Ionized Gas in High-redshift galactic halos

Andrew Fox

with Patrick Petitjean (IAP - Paris), Cédric Ledoux (ESO - Santiago), & R. Srianand (IUCAA - INDIA)

The High Ions
Transitions in the UV

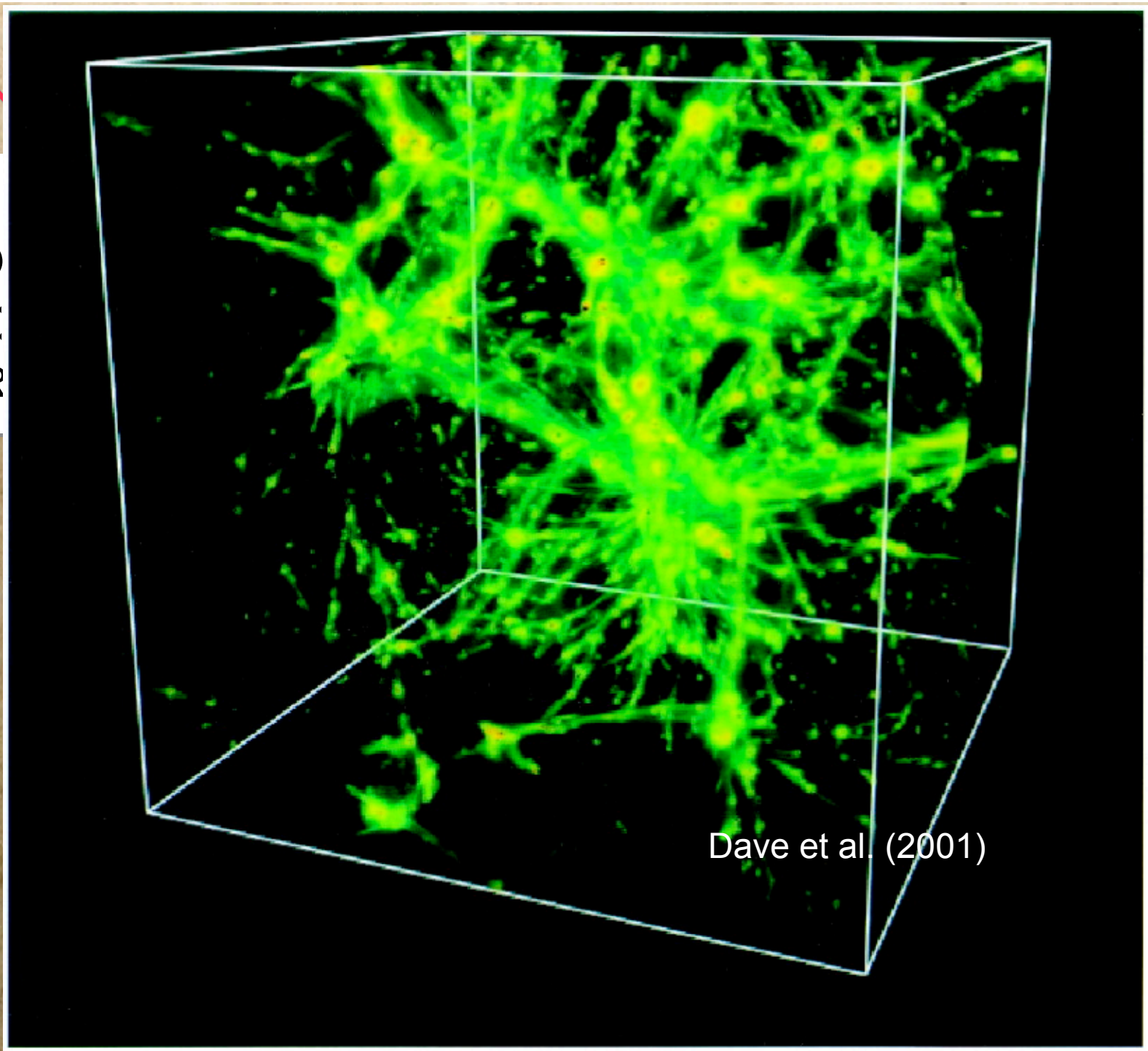
Ion	λ_0 (Å)	From Ground	z=0	T_{coll} (K)
O VI	1031, 1037	z>1.9	FUSE	3×10^5
N V	1238, 1242	z>1.4	HST	2×10^5
C IV	1548, 1550	z>0.9	HST	1×10^5
Si IV	1393, 1402	z>1.2	HST	0.8×10^5

Lines seen in absorption toward background QSOs

Scien

1. Mis

At z=0
pre
bar



Scientific themes with High ions

1. Missing Baryons at low redshift

   At z=0, gas at 10^{5-7} K (Warm-Hot IGM) may contain 30% of all the baryons (Dave et al. 2001)

