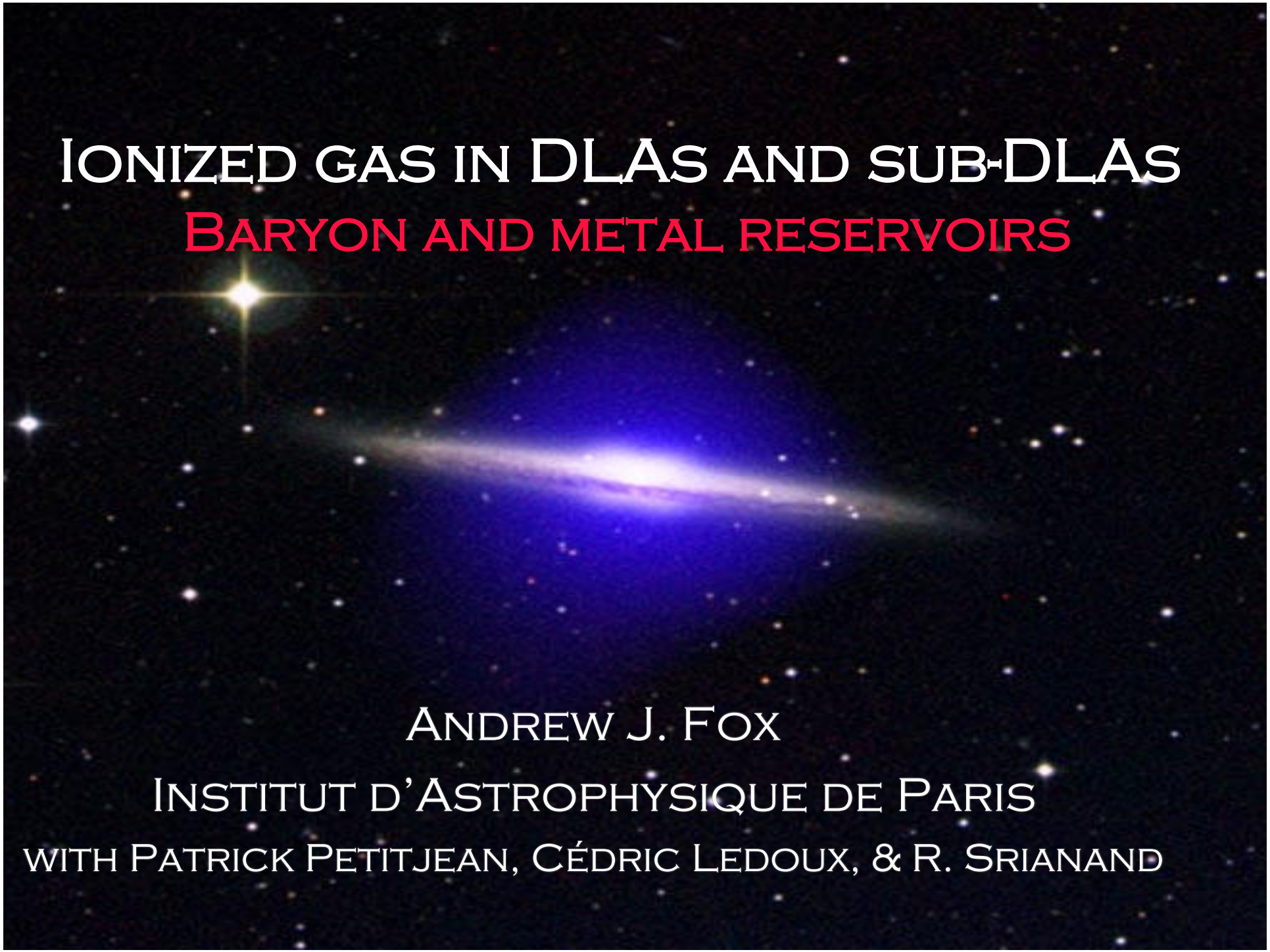

Ionized gas in DLAs and sub-DLAs

Baryon and metal reservoirs

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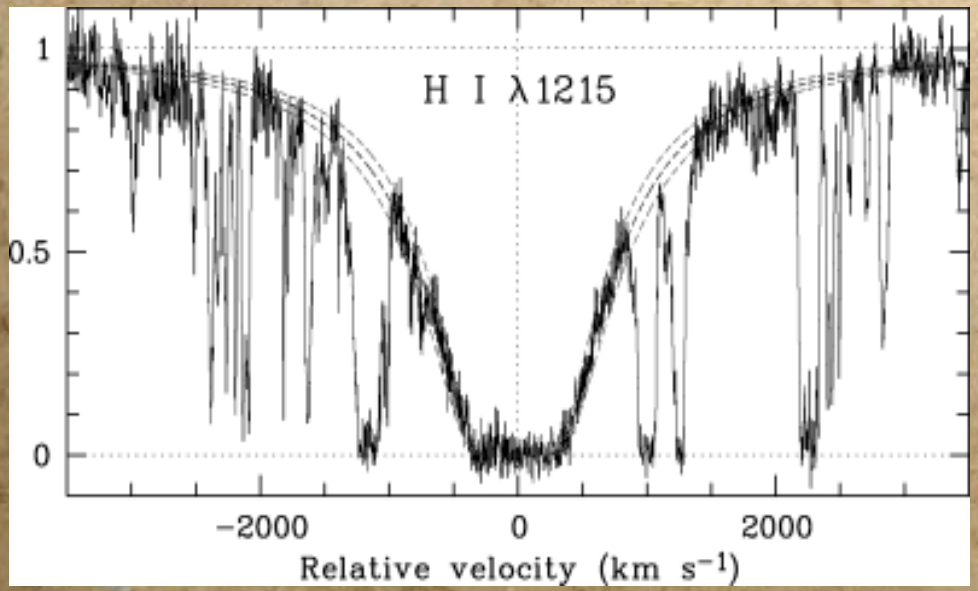
Damped lyman-α systems (DLAs): An Intro



Definition of DLAs/sub-DLAs. QSO absorbers with

