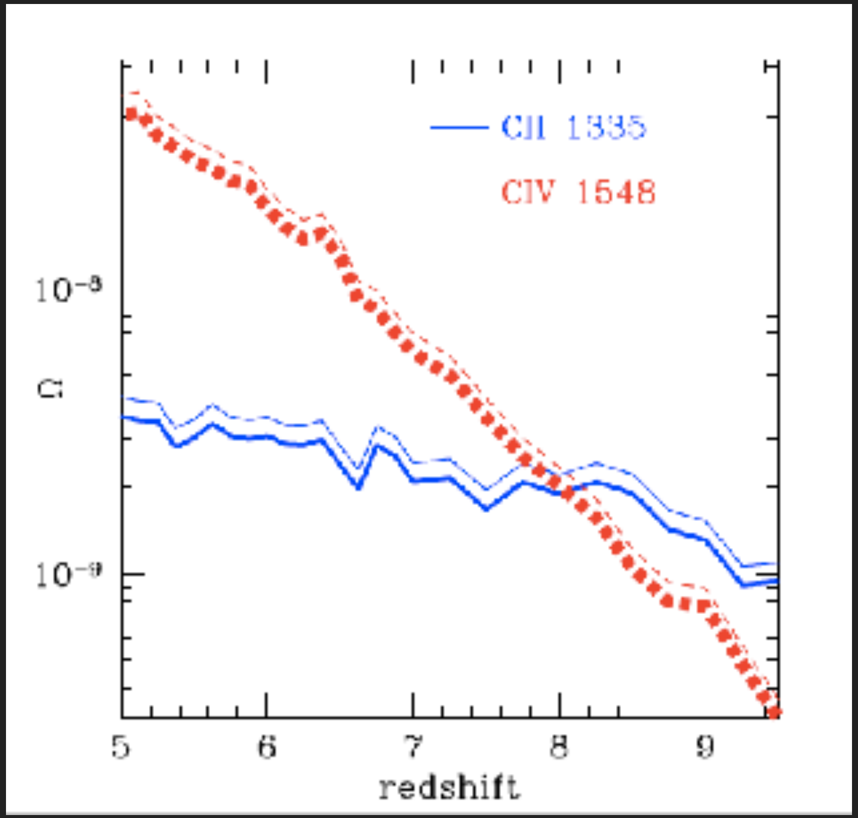
CIV COSMOLOGICAL MASS DENSITY



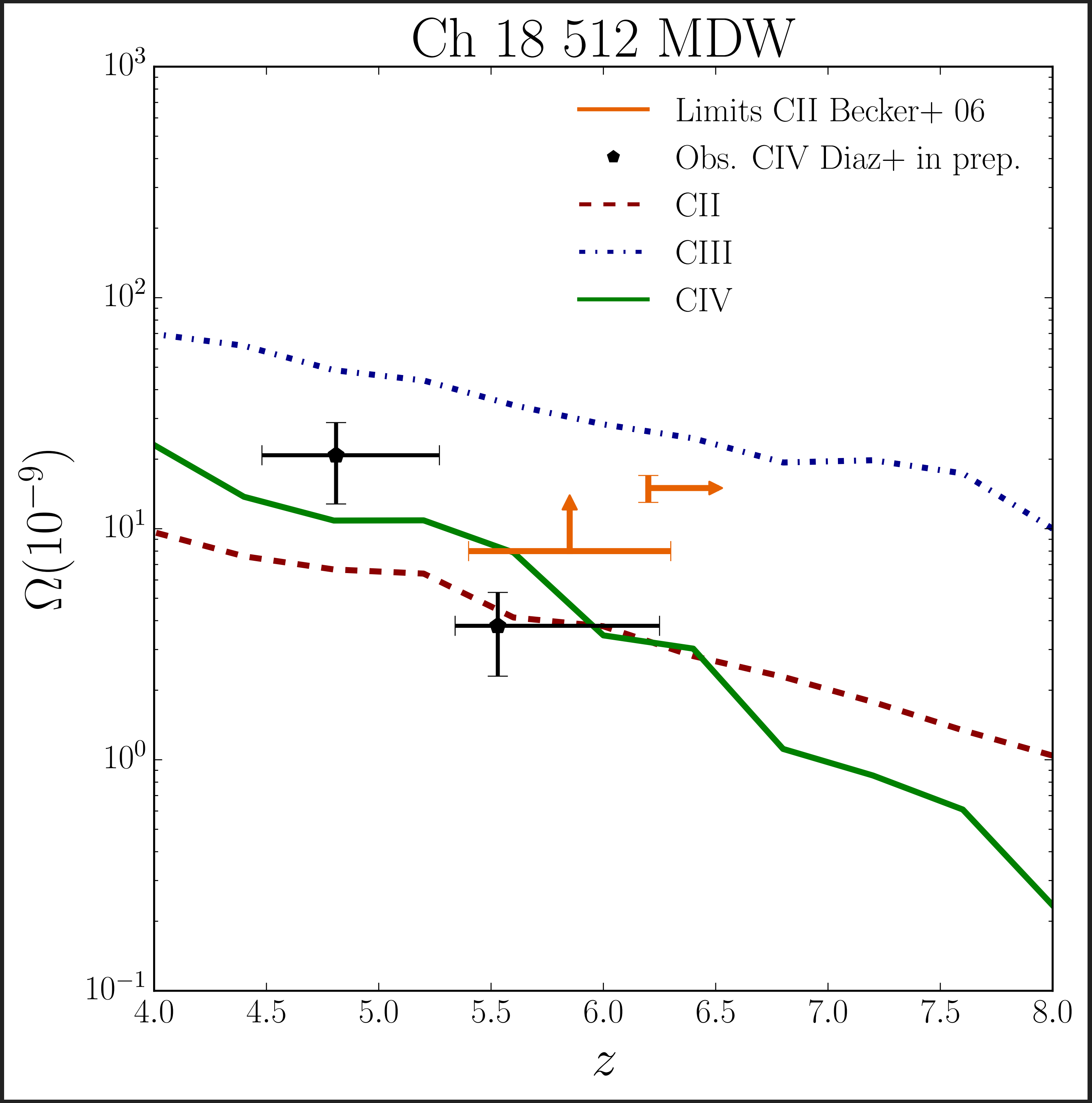
$$\Omega(\text{ion}, z) = \frac{H_0 m_{\text{ion}}}{c\rho_{\text{crit}}} \frac{\Sigma N(\text{ion}, z)}{\Delta X n_{\text{LoV}}}$$

Adapted from García et al. 2017a
with new data

C STATES COSMOLOGICAL MASS DENSITY

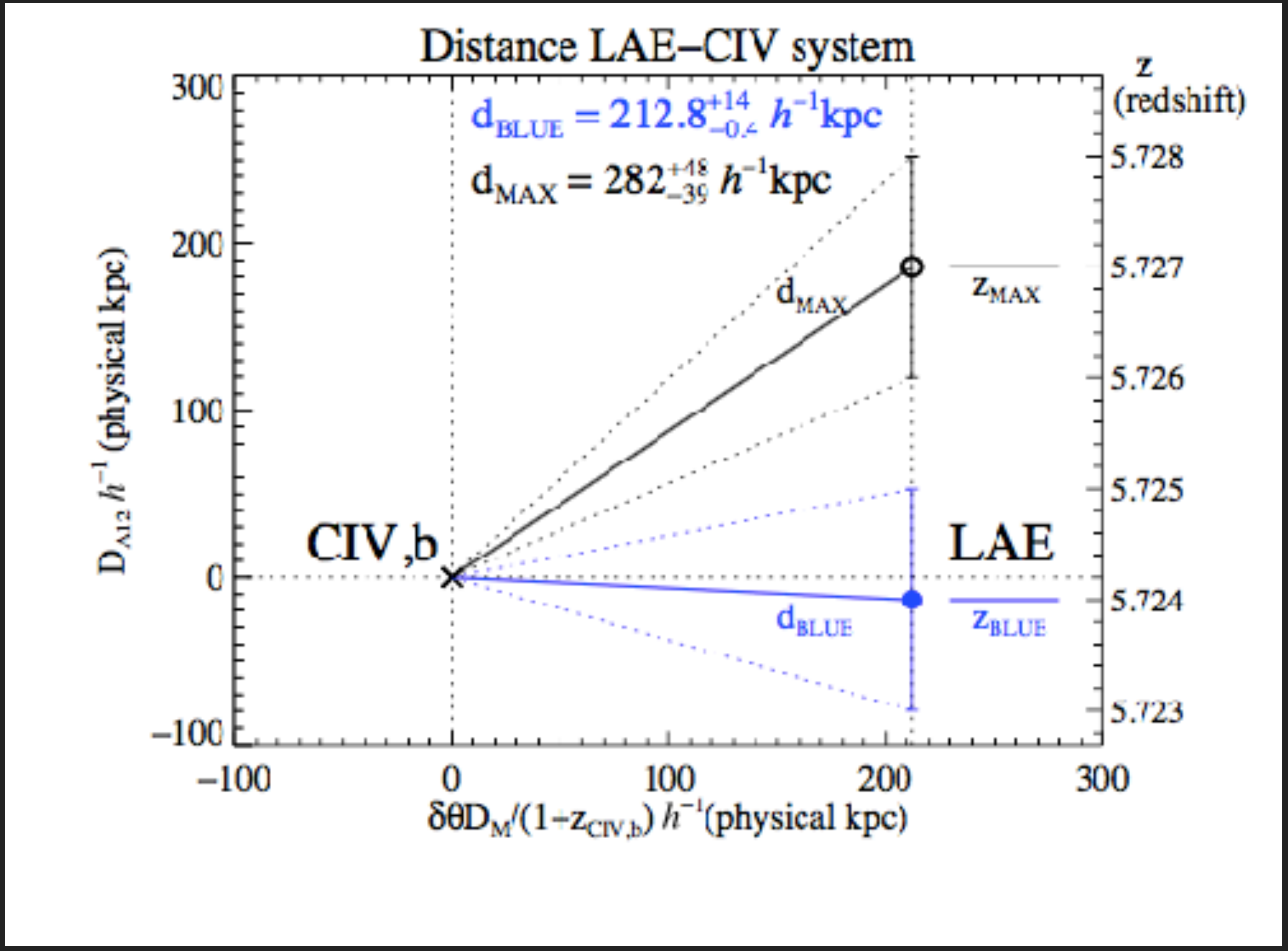


Finlator et al. 2015



LAE - CIV absorption pair

212 pkpc = 1360 ckpc



Díaz et al. 2015

$M_{UV} = -20.7$ (detected LAE)

