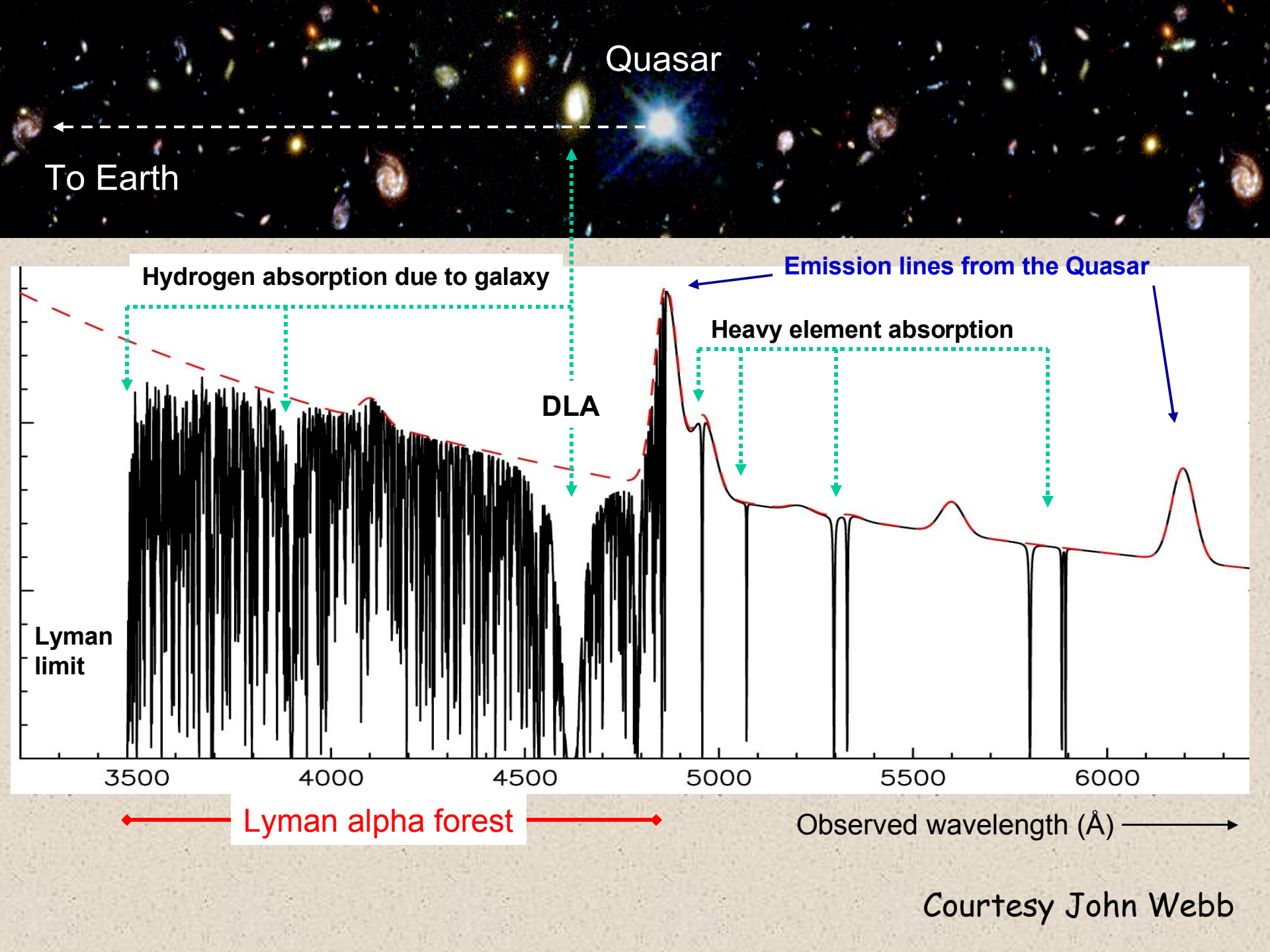
Does nearly all of the intergalactic HI reside in metal-free gas?

