New Observations of Metals in the z~6 IGM

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24th IAP Colloquium
July 2008

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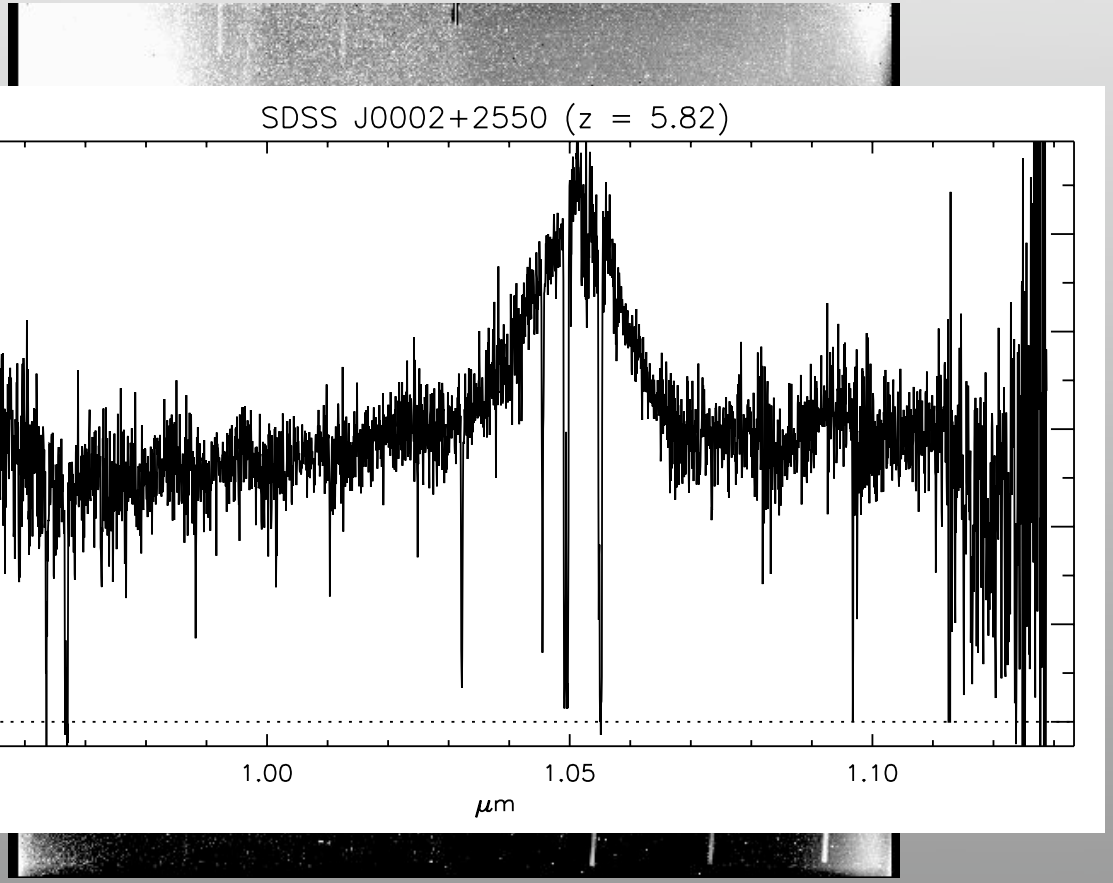
Metals at high z

