Metals in Absorption at the Conclusion of Reionization

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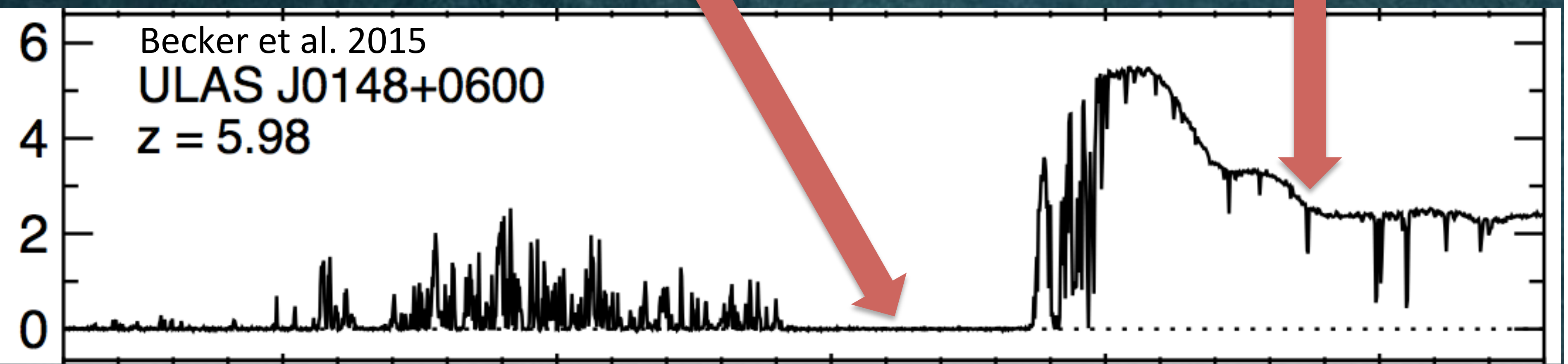
PhD students: Gonzalo Diaz (ICATE, Argentina), L. Angela Garcia, Alex Codoreanu
Papers: Diaz et al. (2014; 2015) and others in prep.

Co-authors: Cooke, Koyama, Ouchi, Shimasaku, Nakata
Collaborators: Becker, Crighton, Pettini, Madau, Tescari, Venemans, Wyithe

Our approach in a nutshell

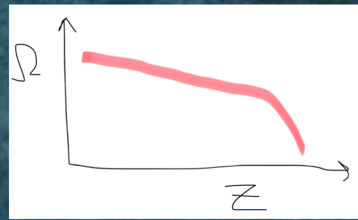
Complementary information on the intergalactic medium (IGM) can be obtained from metal absorption line systems.

It's challenging, but not impossible to extract information from Lyman-α absorption at z~6



Summary/Contention

Rapid evolution in Ω(CIV) from z~5 to 5.7 could be due to



1. decrease in mean cosmic metallicity
2. change density/temperature of IGM that produces CIV
3. increase in neutrality of the universe due to density fluctuations
4. increase in neutrality due to the tail end of reionization

I will argue that 1 & 2/3 (same effect) can account for most of this drop, thus *the tail end of reionization* could contribute, but is not required within the errors.

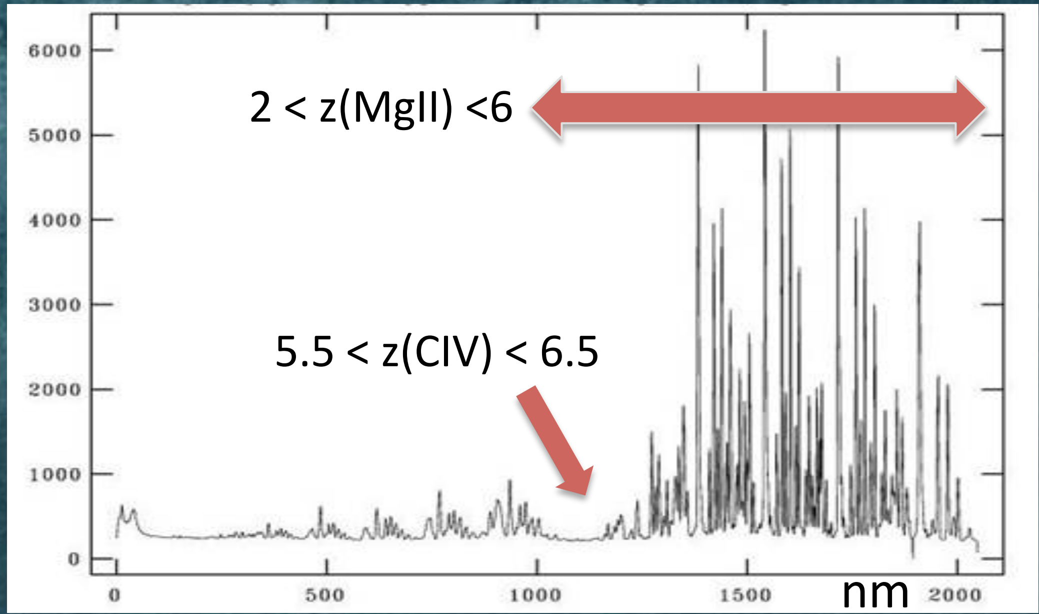
Evolution in low ionization absorbers supports this contention

- Ω(CII) exceed Ω(CIV) at z~6
- Flat Ω(MgII) from z~4 to 5

Furthermore

- CIV absorbers at z~6 arise in LAE filaments – *not* in the CGM of LGBs, which is the case at z~3.

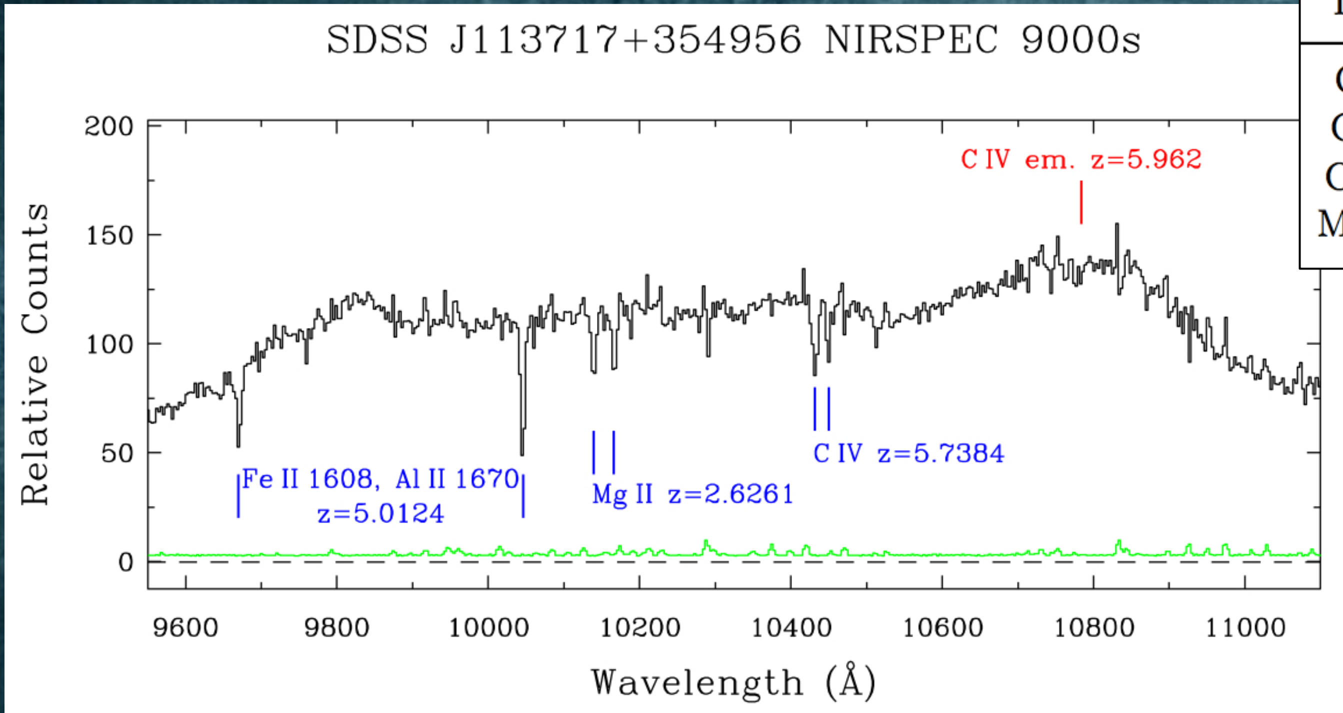
Significant challenges:
OH skylines, atmospheric absorption



Demonstrated that medium resolution quasar absorption line spectroscopic is viable in the near-IR (ERW+06; Simcoe '06)

