Shaping the metal enrichment history of the IGM with a high-resolution spectrograph at the E-ELT

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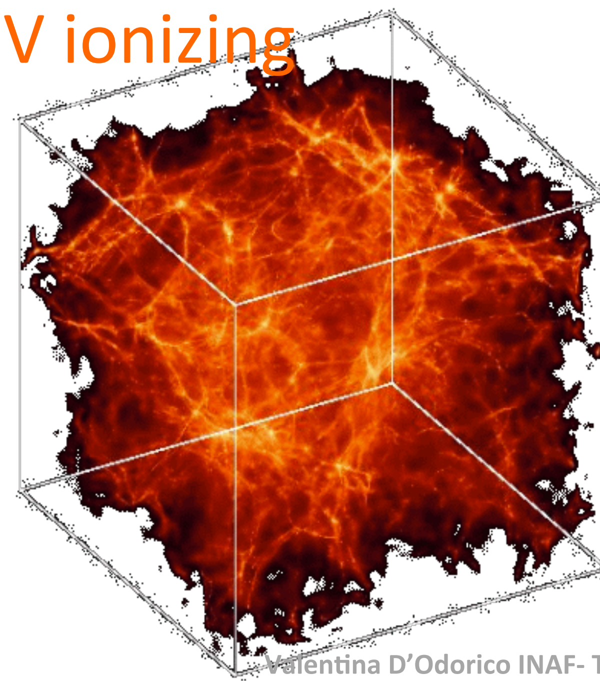
Metals in the IGM: why do we bother?

Metals in the IGM: why?

3 Key Questions in Cosmology and Galaxy Formation

- When and how was the Universe reionized (H and HeII) ?
- Which sources contribute to the UV ionizing background at the different redshifts?
- What is the nature of feedback processes in galaxies and AGN?



Metals in the IGM: why?

At z >1.5 about 90 % of the baryons are diffused in the IGM

Constant interplay between galaxies and IGM

- IGM gas feeds galaxies in the formation process
- SNe and AGN driven winds deposit enriched gas in the outskirts of galaxies

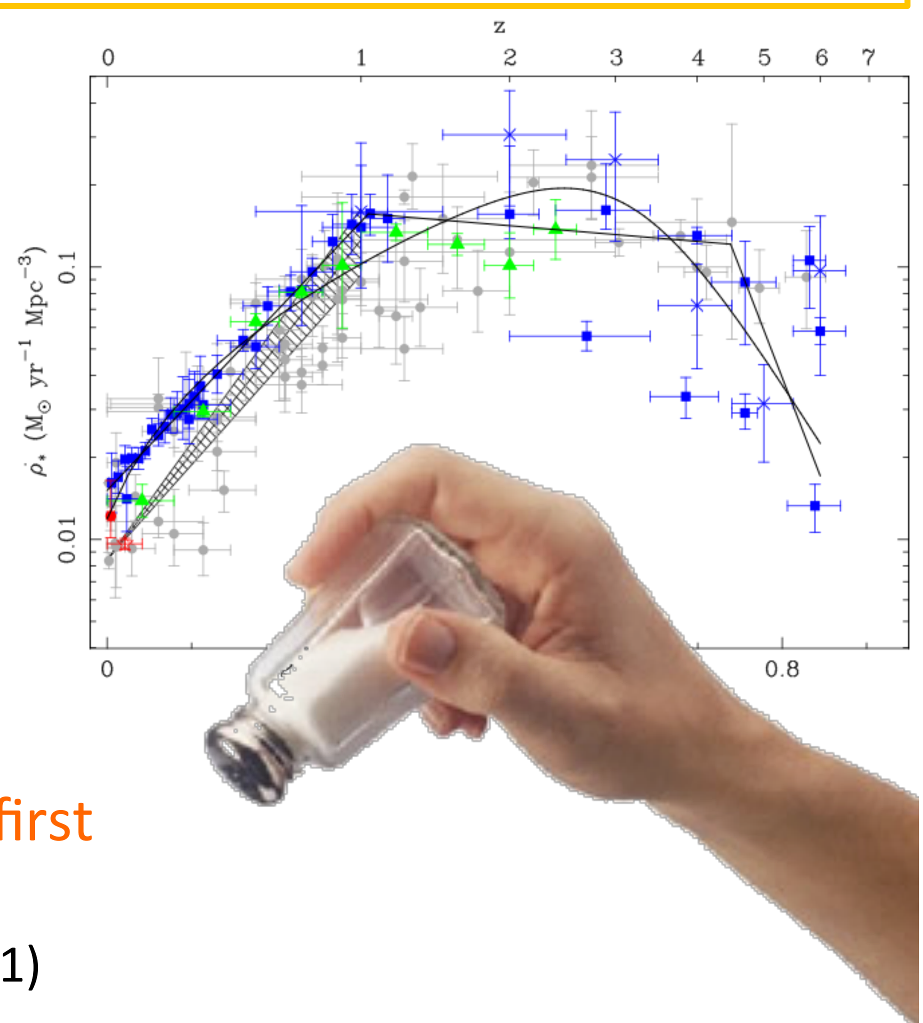
METALS are tracers of the life cycle of gas

Metals in the IGM: why?

Different enrichment scenarii predict different metal properties

Metals outflowing from starburst galaxies at z~2-3 and confined in their proximity?

(e.g. Adelberger+ 2003,2005)

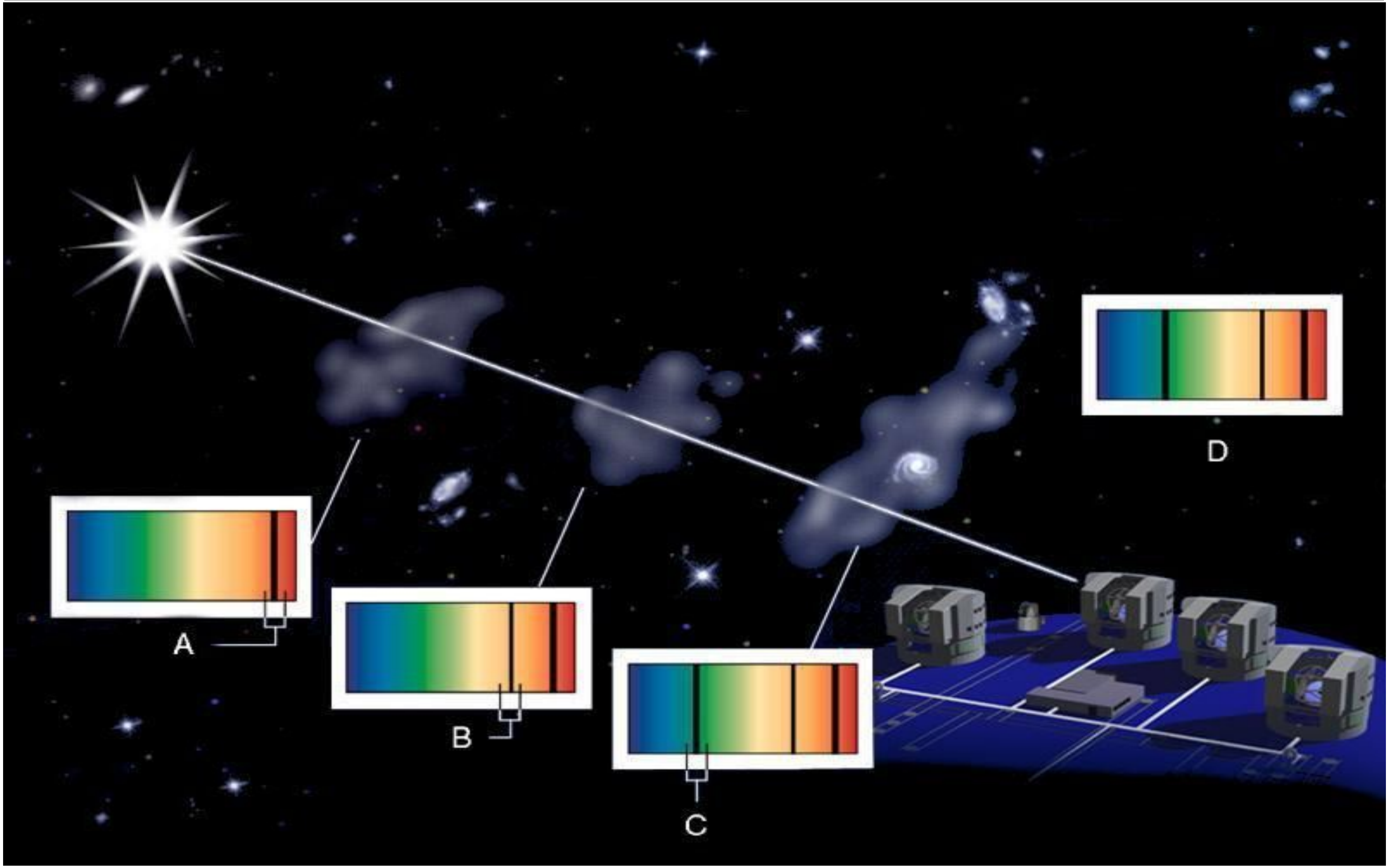


Metals sprinkled-in by the first ionizing sources at z>>6?