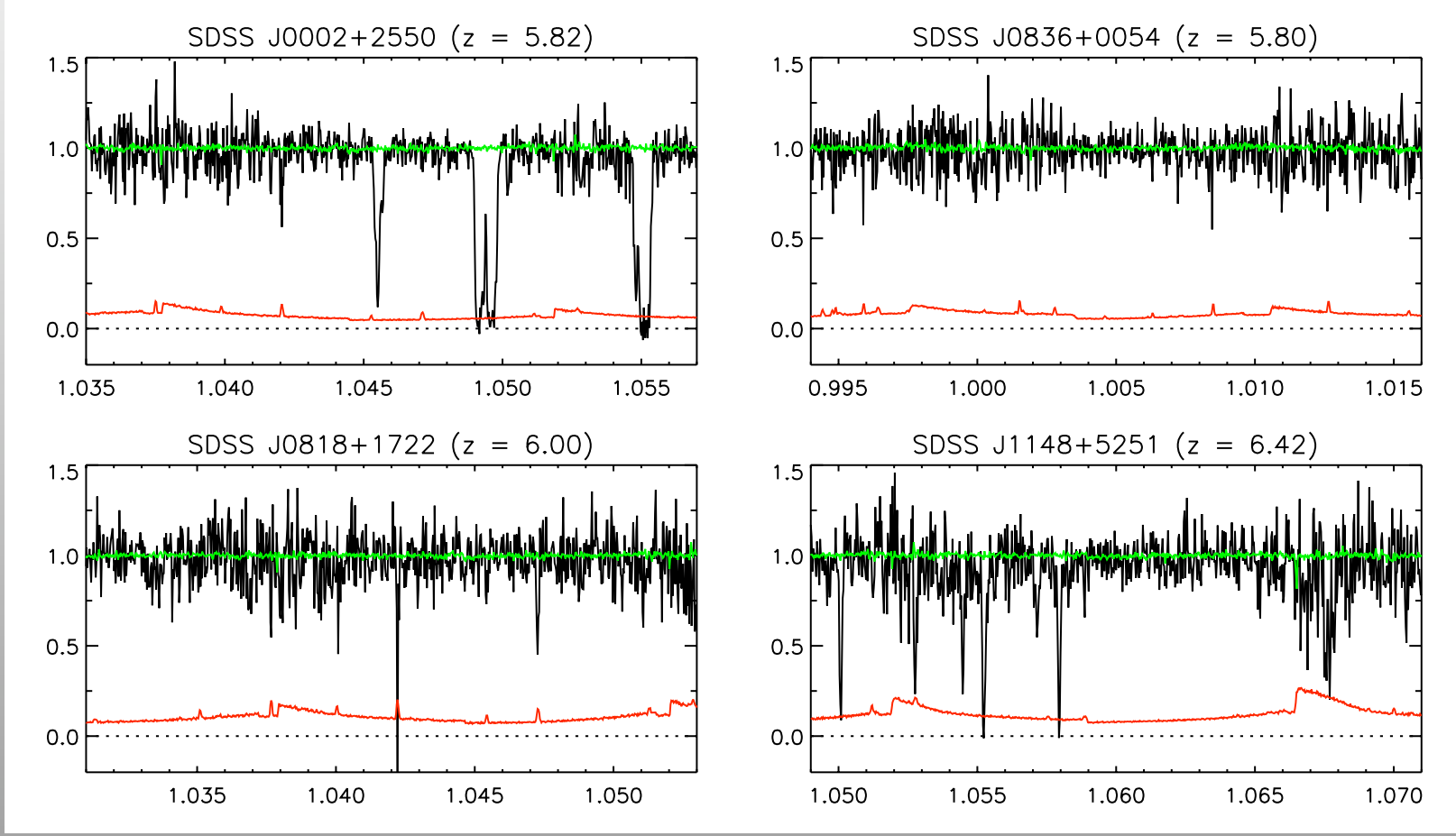
- Encode information about high-z galaxies and galaxy/IGM interactions
  - star formation, winds, stellar populations...
- Absorption lines can be markers for galaxies too faint to detect directly
- Reionization probe (Oh 2002)
  - O I, C II, Si II $\Delta E(\mathrm{O\,I}) \approx \Delta E(\mathrm{H\,I})$
  - O ↔ H charge exchange: $X_{\mathrm{H\,I}} \equiv \frac{n_{\mathrm{H\,I}}}{n_{\mathrm{H}}} \approx \frac{n_{\mathrm{O\,I}}}{n_{\mathrm{O}}}$
  - Joint constraint on enrichment & ionization - MUST MEASURE HIGH AND LOW-IONIZATION SPECIES