Further CIV studies: Becker+09; ERW+09; Simcoe+11 & D'Odorico+13.
MgII studies: Matejek & Simcoe '10 (dN/dz incidence rate)

Search for CIV at 5<z<6.3 & MgII 2<z<5.5



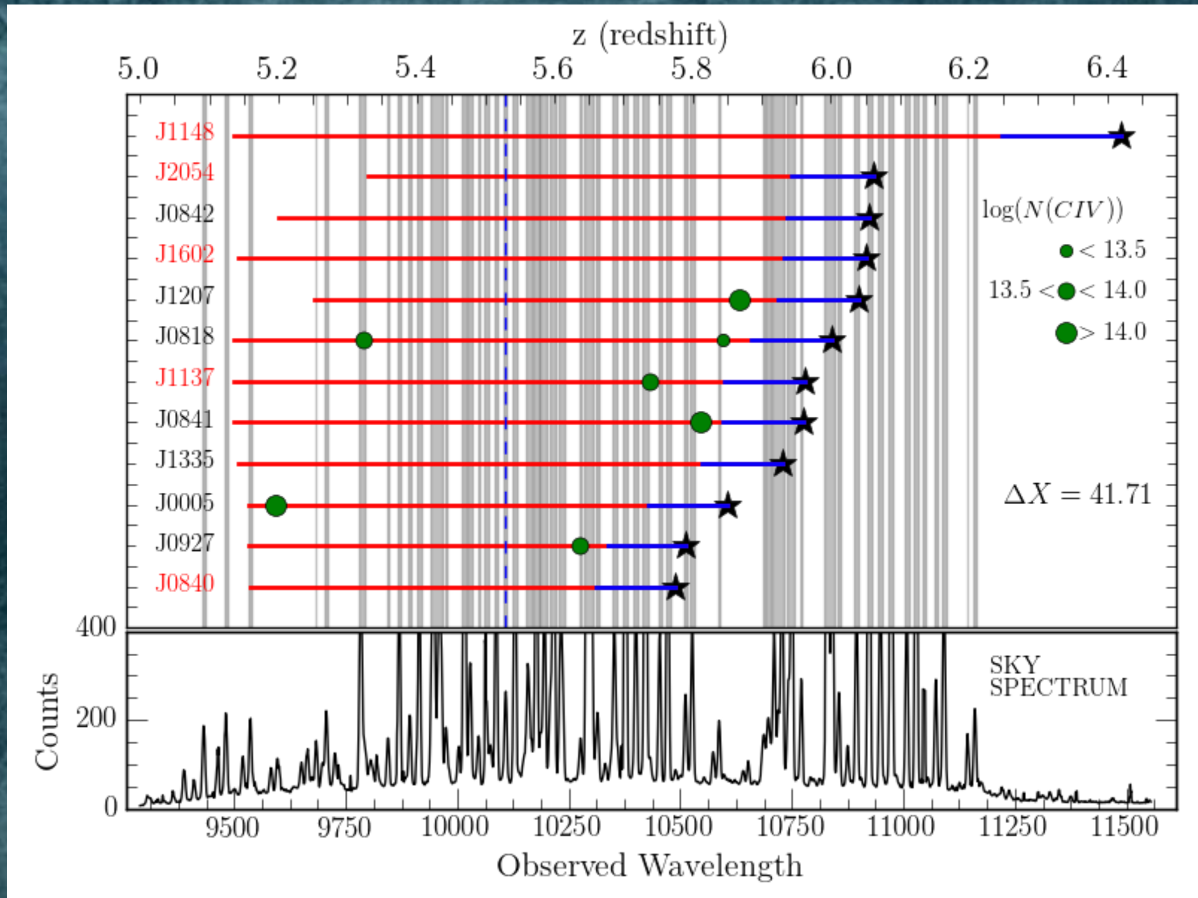
Ion	λ (Å)	ΔE (eV)
O I	1302.2	< 13.62
C II	1334.5	11.26 – 24.38
C IV	1548.2	47.89 – 64.49
Mg II	2796.4	7.64 – 15.03

Courtesy Keating+16

Currently ~ 70/179 quasars with z_{em}>5.7 bright enough (J<20) for follow-up spectroscopy with 6-10m telescopes (discovered in SDSS, UKIDSS, CFHQS, VIKING, PANSTARRS).