LAE: Lyman alpha emitter

LAE - CIV absorption pair

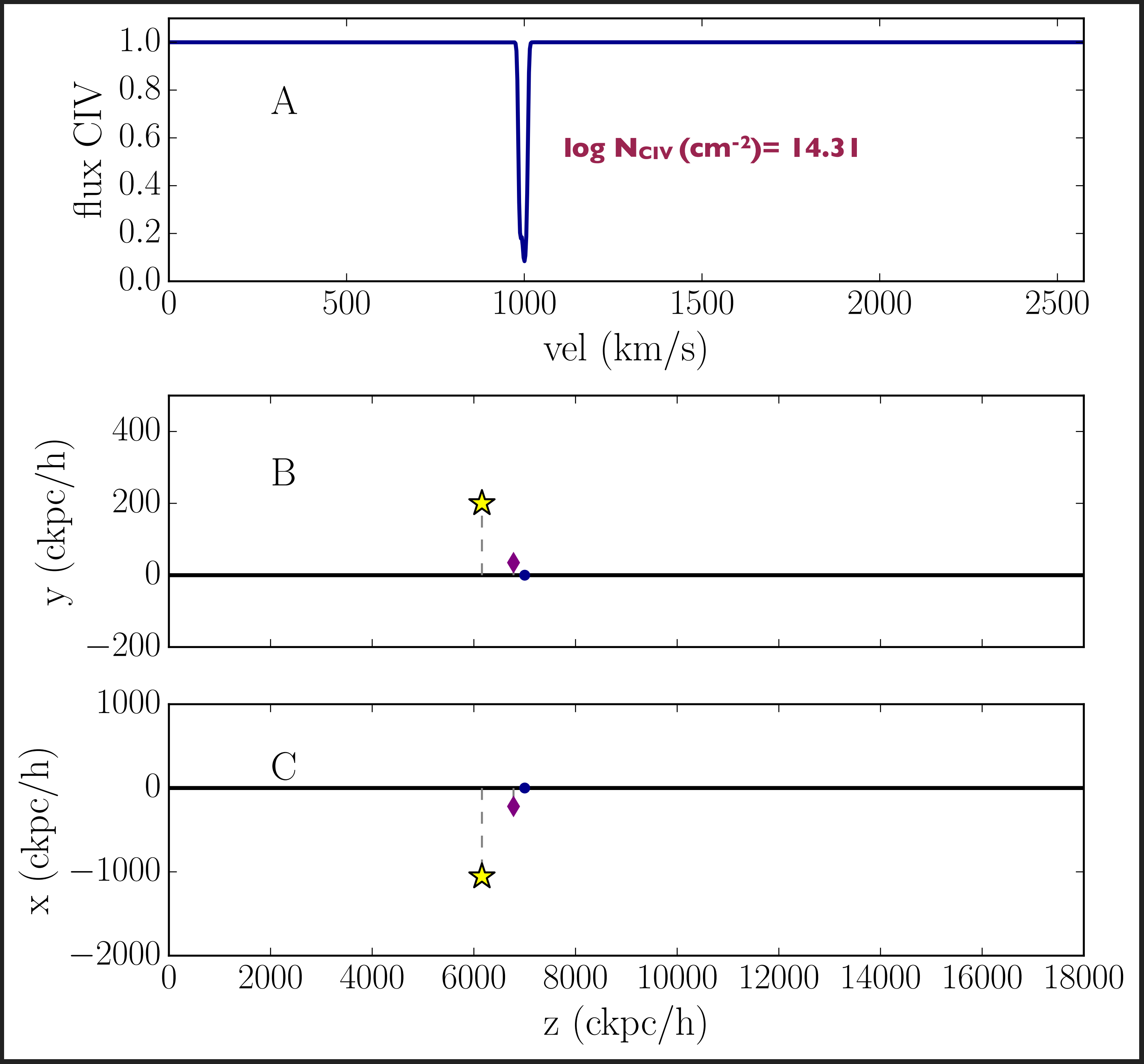
Box size (cMpc/h)	M_h ($\times 10^{11} M_\odot$)	v_w (km/s)	t (Gyr)
18	4.9	446	0.73

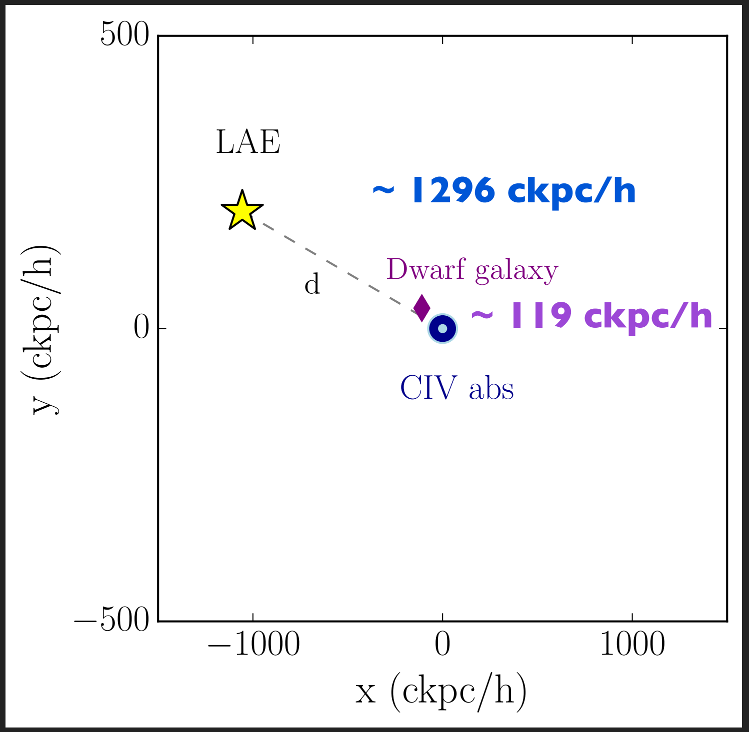
$$v_w = 2\sqrt{\frac{GM_h}{R_{200}}}$$

García et al. 2017b

In our simulations, the enrichment of the region cannot be caused by LAEs at a distance of ~1360 ckpc/h at z = 5.6

LAE – CIV absorption pair

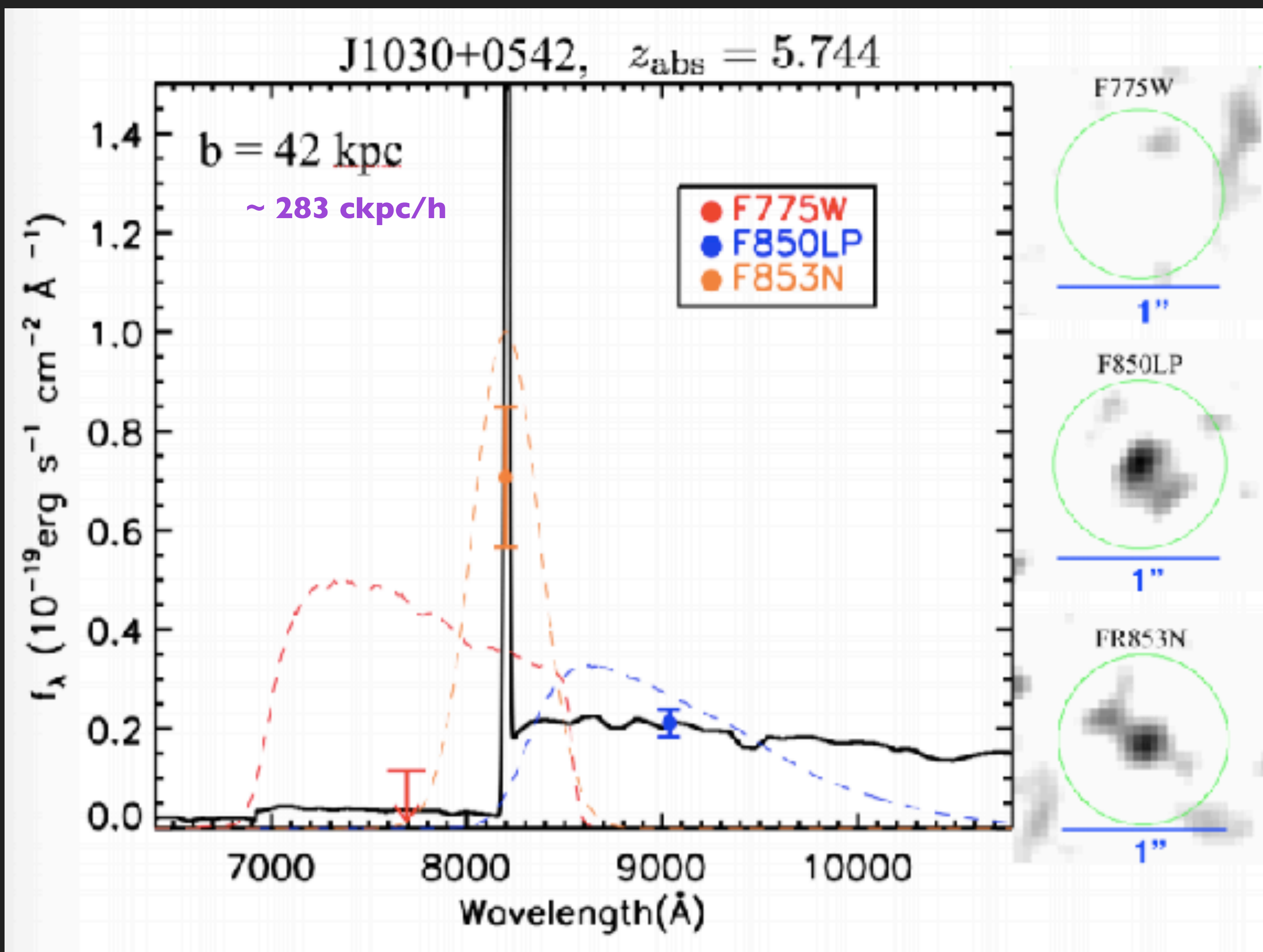




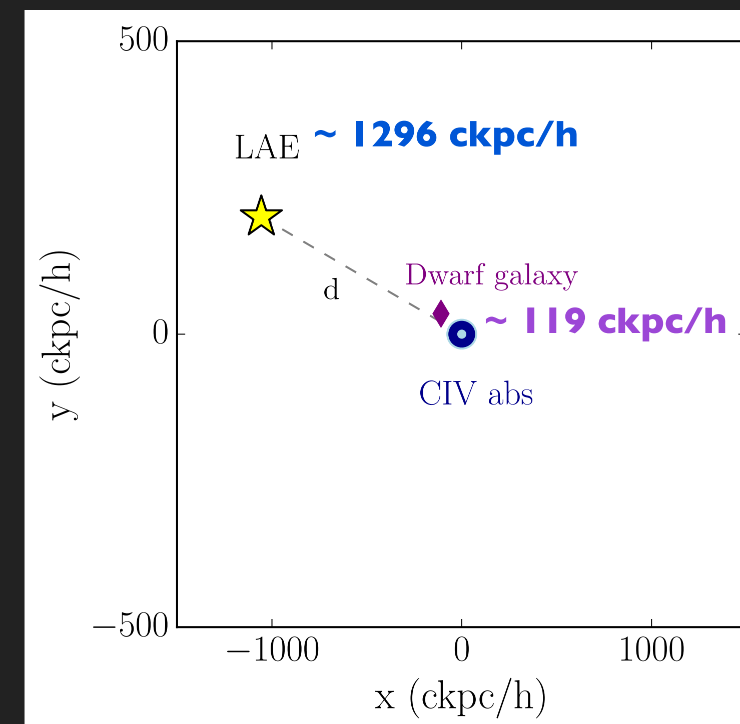
García et al. 2017b

Enrichment is caused by undetected galaxies in the field… the same type of galaxies that complete the budget of ionising photons in the EoR.