NIRSPEC Echelle

C IV at z~5.3-6



Four new z~6 sightlines



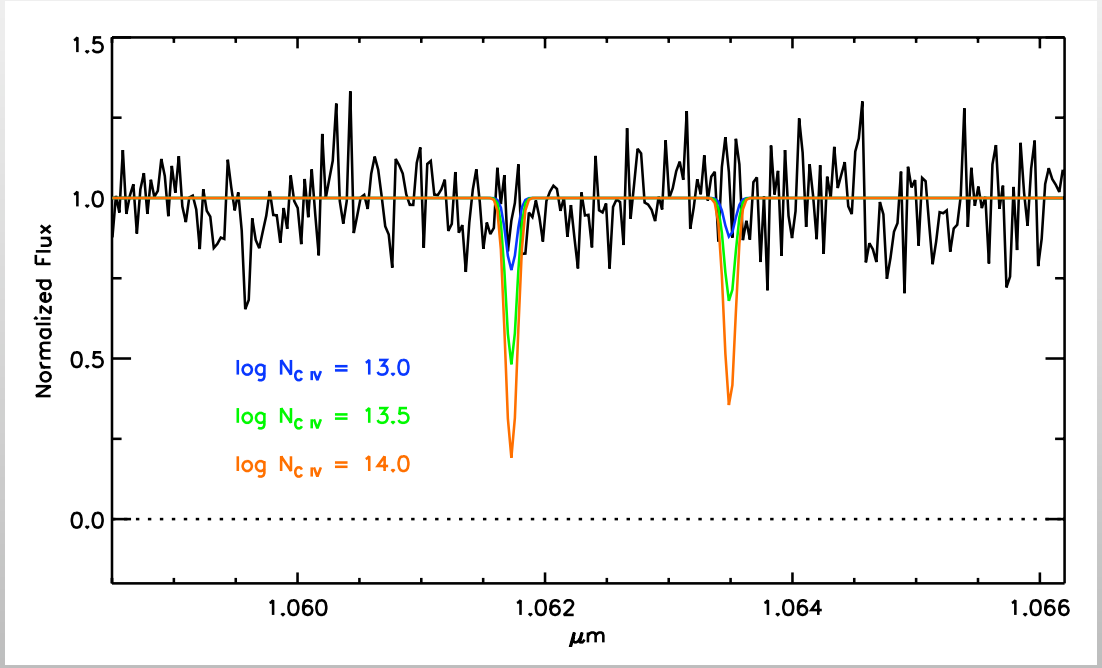
Example sections

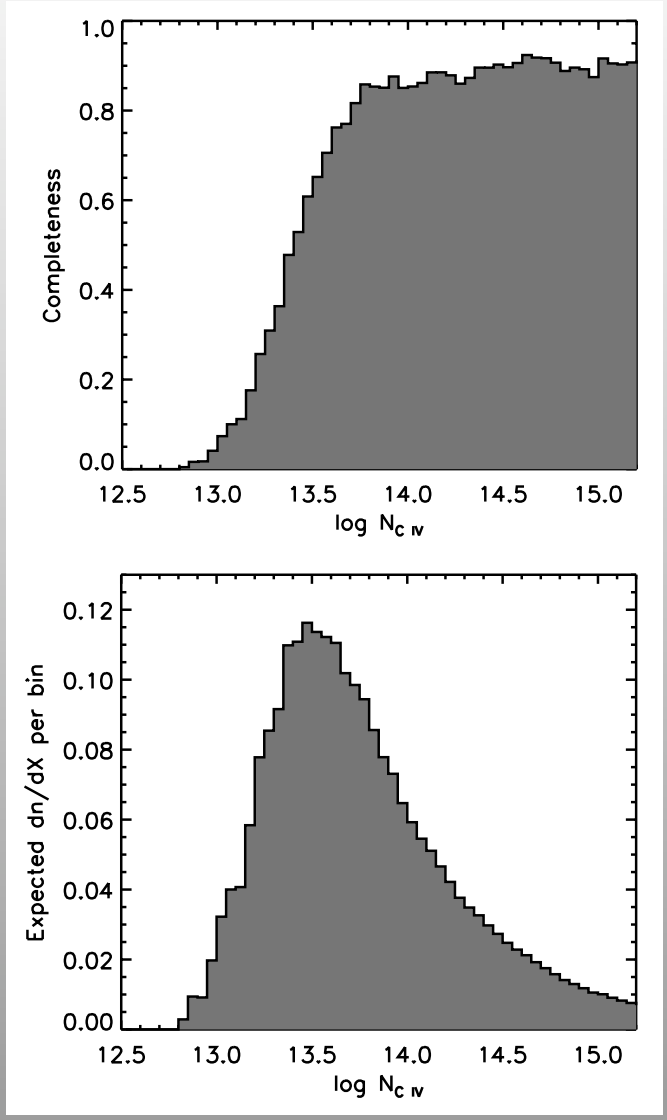
R≈13,000

(1/3 of HIRES, UVES)

Good C IV coverage over z = 5.3 - 6.0

Sensitivity





Convolve completeness with Songaila (2005) z ~ 3 column density distribution:

$$\frac{\partial^2 n}{\partial N \partial X} \propto N^{-1.7}$$

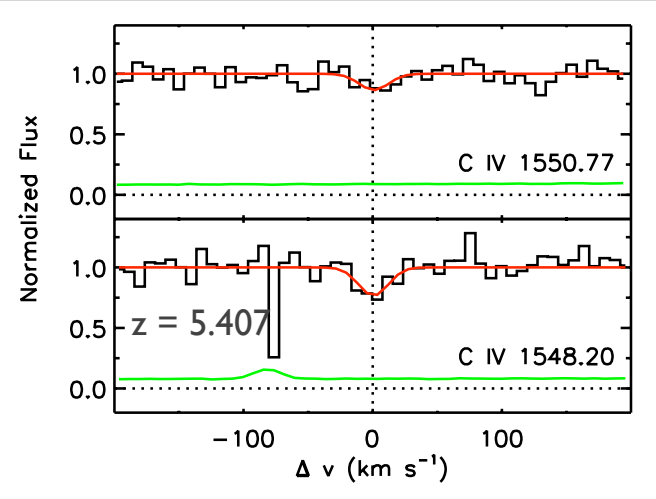
Expect 19 C IV systems,

13 with $N > 10^{13.5}$ cm^{-2}

We find...