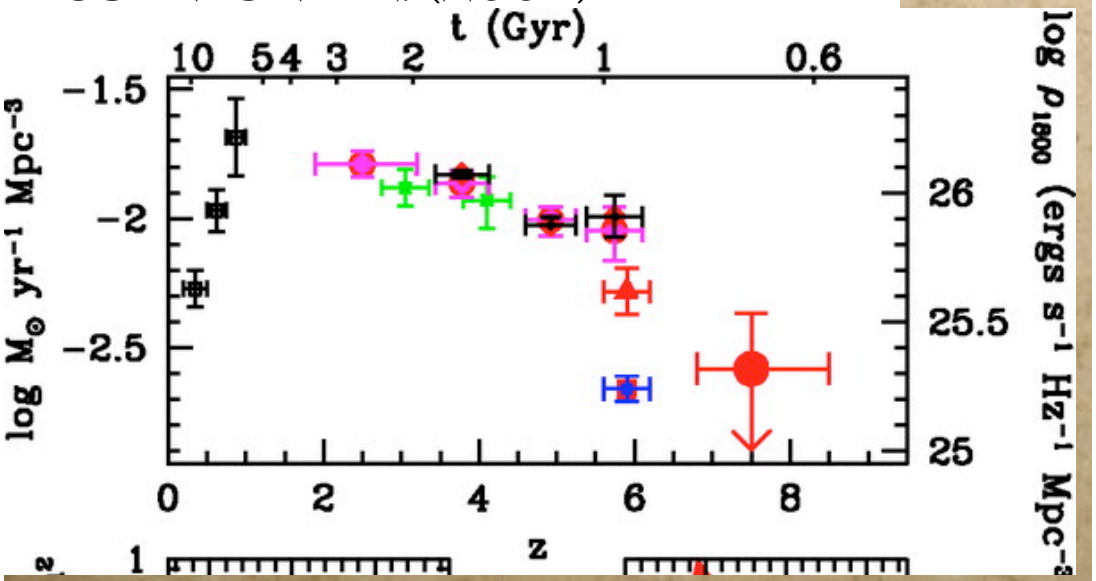
2. Missing Metals at high redshift

   ~50% of the metals produced by star formation at z>2 are yet to be found. They could reside in ionized halos (Pettini et al. 1999)

The missing metals problem

(Pagel 1998, Pettini 1999, Ferrara et al. 2005)

Star formation history from Bouwens et al. (2004)

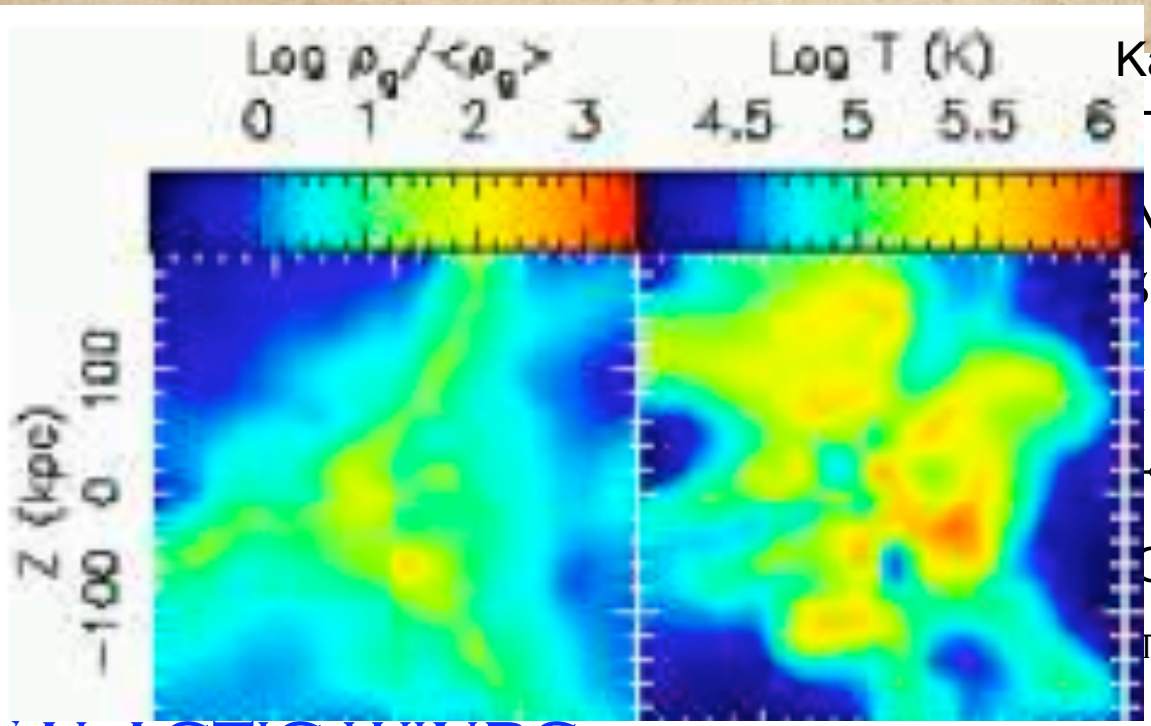


By measuring the star formation history of galaxies, and assuming a metal yield ($y=1/42$), one can predict the total amount of metals produced in the Universe since $z_{MAX}\approx 7$

$$\Omega_{Z,\,TOT}=(3.0\pm0.3)\times10^{-5} \text{ up to } z=2$$

Where are these metals?