DLA: log N(HI)>20.3

sub-DLA: 19.0<log N(H I)<20.3

- DLAs contain the majority of all neutral gas at z=0–5 (Wolfe et al. 2005)

  ⇒site for star formation

- DLAs also contain molecular and ionized gas

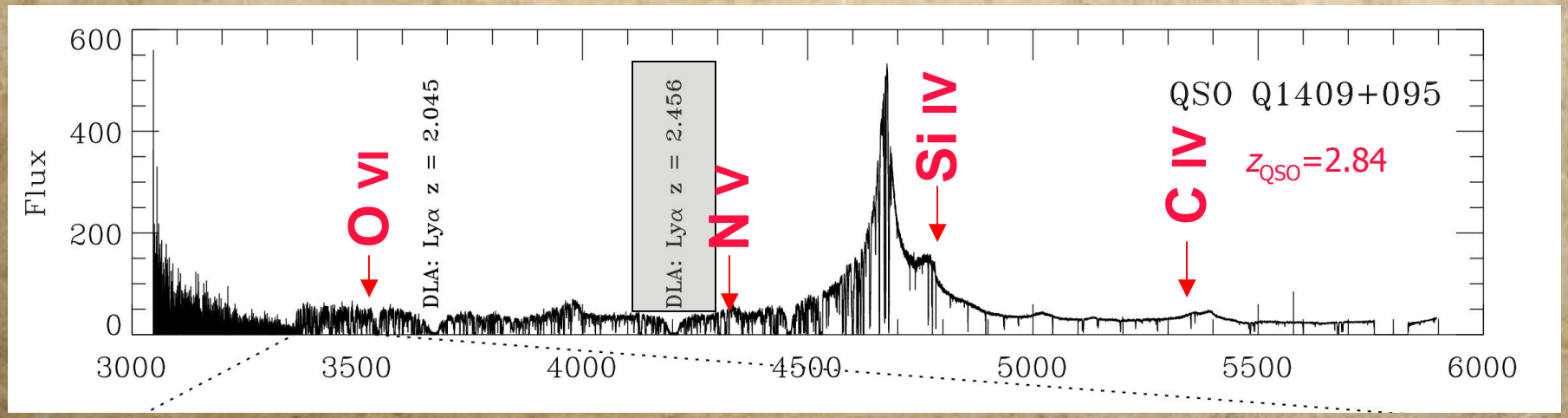
  ⇒multiphase interstellar medium in high-redshift protogalaxies