MNRAS, in press, astro-ph/0701761

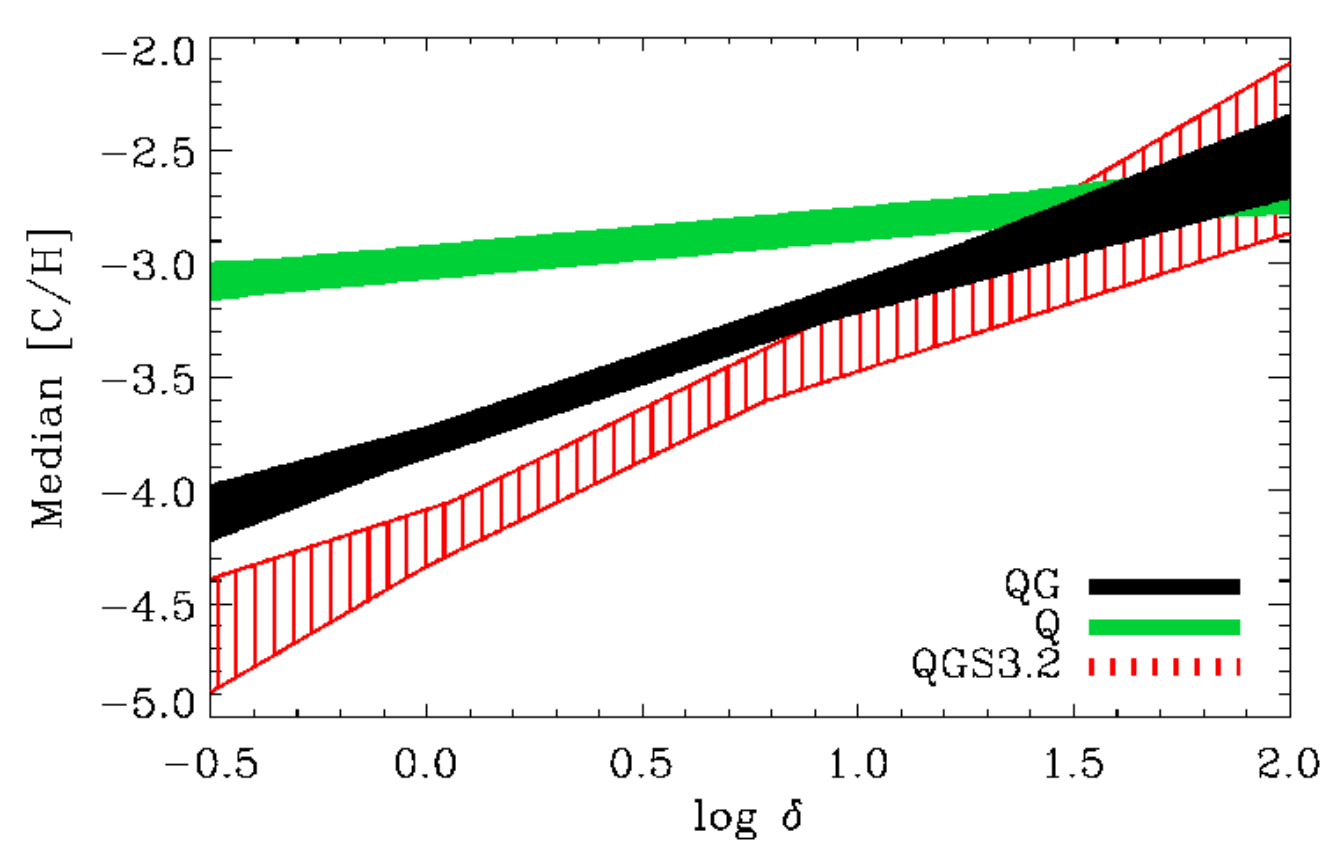
Joop Schaye, Bob Carswell, Tae-Sun Kim



Courtesy John Webb

The median metallicity of the IGM

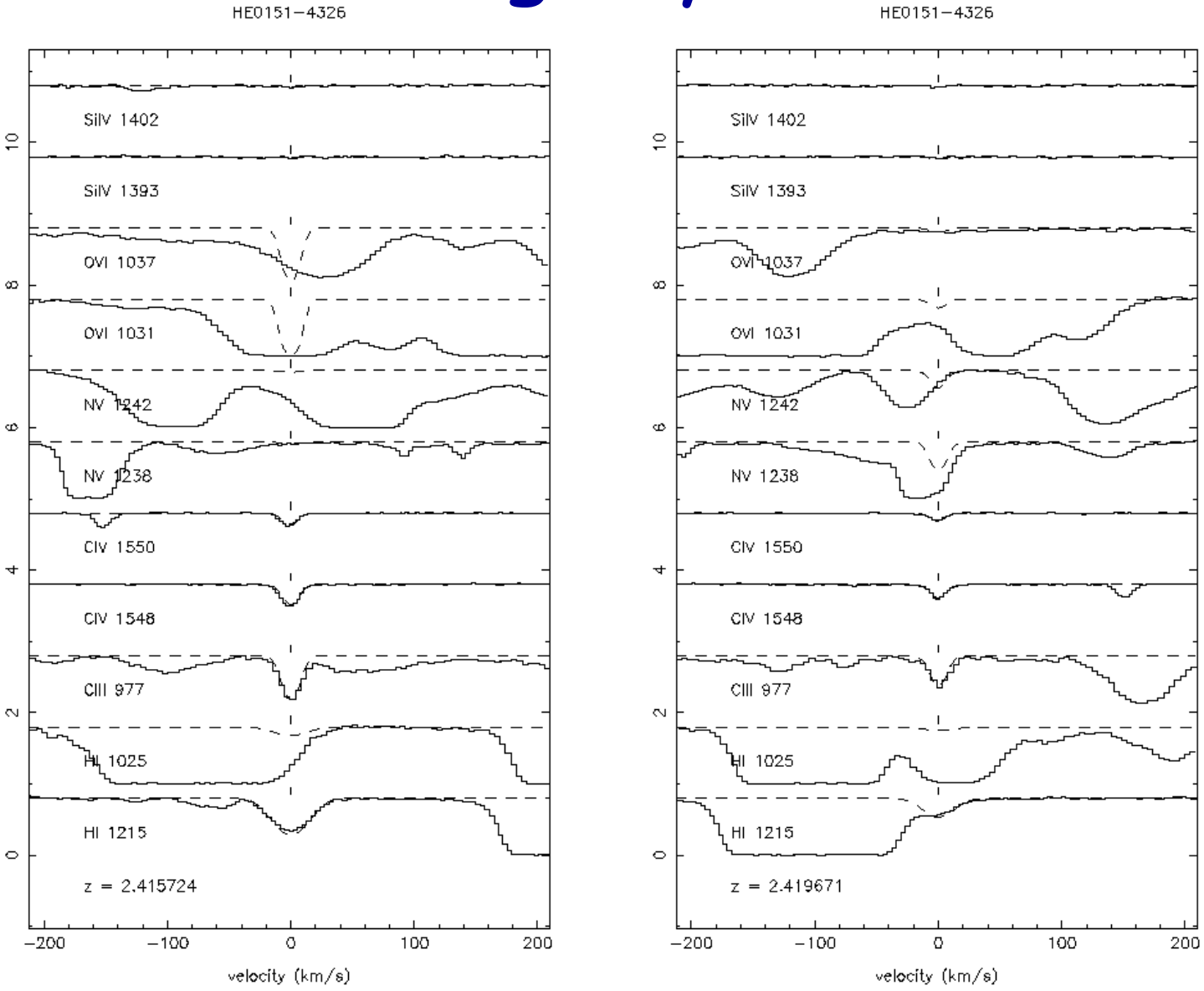
$z = 3$



JS et al. (2003)

BUT: Measurements are implicitly smoothed (in 1 