Scientific themes with High ions



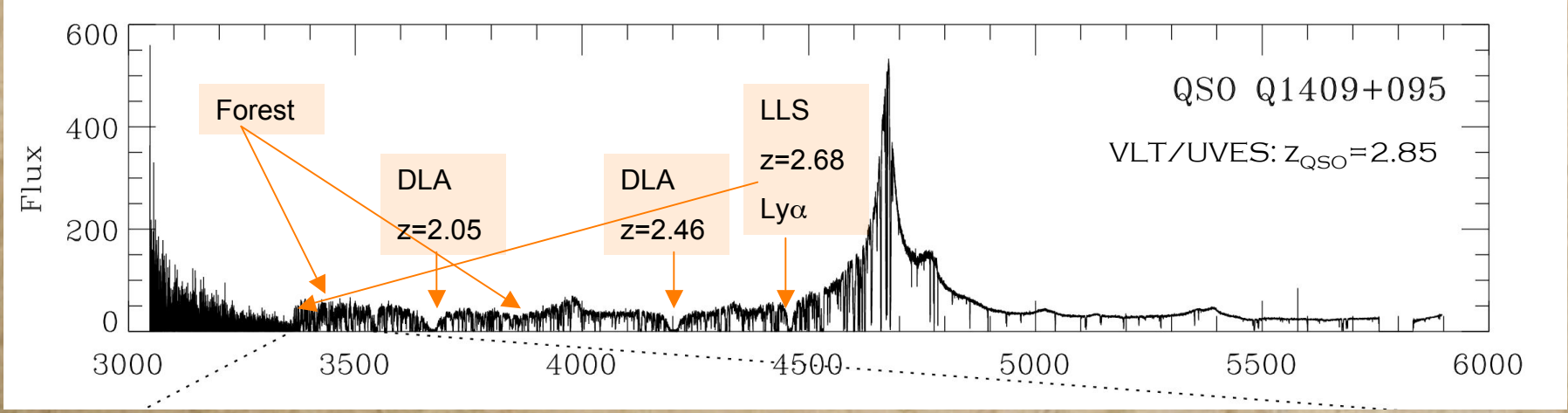
Kawata & Rauch (2007)

1. M HIFT
   A M) may
   (Dave et al. 2001)
2. M FT
   ~5 AR
   ound. They
   ttini et al. 1999)
3. Galactic winds

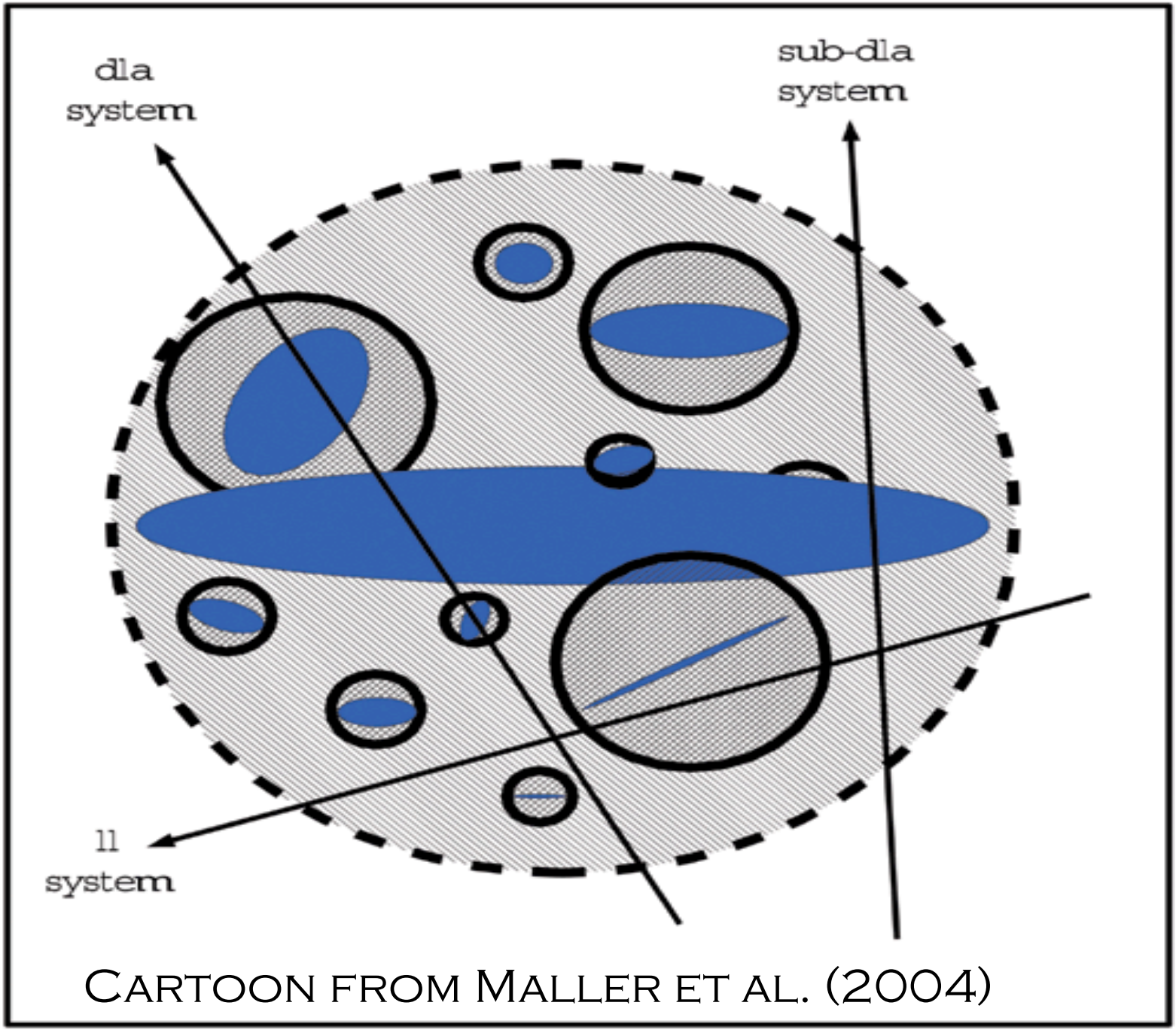
   Feedback from star formation.