(e.g. Madau, Ferrara & Rees 2001)

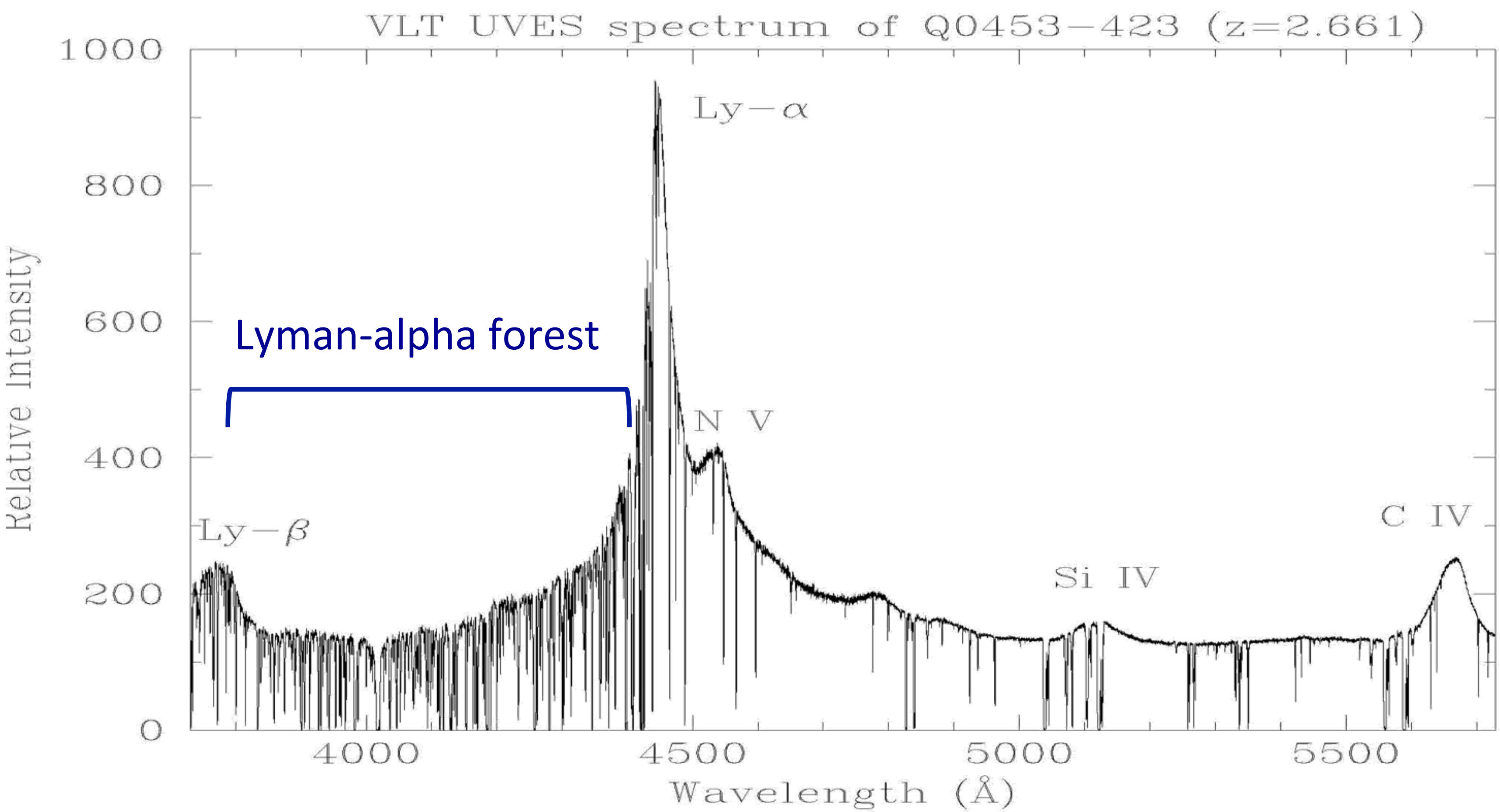
Metals in the IGM:
how do we study them?

Metals in the IGM: how?



Metals in the IGM: how?

Ly-alpha forest lines trace the IGM density fluctuations



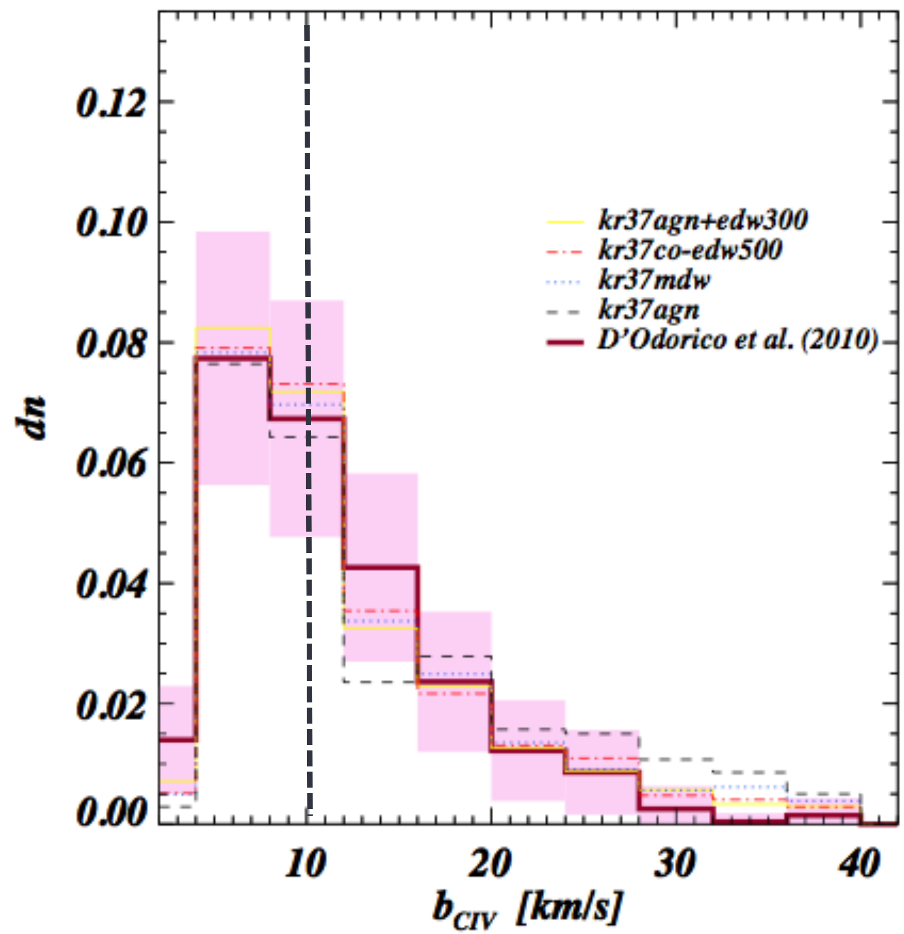
Metals in the IGM: how?