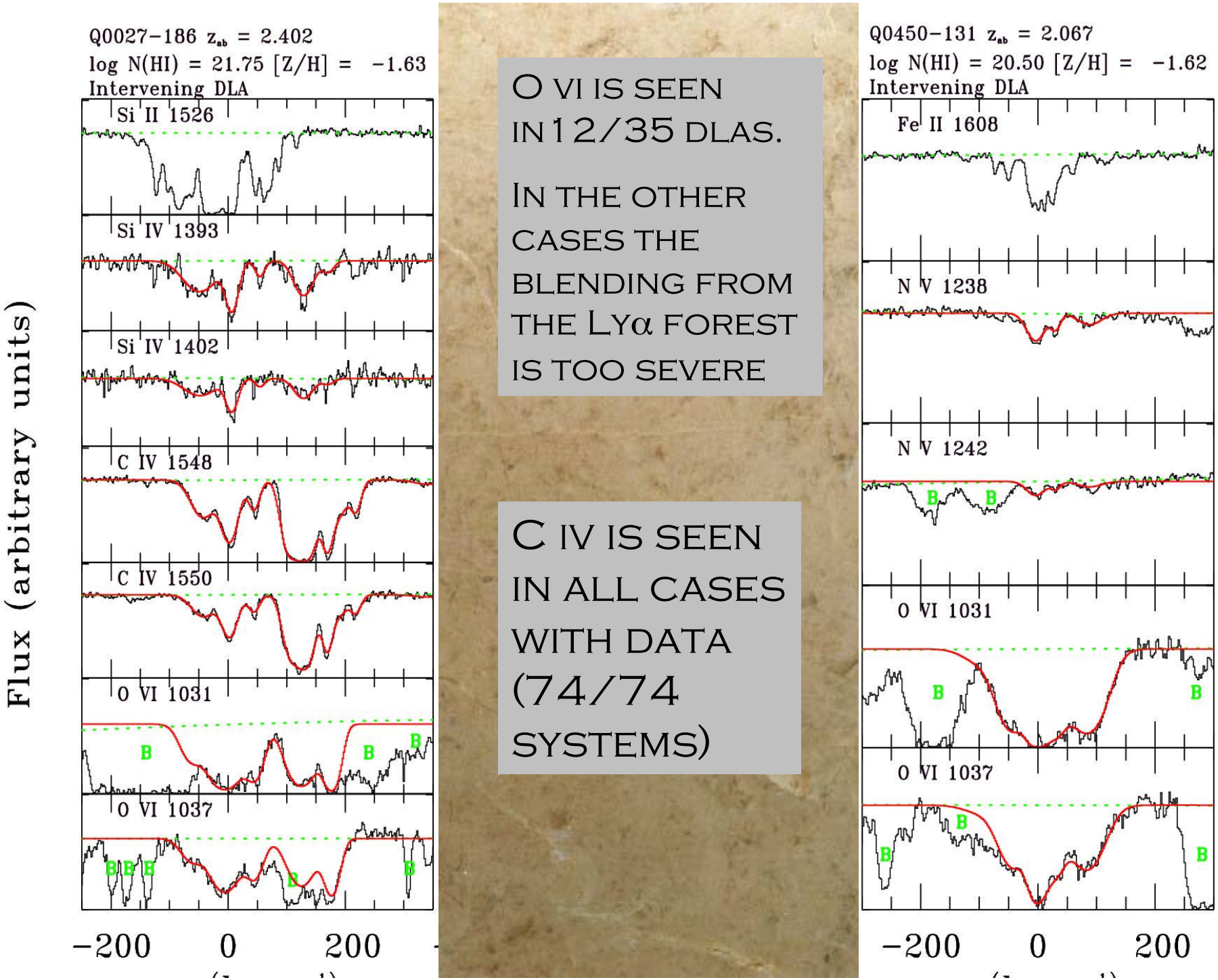
Search for the High Ions

Ion	λ_0 (Å)	From ground	$E^{i-1} \Rightarrow E^i$ (eV)	T_{coll} (K)
O VI	1031, 1037	z>1.9	114	3×10^5
N V	1238, 1242	z>1.4	78	2×10^5
C IV	1548, 1550	z>0.9	48	1×10^5
Si IV	1393, 1402	z>1.2	34	0.8×10^5

