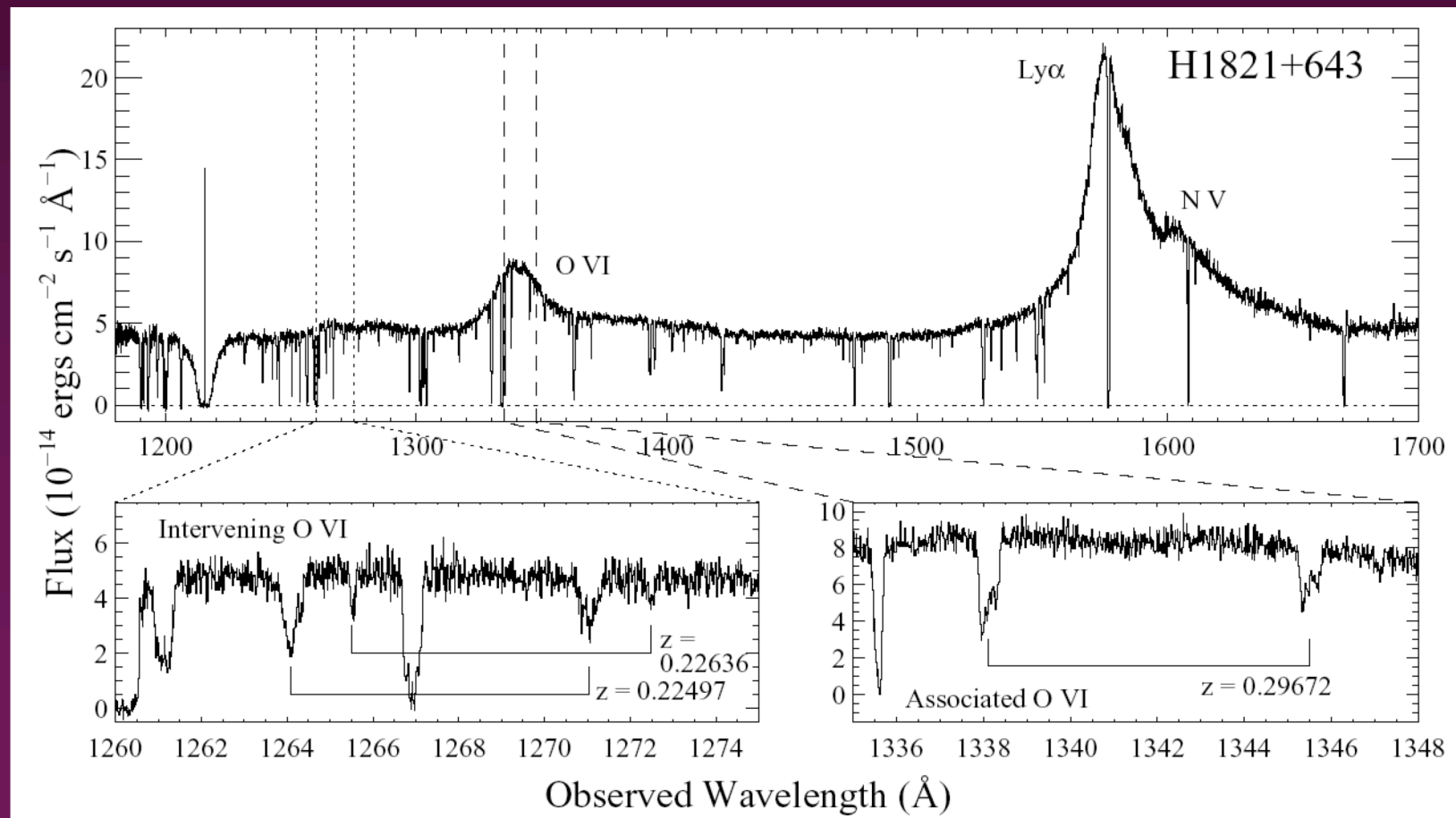
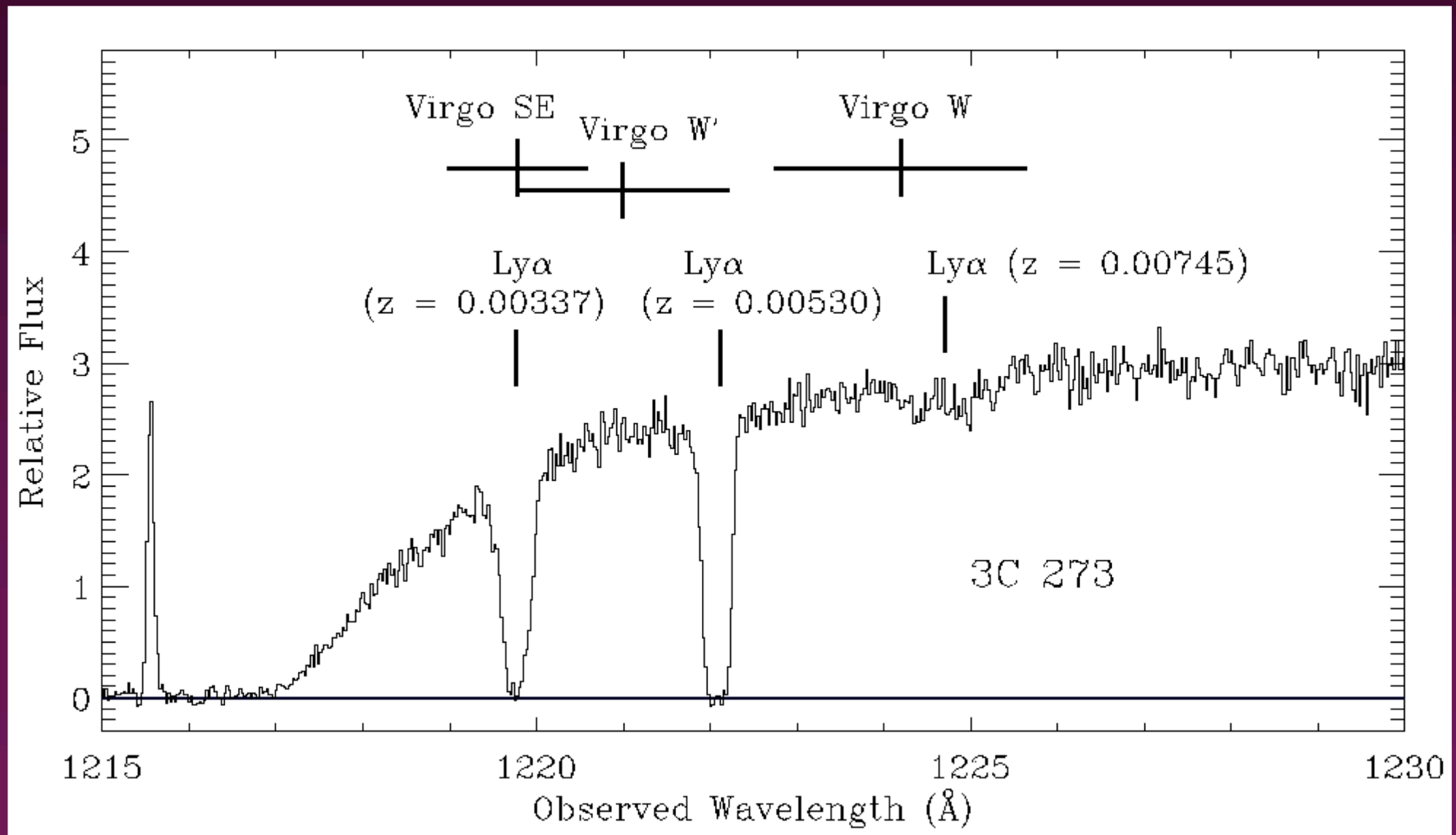


Low-Redshift QSO