Metals outside galaxies detected by their absorption lines in high-z QSO spectra, thanks to the advent of 8-10m class telescopes and high res spectrographs (HIRES, UVES)

All Lya systems with log N(HI) > 15 and 50-60 % of those with log N(HI) > 14.5 show associated CIV lines

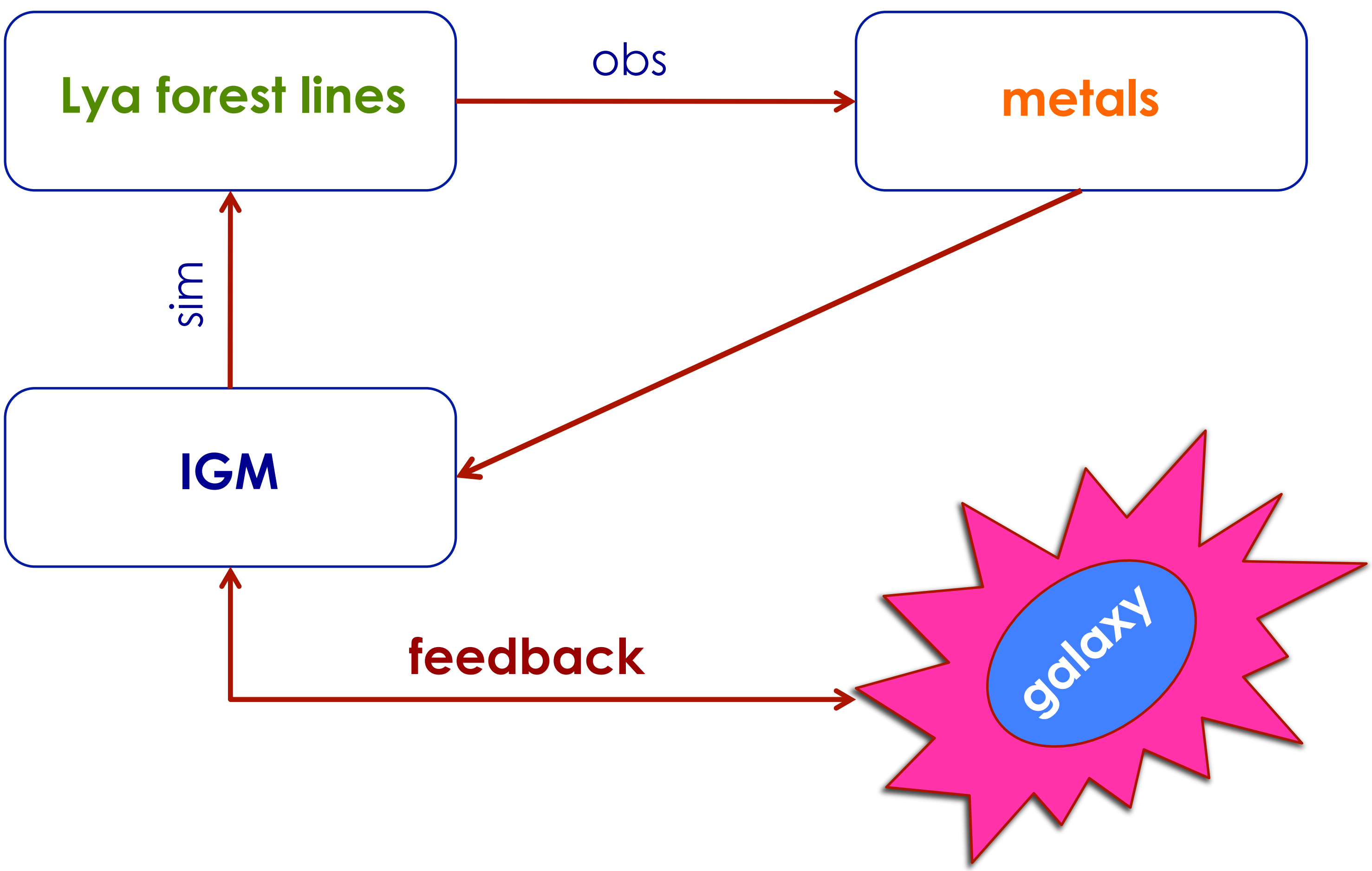
$10^{-3} < Z/Z_o < 10^{-2}$ at z~2-3

Probability distribution function of b(CIV)



Tescari et al. 2010

Metals in the IGM: how?



Metals in the IGM: how?

- What is the distribution of metals (wrt galaxies, volume filling factor) ?
- What are the relative abundances of chemical elements?
- What is the ionization state of the observed elements?
- What is the evolution with redshift of the previous properties?

INTERPRET WITH SIMULATIONS

Metals in the IGM: the role of HIRES at the E-ELT

1. Low density IGM
2. High redshift IGM

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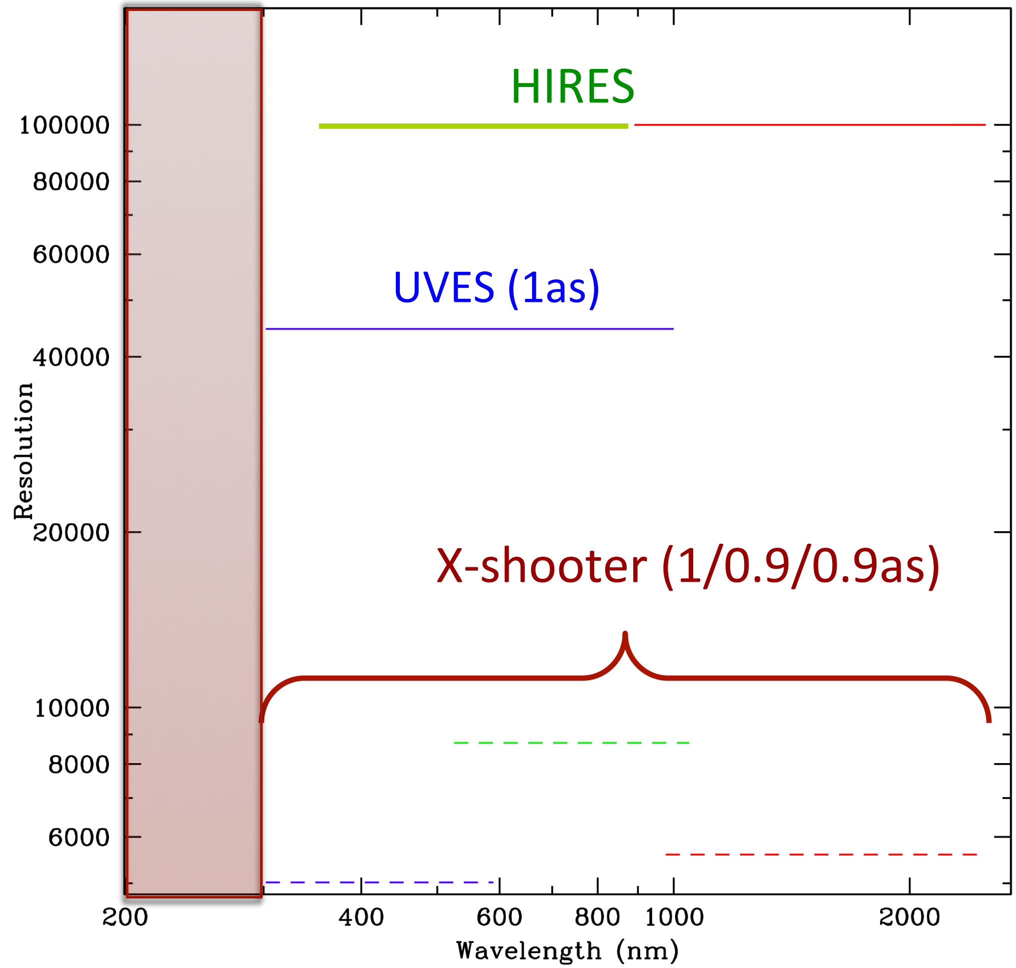
HIRES

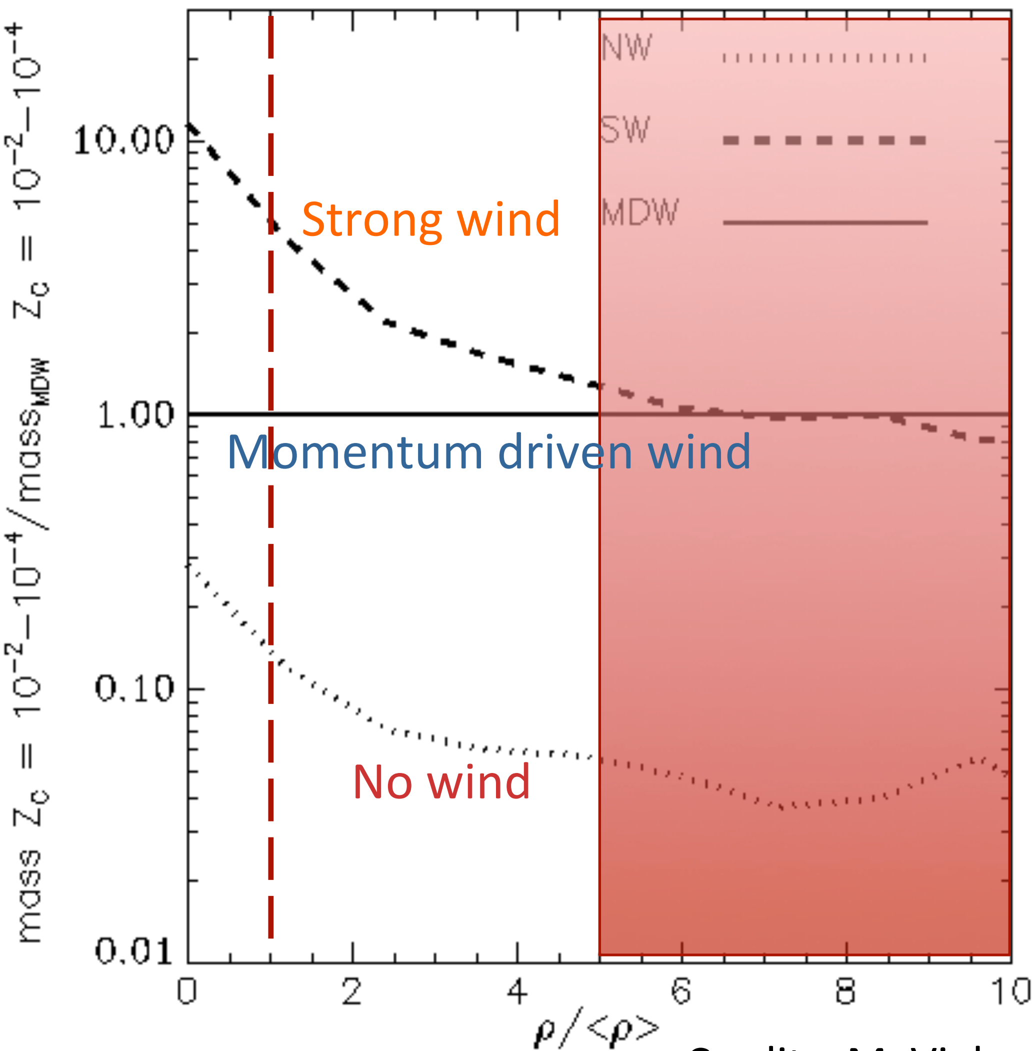
ESO biased view of the most performing spectrographs