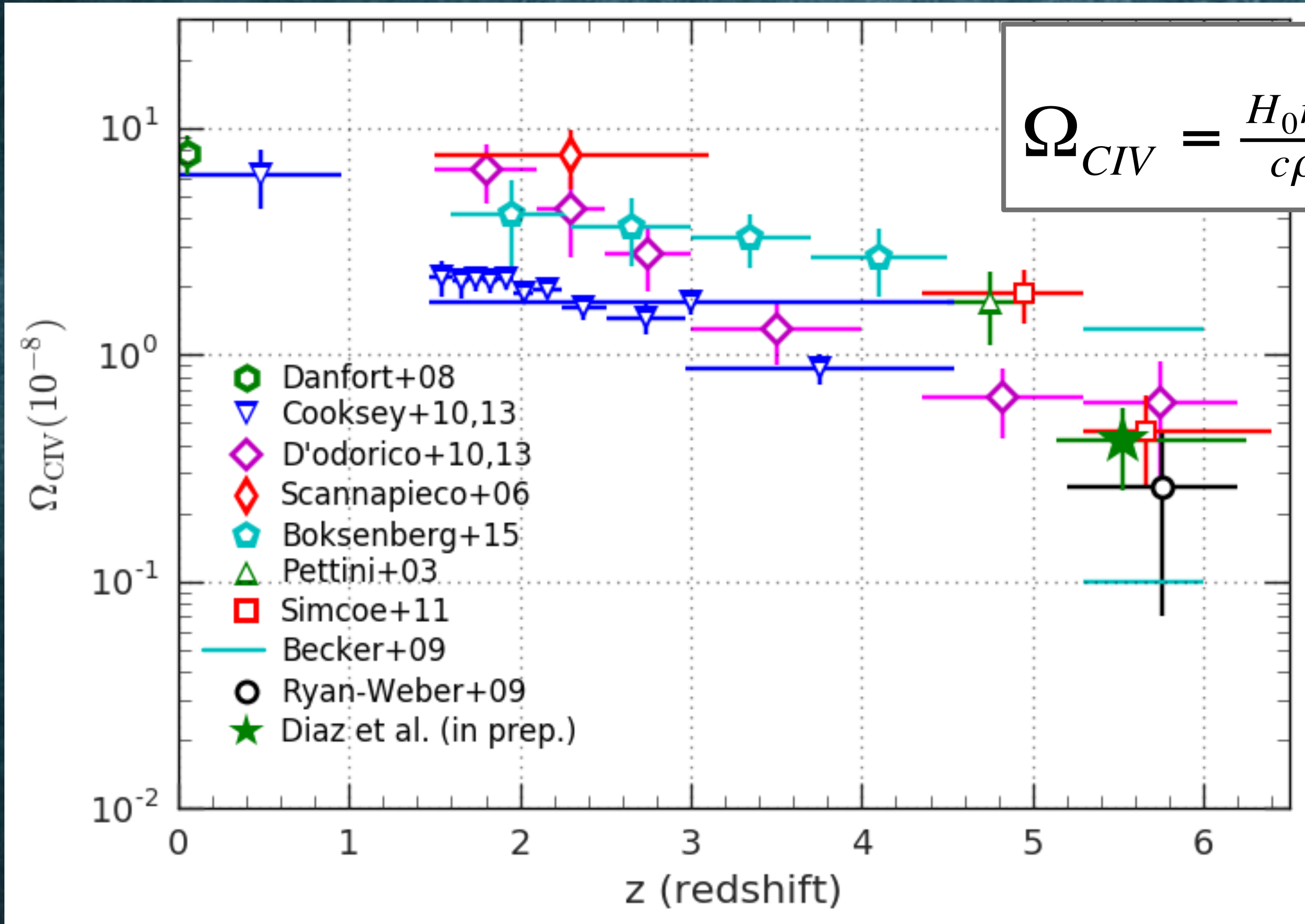
Keck/NIRSPEC survey for CIV

12 QSO lines of sight
(Diaz+ in prep)



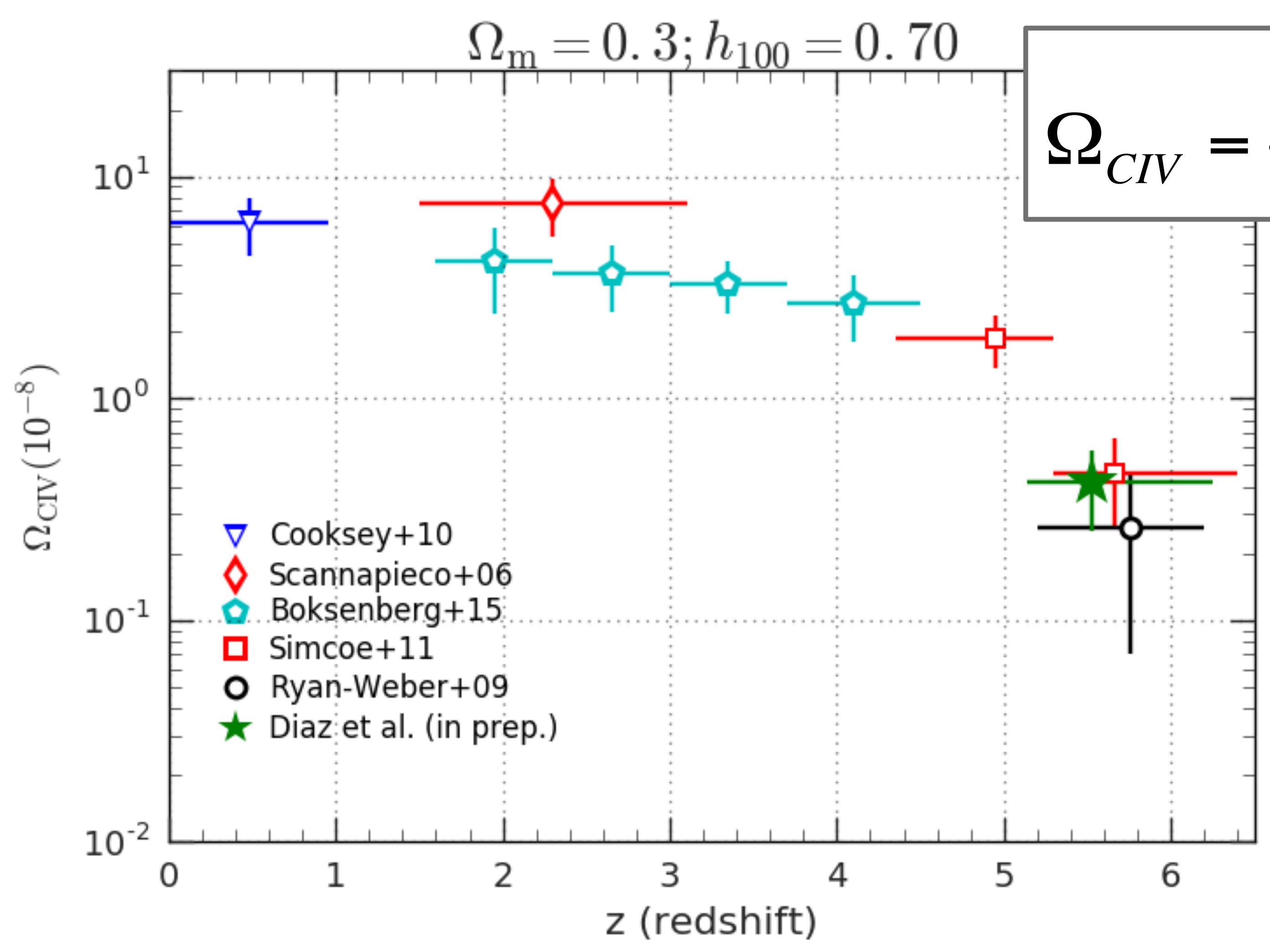
Includes reanalysis of 5 NIRSPEC lines of sight from ERW+09 with consistent completeness correction.

Cosmological Mass Density



$$\Omega_{CIV} = \frac{H_0 m_{CIV}}{c\rho_{crit}} \frac{\sum N_{CIV}}{\Delta X}$$

Cosmological Mass Density



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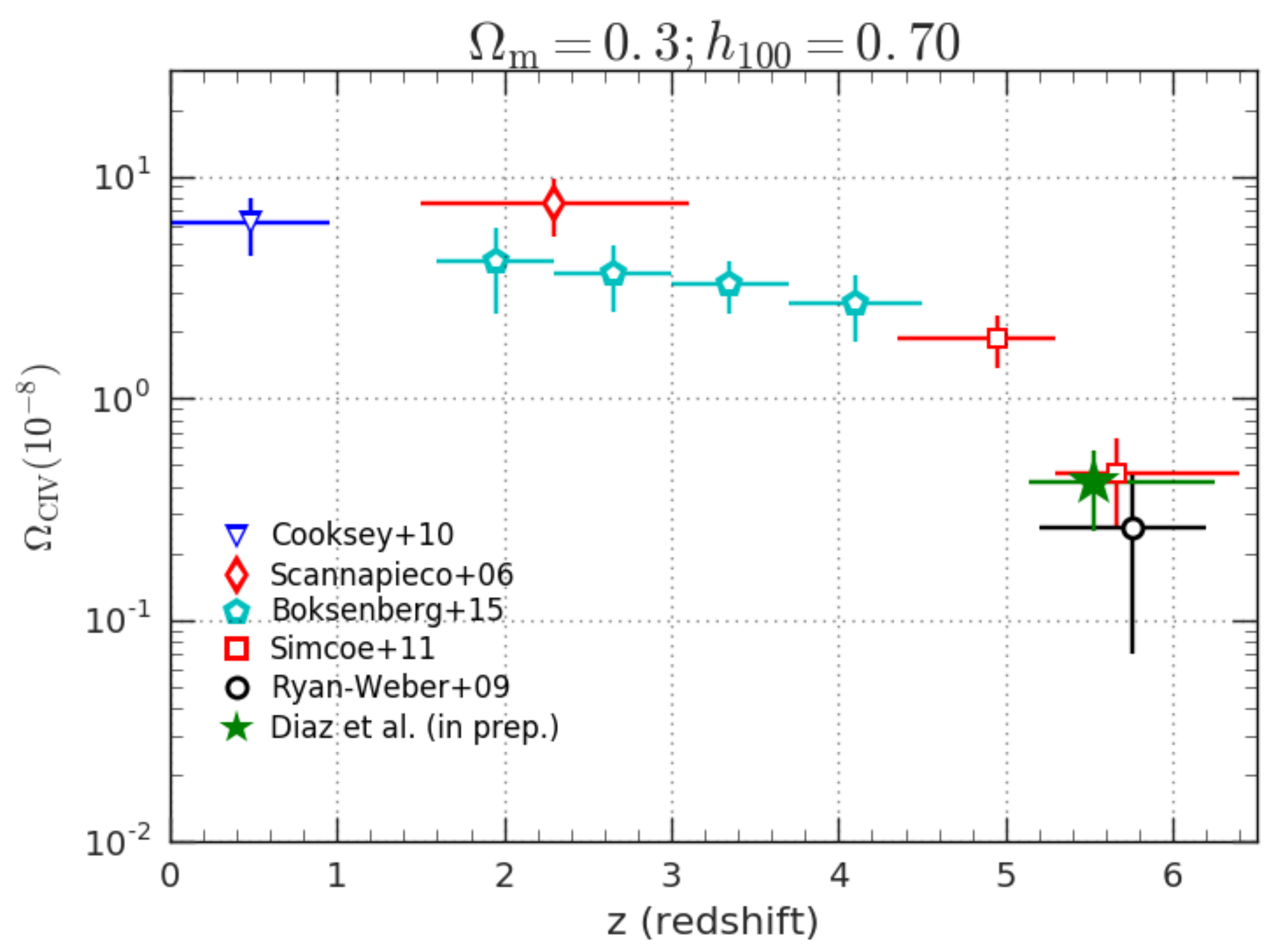
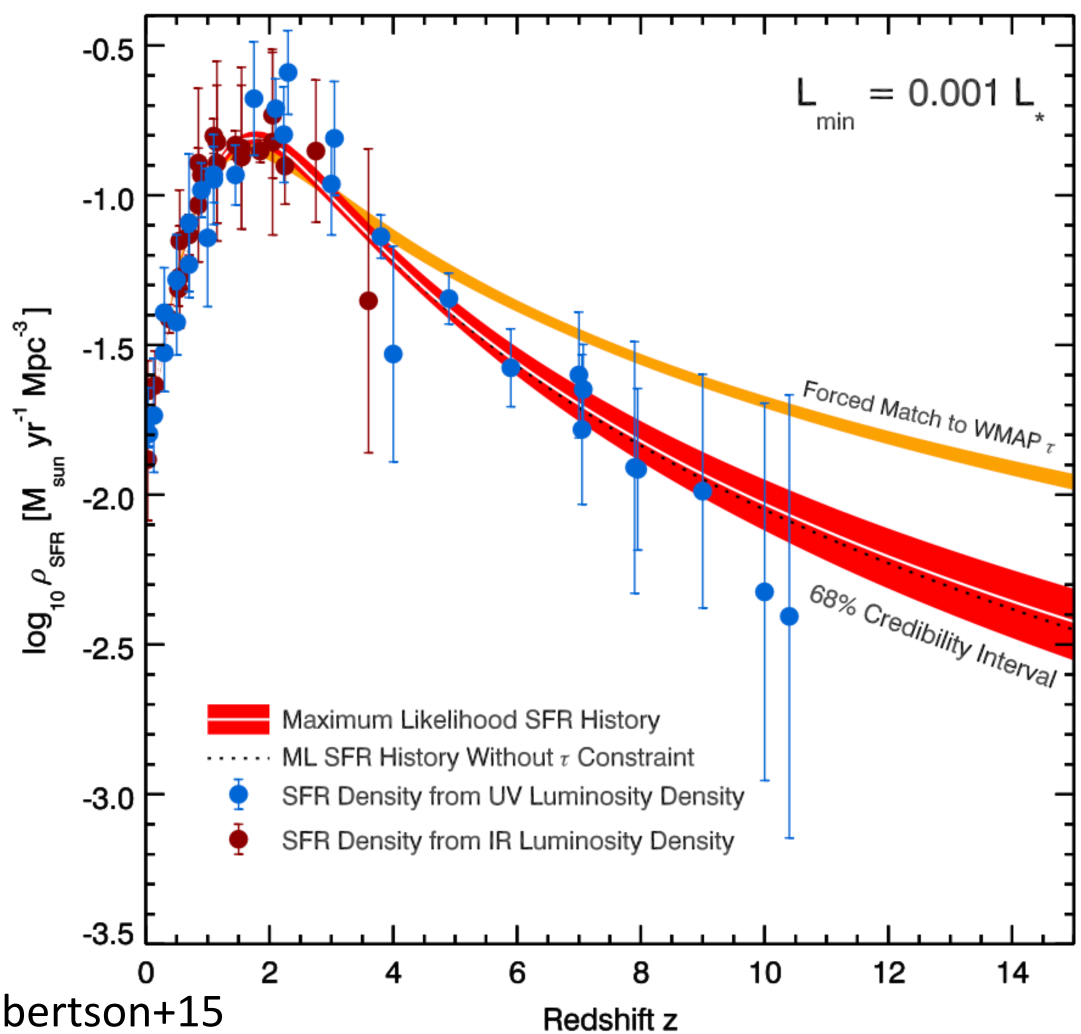