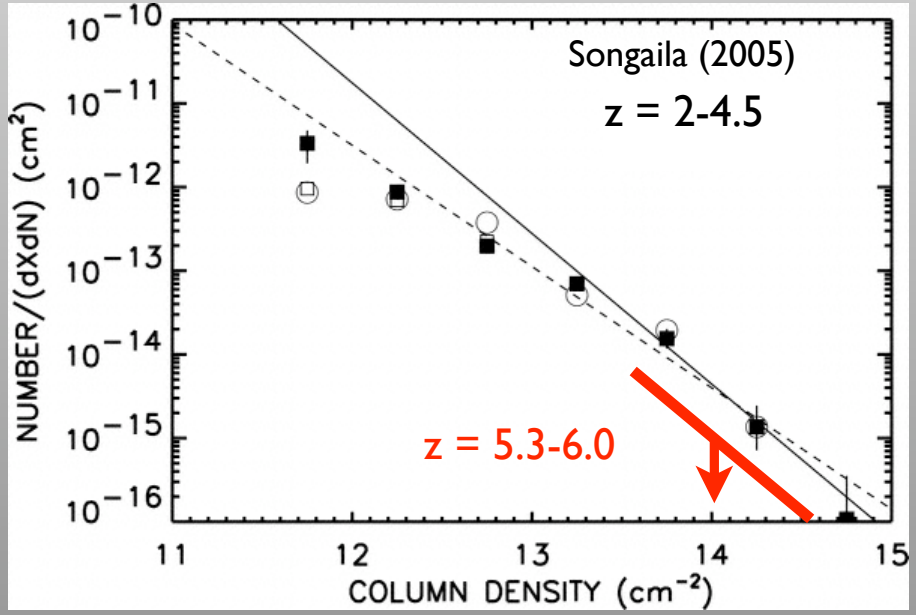
0

Well, maybe one...

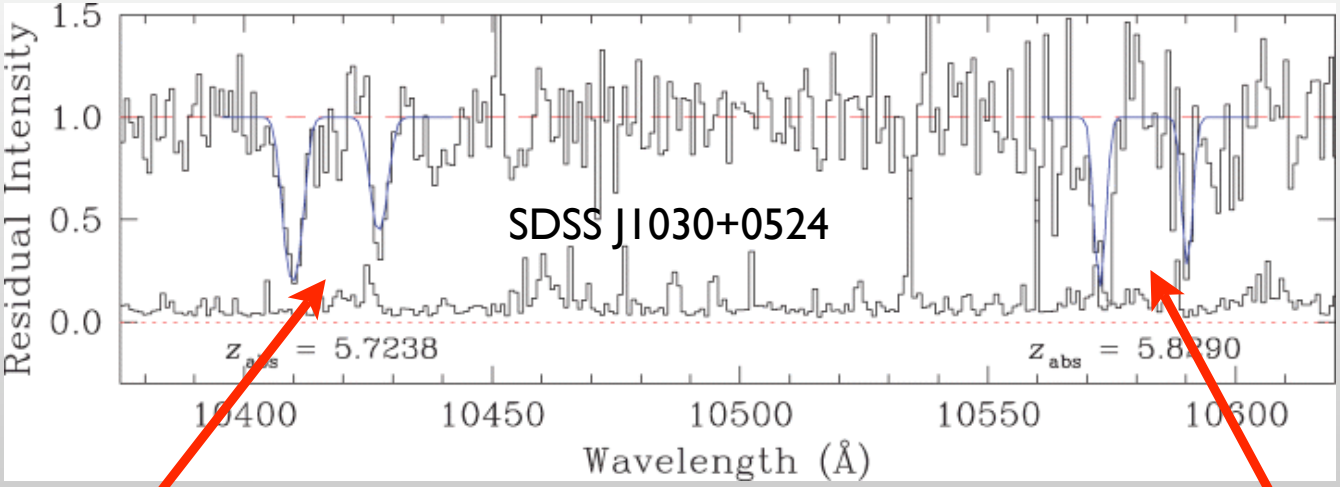


...but it's weak, at the lowest redshift end, shows no Si IV, and may just be noise.

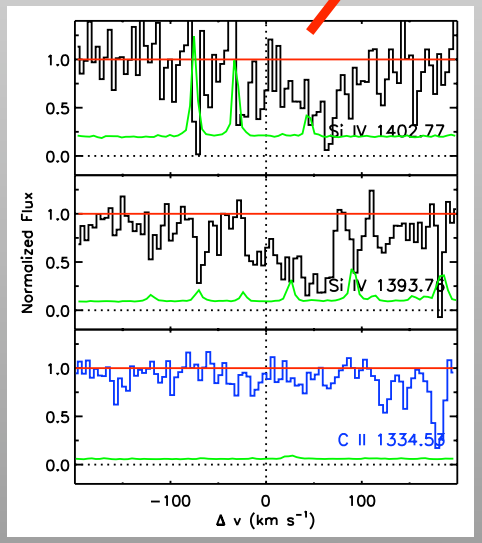
95% upper limit on the expected number of strong (log N > 13.5) systems is 3.0, a x4.3 *decrease* from z~2-4.5



There is *some* C IV at z~6...