LAE - CIV absorption pair



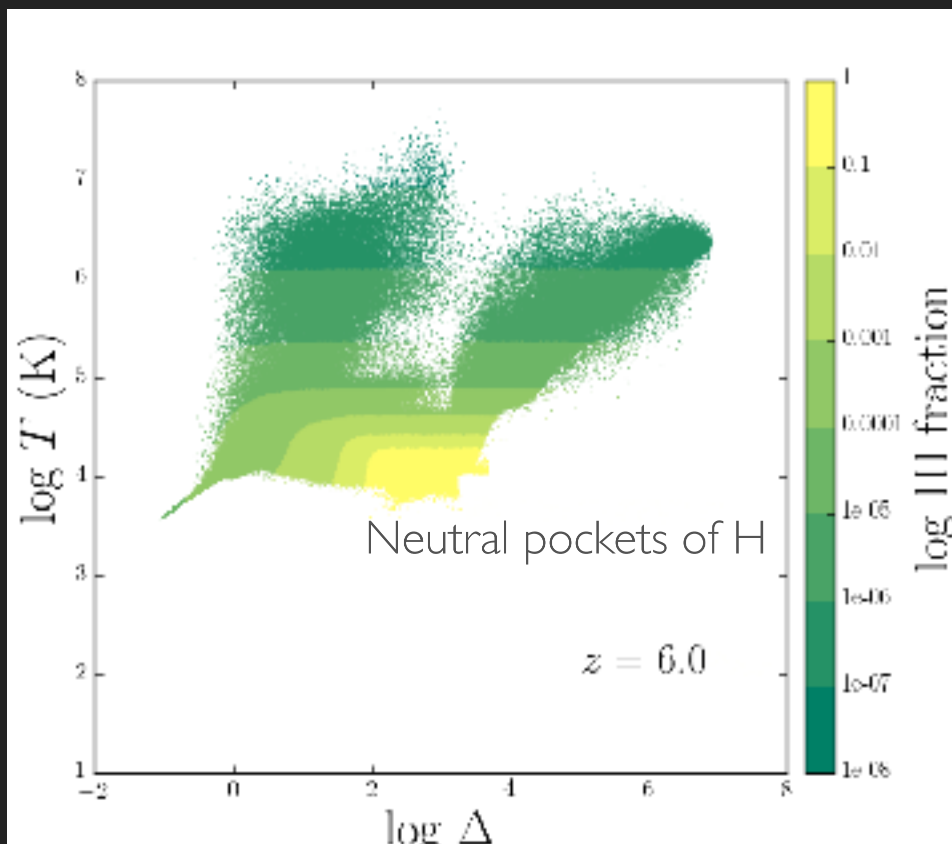
Cai et al. 2017

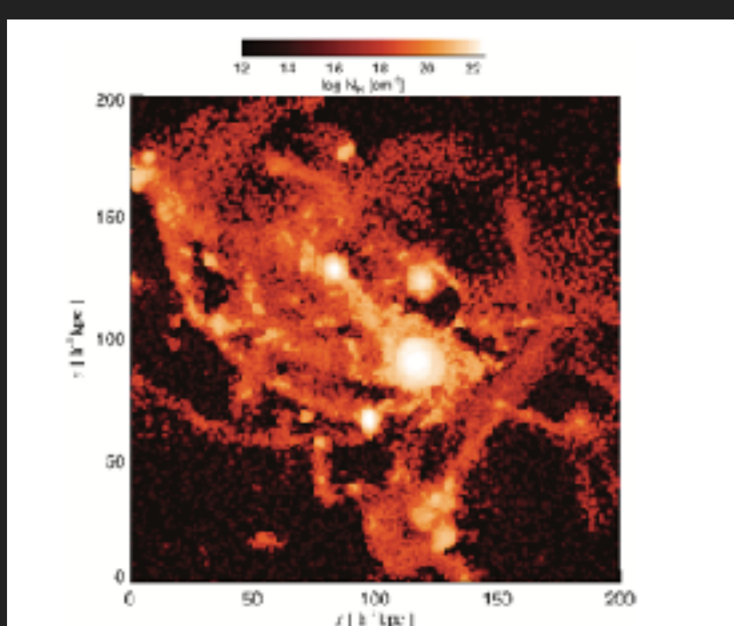


García et al. 2017b

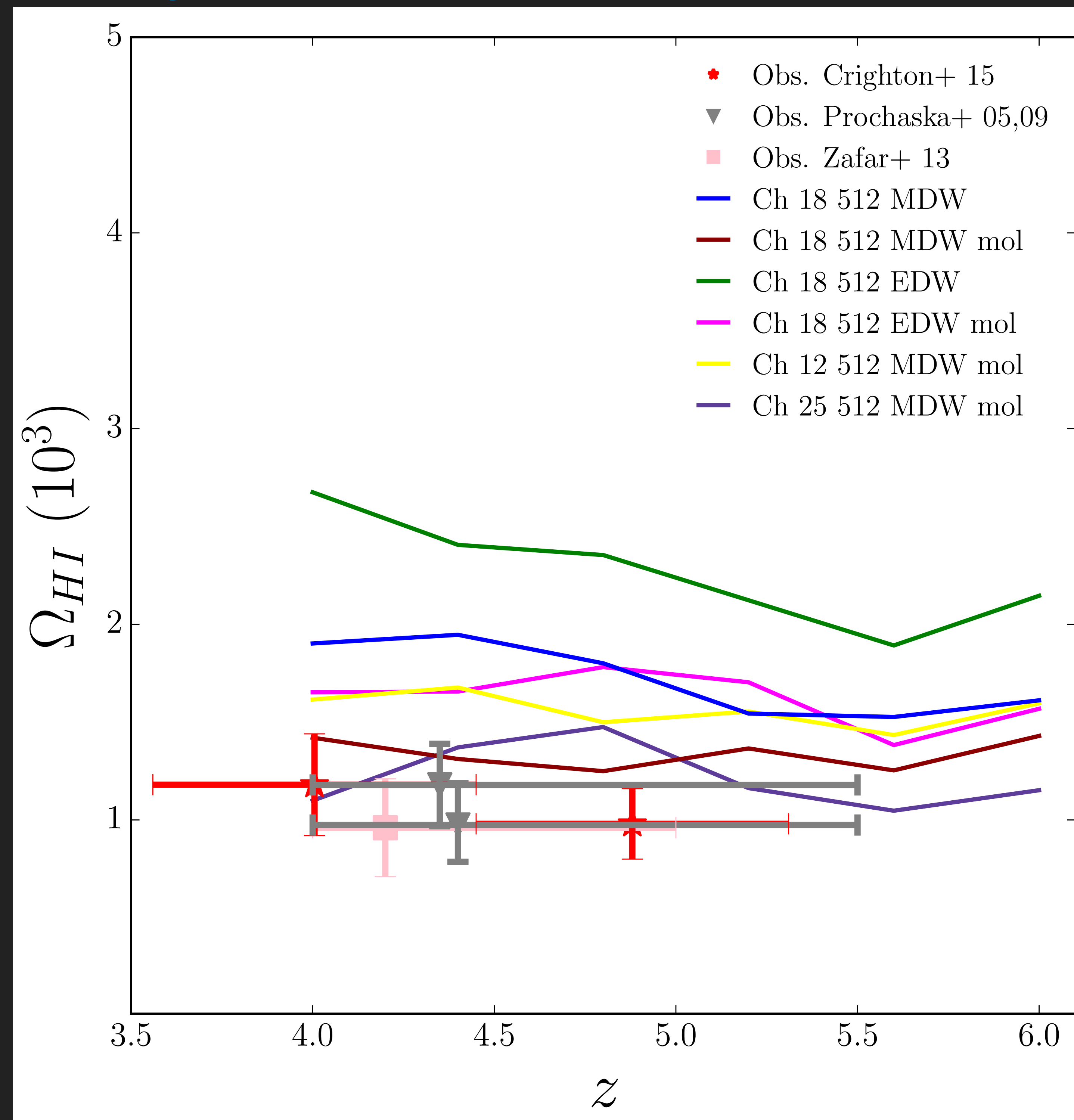
Detections with HST proved that there is an undetected galaxy with SFR = 2 M_o / yr in the field, consistent with our prediction for a dwarf galaxy!!