Lines seen in absorption toward background QSOs

Searching for O VI and C IV

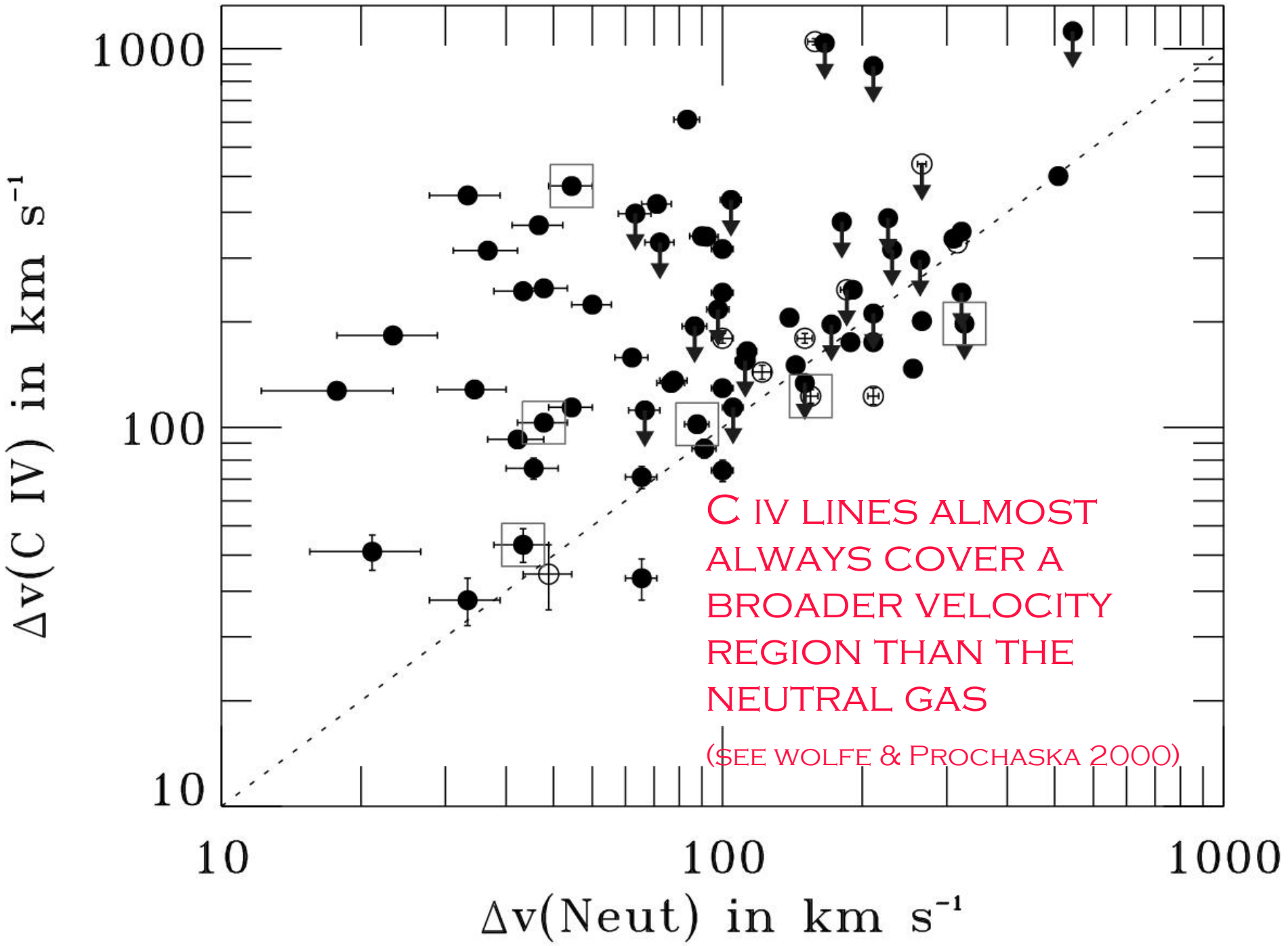




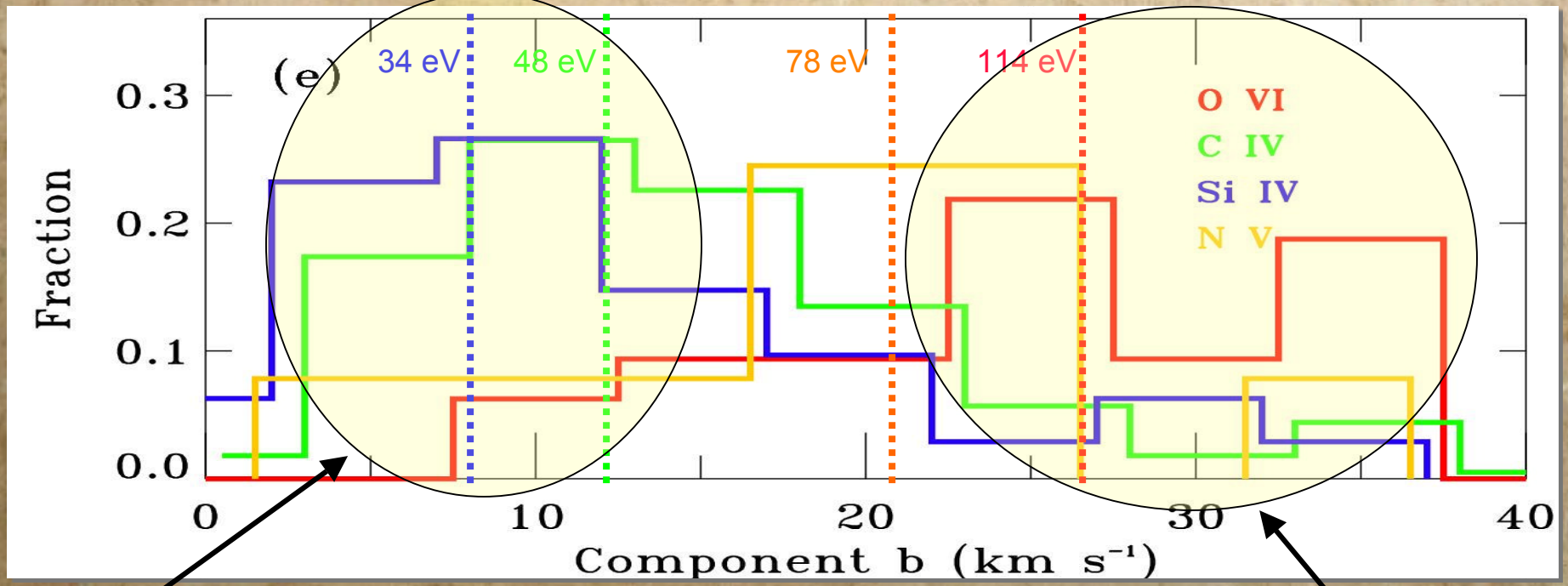
O VI IS SEEN IN 12/35 DLAS.

IN THE OTHER CASES THE BLENDING FROM THE LYα FOREST IS TOO SEVERE

C IV IS SEEN IN ALL CASES WITH DATA (74/74 SYSTEMS)


1000
100
10
10
100
1000
Δv(C IV) in km s⁻¹
Δv(Neut) in km s⁻¹
C IV LINES ALMOST ALWAYS COVER A BROADER VELOCITY REGION THAN THE NEUTRAL GAS
(SEE WOLFE & PROCHASKA 2000)