dimension) on the scale of the HI absorbers: ~ 10 - 100 kpc

Strange systems



Problems with ionization modeling based on line fitting

- Line blending
- Contamination
- Multiple phases
- Noise

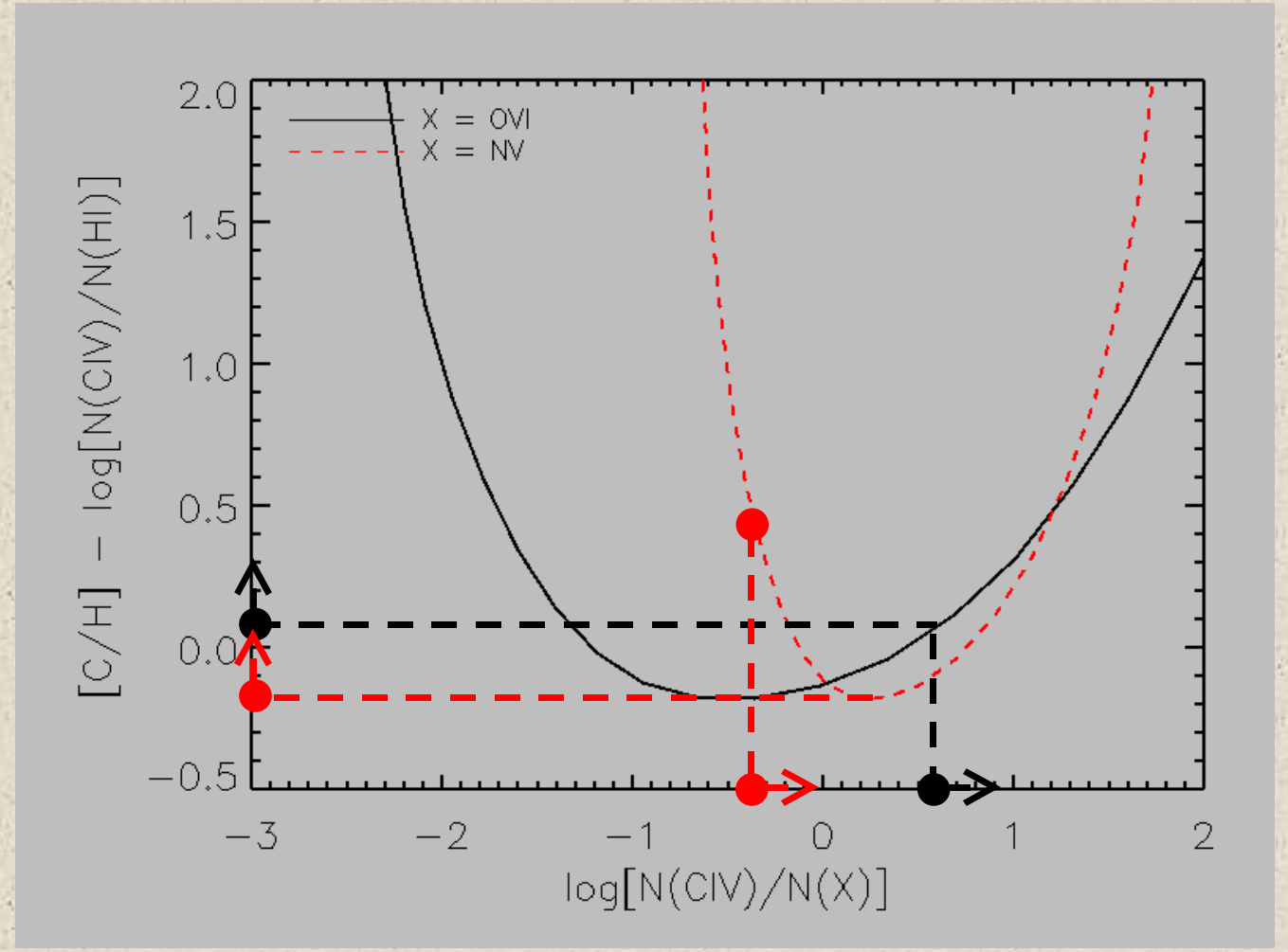
Solution: Only use upper limits on column densities