   Must be invoked to explain metals in the IGM.

   Likely to be highly ionized



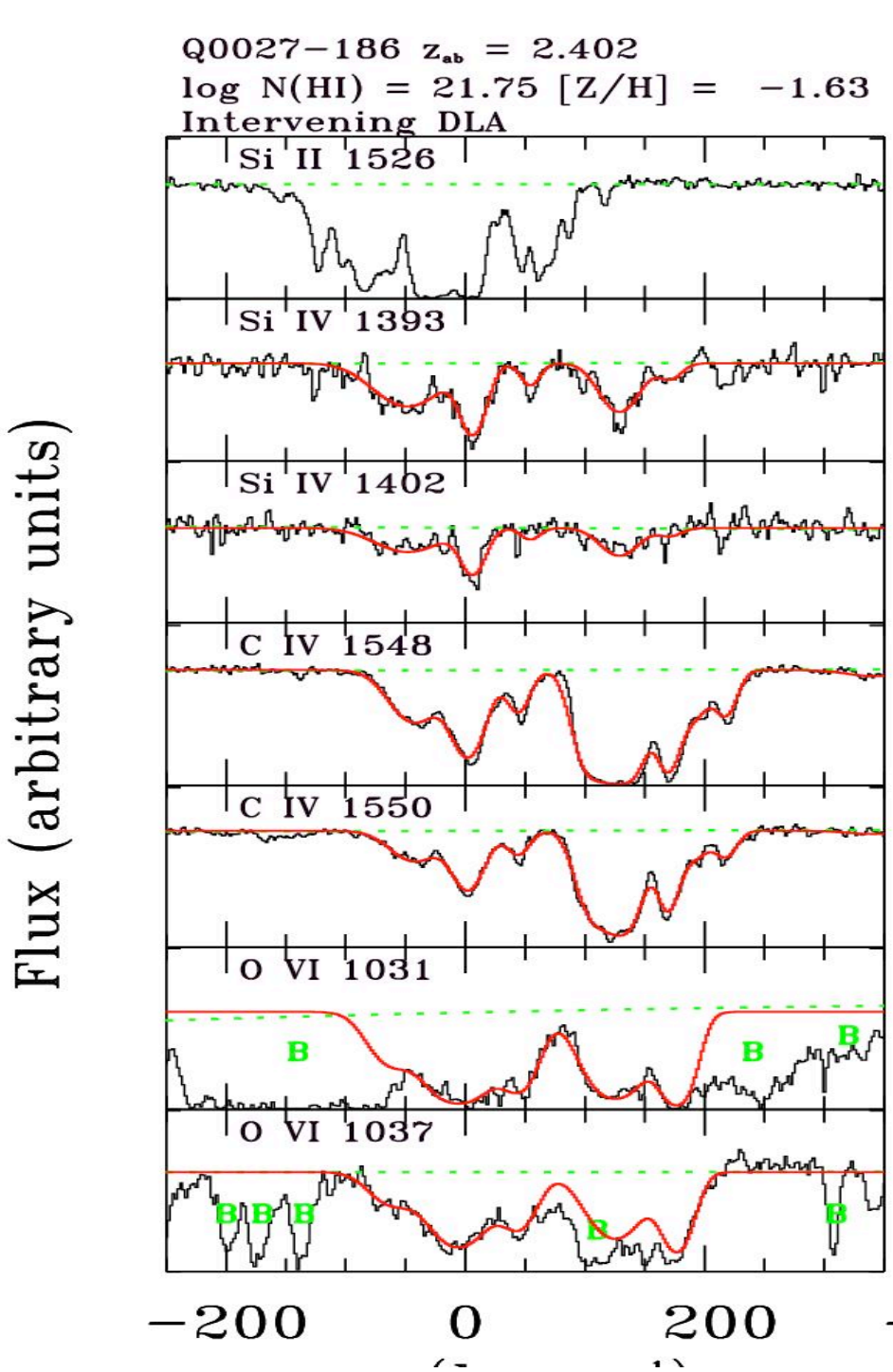
QAL Category	Log N(H I)	Notes
Lyα forest (IGM)	<17	Photoionized, δ~1–10 Contain most baryons at z>2, polluted by metals
Lyman limit systems (LLS)	17–20.3	Mostly ionized Extended gal. halos?
Damped lyman-α (DLA) systems	>20.3	Protogalaxies? δ~100



Cartoon from Maller et al. (2004)