Ω(CIV) drops 4x
in 200 Myrs

from z=5 to 5.7

Star formation rate density

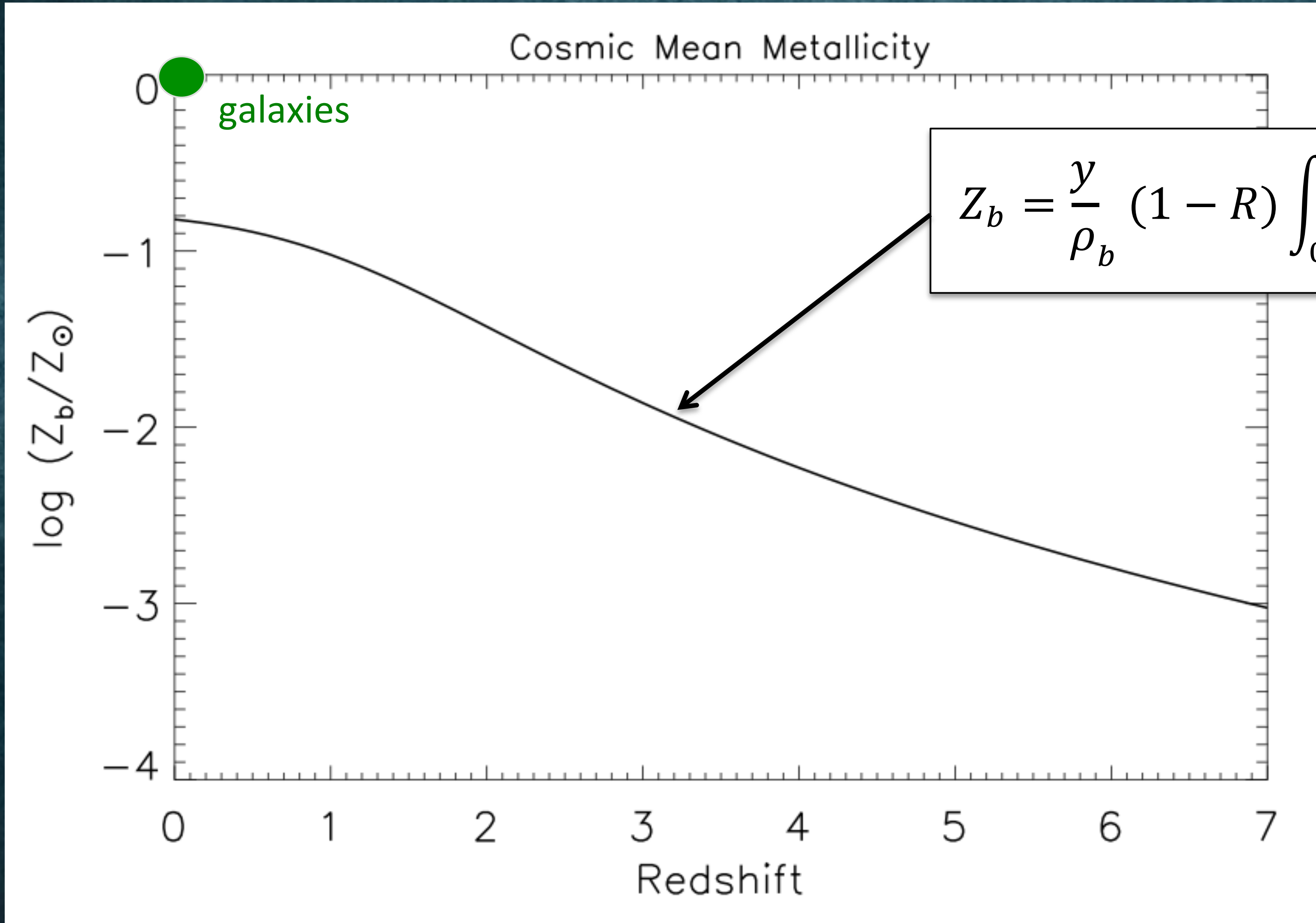


Robertson+15

Maximum likelihood SFRD from joint constraint of τ(Planck 2015)=0.066 and compilation of UV & IR SFRDs from Madau & Dickinson (2014).

Integrate SFRD with return fraction, R and yield, y to obtain the mean metallicity of the Universe.

1. Mean Metallicity of the Universe



$$Z_b = \frac{y}{\rho_b}(1-R)\int_0^{t(z)} \rho_{SFR}\,dt$$

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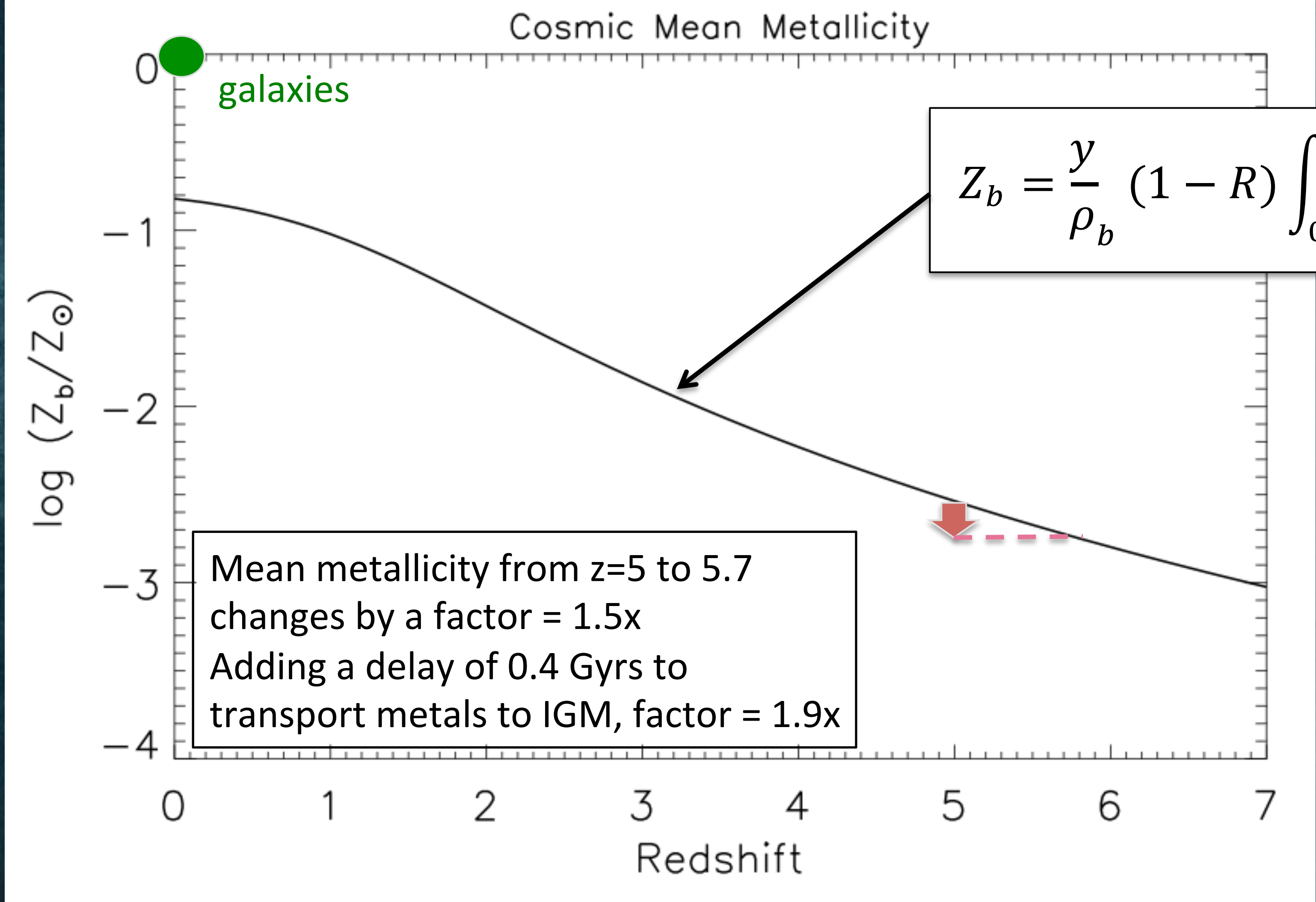