TOP LEVEL REQUIREMENTS

- Targets: point sources
- Spectral coverage:
  0.37-2.45 µm
- Spectral resolution:
  ~100,000 + single obj
- Multiplex at lower resolution
- AO assisted mode in the NIR
- See talk by R. Maiolino

Metals in the IGM: low density



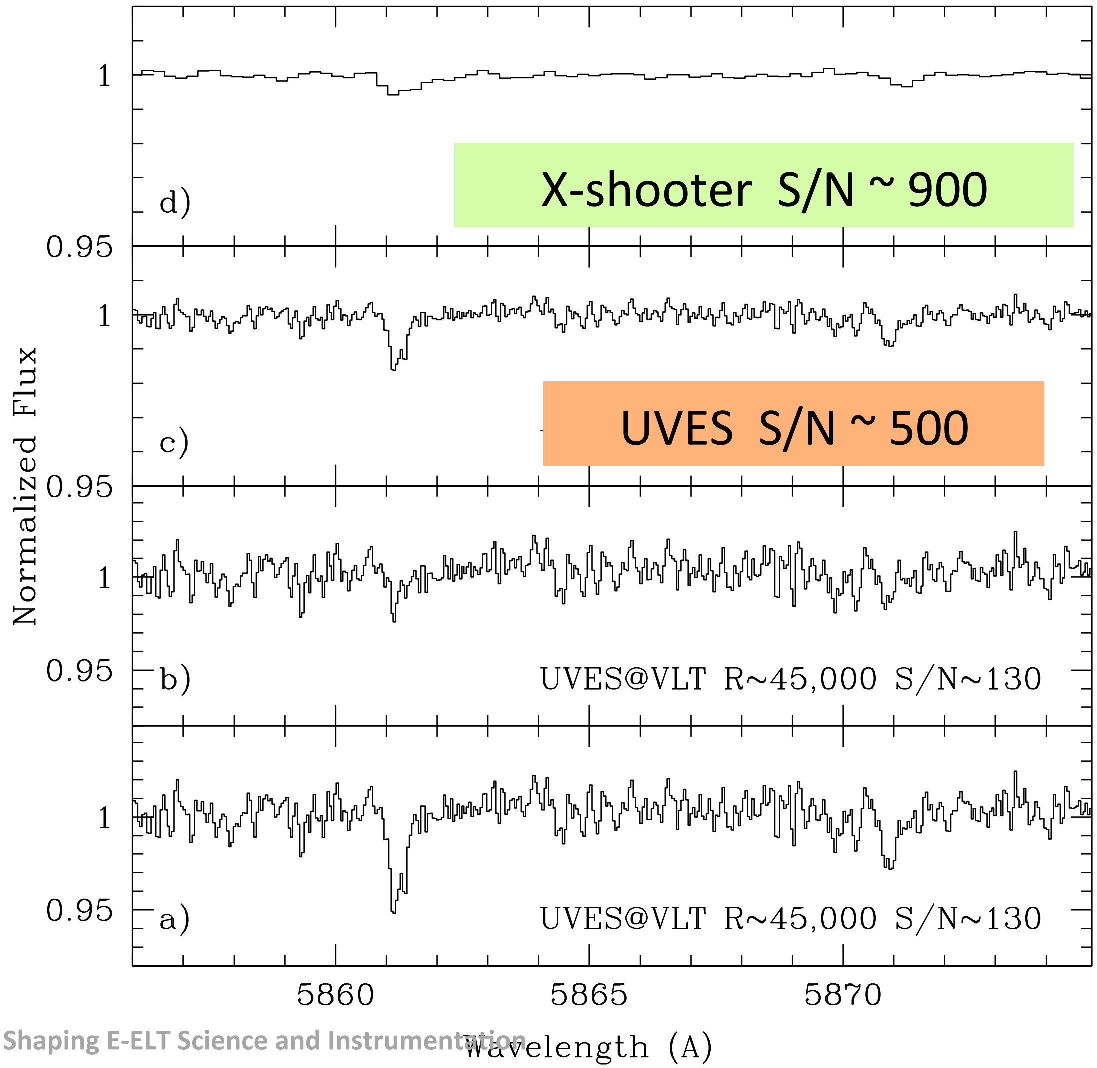
Credits: M. Viel

Discriminate between:

- different enrichment scenarii;
- different kind of winds

Metals in the IGM: low density

Direct detection with UVES @ VLT



T_{exp} ~ 60 hours
QSO with V=16.9
zem ~ 3

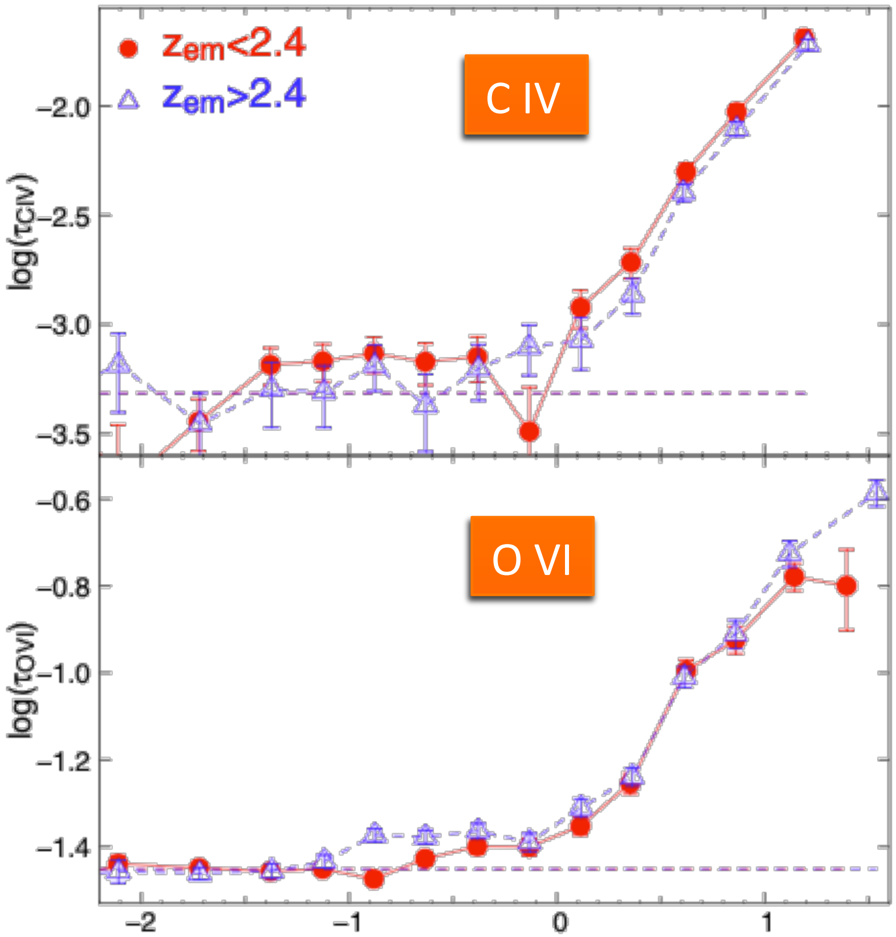
log N(CIV) = 11.5 limit with the deep spectrum

log N(CIV) = 12 present limit at z~3

δ ~ few

Metals in the IGM: low density

Pixel Optical Depth (POD)



log (τHI)

