Constraints on reionization from intergalactic metals at z~6

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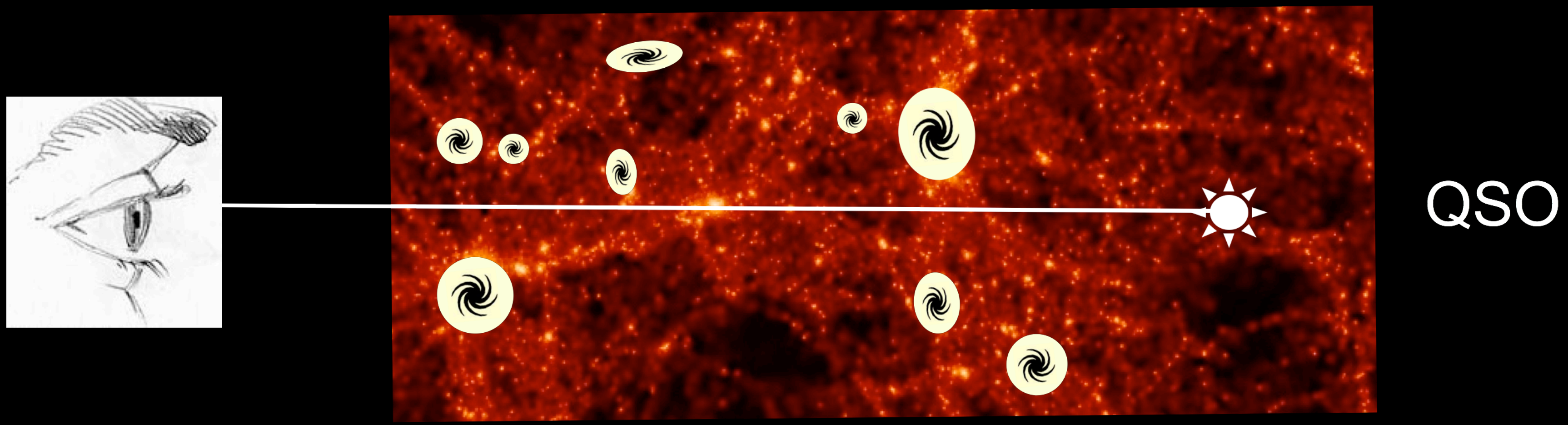
Punch line: pristine gas does not exist at z<6

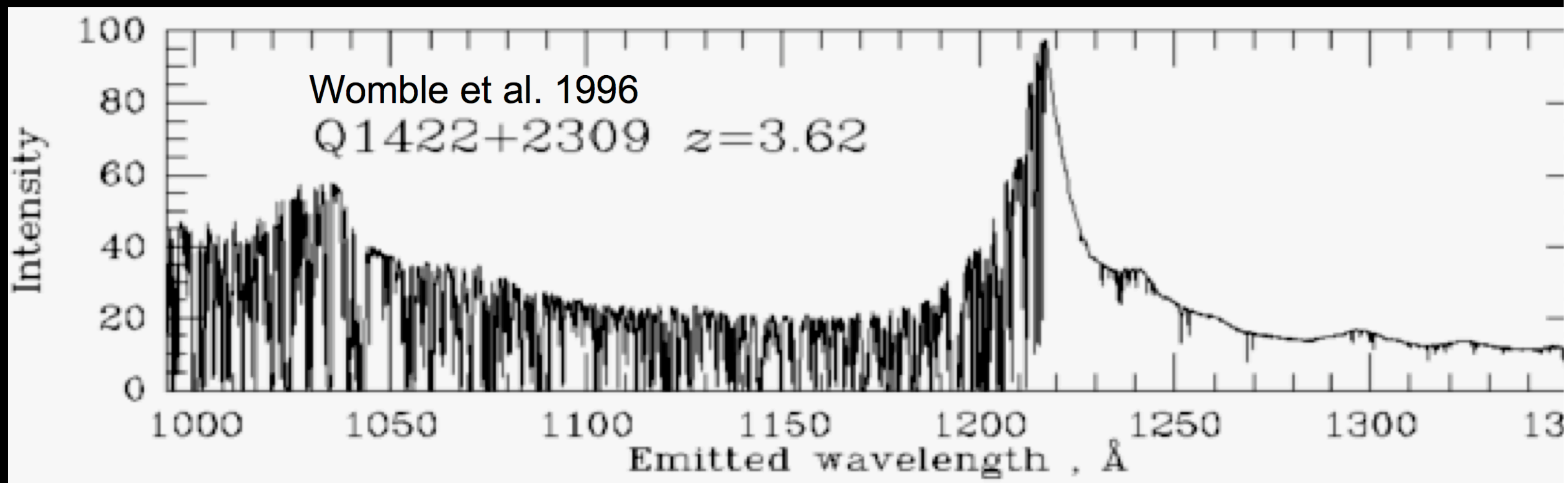
Motivation

The detection of intergalactic metals at high redshift holds important implications for many topical issues in astrophysics

- Chemical history of the Universe
- Distribution of baryons
- Observational constraints on the epoch of reionization
- Understanding galactic winds and outflows
- The importance of 'feedback' in the ΛCDM paradigm
- Detecting the nucleosynthetic products of the first stars