Histograms of Component line widths

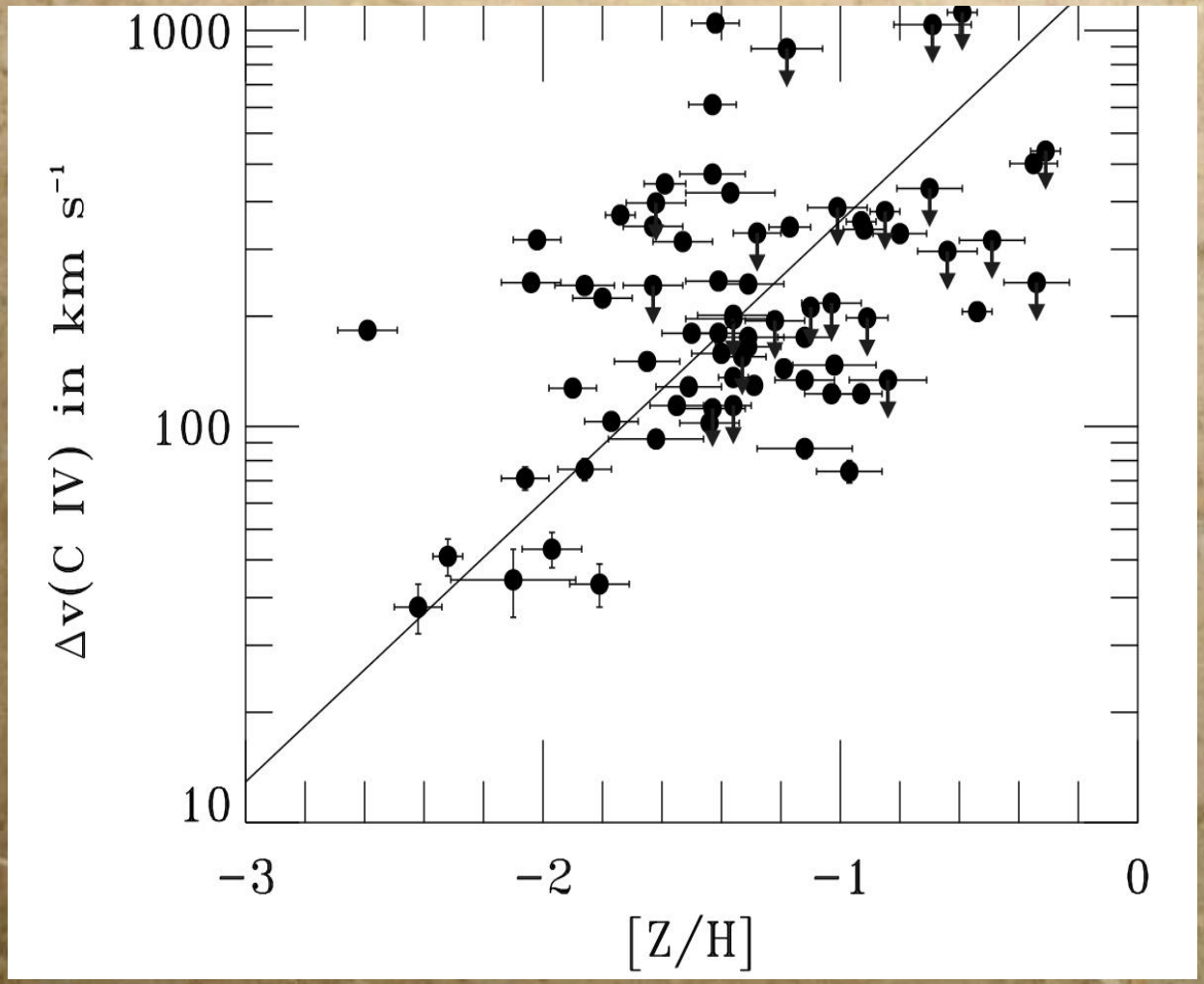


Warm, Photoionized Gas

The O VI components tend to be broader than the C IV components. The average width increases with ionization potential

Hot, Collisionally Ionized Gas

Correlations of High-ions with Metallicity



⇒Higher metallicity systems tend to show:

stronger C IV

Broader C IV

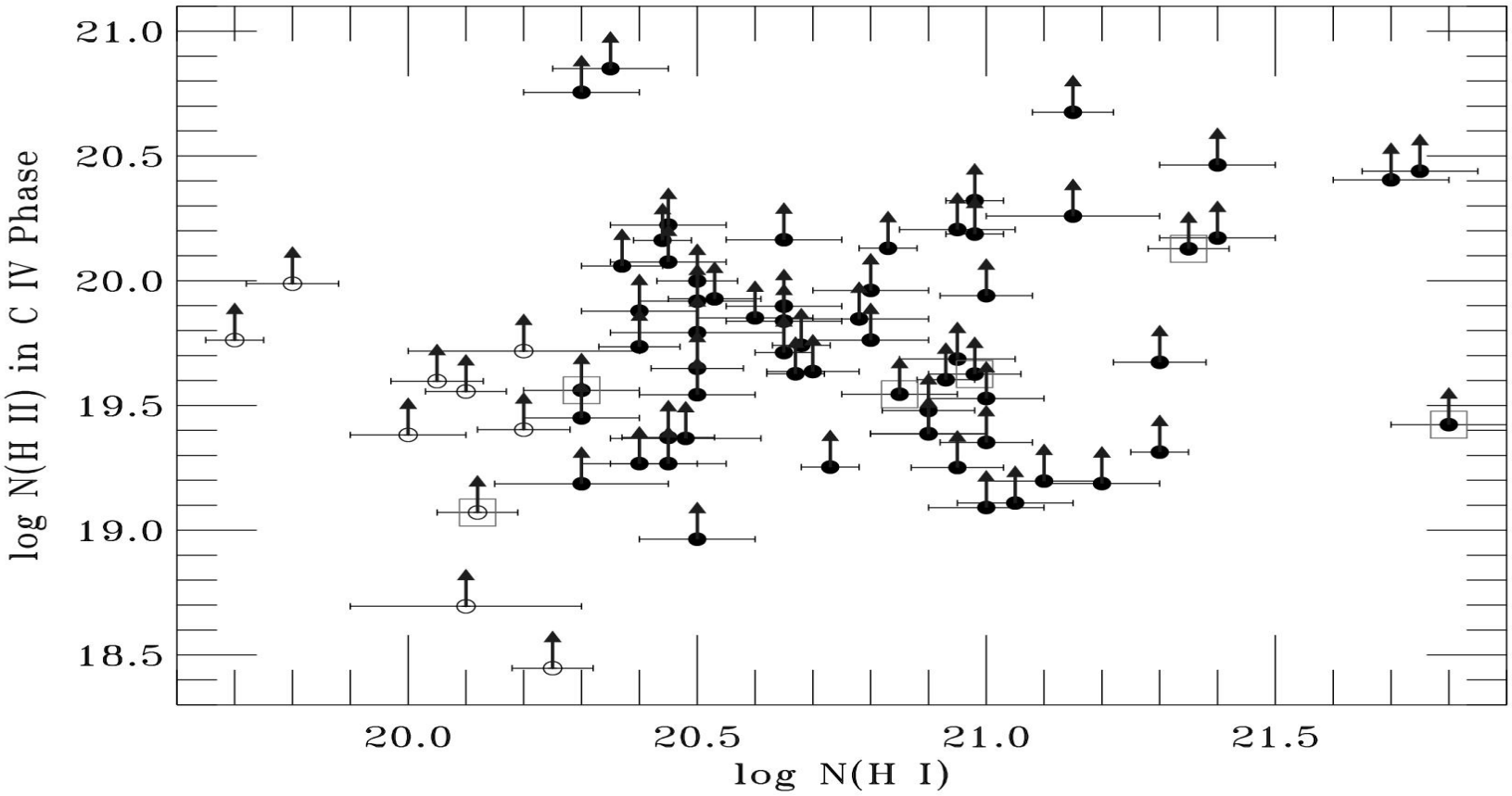
Hot Hydrogen Column Density

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

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

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)



HOT GAS (O VI): $\langle N(\mathrm{H\ II})/N(\mathrm{H\ I})\rangle = 0.4 / [f(\mathrm{O\ VI})/0.2]$