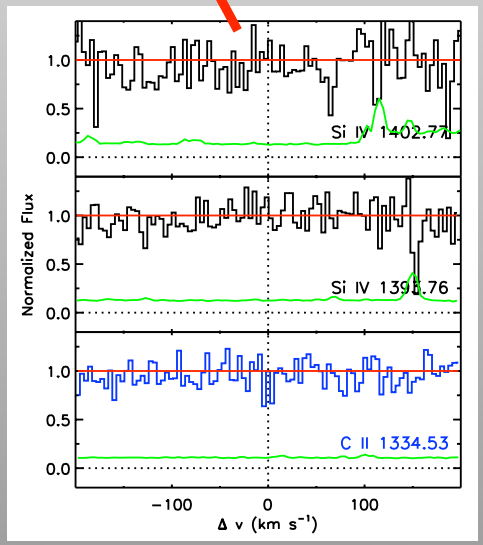


Ryan-Weber et al. (2006)

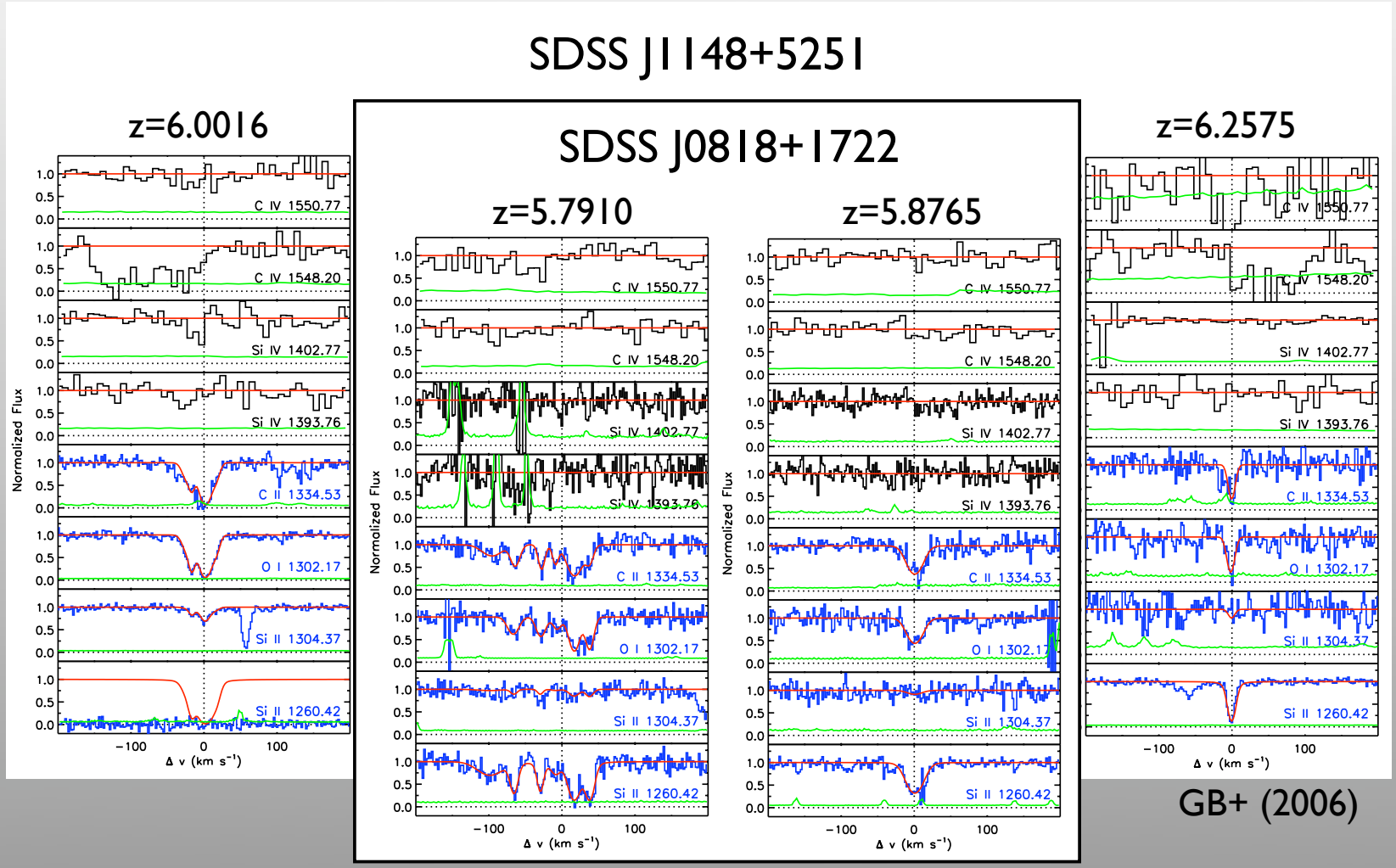


Si IV detected in HIRES data

No Si IV, but also detected by Simcoe (2006)