Observing the IGM





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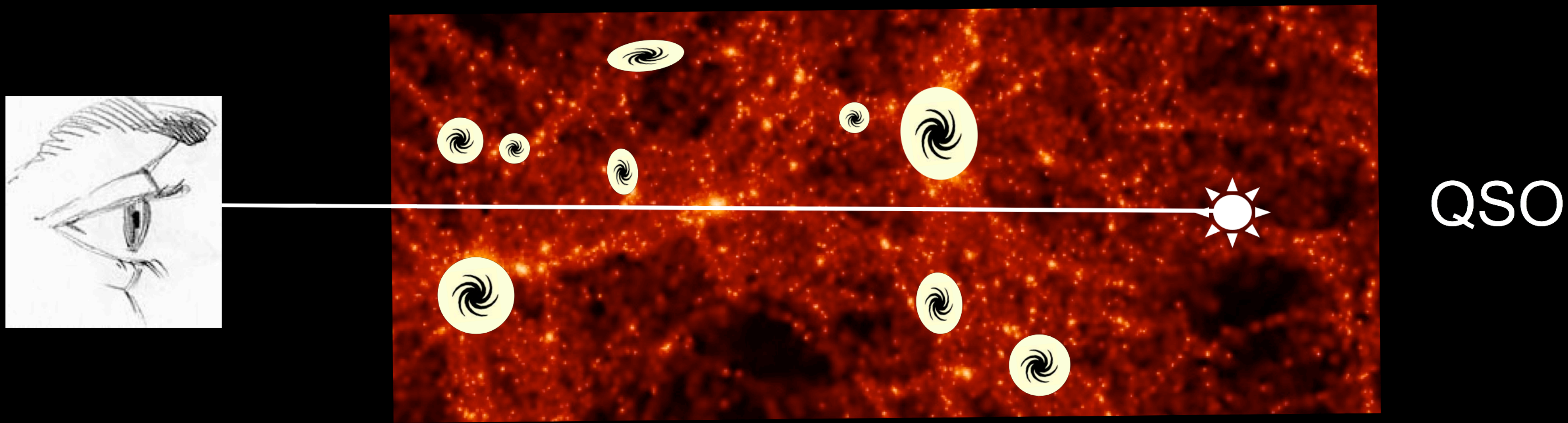
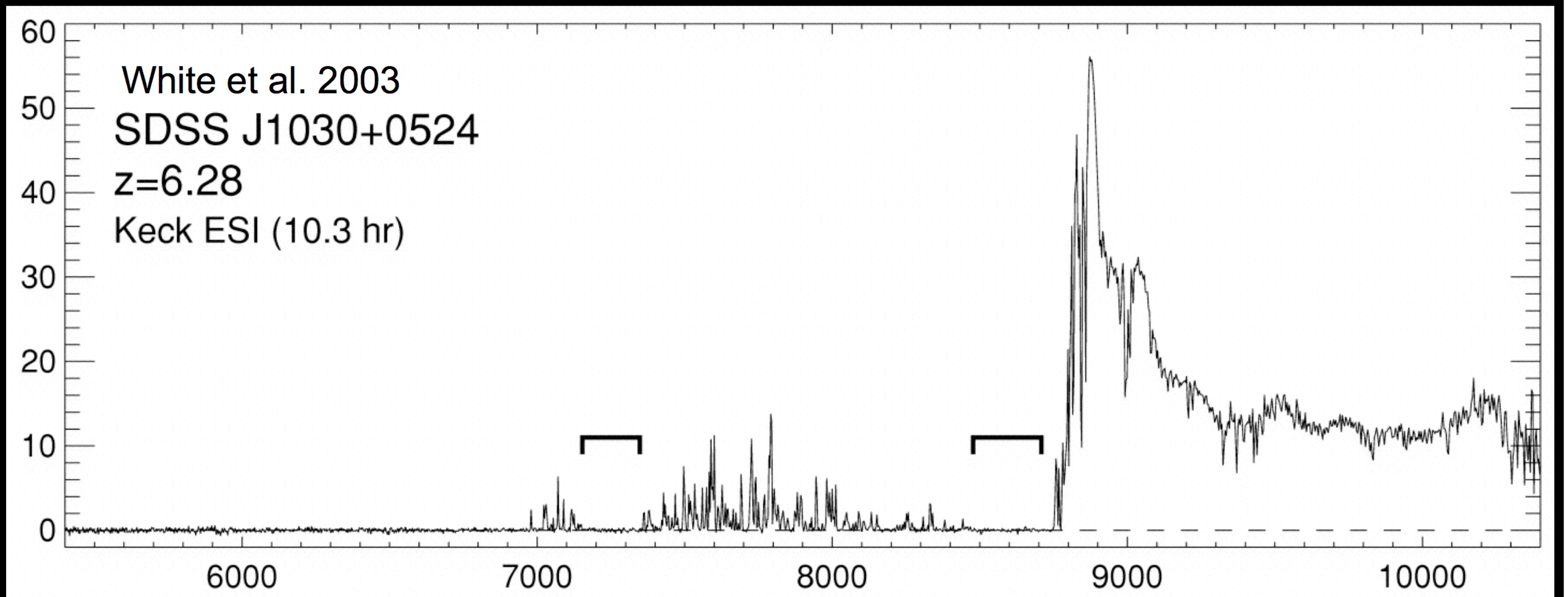




IGM metals at 1.5<z<5

Surprisingly, the IGM is polluted with metals down to the smallest densities and at all redshifts observed to-date.