HI cosmological mass density





Tescari et al. 2009



García et al. 2017a

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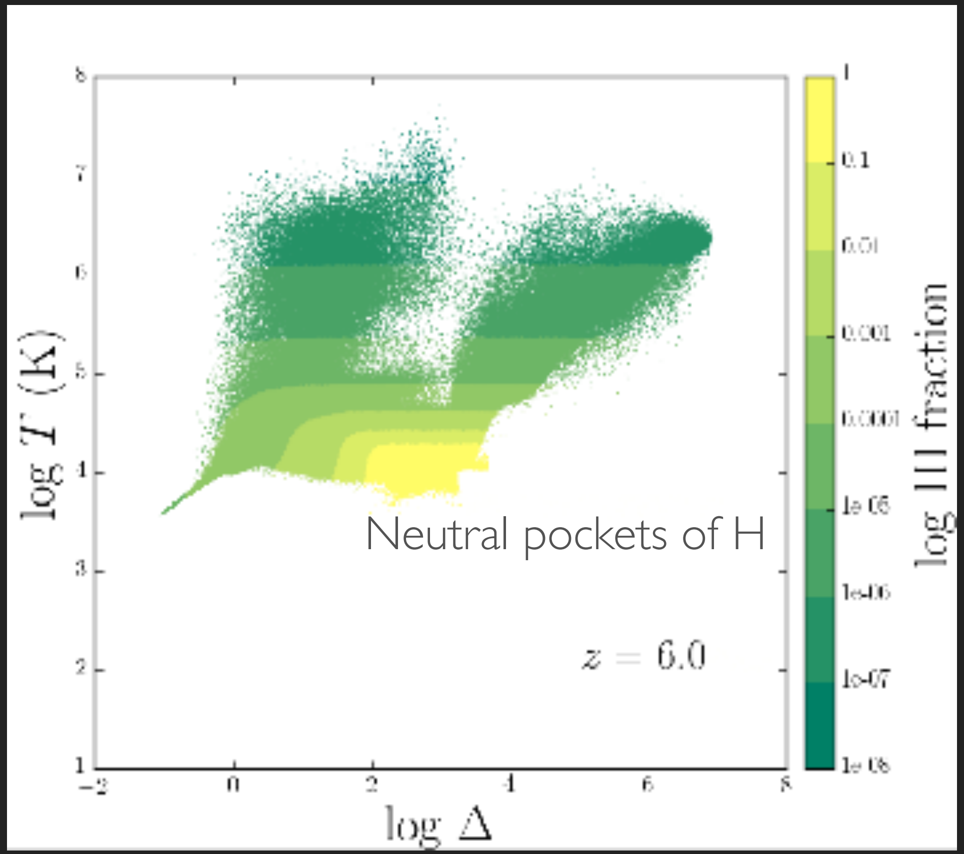
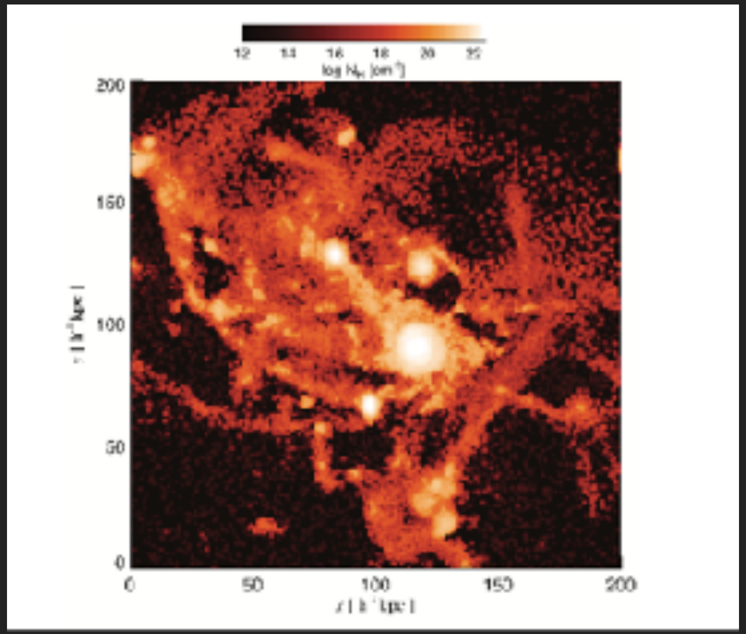
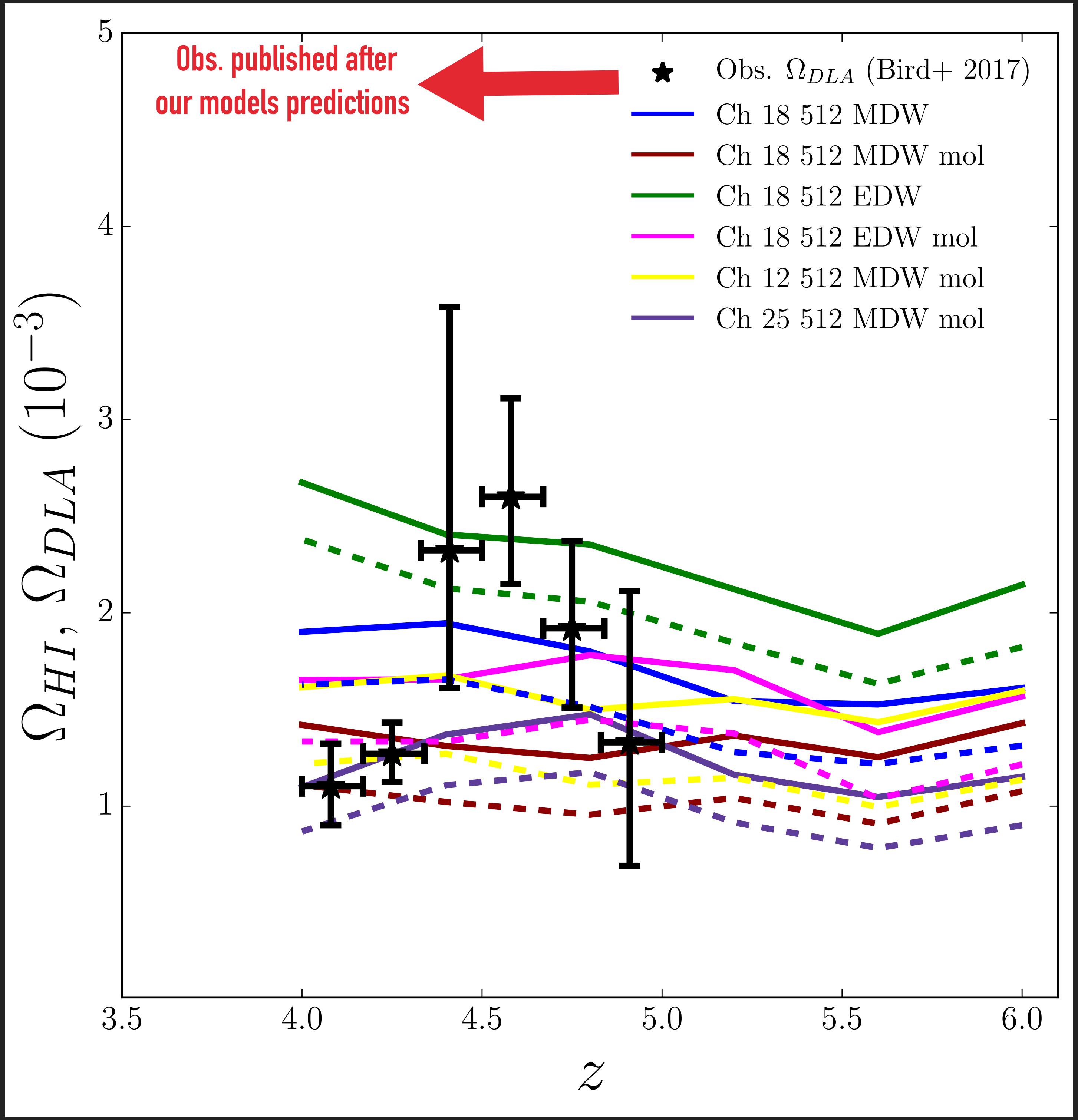