$$Z_b = \frac{y}{\rho_b}(1 - R)\int_0^{t(z)} \rho_{SFR}\, dt$$

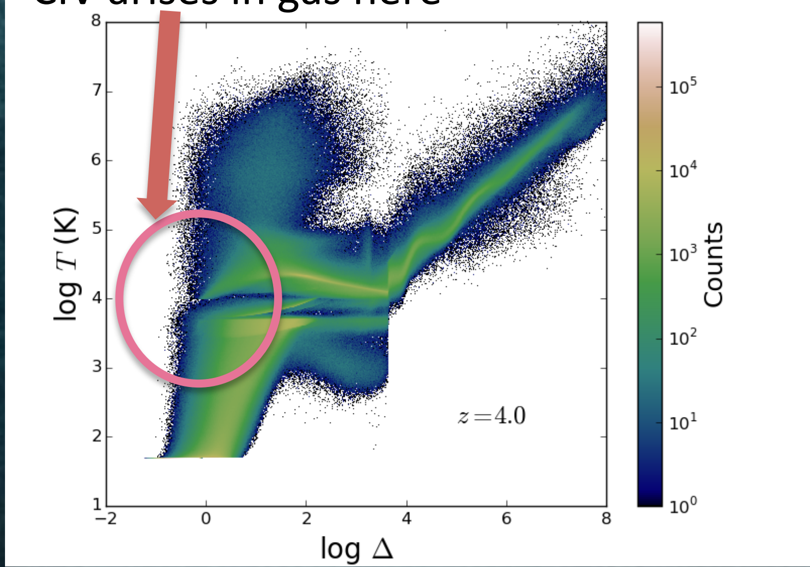
Mean metallicity from z=5 to 5.7
changes by a factor = 1.5x
Adding a delay of 0.4 Gyrs to
transport metals to IGM, factor = 1.9x

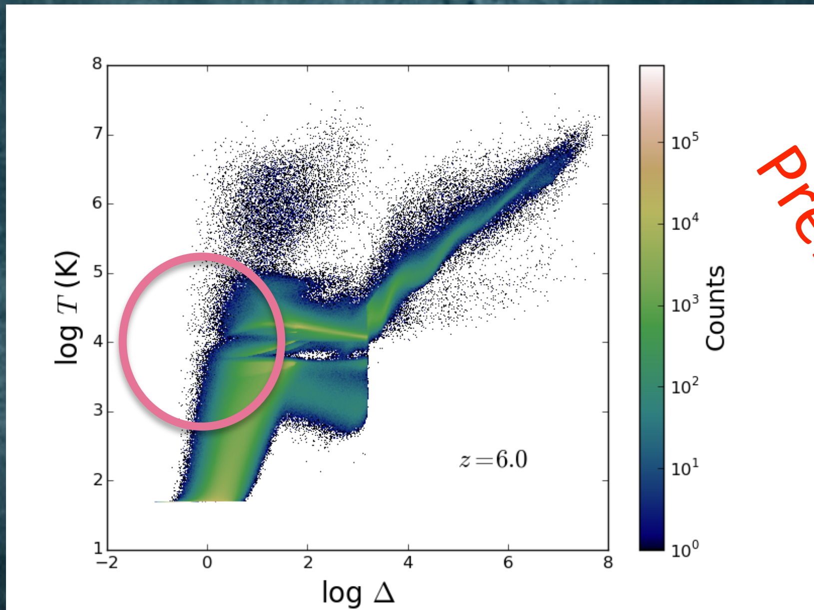
2. Change in IGM temperature/density

$\Delta=\rho/\rho_{crit} \propto (1+z)^{-3}$: changes by a ***factor of 1.4*** from z=5 to 5.7

Simulations (P-GADGET3) with 2 different wind prescriptions:
Momentum and Energy driven winds
Angela Garica's PhD work (Garcia, Tescari, ERW et al. in prep)

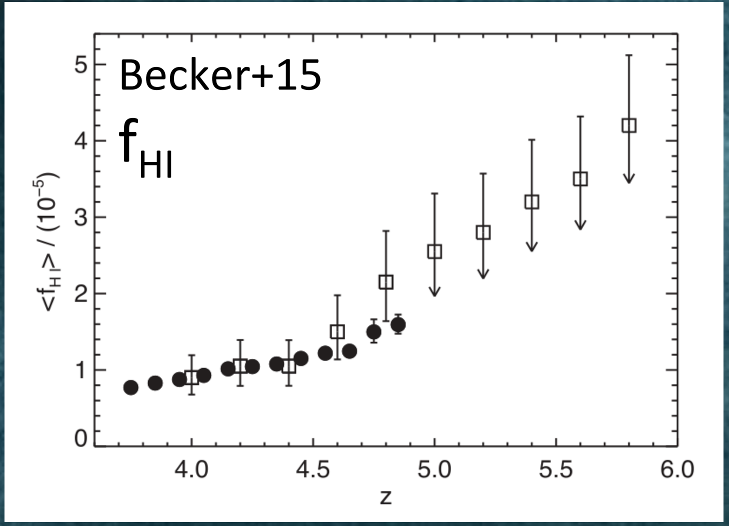
CIV arises in gas here

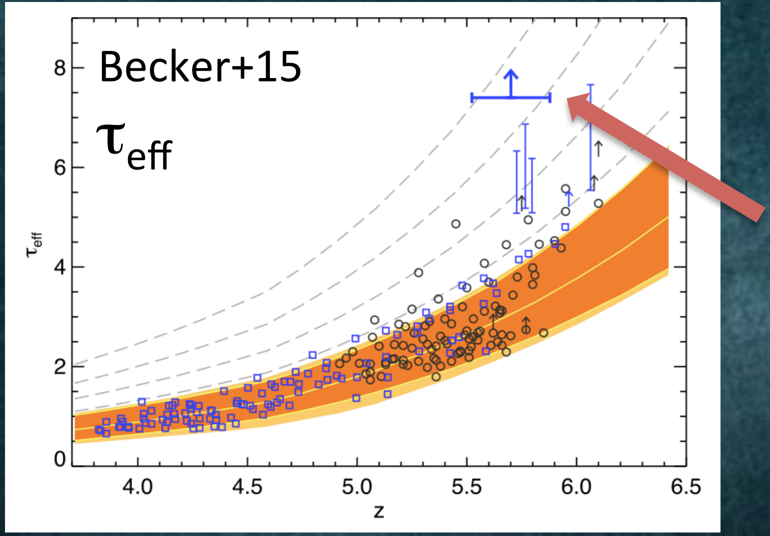




Preliminary

3. & 4. Change in neutrality





Density fluctuations in a uniform UV background alone can account for a ***factor = 1.3x*** increase in the neutral fraction of hydrogen from z=5 to 5.6.

Increased neutrality due to the tail end of reionization is ON TOP of this.