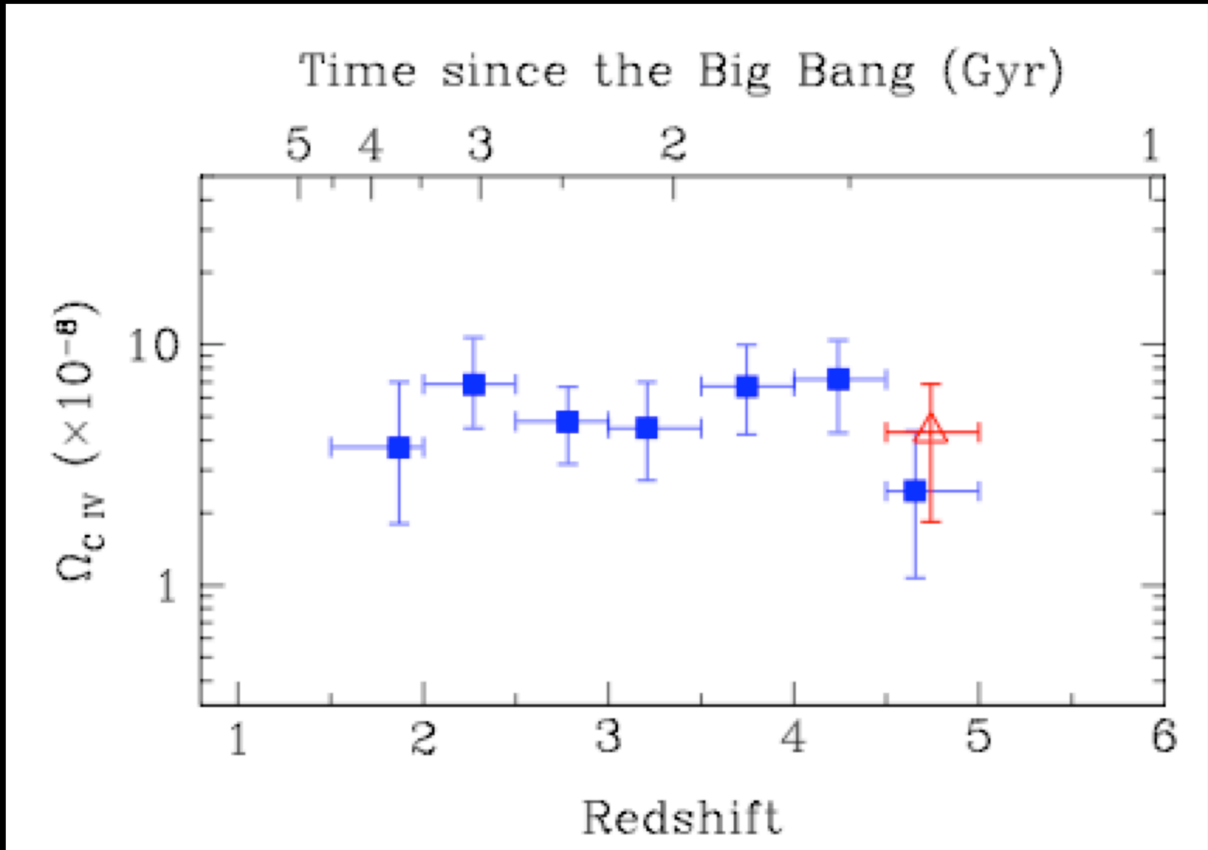
Triply ionized Carbon, C^{3+} or CIV, is the most common metal line in the IGM. Arises in photoionized gas.

The Carbon abundance is somewhat inhomogeneous: at a fixed overdensity, δ and redshift, the probability density function is a Gaussian with width ~ 0.5 to 1.0 dex (Schaye et al. 2003). Similar results hold for Oxygen (Simcoe et al. 2004).

The median Carbon abundance increases with density (Schaye et al. 2003).

There is even Carbon found in some under dense gas!

Cosmological Mass density

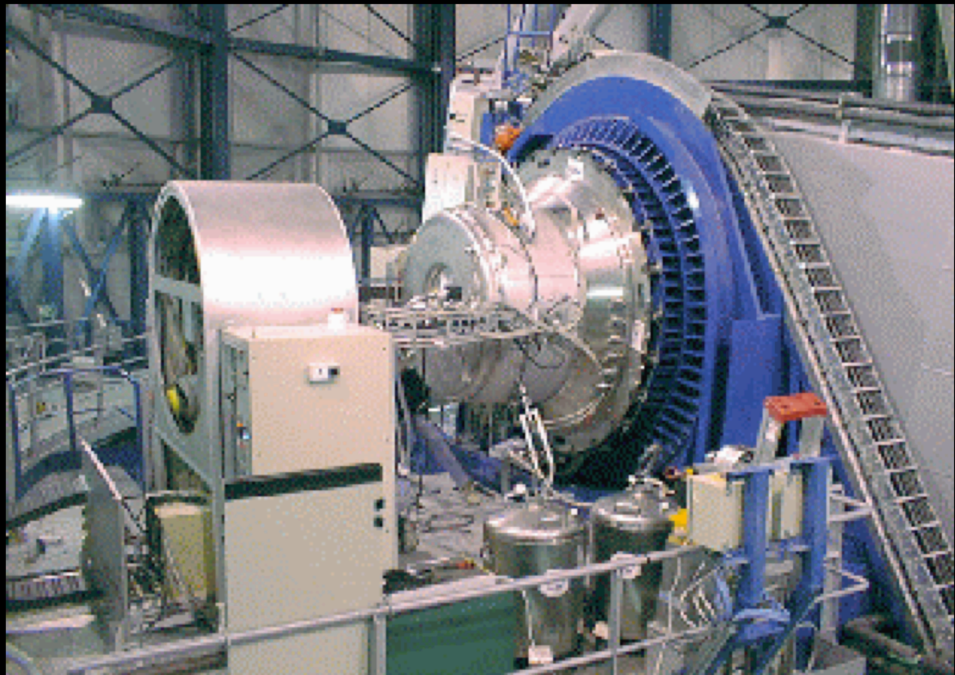


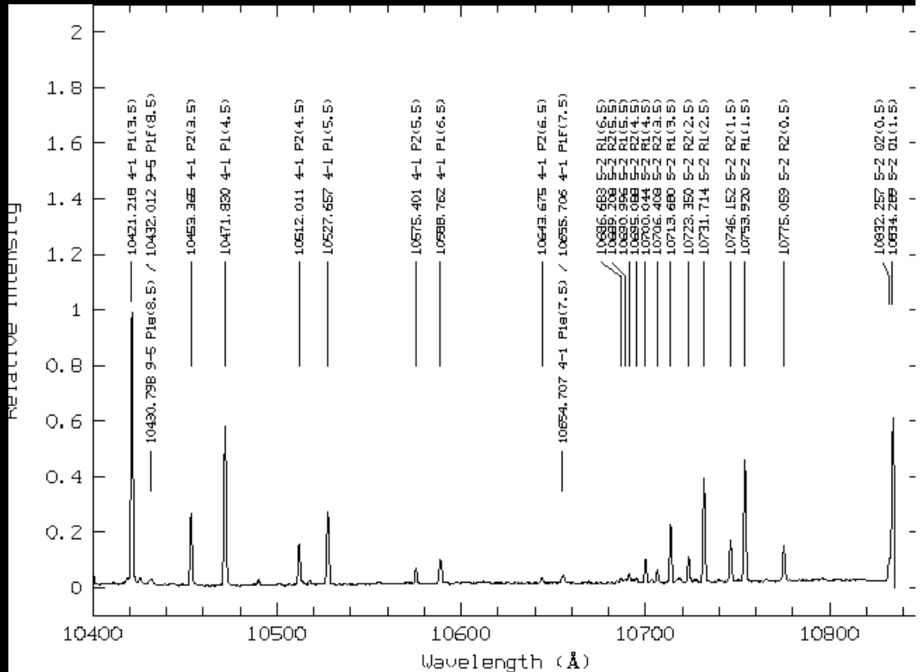
Songaila (2001)
Pettini et al. (2003)