Aracil et al. 2004

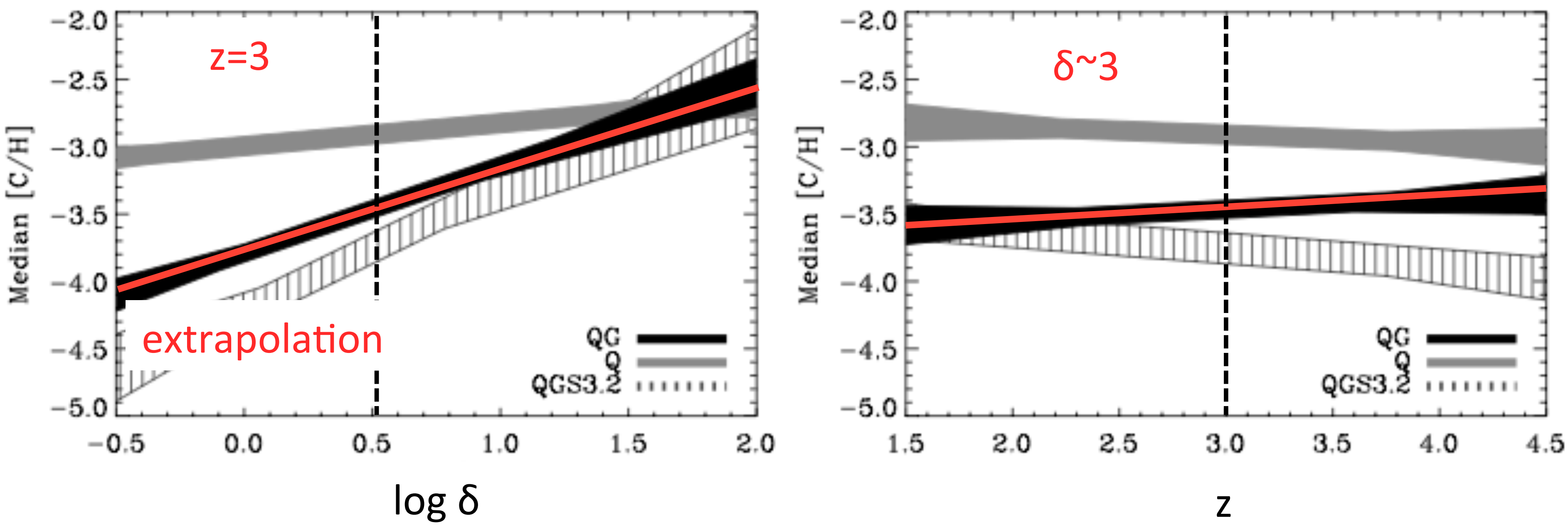
Statistical approach to detect metals at lower densities (Cowie & Songaila 1998; Ellison et al. 1999, 2000; Aguirre et al. 2002)

F = exp(-τ) : correlate the optical depth in HI with that of metals (CIV, OVI, SiIV)

Significant correlation → metal detected

Metals in the IGM: low density

Pixel Optical Depth (POD) ➔ Median metallicity



HI and CIV optical depth translated into δ and [C/H] with simulations and Cloudy

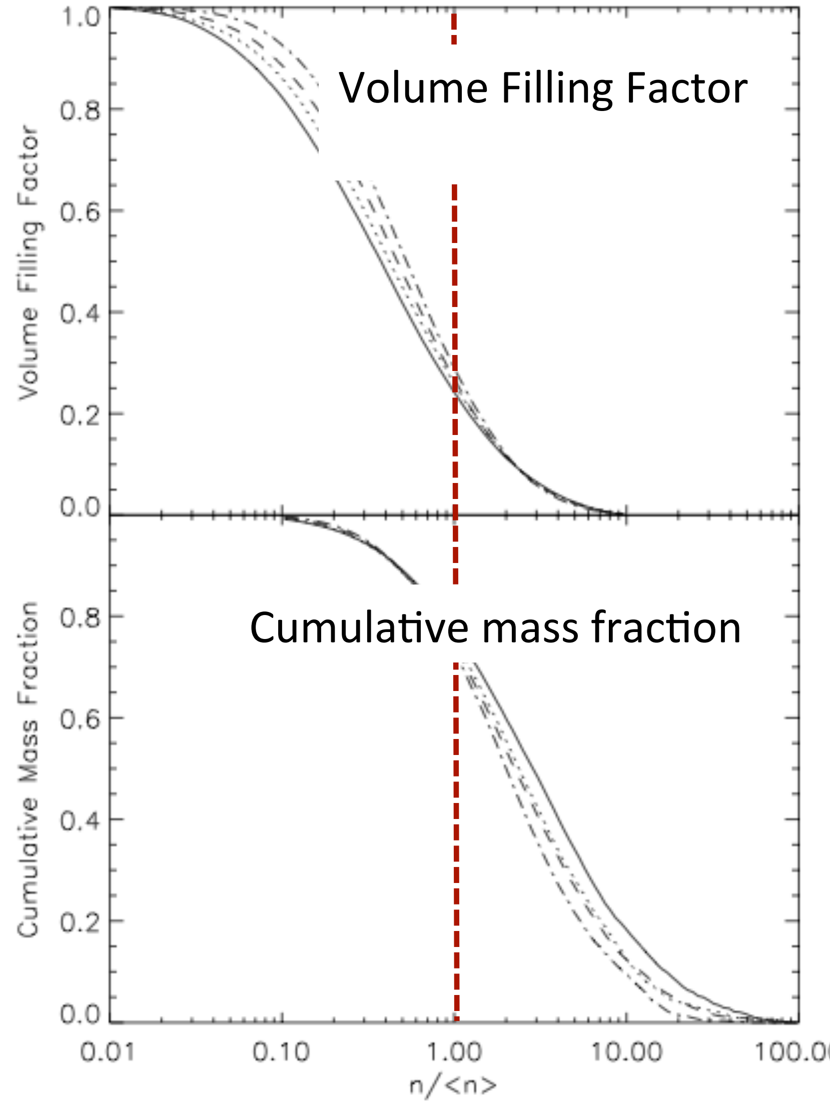
Schaye et al. 2003

Metals in the IGM: low density

Pixel Optical Depth (POD)

Mean density not reached

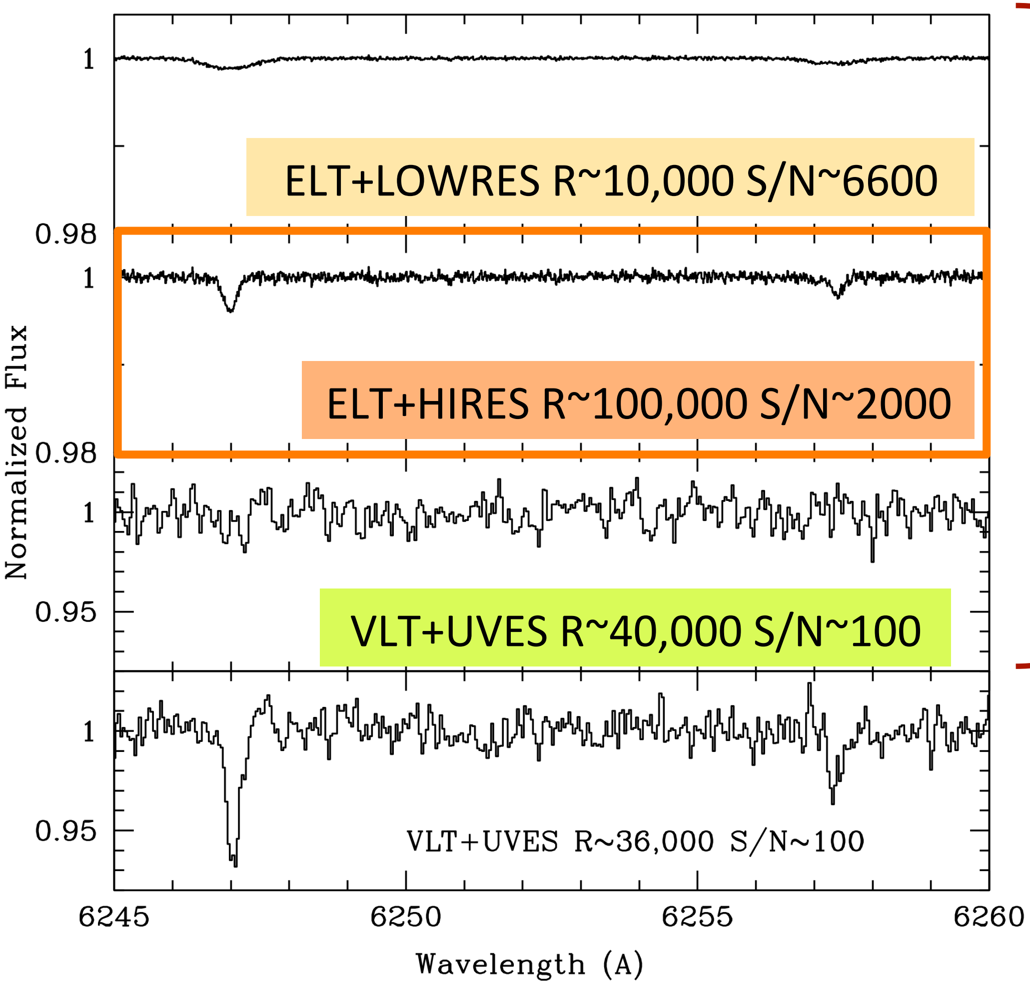
Probing less than 2% of the volume of the Universe (Pieri & Haehnelt 2004)