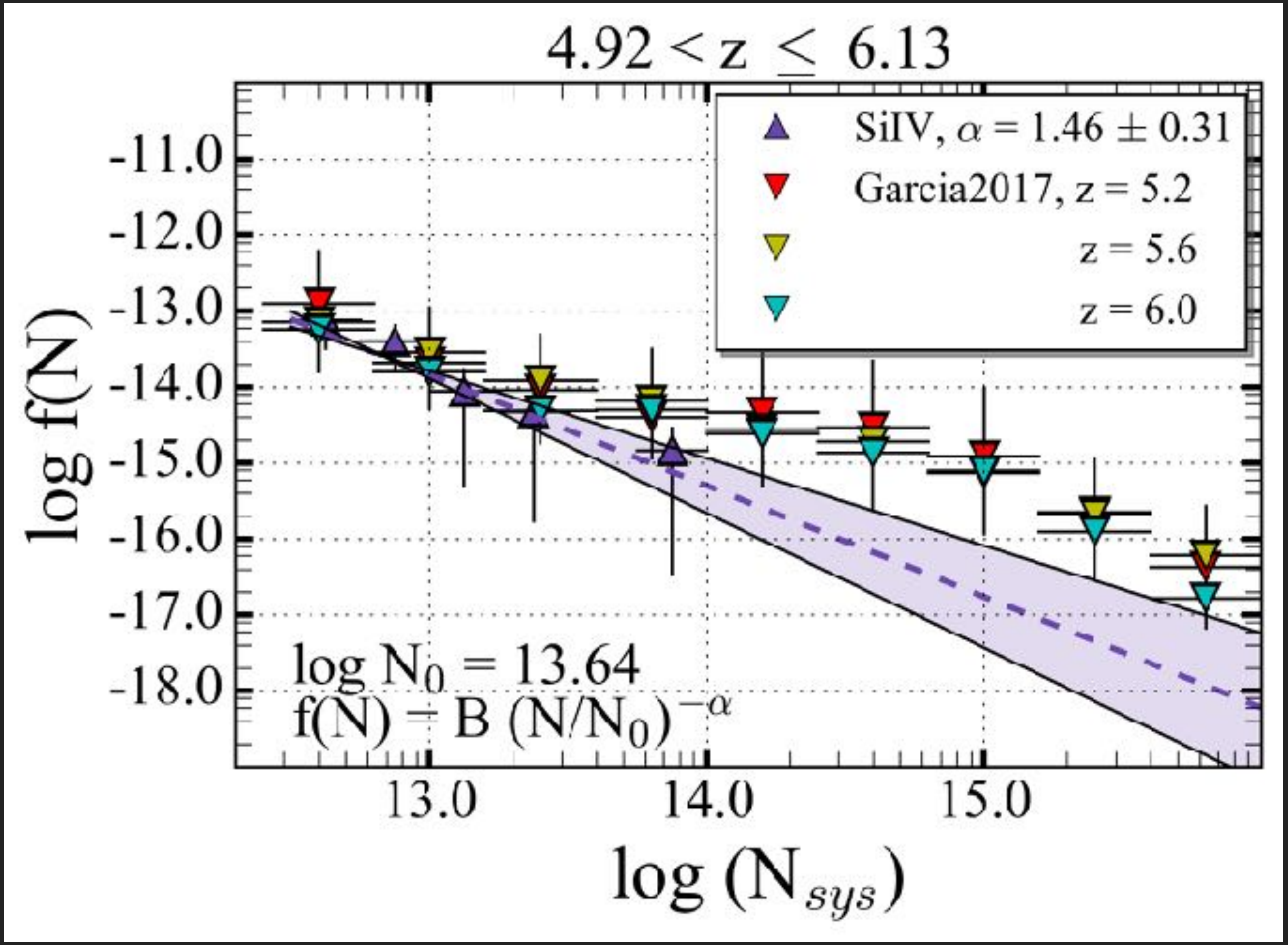


Tescari et al. 2009



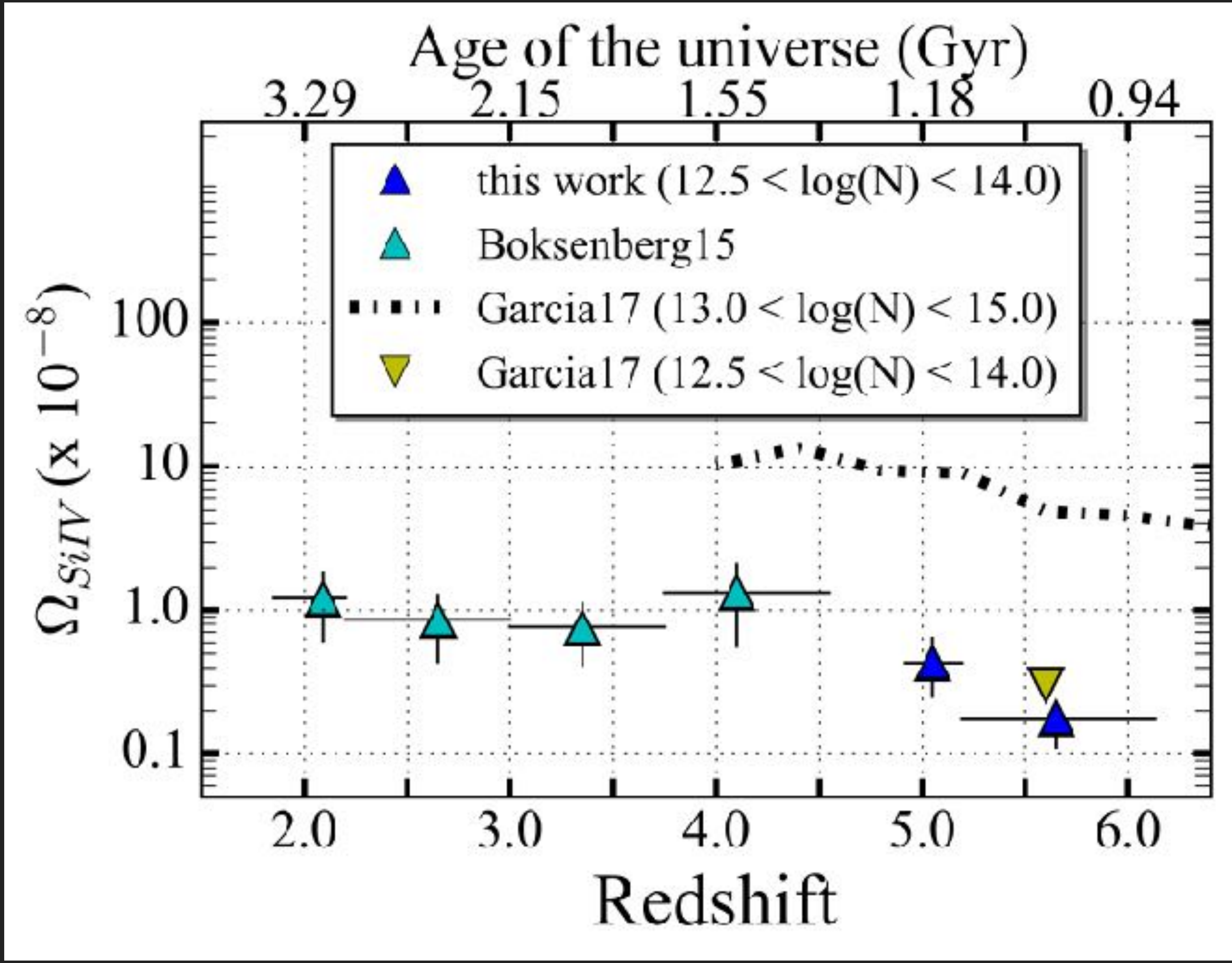
García et al. 2017a

SiIV statistics



Codoreanu et al. in prep.

SiIV cosmological mass density



Z ~ 5.6

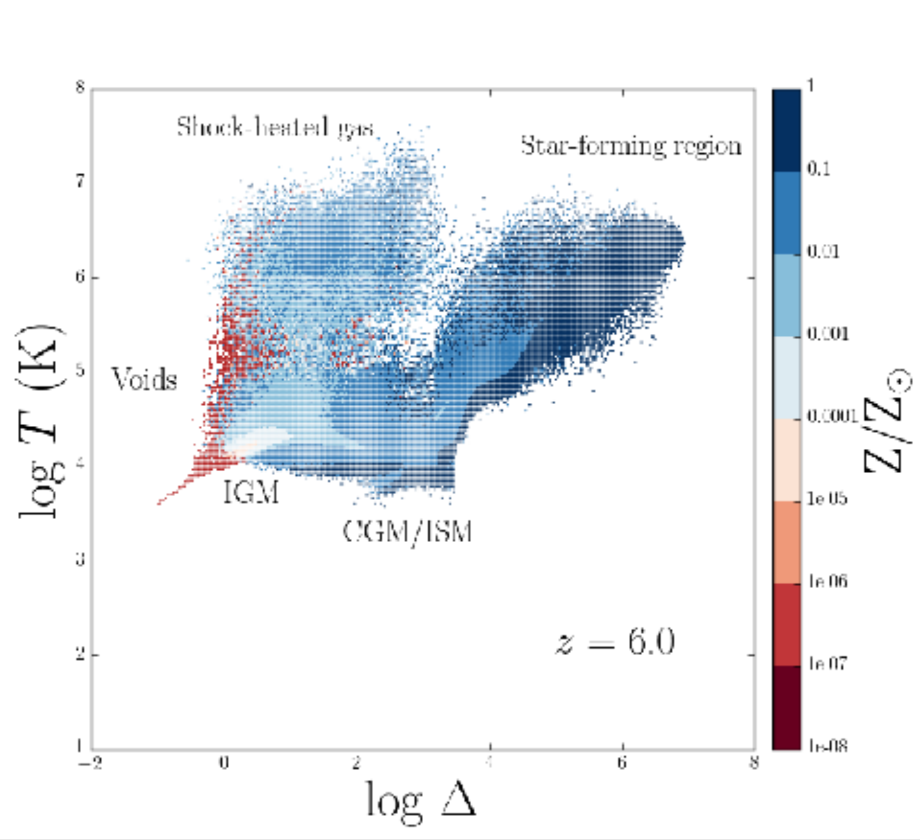
Codoreanu et al. in prep.

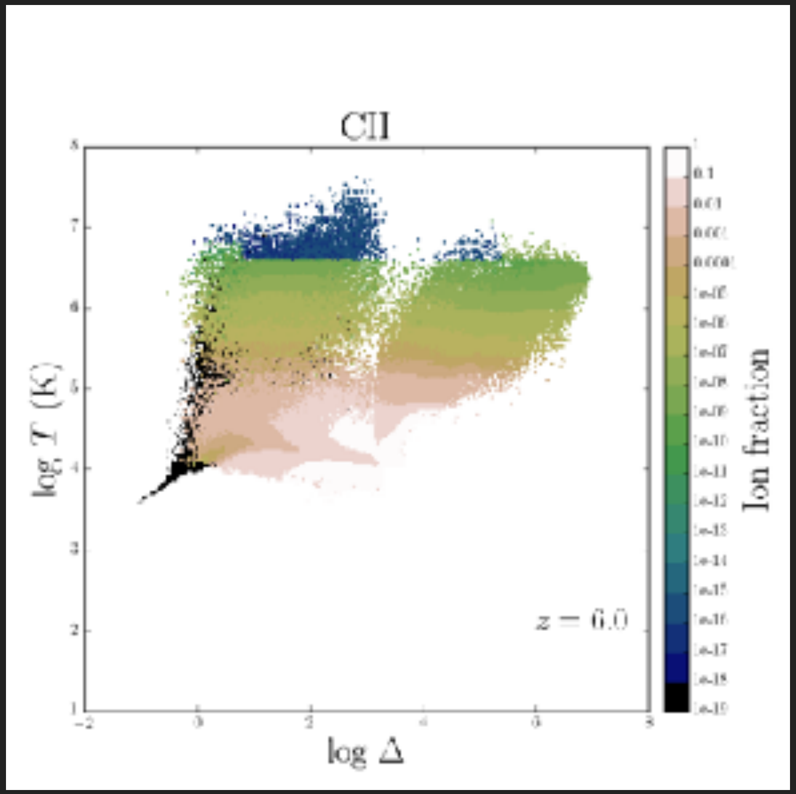
Conclusions

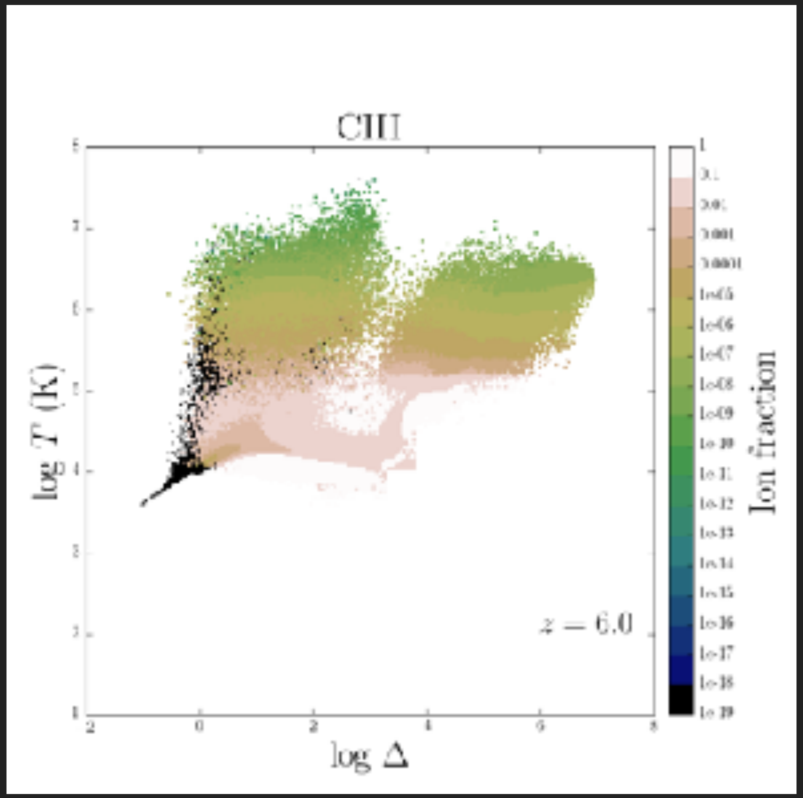
By using hydrodynamical simulations it is possible to study metal absorption systems that are undetectable with the current observational techniques:

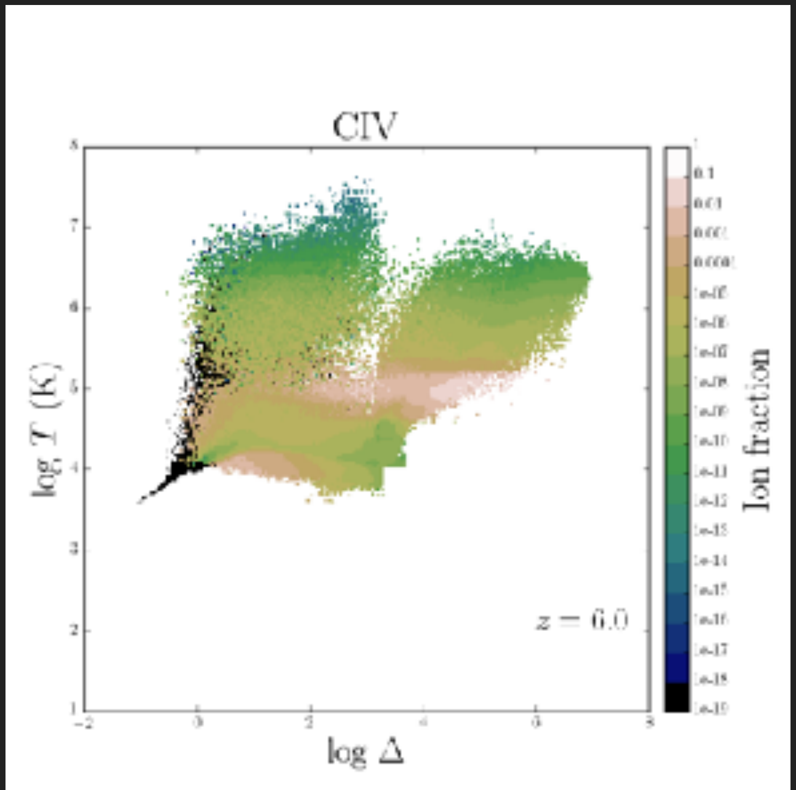
* The evolution of the ionization states of C, in particular CIV are compatible with all of the observations.
* The ratio of the comoving mass densities of CII and CIV at $z > 6$ is raising indicating that the Universe is more neutral at early times.
* We reproduce the observations of HI at $z = 4$, especially when molecular cooling is introduced, and make a prediction of HI content at higher redshift.
* The confirmation of the pair LAE-CIV absorber provides an explanation of the chemical enrichment with metals by dwarf galaxies.
* Our models reproduce Si IV observed systems and predict high column density absorbers that could be detected in the future… Stay tuned to Codoreanu et al. in prep.!