HIGH IONS IN DLAs

- Goal: To detect and characterize ionized gas halos at high redshift
- We use The VLT/UVES DLA Sample
  - Over 100 DLAs
  - R = 40 000 = 6.6 km s^{-1} ; S/N = 30 - 100
  - Data collected for study of molecular gas in dlas (Ledoux, Srianand, Noterdaeme)



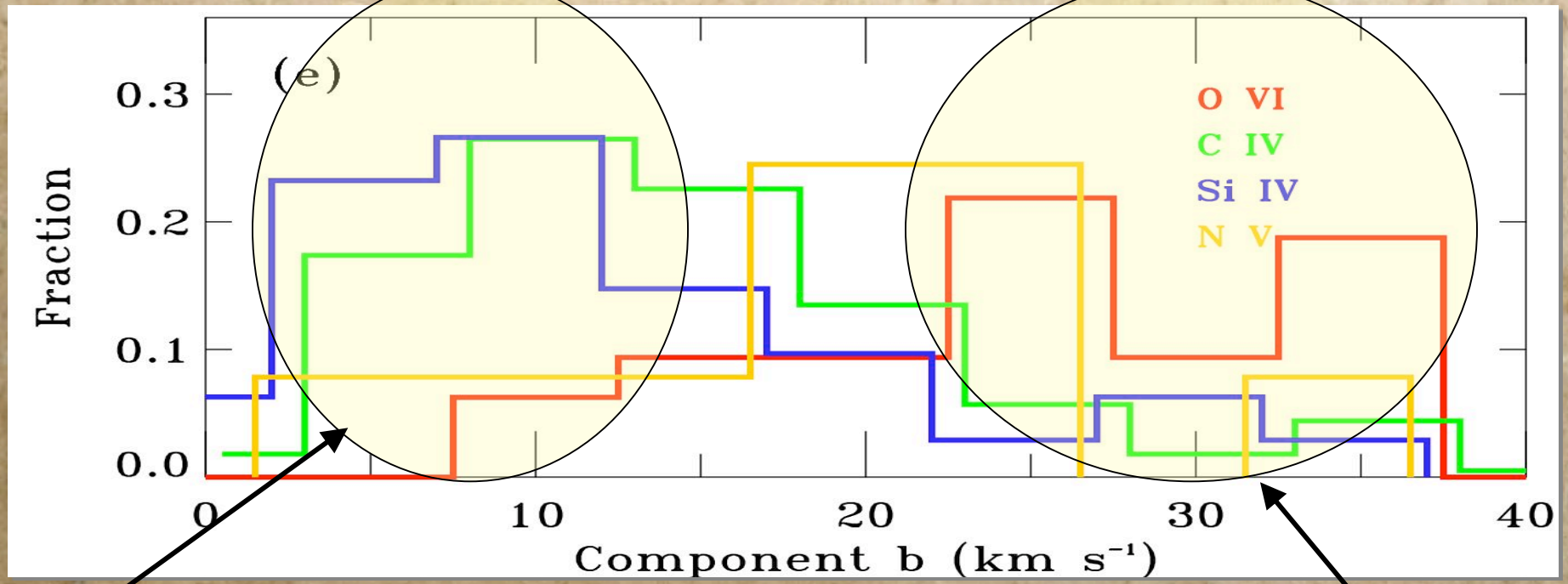
O VI SEEN IN 12/35 DLAS WITH COVERAGE OF THE RIGHT WAVELENGTH

THE OTHER CASES ARE BLENDED WITH Lyα FOREST

C IV SEEN IN 74/74 DLAS

Distribution of high ion component line widths

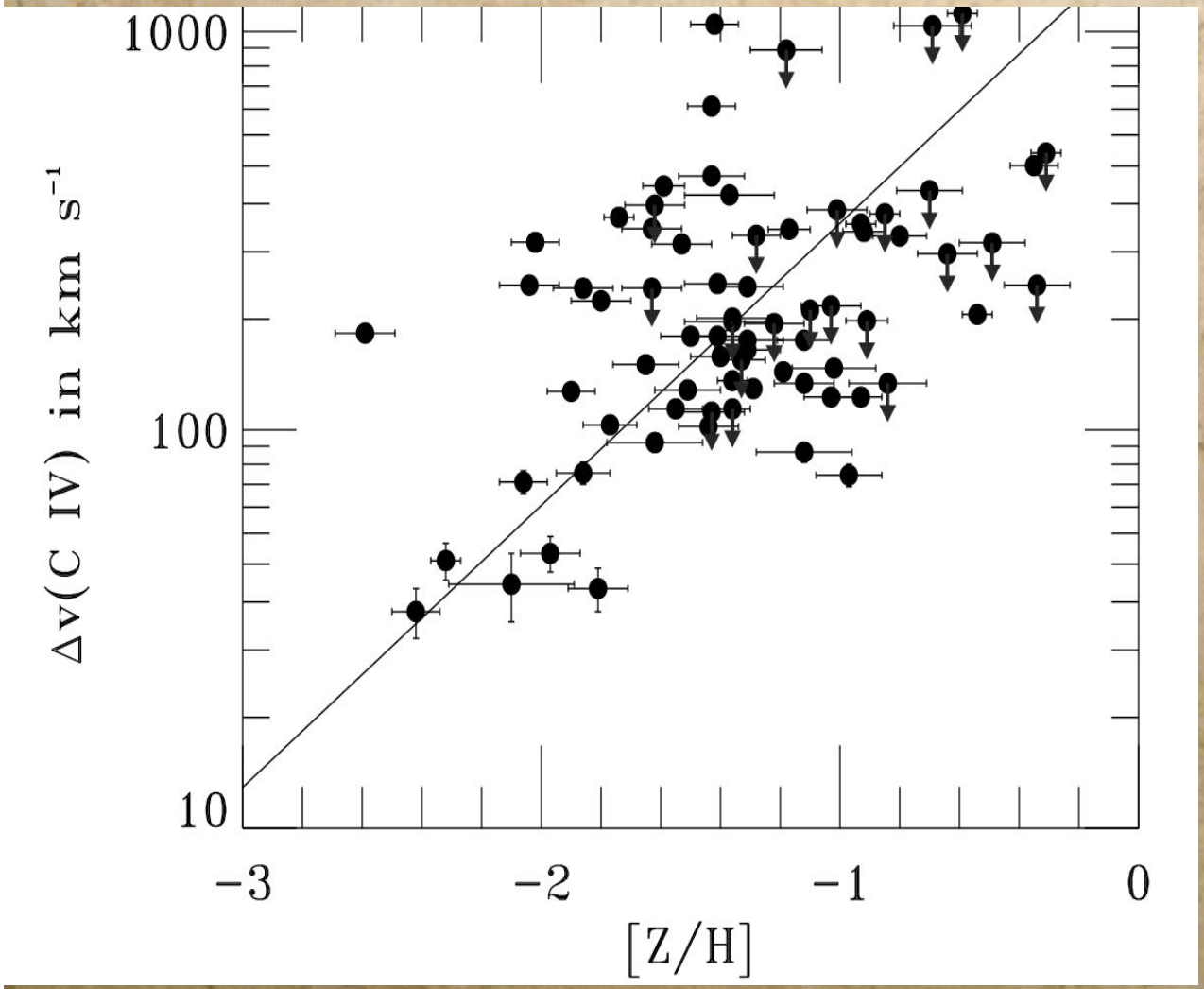
In 12 DLAs with O VI detections



Warm, Photoionized Gas

Hot, Collisionally Ionized Gas

Correlations of High-ions with Metallicity



⇒Higher metallicity systems tend to show:

stronger C IV

Broader C IV

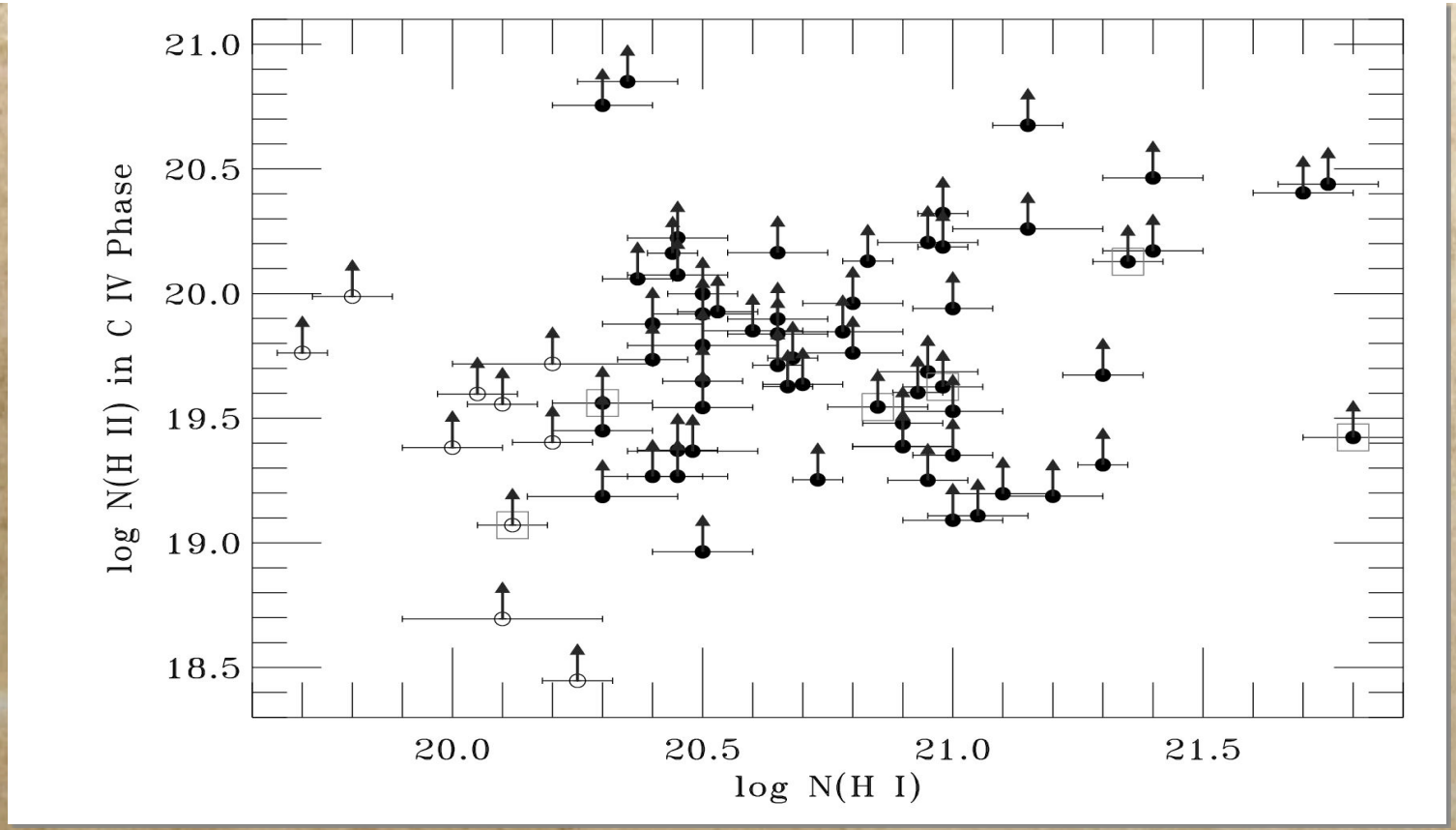
Hot Hydrogen Column Density

$$N(H\,II, hot) = \frac{N(O\,VI)}{f(O\,VI)(O/H)}$$

$$N(H\,II, warm) = \frac{N(C\,IV)}{f(C\,IV)(C/H)}$$

f(O VI) is the fraction of Oxygen atoms in O VI

- *f*(O VI) < 0.2 & *f*(C IV) < 0.3 from ionization models
- Assume [O/H] = [C/H] = [Zn/H] (measured)