CONCLUSION

Both <u>direct detection</u> of metal lines and <u>statistical detection</u> of metallicity at the mean density (and below) require HIGHER SIGNAL TO NOISE and HIGH RESOLUTION

Reaching the mean density with HIRES@ELT

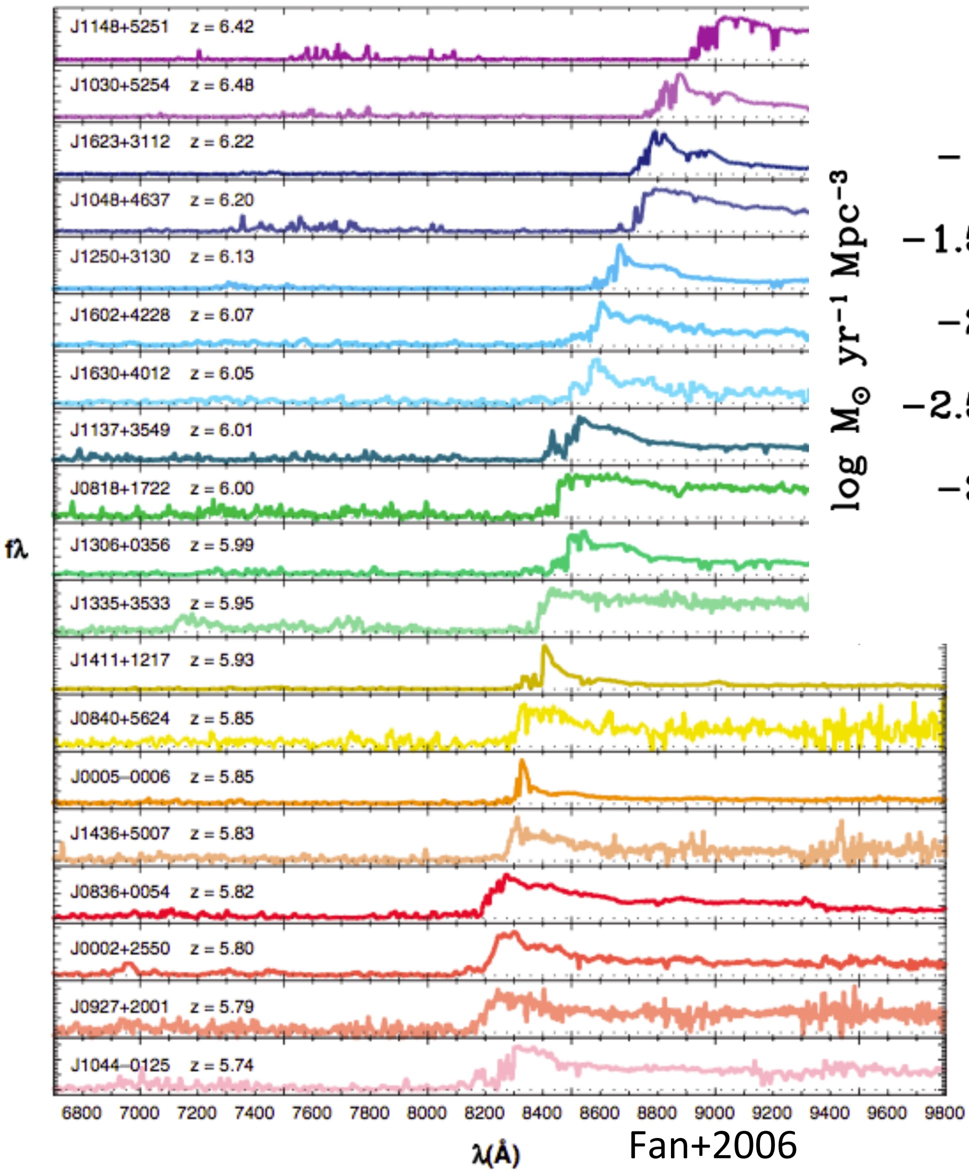


T_{exp}~20 h for an R~16 QSO at z~3

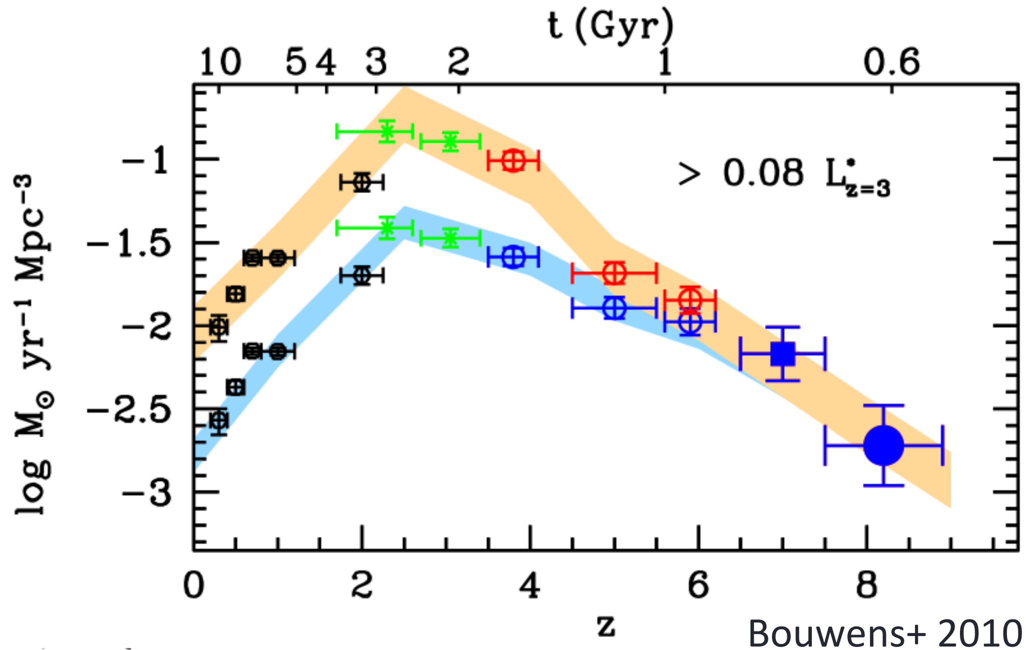
Scaled to the mean density:
log N(CIV) ~ 11