Ionization model assumptions

- Exposed to the z=2.3 UV/X-ray background model of HM01
- Log T = 4
- Relative abundances solar
- Ionization equilibrium

Selecting for high metallicity

Upper limits on N(H I), N(N V), N(O VI) for every C IV component



General characteristics

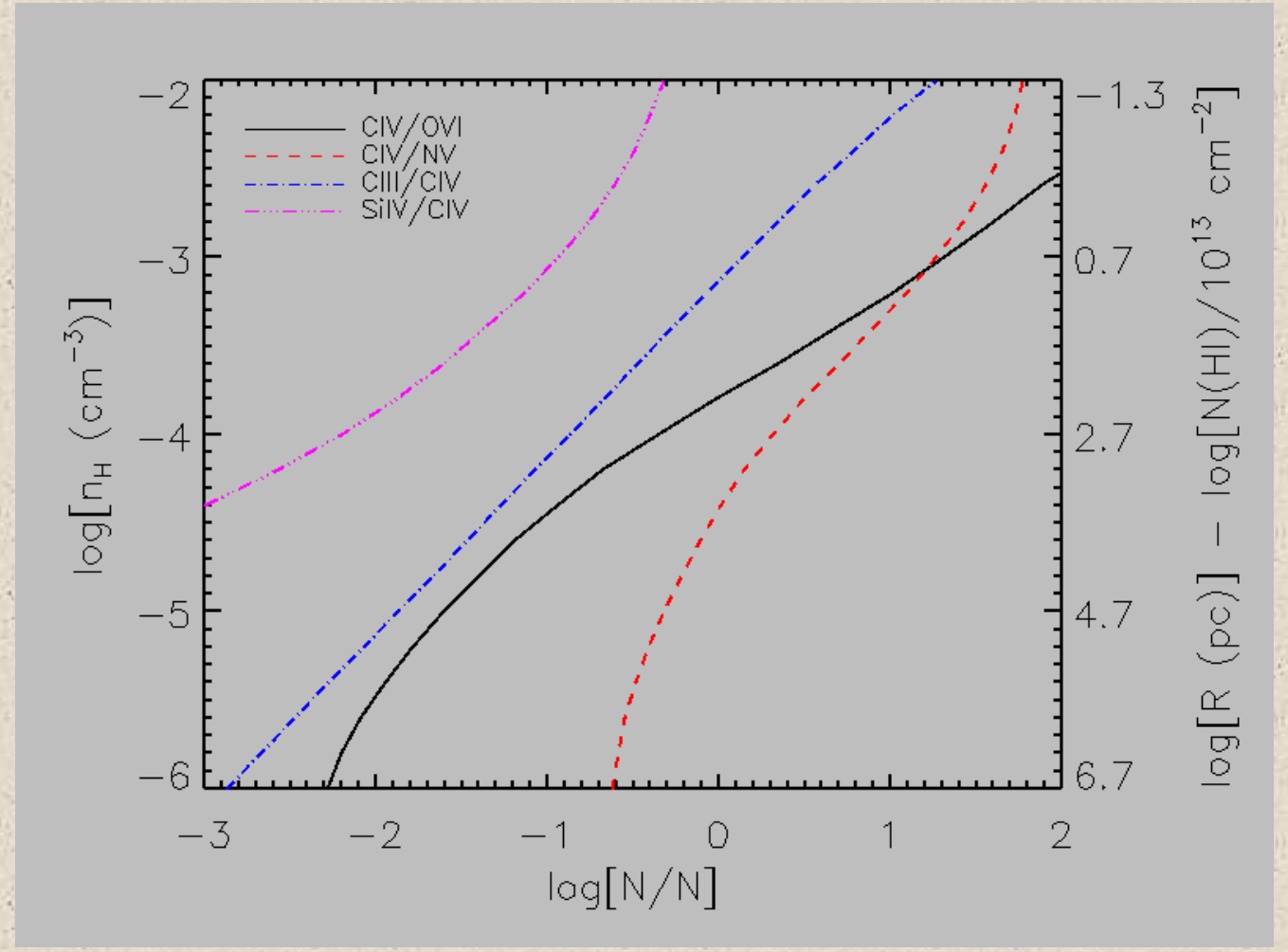
- Survey using 9 QSO VLT/UVES spectra
- Median redshift z = 2.25
- Found 28 high-metallicity components in 12 systems