WARM GAS (C IV): $\langle N(\mathrm{H\ II})/N(\mathrm{H\ I})\rangle > 0.1$

HOT GAS (O VI): $\langle N(\mathrm{H\ II})/N(\mathrm{H\ I})\rangle > 0.4$

⇒A SIGNIFICANT FRACTION (>1/3) OF THE BARYONS IN THESE HIGH-REDSHIFT GALACTIC HALOS ARE IONIZED

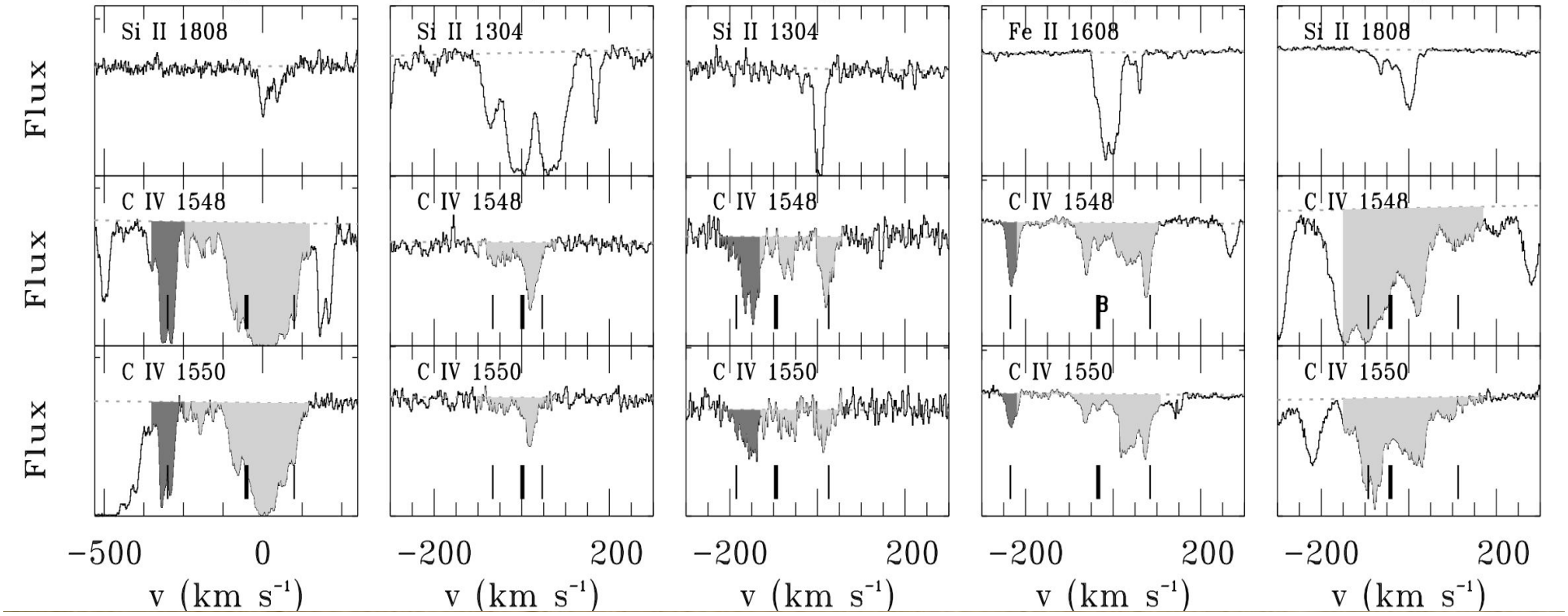
Space UV observations (e.g. COS) will be able to extend the study of ionized gas halos to low redshift