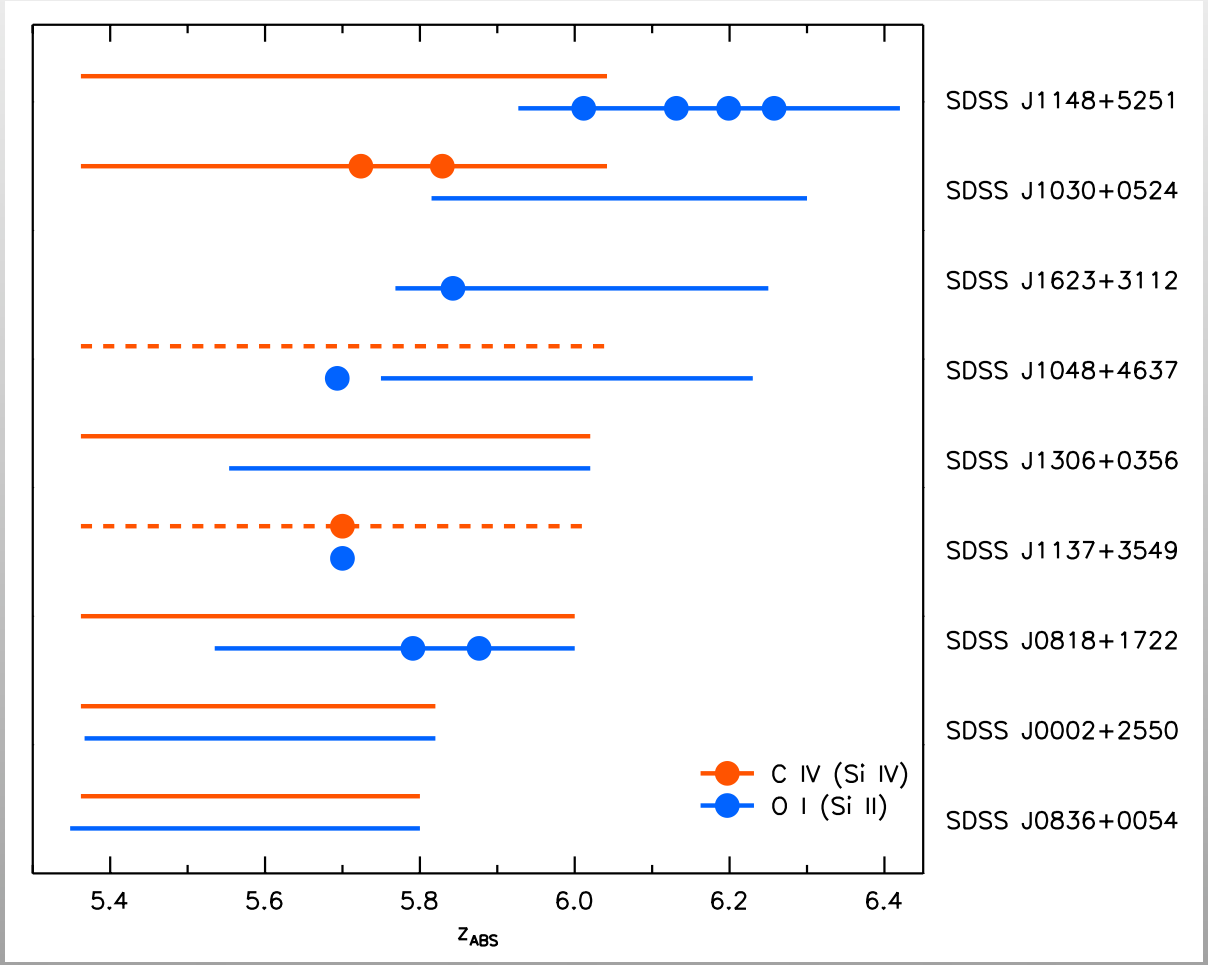


O I Systems



Do not show strong high-ionization lines

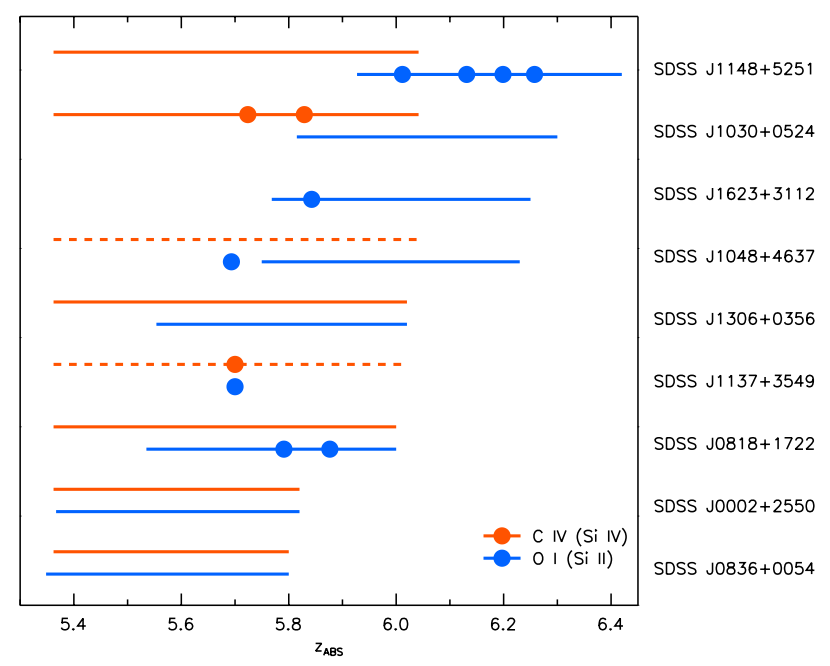
Large-scale enrichment/ionization variations