ULAS J0148+0600

Evolution in the mass density of CIV

Rapid evolution (factor of 4±2) in Ω(CIV) from z=5 to 5.7 could be due to

1. decrease in mean cosmic metallicity
   factor of 1.5x or 1.9x (with travel delay)
2. change density/temperature of IGM that produces the CIV
3. increase in neutrality of the universe due to density fluctuations
   factor of 1.3x

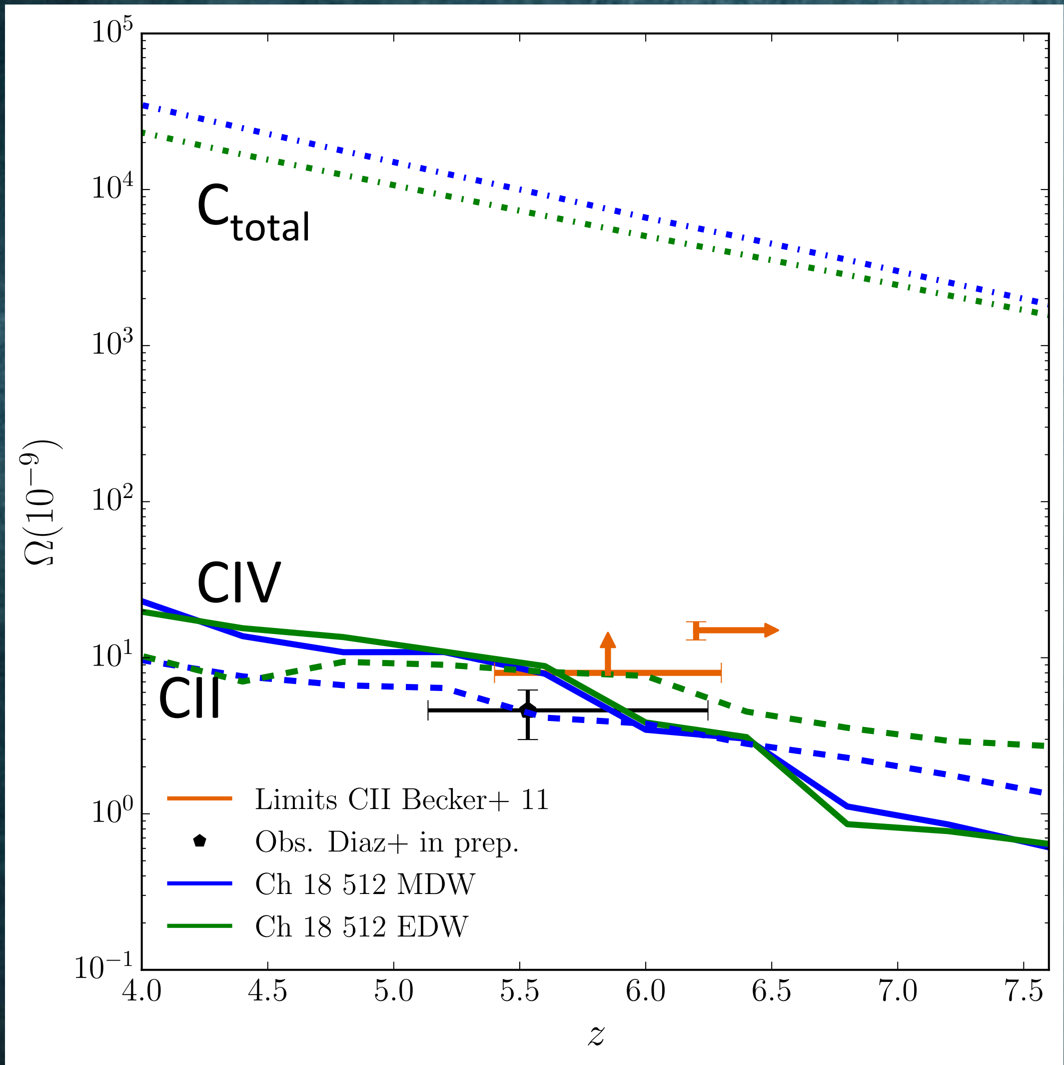
These two factors can account for 2 – 2.5x

4. increase in neutrality due to the tail end of reionization

Probably accounts for the remainder, but not formally necessary within the errors.

CIV is a high ionization state, what about low ionization ions?
Metallicity will still cause a decrease, but density/neutrality should cause an increase.

Cosmological Mass Density: CII & CIV



Garcia+ in prep

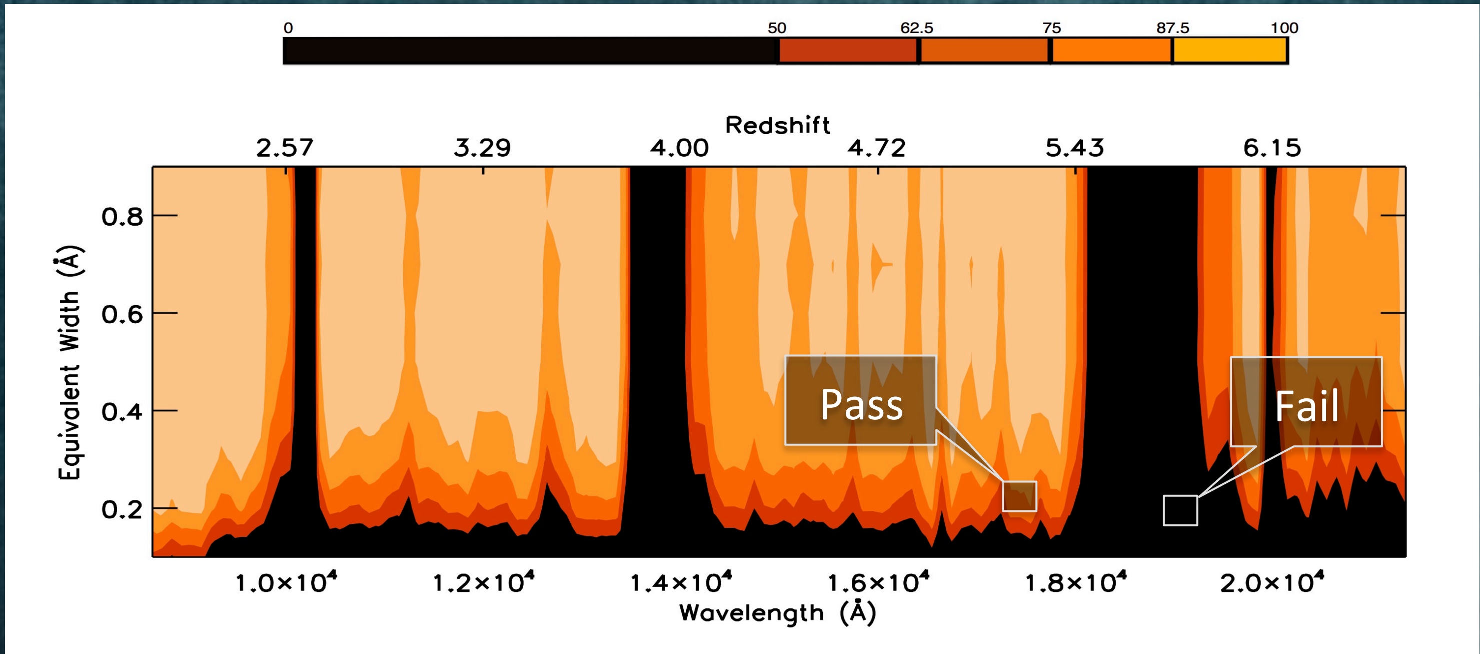
Simulations correctly reproduce observations that Ω(CII) should overtake Ω(CIV) at z~6.

Singly ionized Magnesium, MgII

Alex Codoreanu's PhD Work (Codoreanu, ERW, Crighton et al. in prep).