MULTIPHASE GAS – METALLICITY

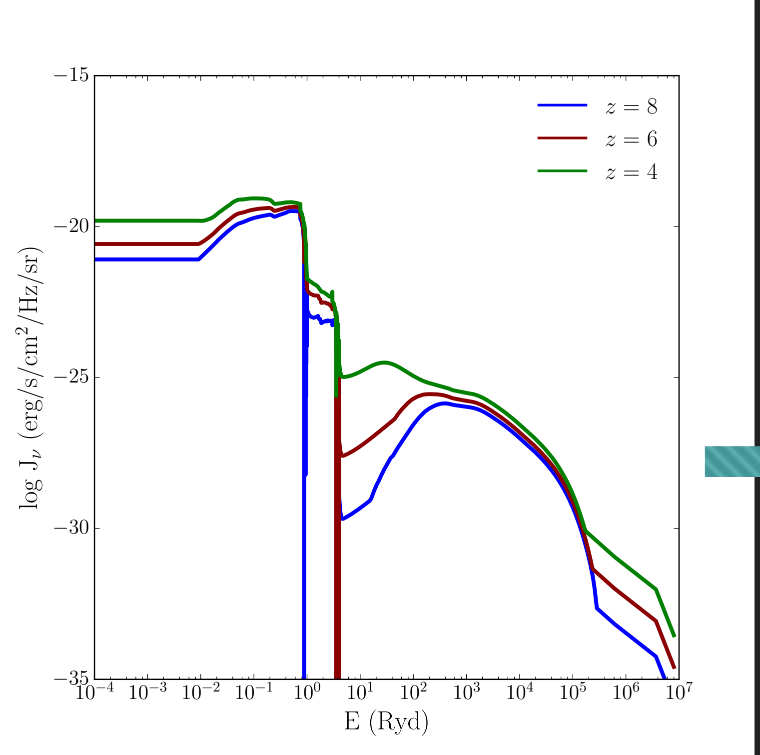


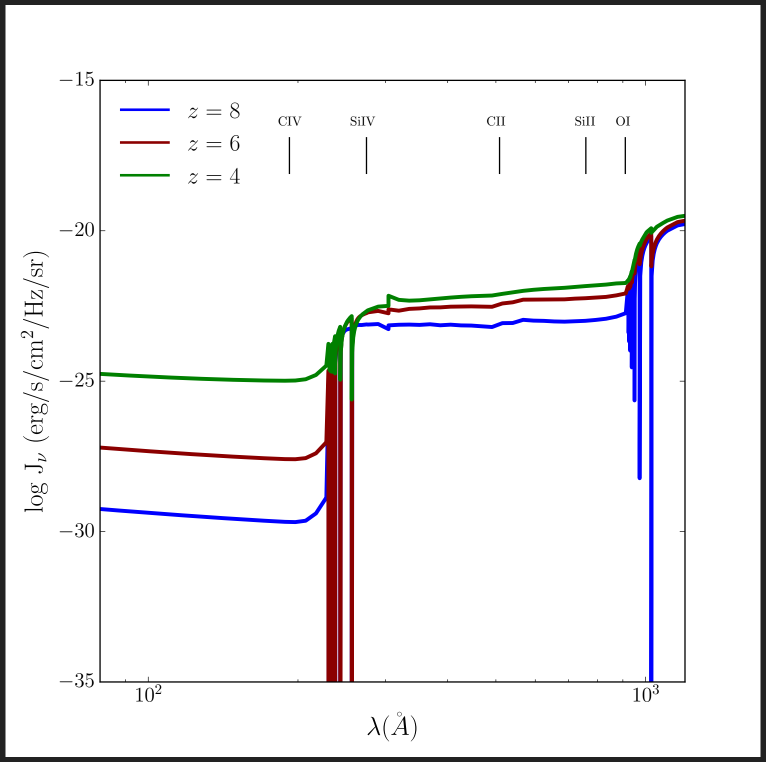


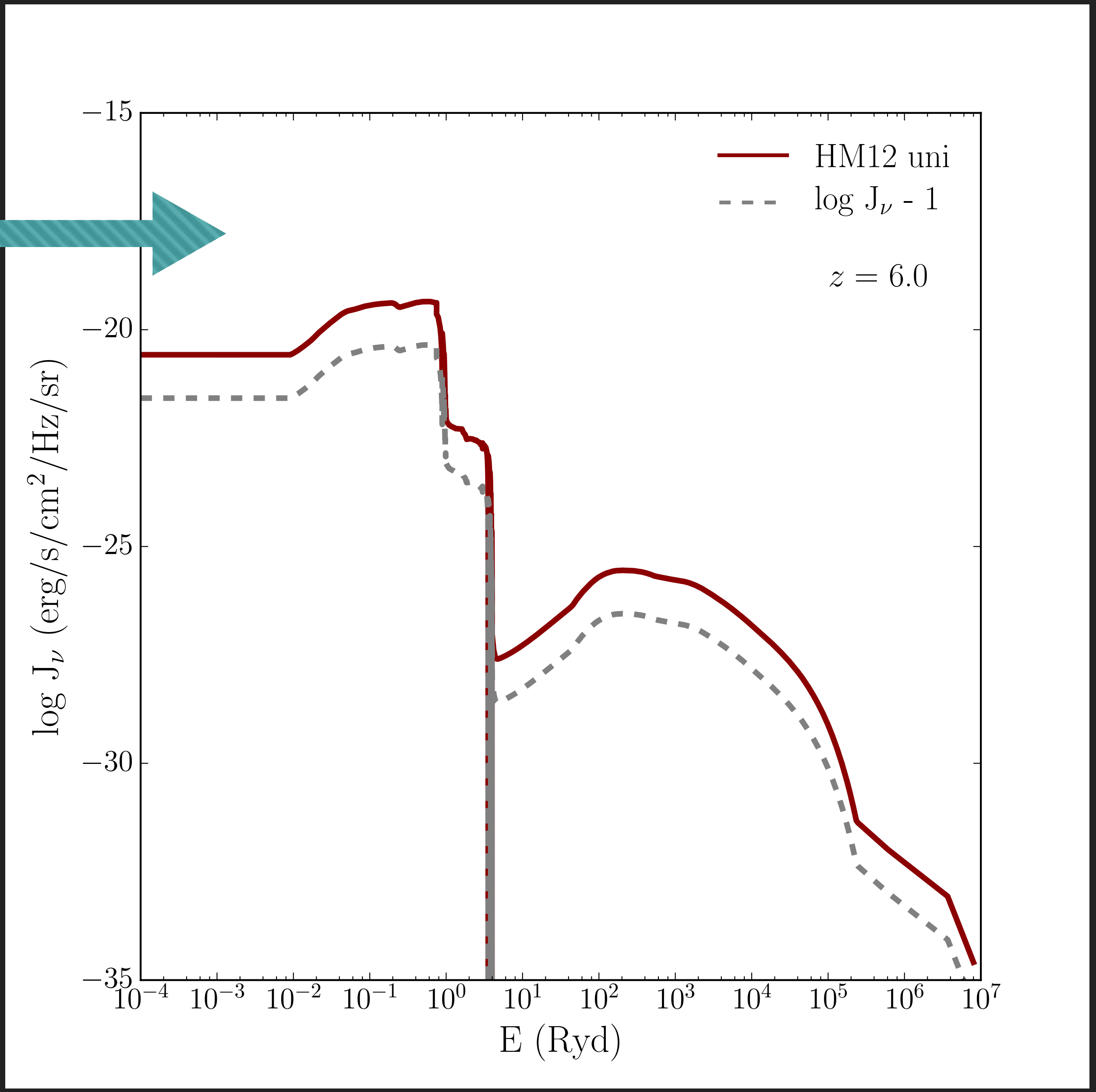




Variations of the assumed UVB

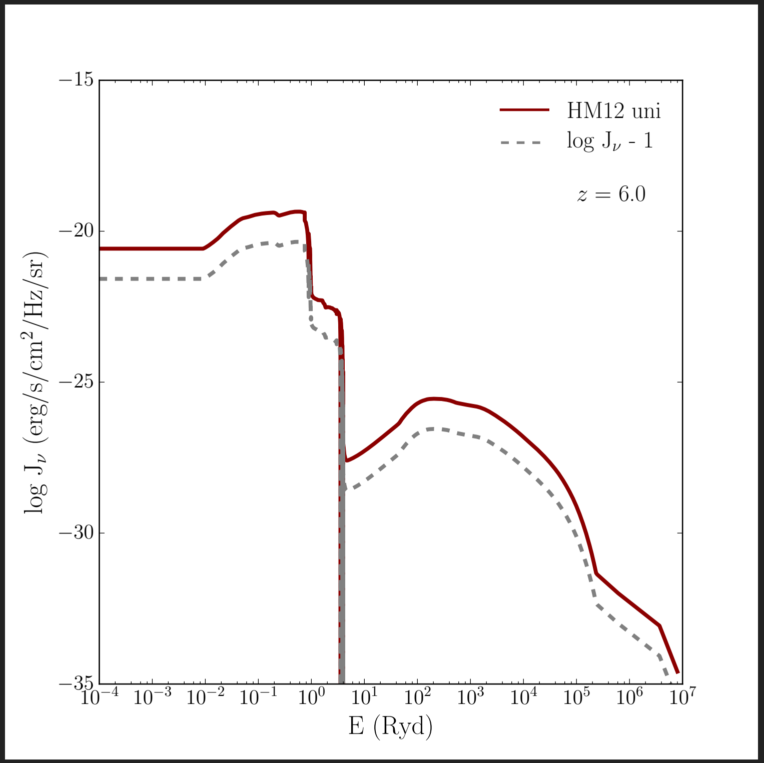




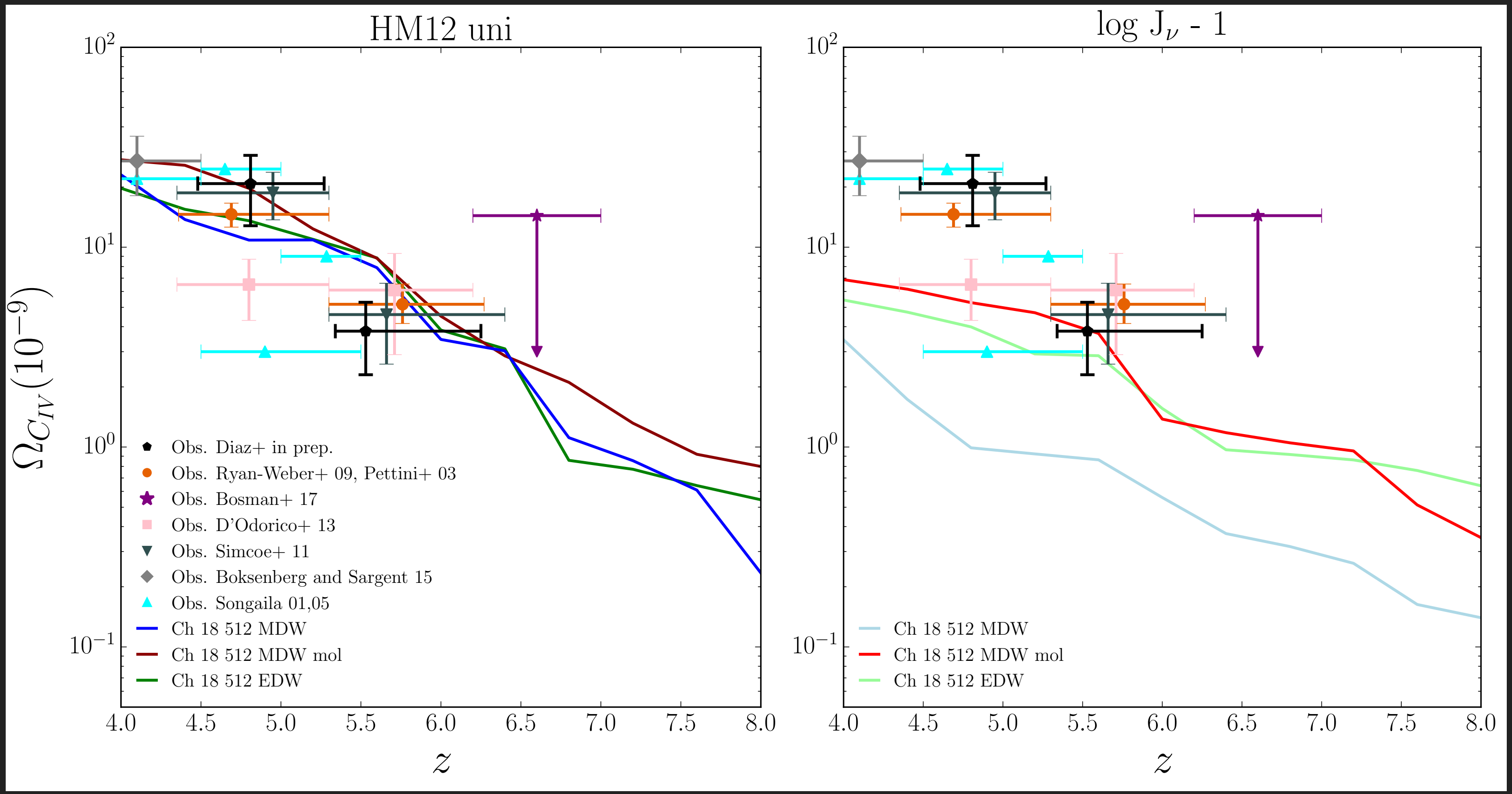


García et al. in prep.

Variations of the assumed UVB



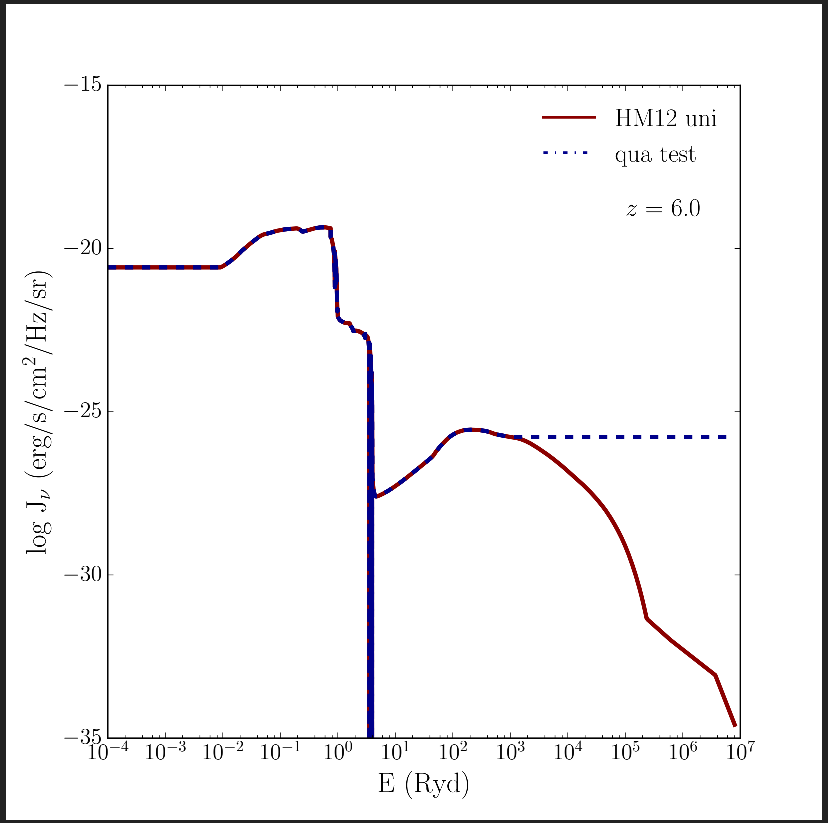
Work in progress

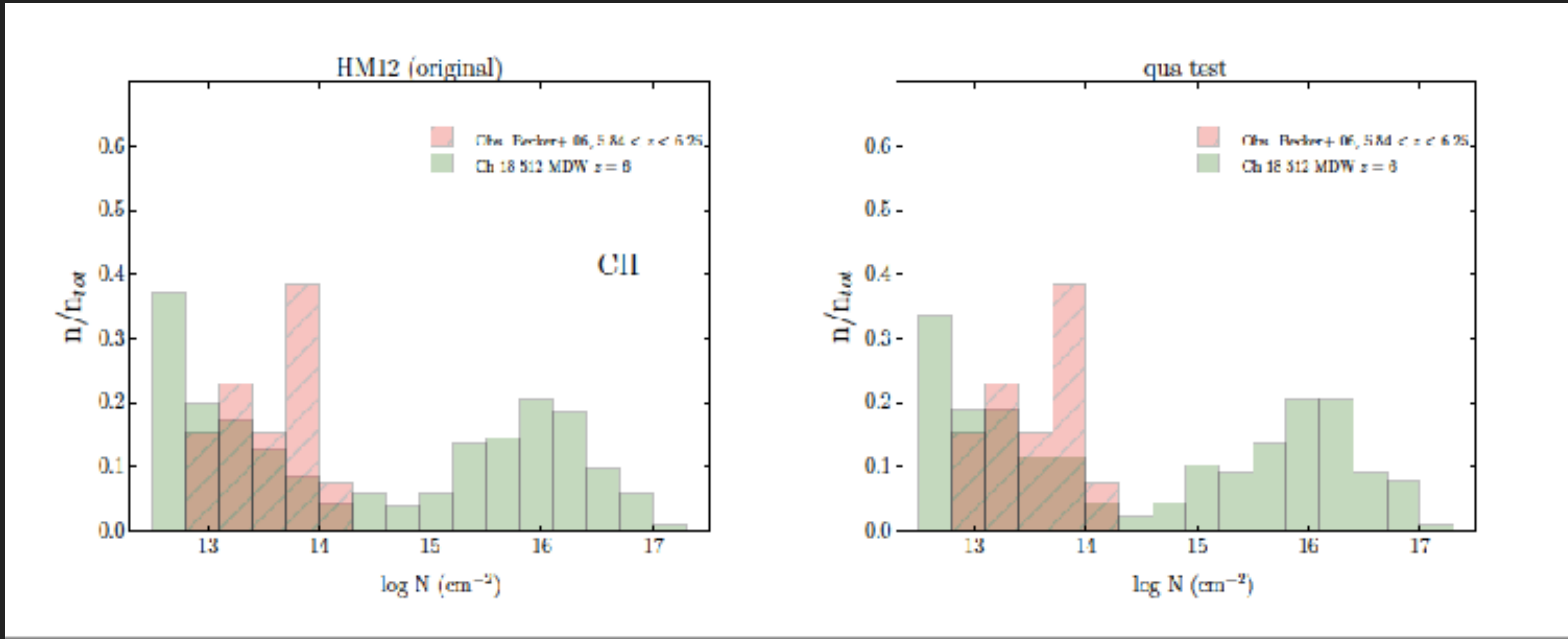


García et al. in prep.