Ω_{CIV} is flat 1.5<z<5

CIV at z=5 corresponds to ~9300 Å, the wavelength where the efficiency of optical CCDs begins to decline

Infrared Spectrometer And Array Camera (ISAAC) VLT observations

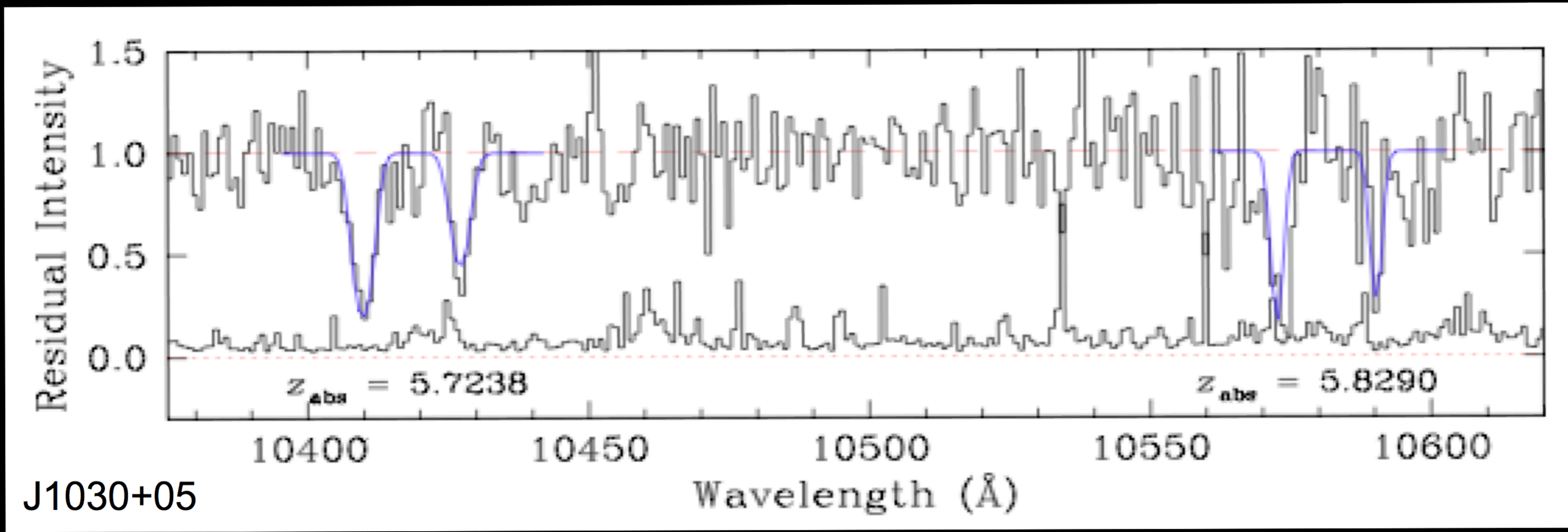




Demonstrate that medium resolution QSO absorption line spectroscopy is viable in the near Infrared.

Significant challenges: OH skylines, atmospheric absorption

ISAAC/VLT Results



Ryan-Weber, Pettini & Madau, 2006, MNRAS 371, 78

Pilot study: Took spectra of 2 high z QSOs.

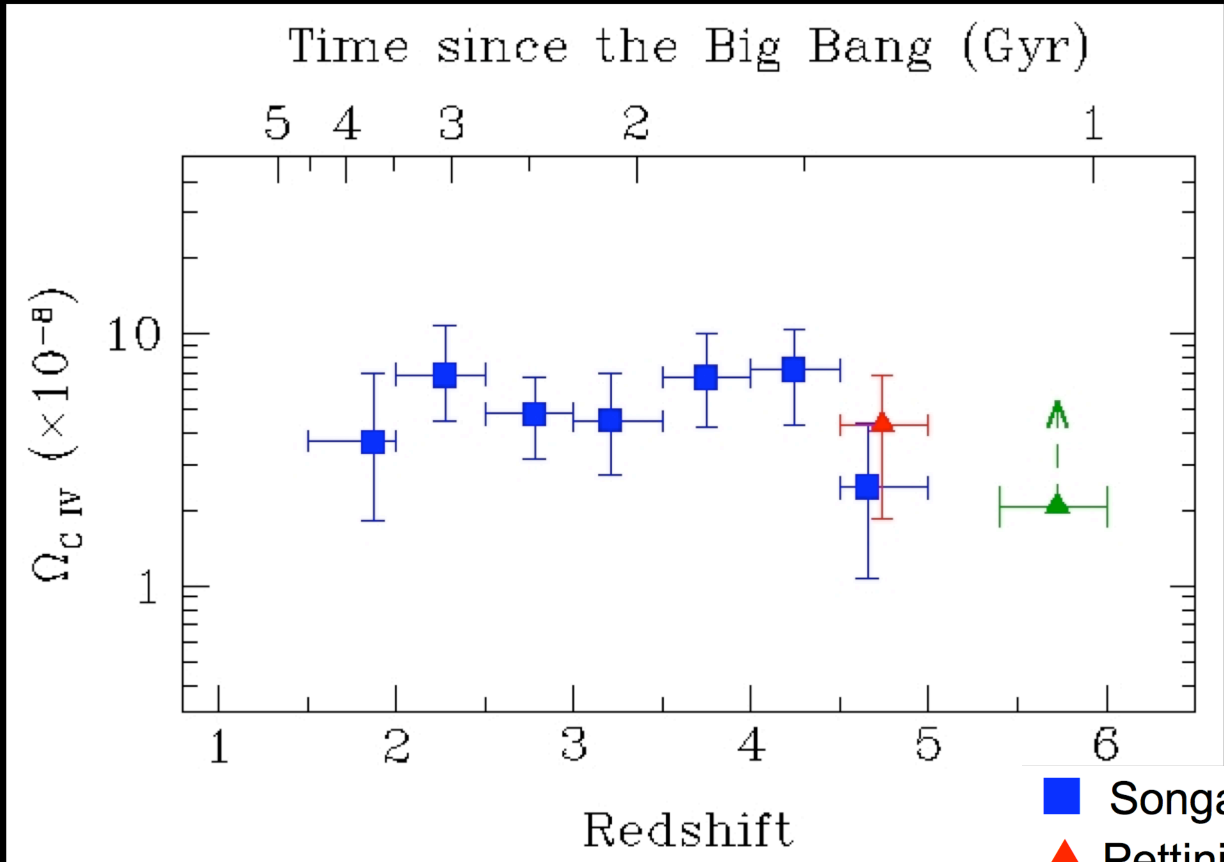
SDSS J1030+0524 (z_{em}=6.28) - 2 CIV systems detected