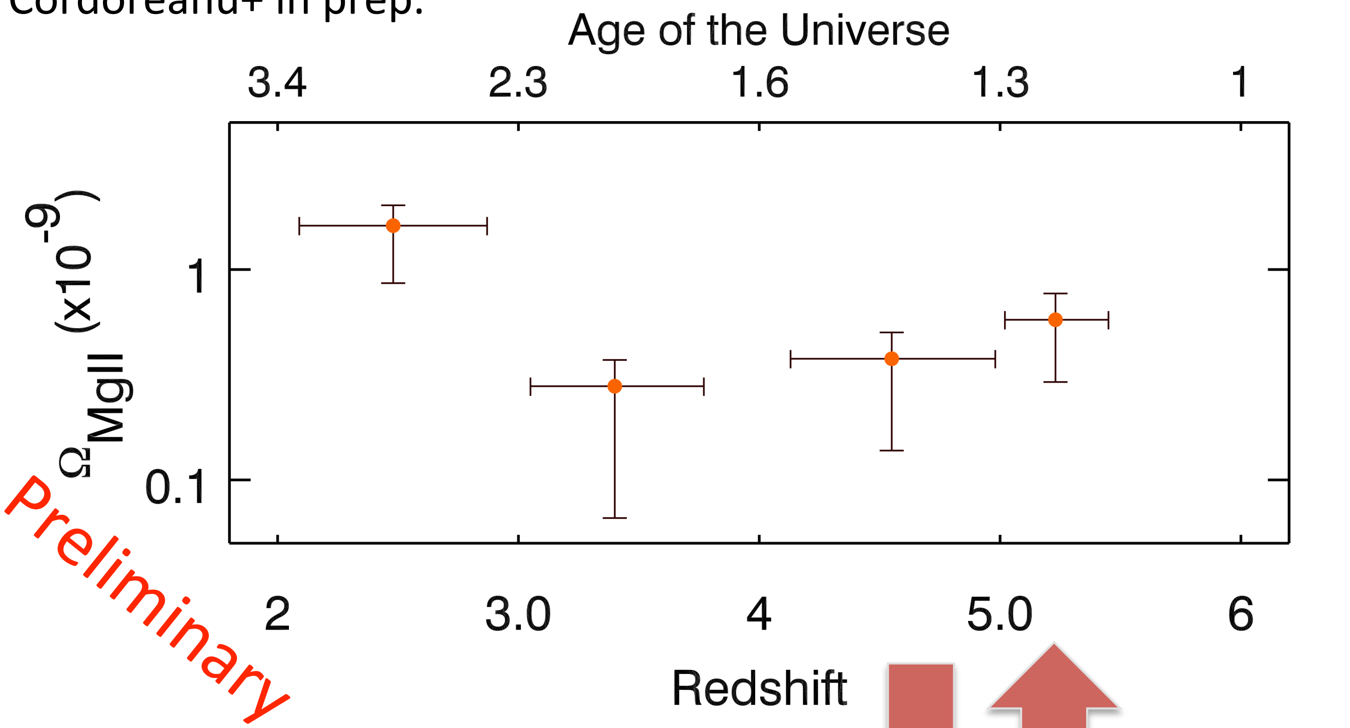
VLT/X-Shooter spectroscopy of 4 z~6 QSOs with high S/N.
Uncovered 27 MgII absorption systems from 2<z<5.5 that meet the >50% completeness criteria.

Preliminary



Cosmological Mass Density MgII

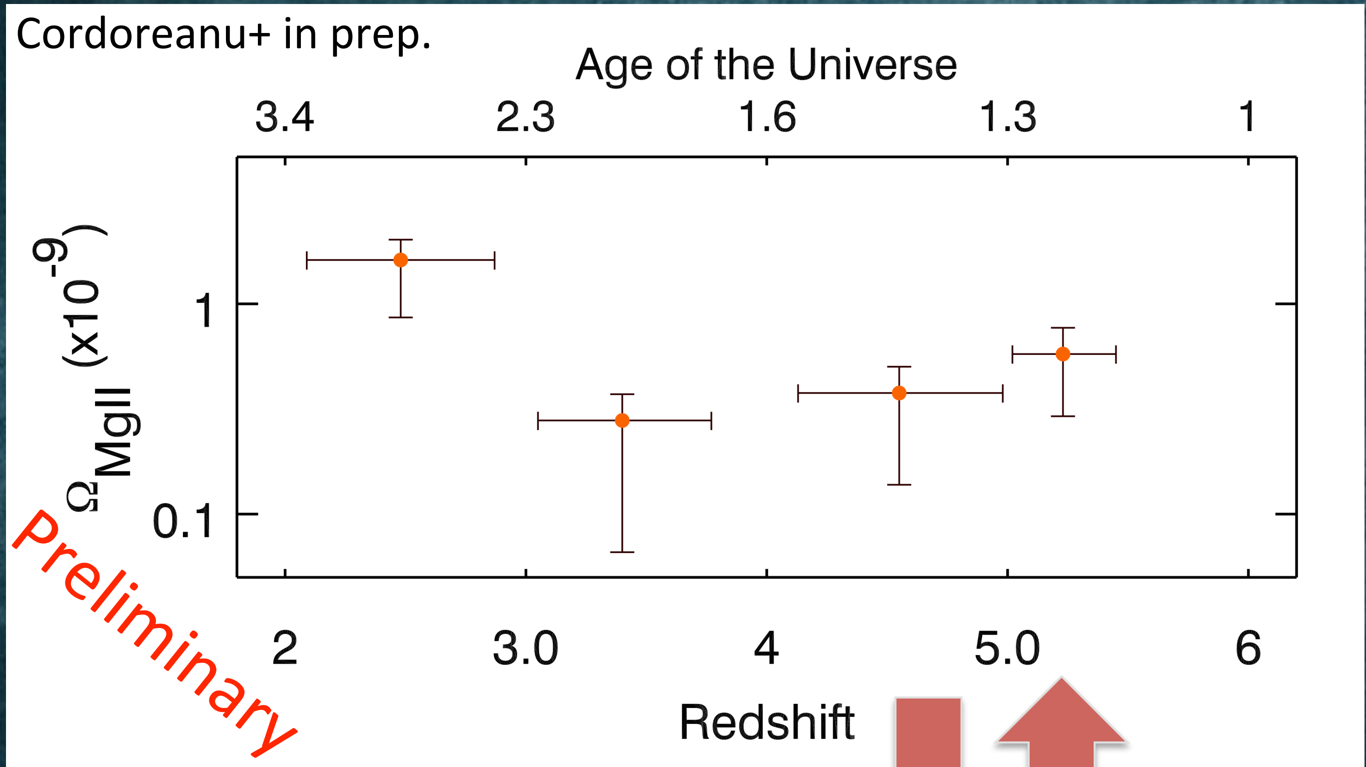
Cordoreanu+ in prep.



mean metallicity decreases by a factor =1.5x or 1.9x (with 0.4 Gyr delay)

Neutrality from density fluctuations alone increases by 1.9x

Cosmological Mass Density MgII



From z=4.6 to 5.2 expect small or no net increase in Ω(MgII).

Extra f_{HI} from reionization is *not* required to explain this flat/upturn, especially as z<5.5 .

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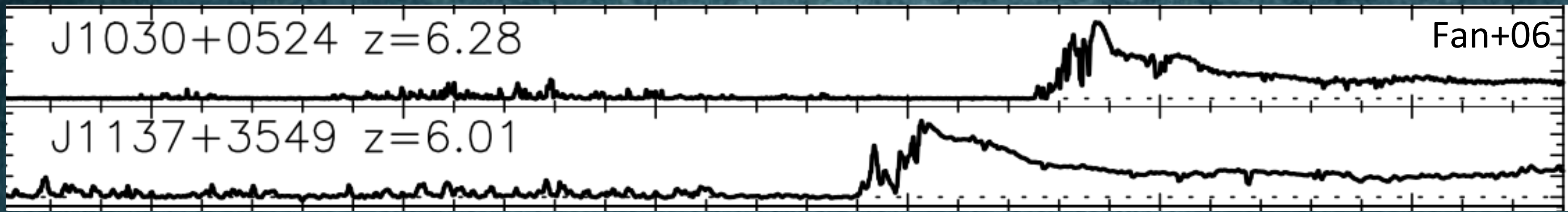
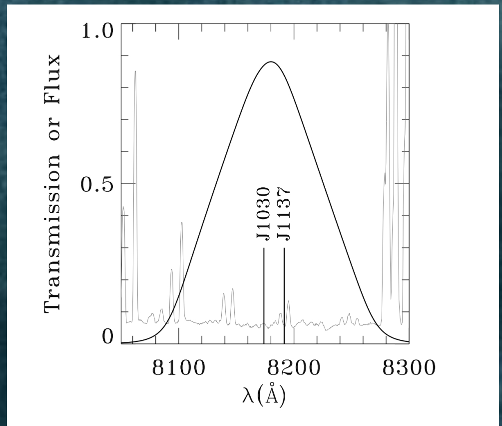
What is the environment of CIV absorbers at z~5.7?





1. Suprime-Cam/Subaru imaging in 2 fields (Diaz+14)

Customized narrow band filter to identify LAEs surrounding the z~5.7 CIV absorbers.

R_c, i', z' broadband imaging to identify LBGs.