- Narrow lines: b ~< 10 km/s
- 1/3 are single components
- 1/2 are associated with log N(HI) > 14.5
- Velocity spread up to 100s km/s

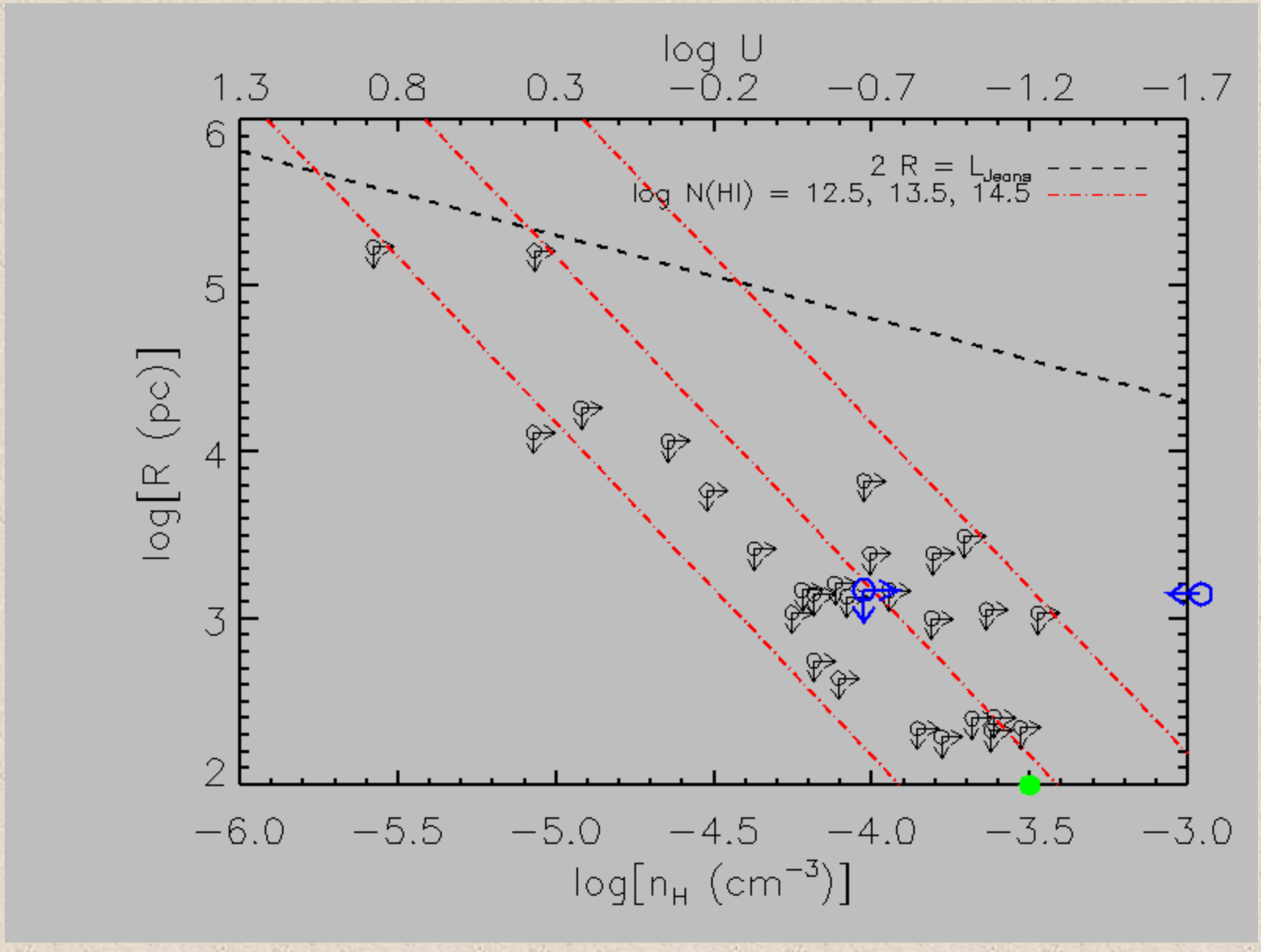
The clouds are intervening and photo-ionized