Limit of present observations:
log N(CIV) = 12 ➔ δ ~ 5-10

Metals in the IGM: high redshift



Fan+2006



Bouwens+ 2010

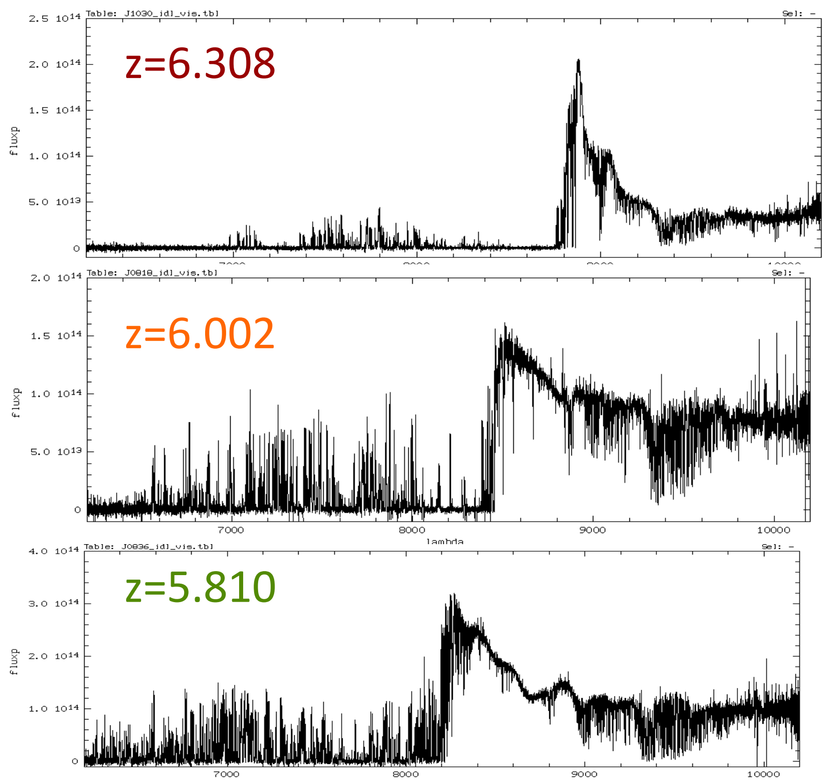
At z>5-5.5

- the Lya forest is completely absorbed
- CIV moves to the NIR

Metals in the IGM: high redshift

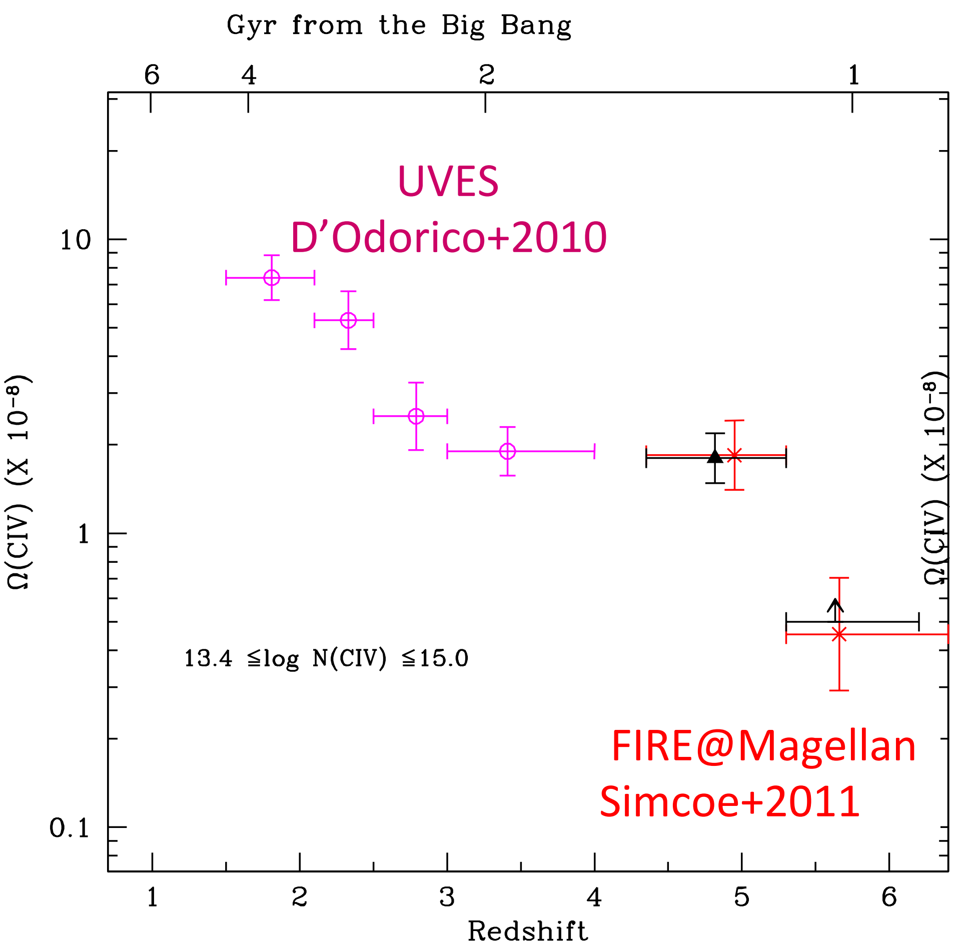
The CIV cosmic mass density

$$\Omega_{\mathrm{C\,IV}} = \frac{H_0\, m_{\mathrm{C\,IV}}}{c\,\rho_{\mathrm{crit}}} \int N f(N)\, \mathrm{d}N \rightarrow \Omega_{\mathrm{C\,IV}} = \frac{H_0\, m_{\mathrm{C\,IV}}}{c\,\rho_{\mathrm{crit}}} \frac{\sum_i N_i(\mathrm{C\,IV})}{\Delta X}$$