This work

GB et al. (2006 & this work), Simcoe (2006), Ryan-Weber (2006 & in prep)

Metals at z~6

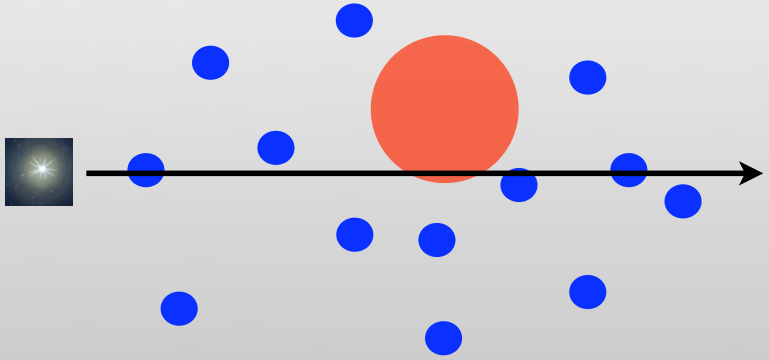


~200 cMpc

1. dn/dz of moderate/strong C IV systems is > 4x down from z~2-4
2. dn/dz of O I is ~ 4x greater than extrapolated dn/dz for DLAs
3. O I and C IV typically don't mix (?)
4. Variations occur on very large scales

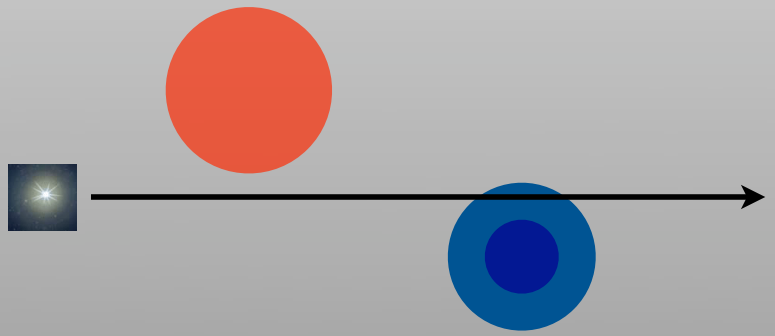
z~6 IGM is enriched, but most of the metal systems are neutral

Possible Scenarios



1. O I systems are dense mini-halos that have not yet been ionized

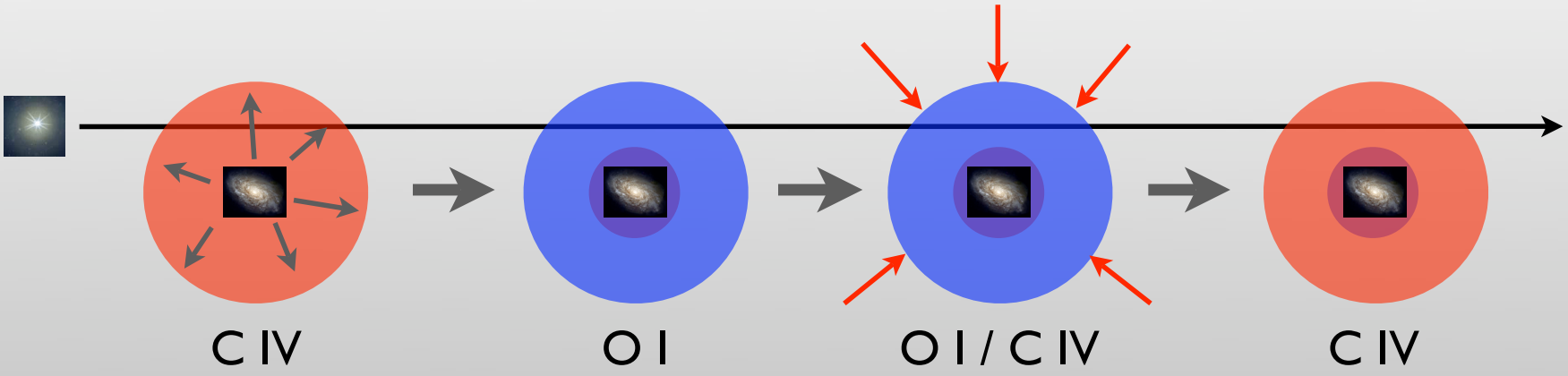
- Observed velocity widths too wide



2. DLAs are larger than expected at z~6 due to a lower UVBG

- Would mix with C IV systems
- Would not be a reservoir for lower-z C IV systems