Variations of the assumed UVB – II

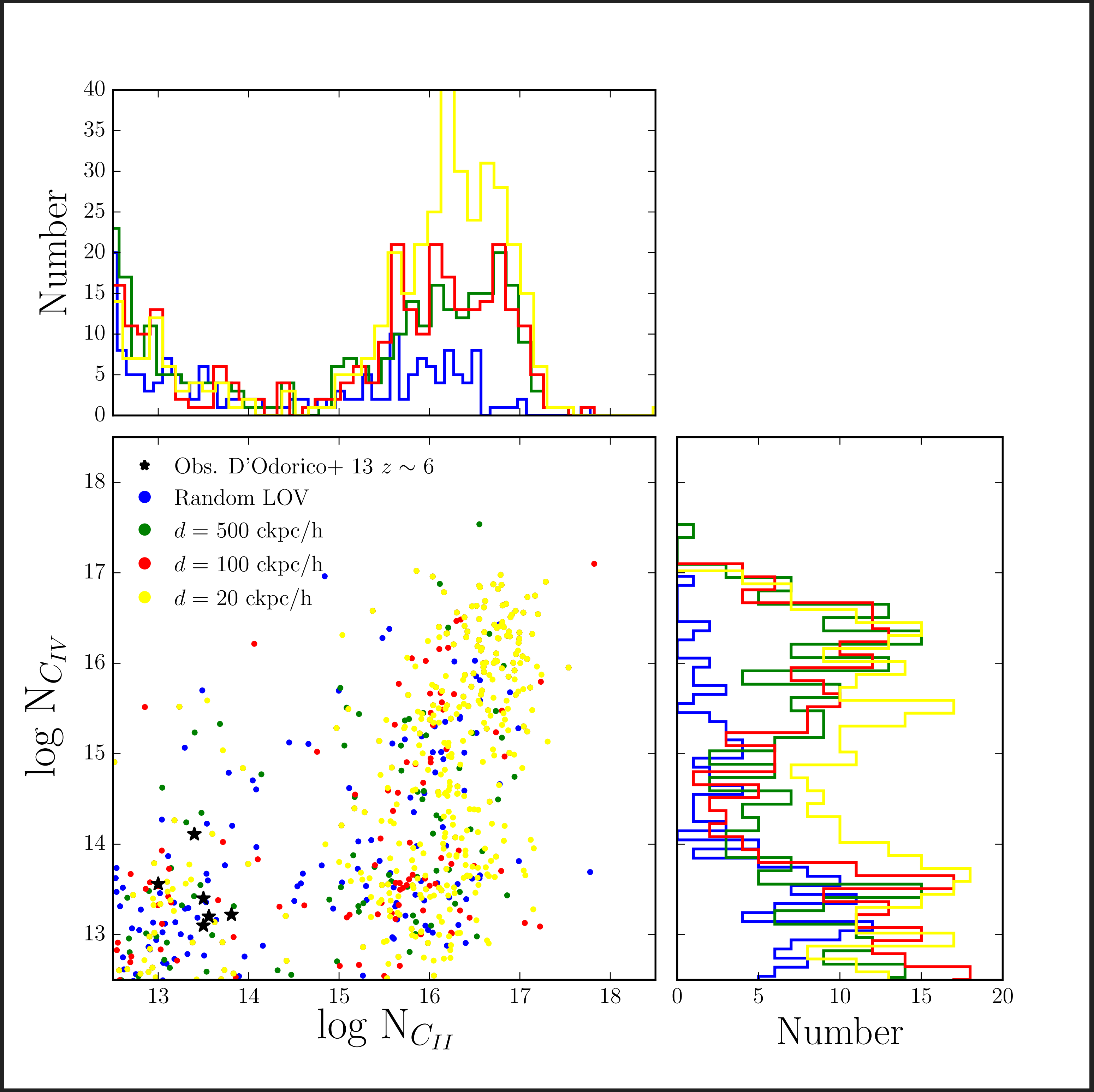
	$\Omega_{CII}(z=6)$ $(\times 10^{-9})$	$\Omega_{CIV}(z=6)$ $(\times 10^{-9})$
HM12 uni	3.78	3.45
qua test	2.89	3.66





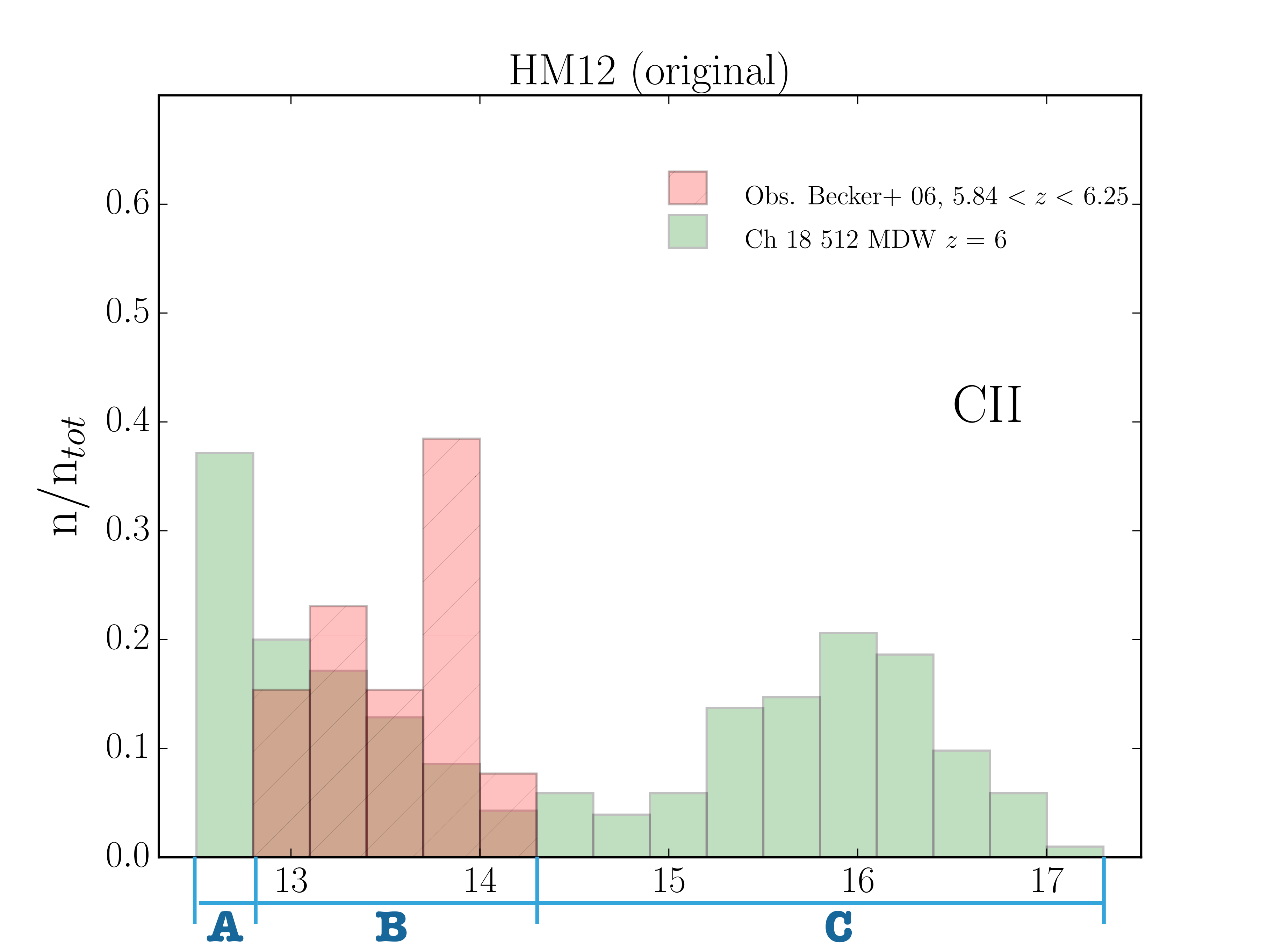
García et al. in prep.

DISTRIBUTION OF CII ABSORBERS



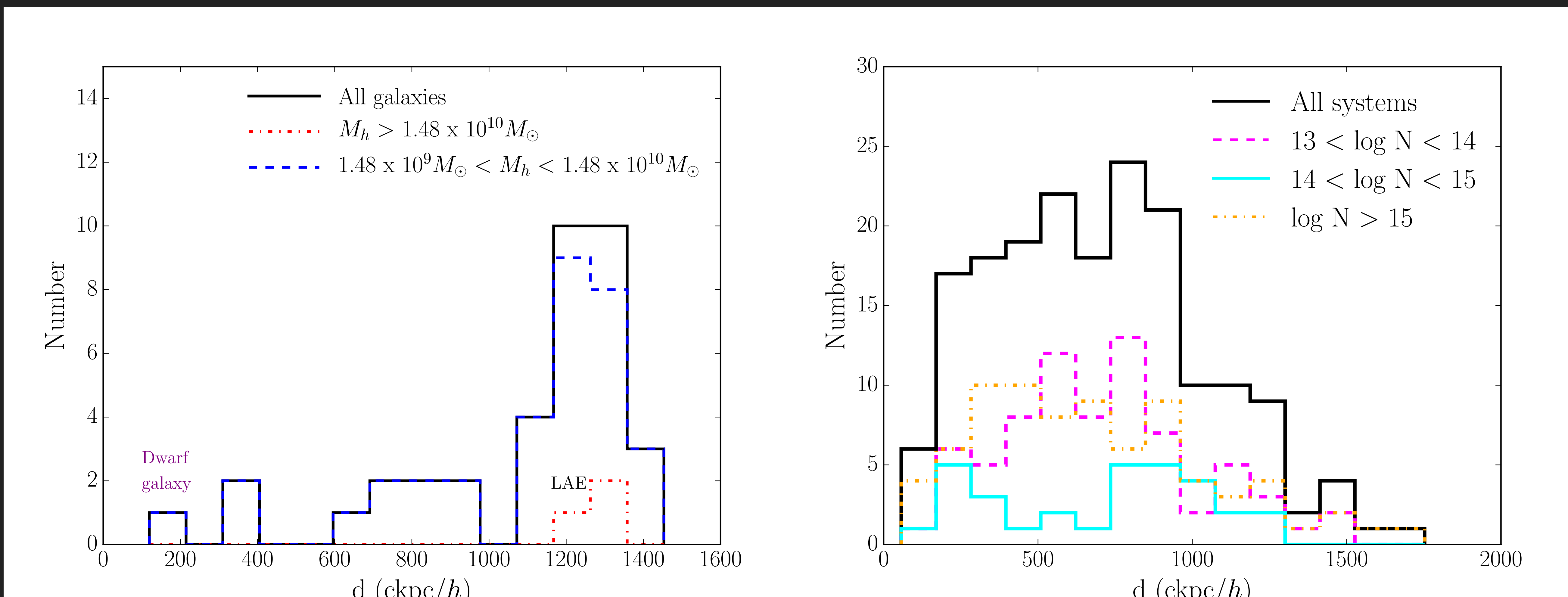
García et al. 2017a

DISTRIBUTION OF CII ABSORBERS



García et al. in prep.

LAE - CIV absorption pair



García et al. 2017b