z=5.7, N_{CIV}=2.3x10^{14} cm^{-2}, b=63 km/s (FWTM=191 km/s)

z=5.8, N_{CVI}~3x10^{14} cm^{-2}

SDSS J1306+0356 (z_{em}=5.99) - nothing detected (lower S/N)

Cosmological Mass density



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

- Songaila (2001)
- Pettini et al. (2003)
- ERW, Pettini & Madau (2006)

No evidence for a turndown in the mass density of CIV in the IGM as we look back further in time.

Indicates that at least some of the metals at z~6 have an earlier origin.

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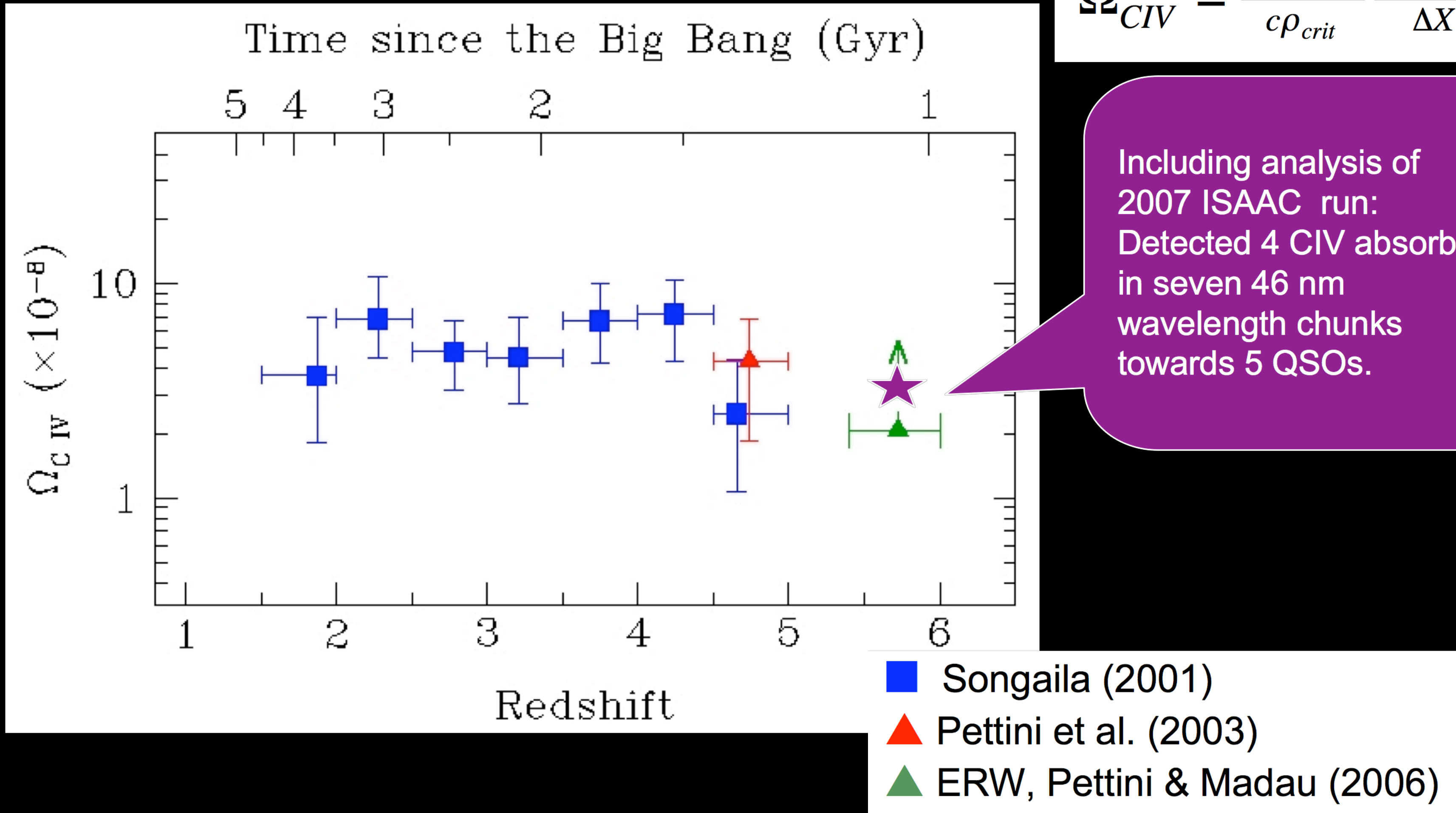