Measuring density and size

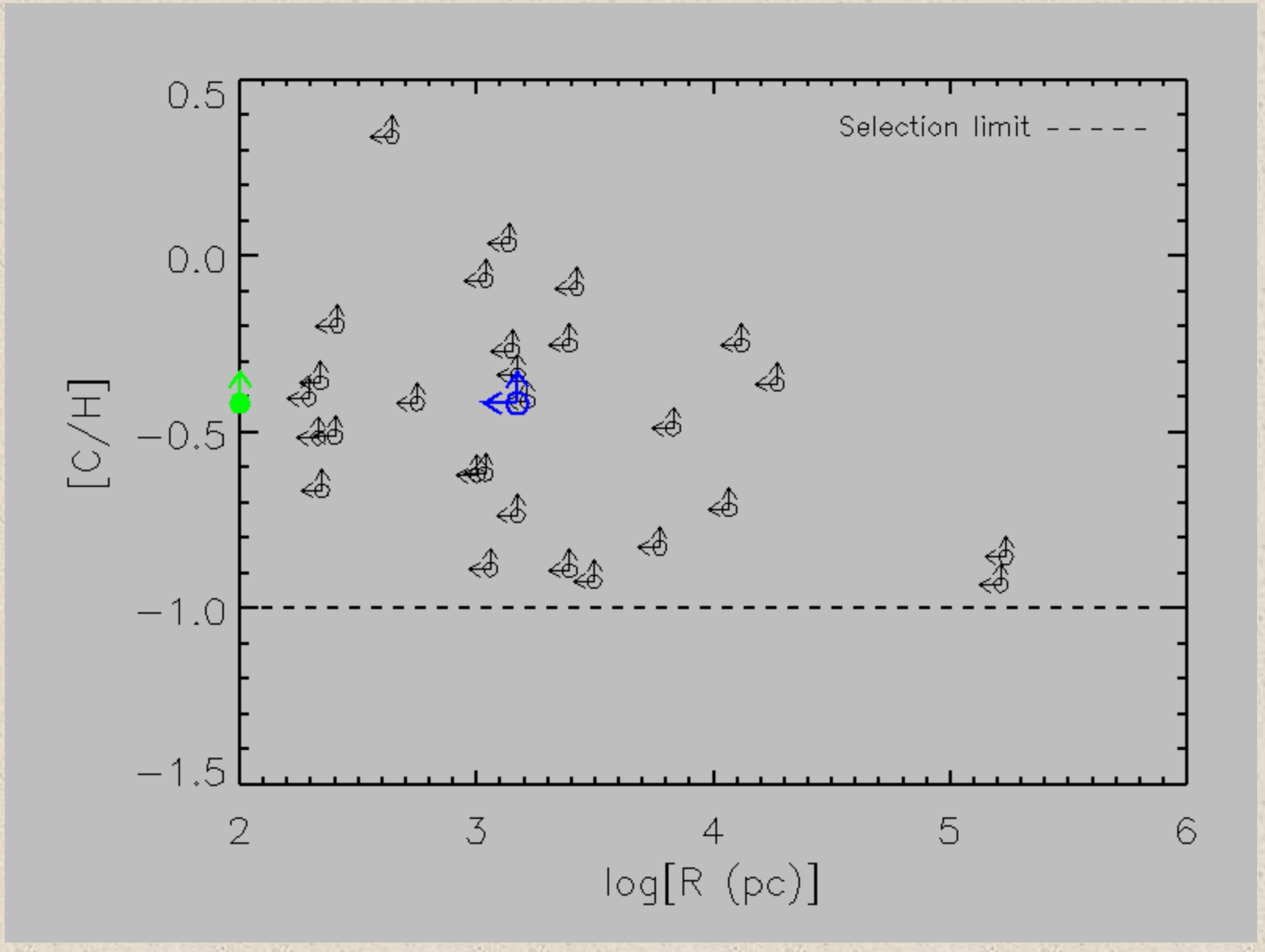
Upper limits on N(H I), N(N V), N(O VI) for every C IV component