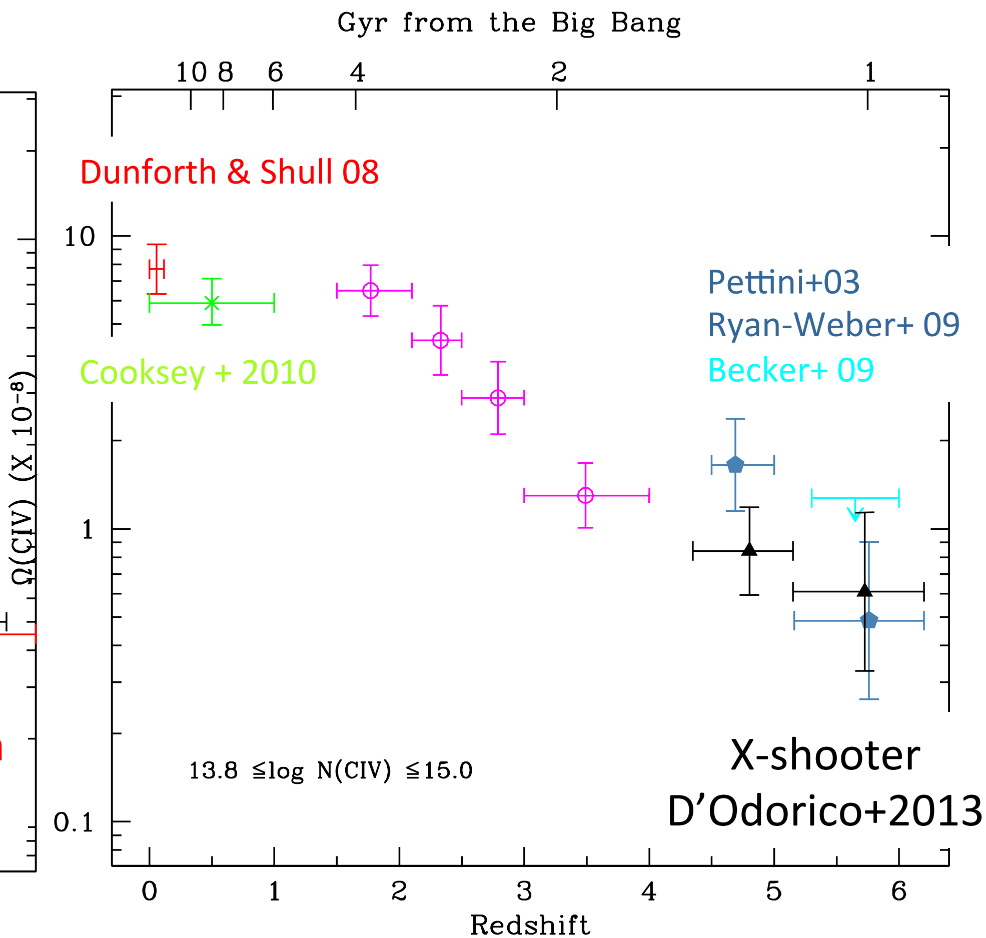


Metals in the IGM: high redshift

Lines with 13.4 < NCIV < 15

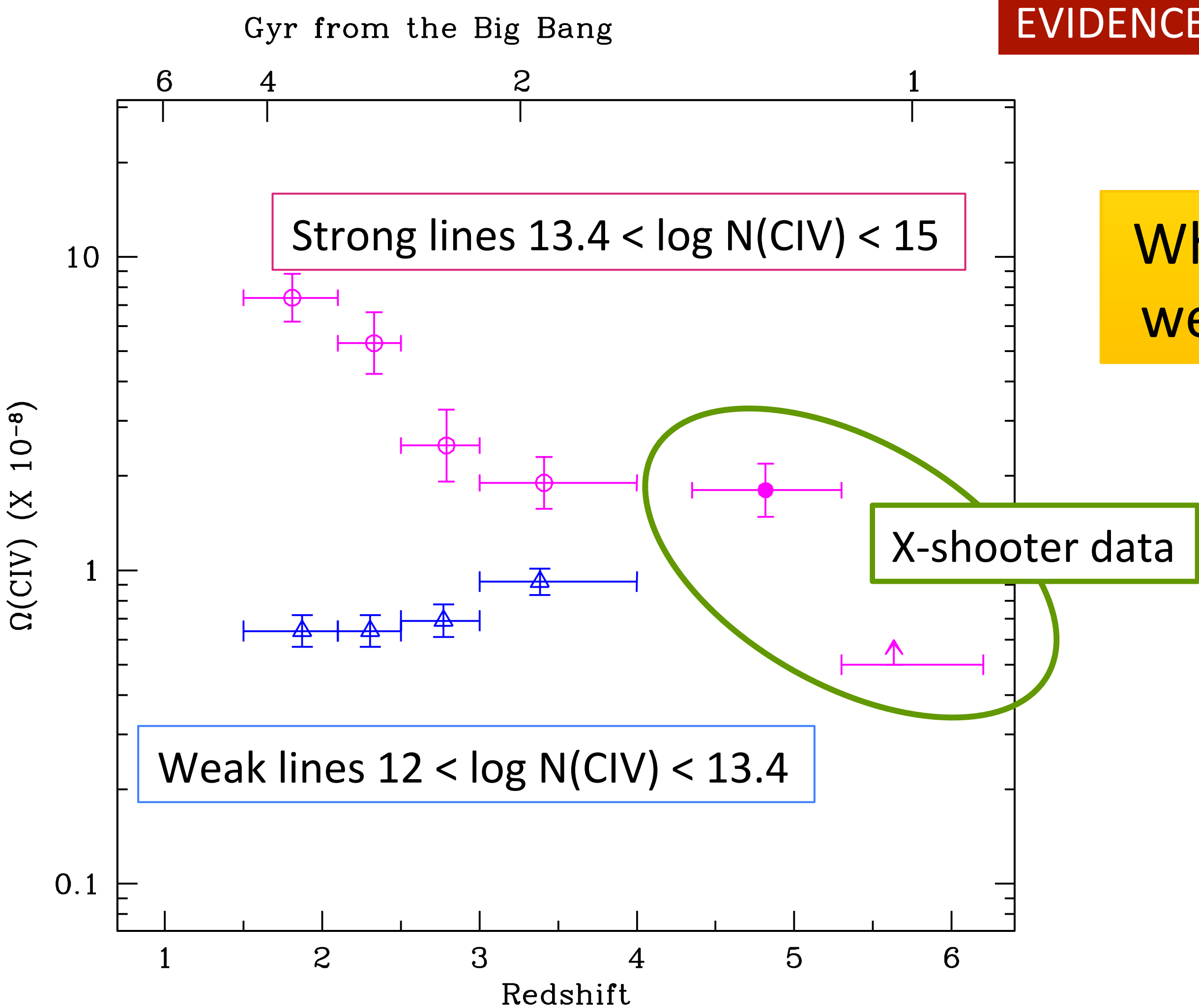


Only strong lines 13.8 < NCIV < 15



Metals in the IGM: high redshift

EVIDENCE of DOUBLE ENRICHMENT!!

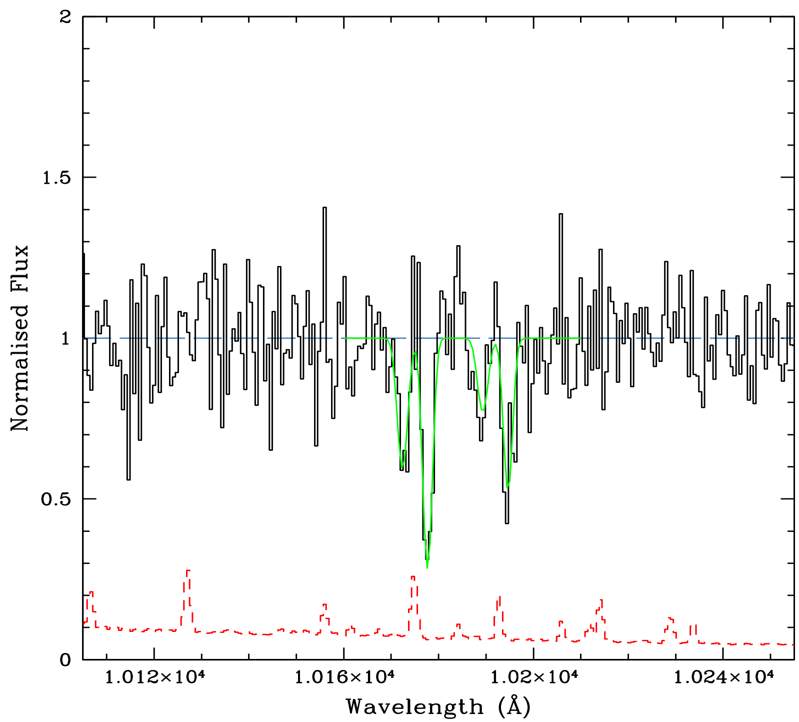


What happens to the weak lines at high z?

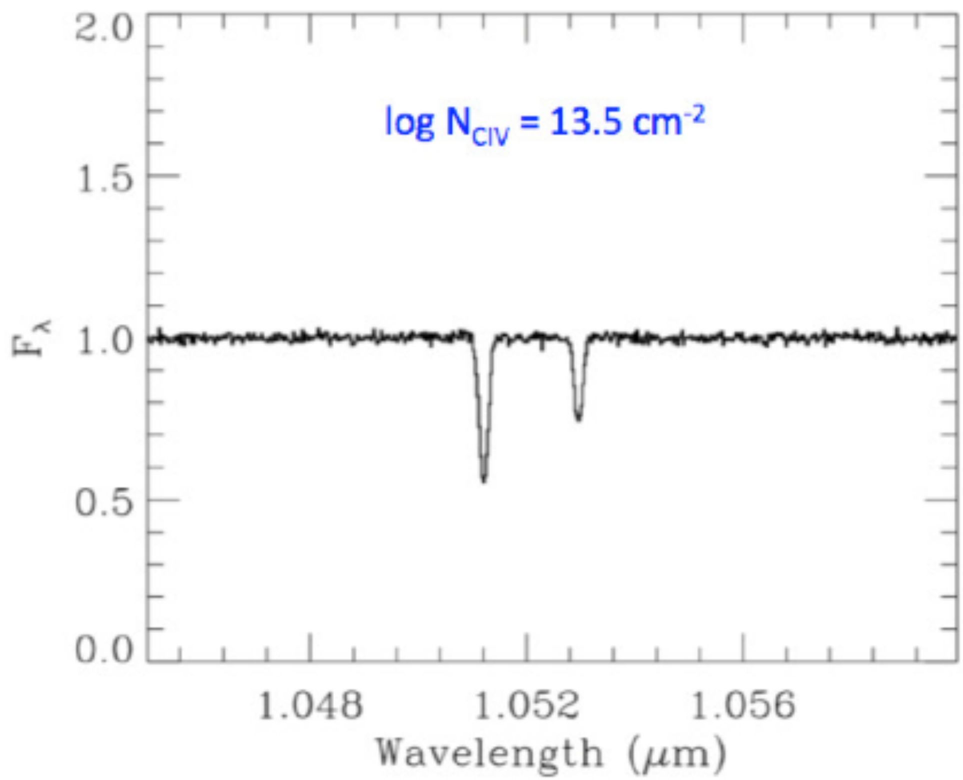
D'Odorico+2013

Reaching high redshift with HIRES@ELT

VLT+X-shooter 10 hr



EELT+HIRES 1 hr



Metals in the IGM: near future perspectives

- X-shooter LP: 100 spectra of QSOs with z>3.5
  - Extension of the CIV sample (fill the redshift gap)
  - Selection of interesting objects to be followed with UVES

- UVES/HIRES archives and new observations

- Bright quasars at z~6-8 in the south from ongoing and future surveys

- ESPRESSO@VLT (expected 2016)
  - Few objects observed at the highest resolution (variability of fundamental constants)
  - Super-UVES mode at the incoherent focus of the 4UTs

Summary

- The study of metals in the IGM provides key information on the nature of feedback and the process of re-ionization;

- Present observations and simulations have answered to the basic questions, now we want to know more details;

- HIRES@EELT with ~10^5 resolution and coverage extended to the NIR will finally allow to probe the **mean density** and below, up to the **highest redshift ->** solve the metal enrichment conundrum

- In the meantime: X-shooter, UVES, ESPRESSO