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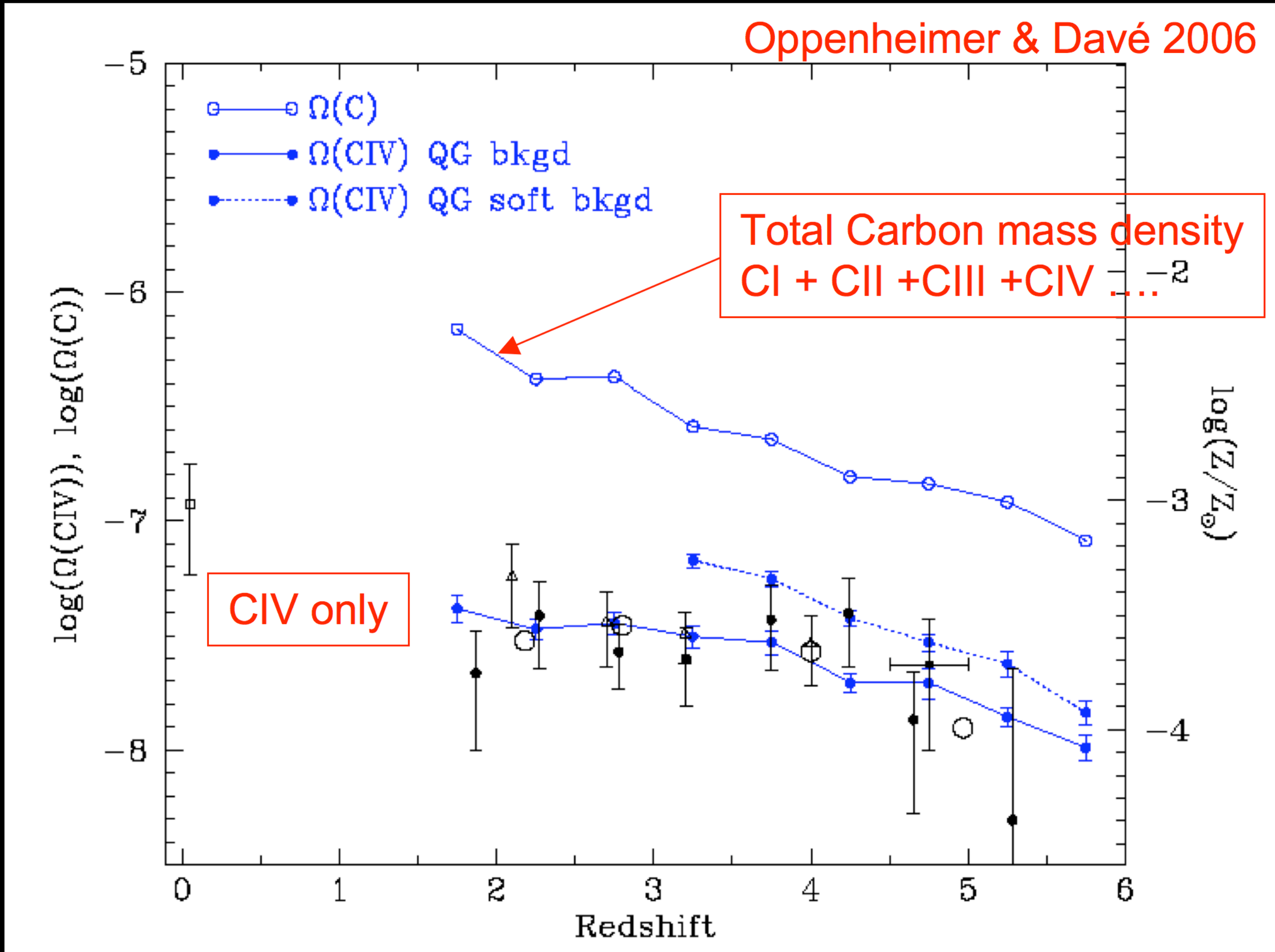
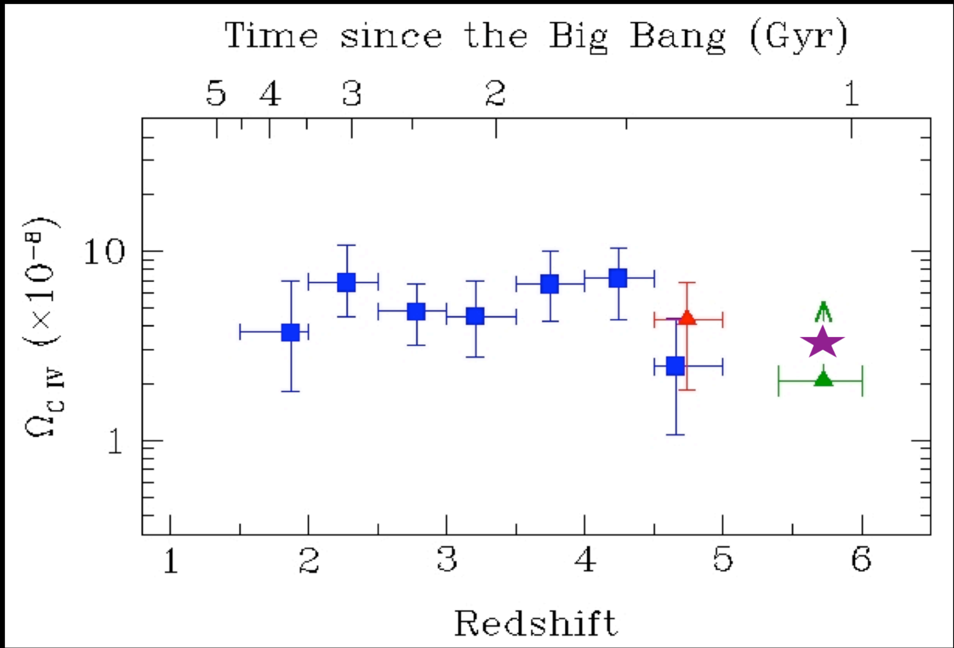
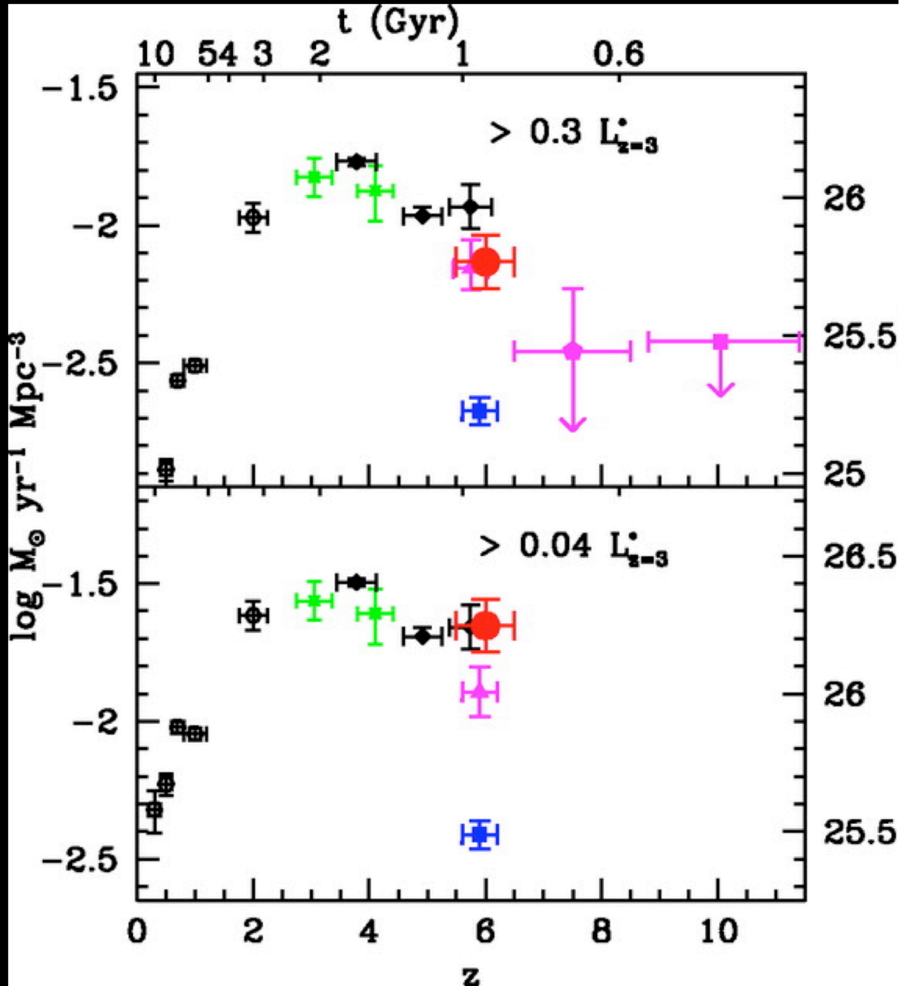
Models of Metal enrichment