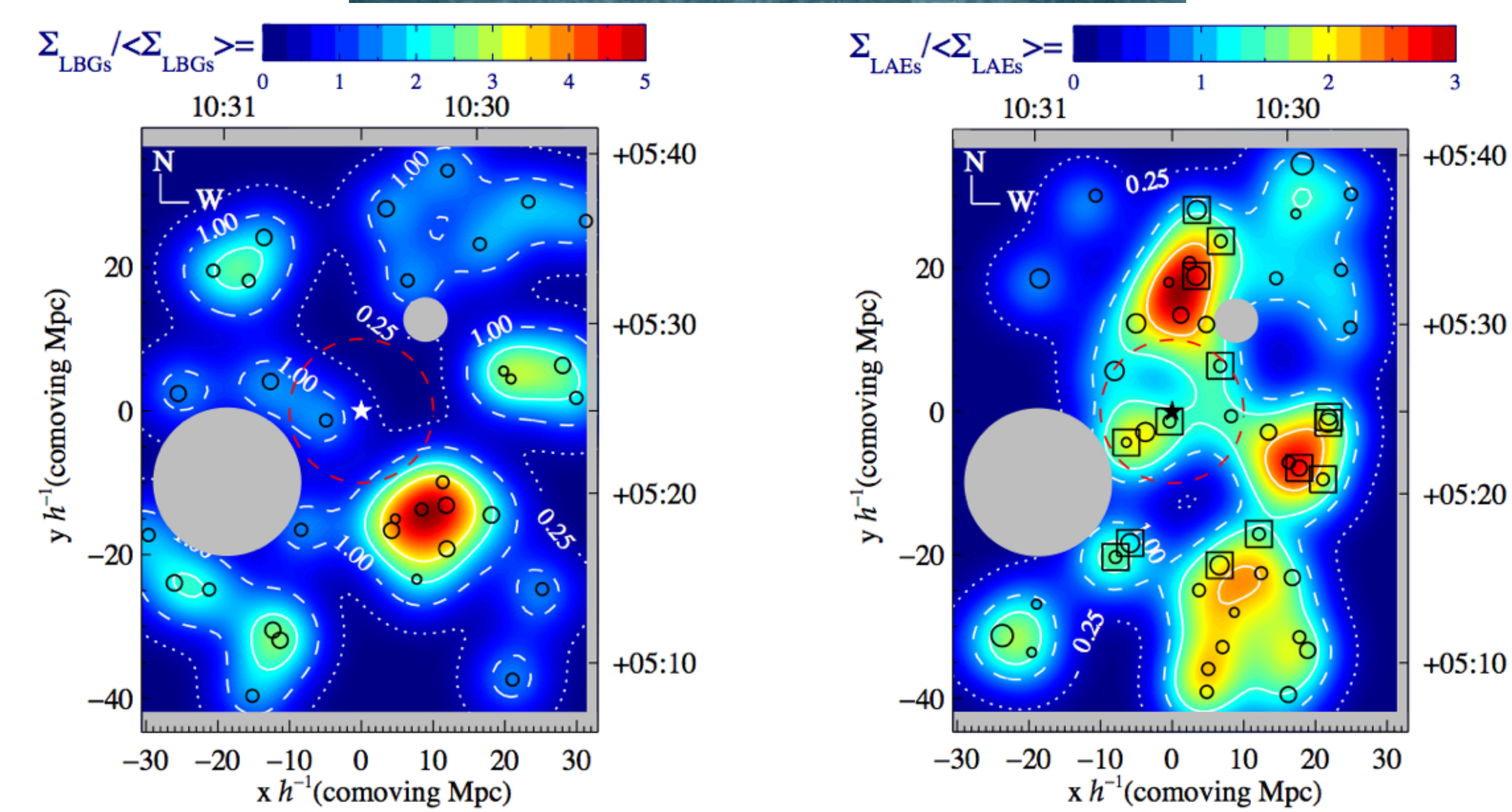
2. DEIMOS/Keck multi-object spectroscopy (Diaz+15)
Followed-up 33 LAEs in 2 fields

Large-scale environment

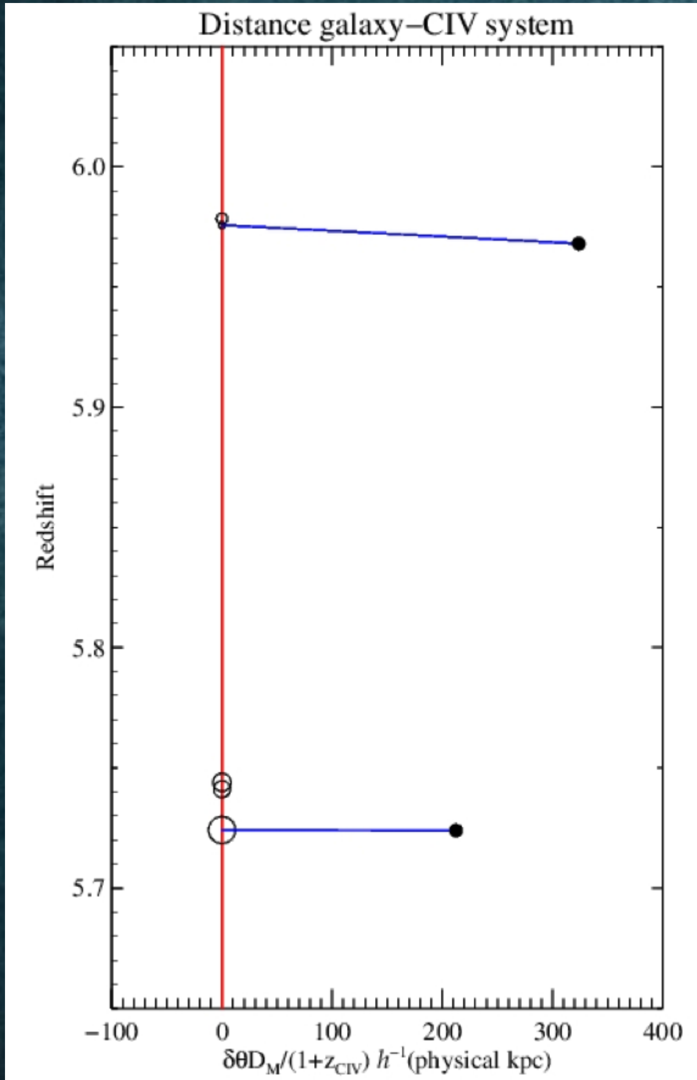
O z~5.7 LBGs

Projected distribution (J1030)

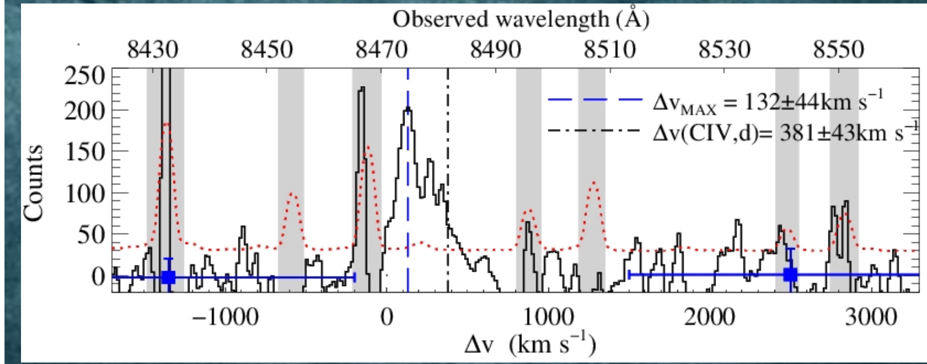
O z~5.7 LAEs



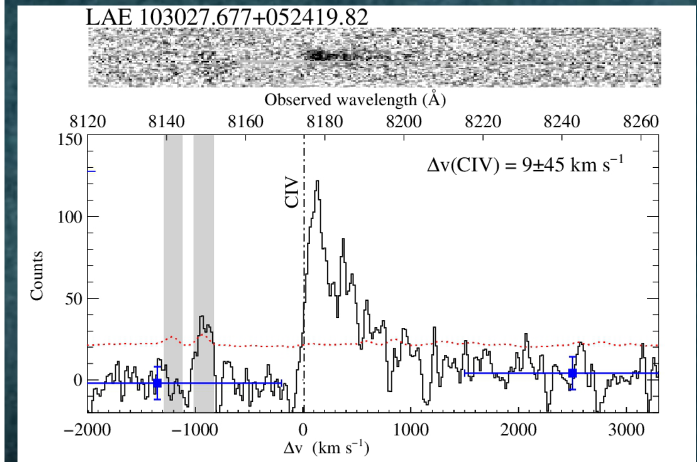
LAE galaxy-CIV absorber pairs



Diaz et al. in prep



Diaz et al. 2015



Travel delay
500 km/s wind takes 0.4 Gyrs to travel 200 physical kpc.

EW = 40 Å
Muv = -20.7
(limit Muv <-20.5)

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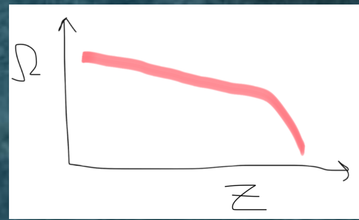

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