Ionization Evolution



1. Star-forming galaxy enriches and ionized surrounding IGM

2. Local star formation decreases, dense regions recombine

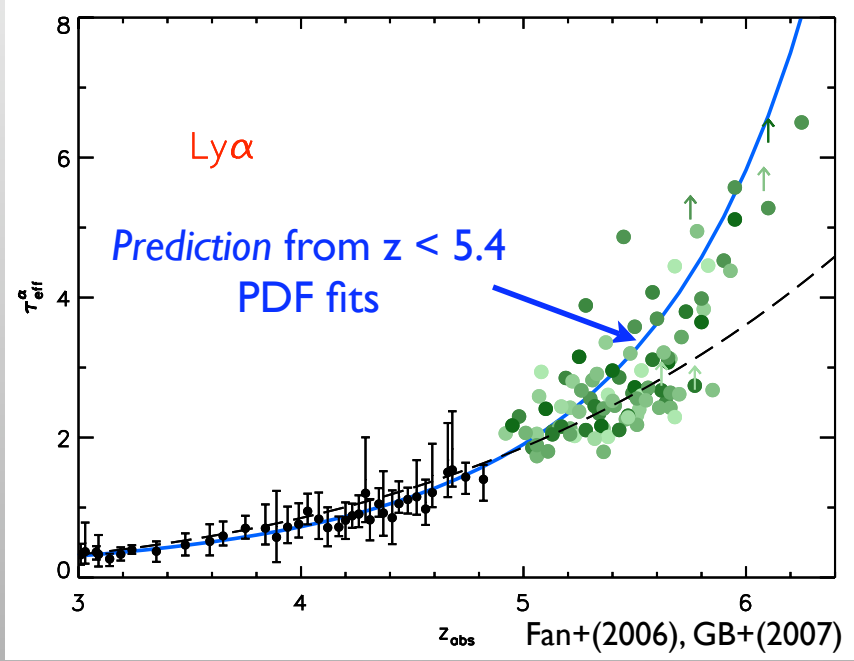
3. External (or internal) UV photons reionize local IGM

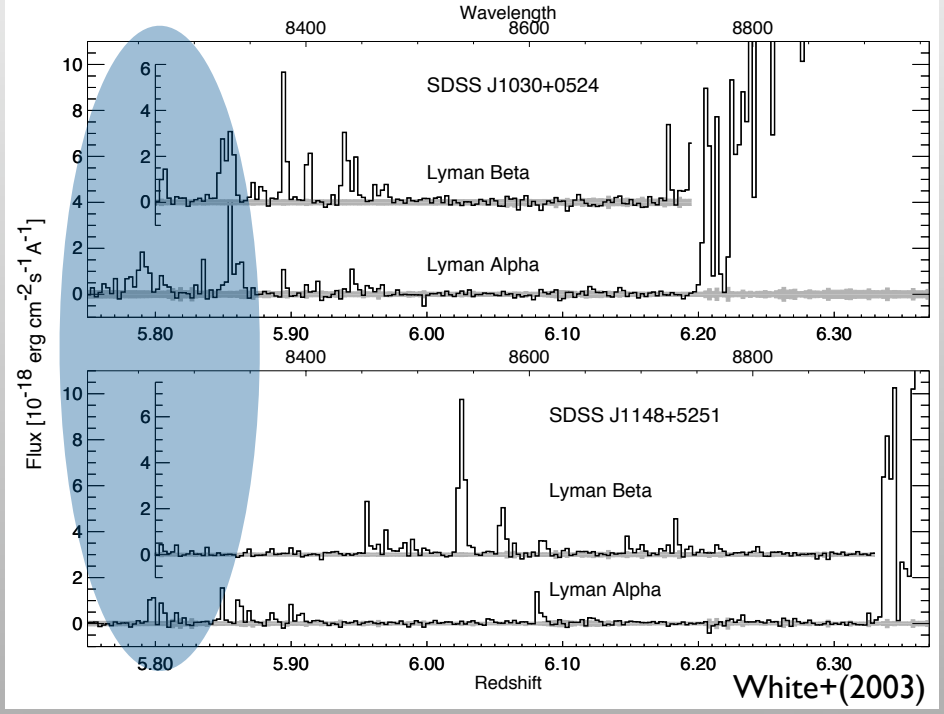
4. High-ionization maintained by UV background

$$t_{\rm rec} \approx 6 \times 10^7 x_{\rm e} \left(\frac{\Delta}{10}\right)^{-1} \left(\frac{1+z}{8}\right)^{-3} \left(\frac{T}{10^4\ {\rm K}}\right)^{0.7}\ {\rm yr}$$

Last stage of reionization

What about the Lyα forest?





The forest tells you only about the voids.
Metals lines trace overdensities.

O I systems persist after the voids become ionized

Conclusions

- New C IV measurements provide a clearer picture of metals in the IGM at z~6
  - In total, the abundance of metal lines implies significant previous and ongoing star formation
  - Number density of C IV systems at z~5.3-6.0 is > 4x lower than over z~2-4.5
  - Number density of O I systems is ~4x higher than would expect from DLAs
  - O I and C IV don't mix?

➡ ***Observed metals in the IGM at z~6 are predominantly neutral***

- Metal ionization states vary on ~200 cMpc scales
- O I systems likely become C IV by z~4.5

➡ ***Very last stage of reionization ends at z ≤ 5.8***

  - Reionization ends in overdense regions
  - Consistent with extended reionization