Models can reproduce the flat evolution in Ω_{CIV} to z~5 with continual outflows from star forming galaxies at z<6 and a standard ionization correction.

Expect metal enrichment to lag SFRD





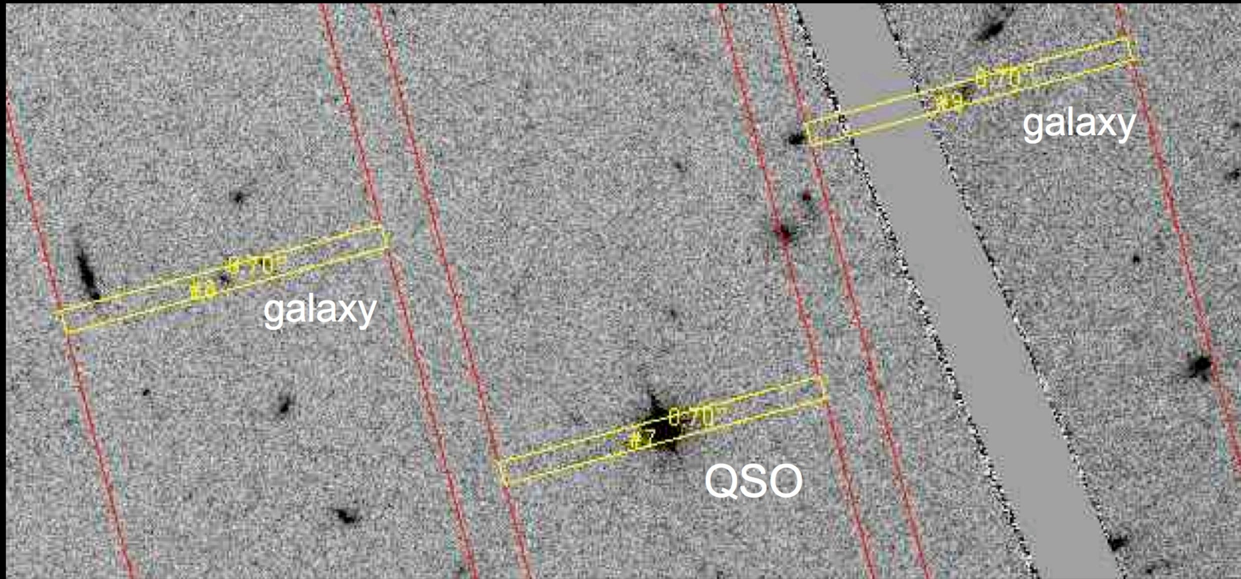
Star formation rate density highly uncertain at z>5

Bouwens et al. (2006); see also Iwata et al. (2007

Expect to see the drop in mass density of IGM metals to occur more recently than the decline in star formation rate density.

Timescale of the delay depends on velocity of winds.

Can we identify the galaxies responsible for the metal enrichment?