Size and density



Metallicity and size



Physical properties

$$n_{\mathrm{H}} \sim 10^{-3.5}\ \mathrm{cm}^{-3}$$

$$R \sim 10^{2}\ \mathrm{pc} \quad (<< \mathrm{L_J} \Rightarrow \text{not self - gravitating})$$

$$Z > 10^{-1}\ Z$$

$$M_g \sim 4\times 10^{1}\ \mathrm{M} \left(\frac{n_{\mathrm{H}}}{10^{-3.5}\,\mathrm{cm}^{-3}} \right) \left(\frac{R}{10^{2}\,\mathrm{pc}} \right)^{3}$$

Connection with galaxies

$$n = 2\times10^{4}\ \mathrm{Mpc}^{-3}\left(\frac{dN/dz}{7}\right)\left(\frac{R}{10^{2}\,\mathrm{pc}}\right)^{-2}$$

Compare LBGs: $n \sim 10^{-2} h^{3}\ \mathrm{Mpc}^{-3}$ down to $0.1L_{*}$

Or, assuming the clouds reside in the halos of galaxies:

$$r = 83\ \mathrm{kpc}\left(\frac{dN/dz}{3}\right)^{1/2}\left(\frac{n}{10^{-2}\,\mathrm{Mpc}^{-3}}\right)^{-1/2} f_{\mathrm{cover}}^{-1/2}$$

Cosmological Implications

$$Z_{\rm cosmic} \sim 10^{-4} Z \left(\frac{dN/dz}{7}\right)\left(\frac{R}{10^2\,{\rm pc}}\right)\left(\frac{n_{\rm H}}{10^{-3.5}\,{\rm cm}^{-3}}\right)$$

But short lifetime: $t_{\rm exp} \sim 10^7\,{\rm yr}\left(\frac{R}{10^2\,{\rm pc}}\right)\left(\frac{T}{10^4\,{\rm K}}\right)^{-1/2}$

$$Z_{\rm cosmic}\,\frac{t_H}{t} \sim 10^{-1} Z \left(\frac{dN/dz}{7}\right)\left(\frac{R}{10^2\,{\rm pc}}\right)\left(\frac{n_{\rm H}}{10^{-3.5}\,{\rm cm}^{-3}}\right)\left(\frac{t}{10^7\,{\rm yr}}\right)^{-1}$$

$\Rightarrow$ Most metals may at one time have resided in compact, high metallicity clouds

Could the clouds be long-lived?

Self-gravitating if: $$M \sim 6\times10^6\,\mathrm{M}\left(\frac{R}{10^2\,\mathrm{pc}}\right)^2\left(\frac{T}{10^4\,\mathrm{K}}\right)^{-1}$$

$$r_{\mathrm{vir}} \sim 1\times10^2\,\mathrm{pc}\left(\frac{1+z_{\mathrm{coll}}}{11}\right)^{-1}$$

$$T_{\mathrm{vir}} \sim 5\times10^3\,\mathrm{K}\left(\frac{1+z_{\mathrm{coll}}}{11}\right)$$

$\Rightarrow$ CDM minihalos from before reionization

BUT: not enough minihalos

Could the clouds be long-lived?

Pressure confinement requires:

$$\frac{P}{k} \sim 10^{0.5}\,\mathrm{cm^{-3}\,K}\left(\frac{n_{\mathrm{H}}}{10^{-3.5}\,\mathrm{cm^{-3}}}\right)\left(\frac{T}{10^{4}\,\mathrm{K}}\right)$$

HI constraint implies medium with:

$$T >> 10^{5}\,\mathrm{K} \quad \Rightarrow \quad n_{\mathrm{H}} << 10^{-4.5}\,\mathrm{cm^{-3}}$$

Timescale for hydrodynamical instability

$$t_{\mathrm{inst}} \sim t_{\mathrm{exp}}\left(\frac{\rho}{\rho_{\mathrm{medium}}}\right)^{1/2}\frac{c_s}{v}$$

$$\sim t_{\mathrm{exp}}\left(\frac{P}{P_{\mathrm{medium}}}\right)^{1/2} \quad \text{if} \quad v \sim c_{s,\mathrm{medium}}$$

$\Rightarrow$ Clouds are probably short-lived

Where does all this lead us?

Cloud (fragments) will expand until pressure confined.