Evidence for Galactic Winds

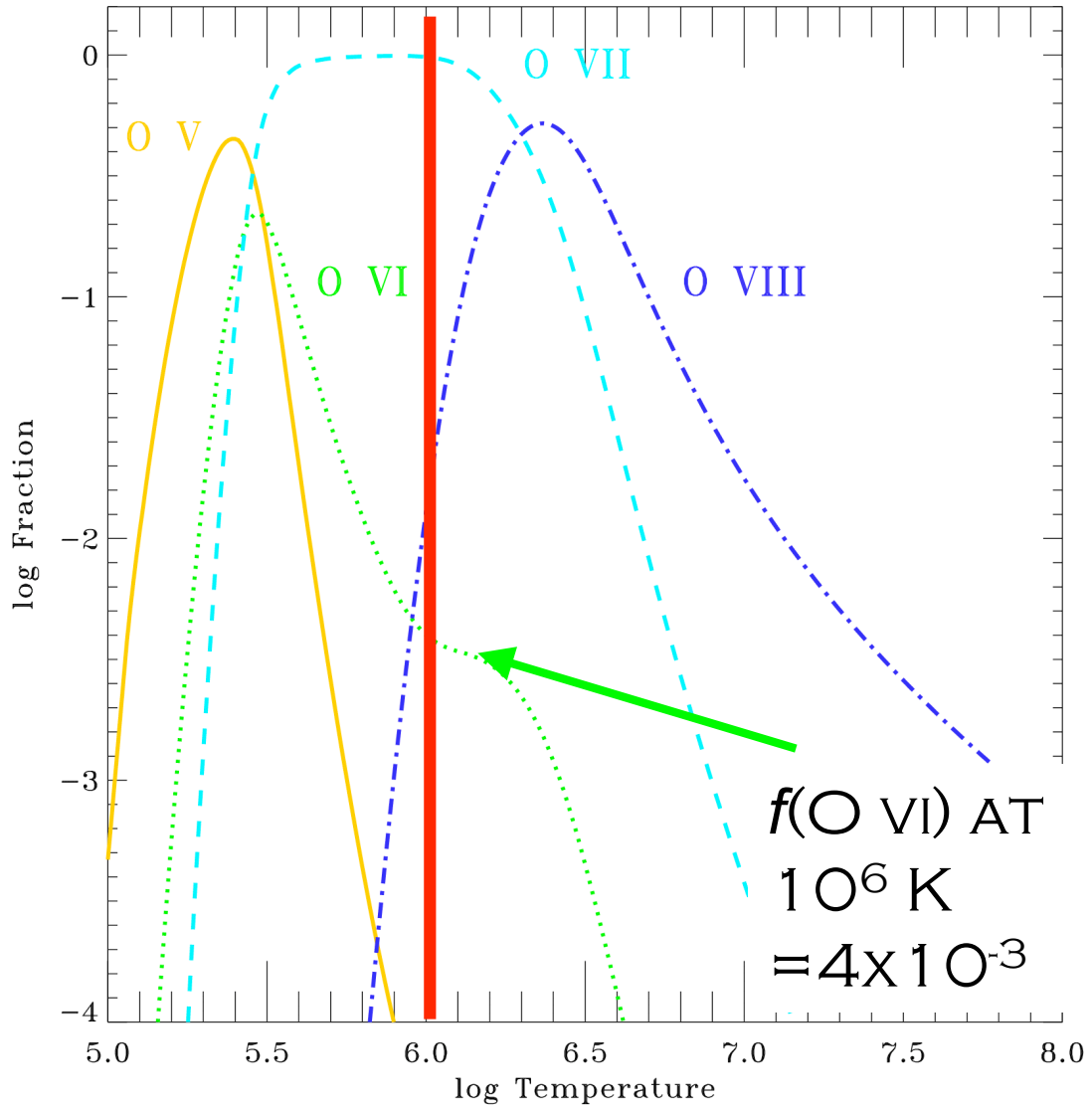
$V_{circ}=\Delta v_{neut}/0.6$ (Haehnelt et al. 1998)

$V_{esc}=\sqrt{2}v_{circ}$

We can determine the escape velocity of the gas in each system, and look for C IV absorption above V_{ESC}. Find it in 30/73 systems



Ionization versus Temperature



- If $T = 10^6$ K, O VII and O VIII would be dominant
- Line width

  b(O VI, 10^6 K) = 30 km s^{-1} consistent with data

  In this event hot gas in DLAs represent Ω_Z(H II) = 7.5×10^{-6} (25% of the metal budget)

  Are these Hot halos observable in the X-ray?

Collisional Ionization Equilibrium Curves (Sutherland & Dopita 1993)

Summary

- UV absorption lines of high ions allow for studies of Galactic winds, the metal budget, and the baryon budget.
- DLAs show neutral, ionized, and molecular gas in a multi-phase ISM. C IV is always detected.
- Observations imply DLAS contain both
  - warm ionized gas (narrow C IV/Si IV components)
  - hot ionized gas (broad O VI components)
- The C IV Column densities correlate with neutral-phase metallicity, suggesting that star formation lead to the ionized gas

Future missions-UV

1150–3000 Å

20 km s^{-1} resolution

O VI at z=0.11–1.91

Cosmic Origins Spectrograph

HST Servicing Mission SM4