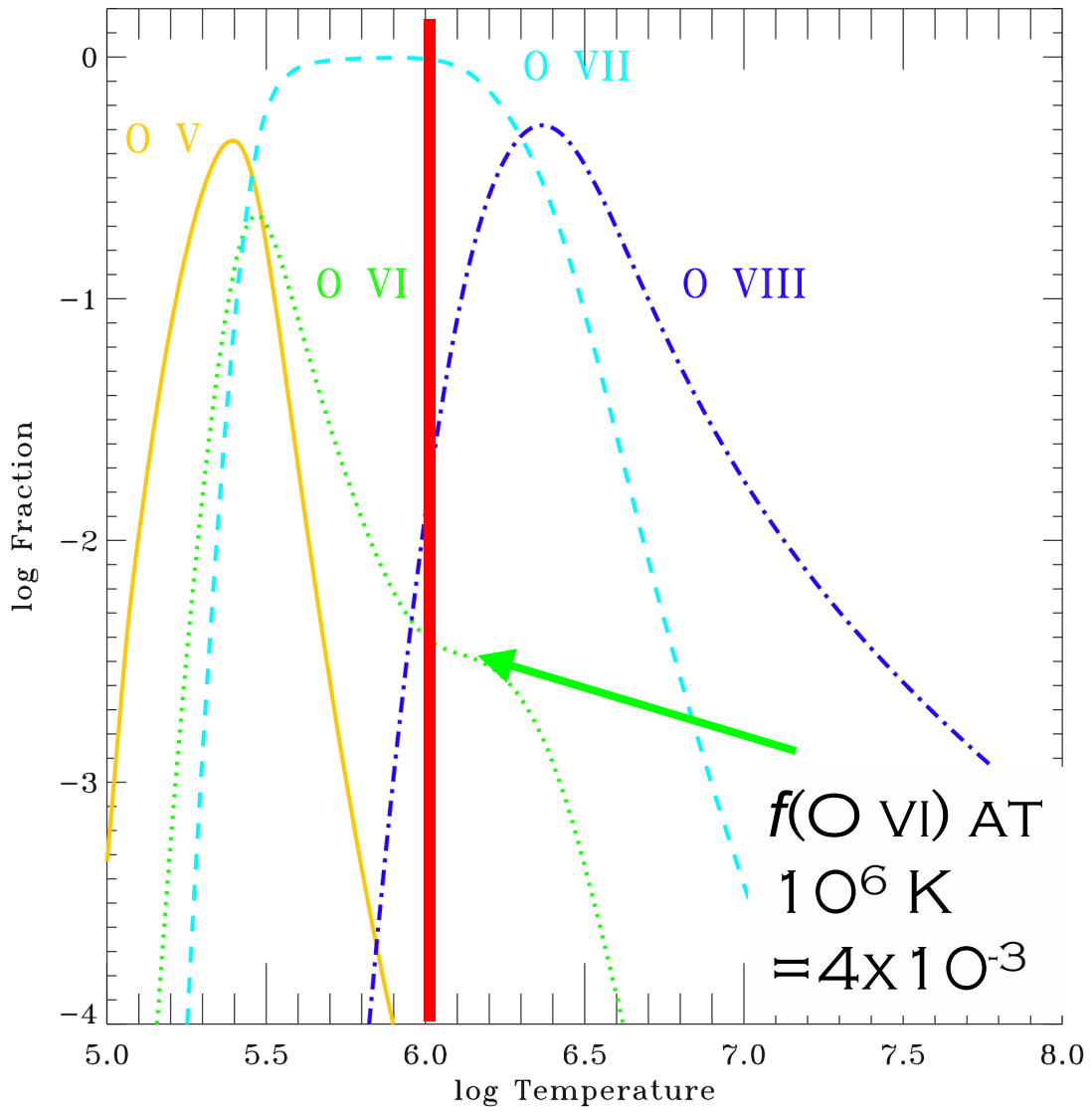
WARM GAS (C IV): $\langle N(\mathrm{H\ II})/N(\mathrm{H\ I})\rangle = 0.1 / [f(\mathrm{C\ IV})/0.3]$

WE KNOW $\Omega(\mathrm{H\ I})=1\times10^{-3}$ (Prochaska et al. 2005)

$\Rightarrow\Omega(\mathrm{H\ II}) = 4\times10^{-4} / [f(\mathrm{O\ VI})/0.2]$

$\Rightarrow\Omega_Z(\mathrm{H\ II}) = 1.5\times10^{-7} / [f(\mathrm{O\ VI})/0.2]$

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 at z=2.5)

  Need X-ray observations to confirm this

Collisional Ionization Equilibrium Curves (Sutherland & Dopita 1993)

Summary

- Absorption line studies of ionized gas in DLAs show evidence for
  - Warm ionized gas (narrow C IV/Si IV Components)
  - Hot ionized gas (Broad O VI/C IV Components)
- C IV lines cover a larger region of velocity space than the neutral-phase lines
- The C IV Column densities and Line widths correlate with neutral-phase metallicity,
- $\langle N(\text{Hot H II})/N(\text{H I})\rangle = 0.4/(f_{\text{O VI}}/0.2)$
  (median from 12 DLAs with O VI)
- $\langle N(\text{Warm H II})/N(\text{H I})\rangle = 0.1/(f_{\text{C IV}}/0.3)$
  (median from 74 DLAs and sub-DLAs with C IV)
- If $T>>3\times10^5$ K, $f_{\text{O VI}} << 0.2$ and contribution of hot H II in DLAs to metal budget increases