VLT/FORS2
multi object spectrosco
To detect Lyα emission
and measure redshifts

Can also do the 'revers
experiment

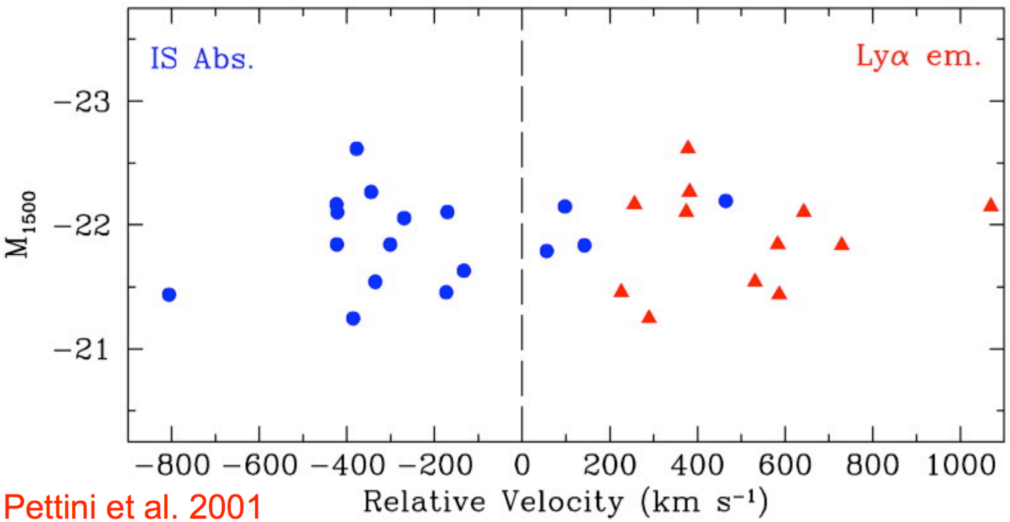
Two candidate z>5.5 galaxies ~90 kpc from J1030+05 line-of-sight are likely to have significant starburst winds
(UV luminosity indicate SFR ~ 60 Msun/yr).

The foreground field of this z_{em}=6.28 QSO has an excess of z>5.5 galaxie
(7 detected, cf 3.33 expected, Stiavelli et al. 2005).

However, an excess of galaxy counts could simply indicate a large scale overdensity, which is expected to be preferentially enriched prior to the en of reionization (Porciani & Madau 2005).

Implications for Reionization

Lyman break galaxies at z~3



Pettini et al. 2001

What if the Carbon we detect did originate in a galaxy 90_{proper} kpc away?

A wind of ~ 200 km/s requires a travel time of 9×10^8 yrs from its birth place in the galaxy.

e.g. for $z_{observed}=5.7$, $z_{ejection}\sim 8.6$

However, gas with v~200 km/s is unlikely to overcome the Hubble flow, which is quite rapid at early times (1000 km/s). Metals must be expelled to densities approaching the cosmic mean to avoid being gravitationally re-accreted onto their parent galaxy.

For wide spread metals to exist in the IGM at z~6, there must have been wide-spread enrichment beyond the gravitational influence of galaxies.

e.g. Dynamical destruction of small haloes at z~9 by an early generation of stars (Madau, Ferrara & Rees 2001)

Summary

We have discovered CIV absorbers at z=5.7 and 5.8 in the IGM.

Together with 2007 ISAAC data, results suggest that there is still no evolution in Ω_{CIV} as z~6 is approached.

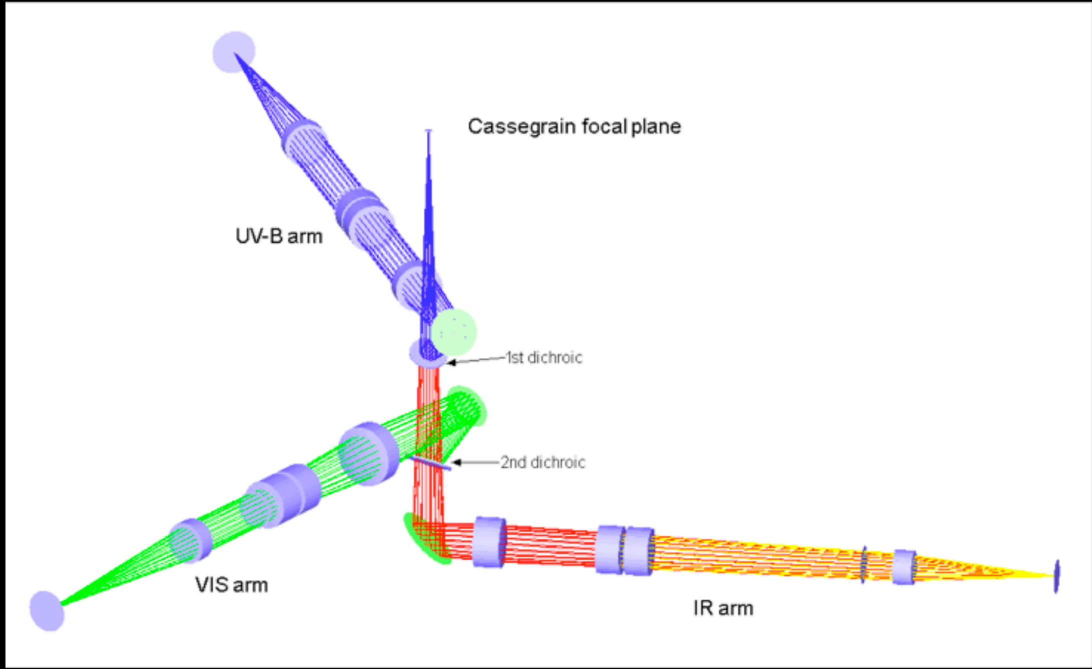
The high mass density of CIV at z~6 presents a challenge to N-body simulations that include momentum driven winds as the only source of IGM enrichment.

- At least some enrichment could be due to smaller mass objects from earlier times, although the interpretation depends on the z~6 luminosity function. (i.e. how likely is it that all our positive CIV sight-lines lie close to massive, star bursting galaxies?)

Further programs are underway to search for CIV in other directions, and measure redshifts of galaxies close to CIV absorbers.

- This will give better stats how widespread metals are in the z~6 IGM, and will place a limit on total number of stars that must have formed by that time.

Future Prospects for detecting IGM metals at z>6



X-shooter: 3 armed UV-VIS-NIR spectrograph for the VLT (installation 2008).
Medium resolution spectroscopy of faint point sources.
Entire QSO path length is acquired with one setting.
Will be used to target bright, newly discovered, high z QSOs.
VISTA hemisphere survey predicted to detect ~40 z>6.4, ~10 z>7 bright QSOs.
Lines of interest range from OI (1302 Å) to FeII (2382 Å).
Expect supernova of very massive Pop III stars to expel their Fe-enriched core.