At that point:

$$T_{\rm cloud} \sim T_{\rm medium} \sim 10^4\,{\rm K} \quad \Longrightarrow \quad n_{\rm H,cloud} \sim n_{\rm H,medium}$$

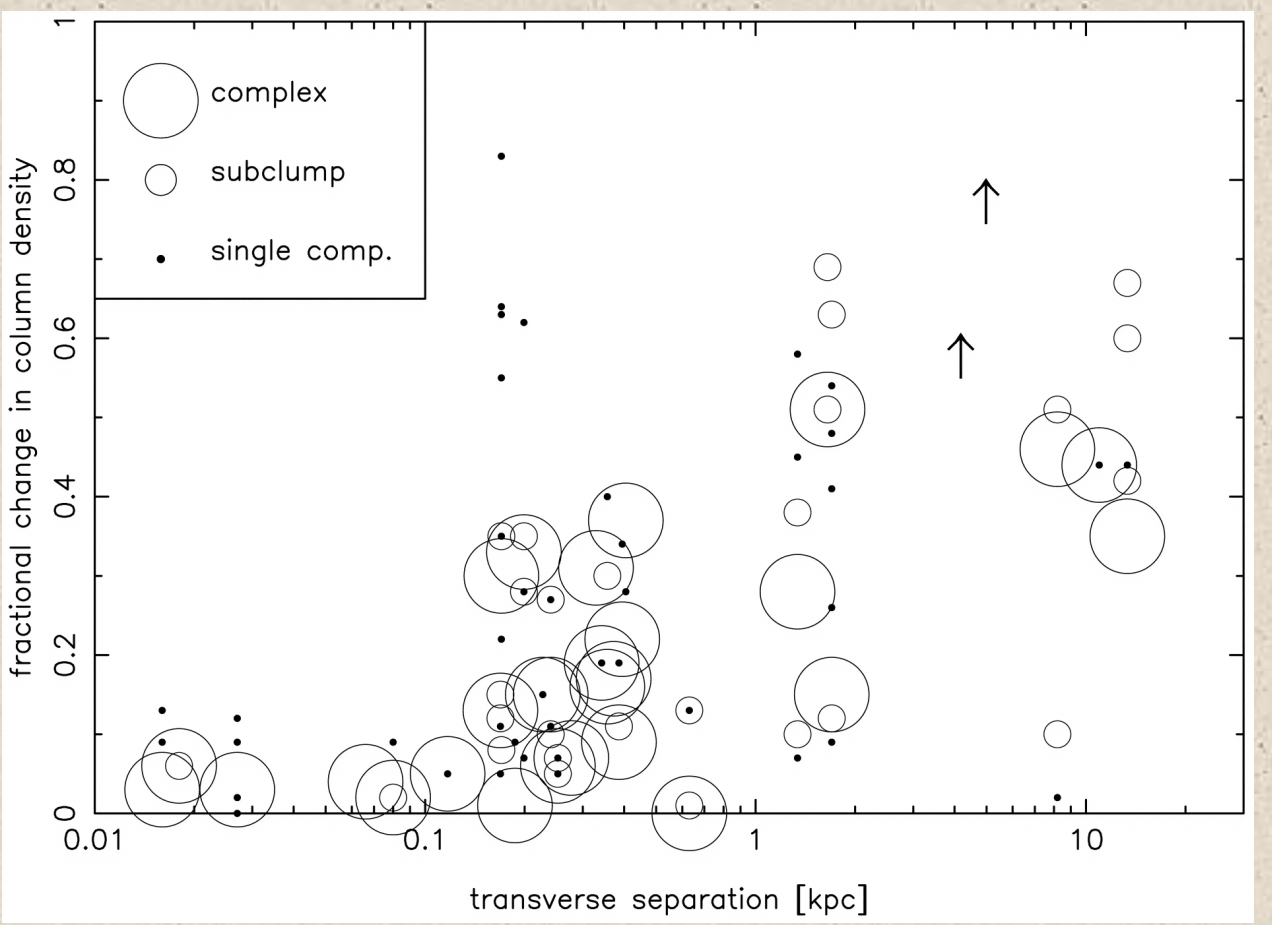
$$L_{\rm Jeans} >> R \quad \Longrightarrow \quad N_{\rm H\,I,\,medium} >> N_{\rm H\,I,\,cloud}$$

They would look like "ordinary" low-metallicity systems!

Prediction : $R({\rm C\,IV}) << R({\rm H\,I}) \sim L_{\rm J}$

Test: gravitationally lensed quasars

The size of CIV absorbers



Rauch et al. (2001)

Conclusions

- There exists an enormous population of highly enriched, compact, intergalactic gas clouds
- Most of the metal transport into the IGM may be in the form of compact, high-metallicity clouds
- Intergalactic metals may be poorly mixed on small scales
- All but a negligible fraction of the baryonic matter in the universe may be of primordial composition