Absorption Lines: New Results on O VI Systems, the Warm-Hot IGM, and Feedback

Todd M. Tripp, University of Massachusetts

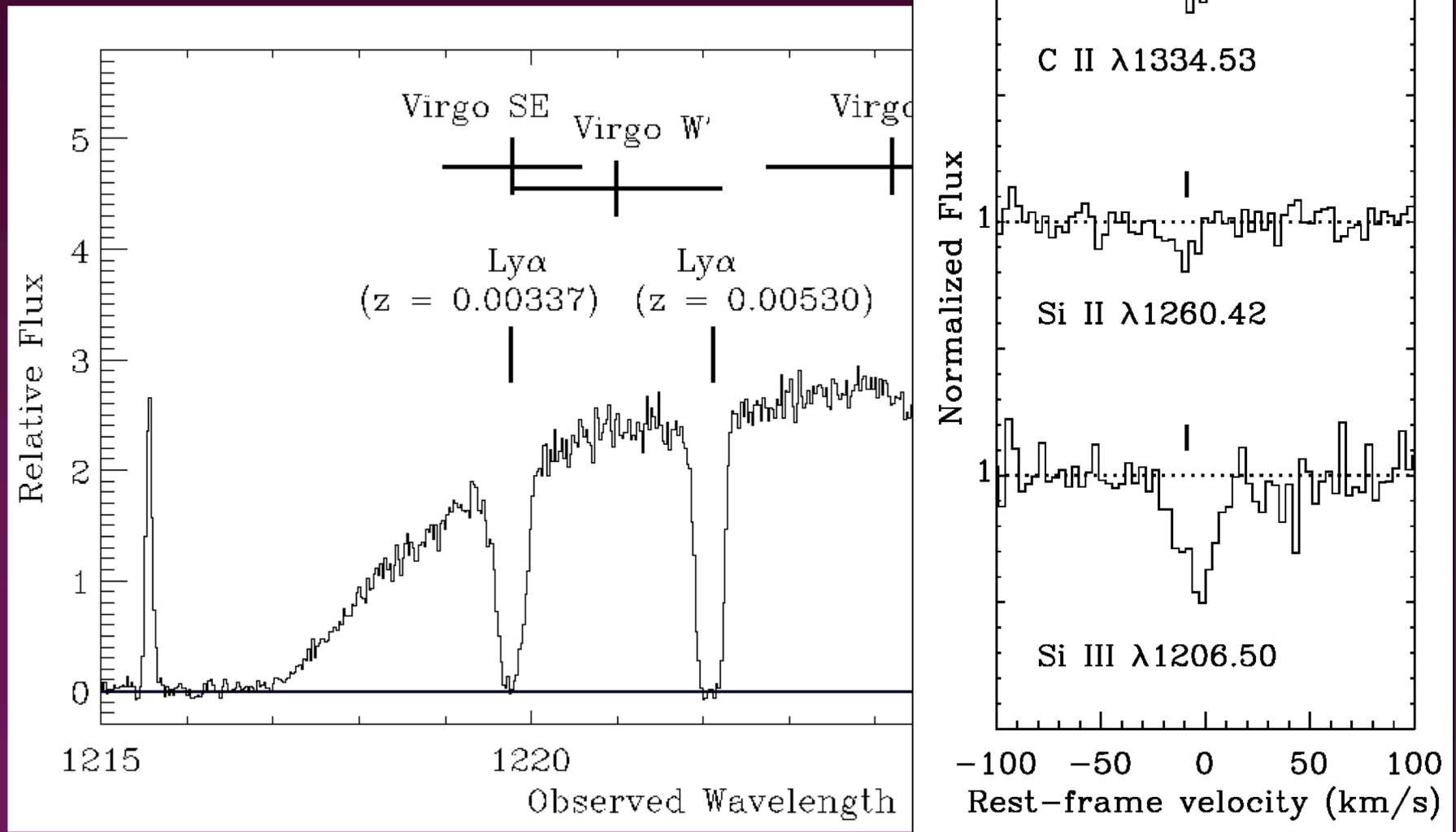


Ly α Clouds in the Outskirts of the Virgo Cluster

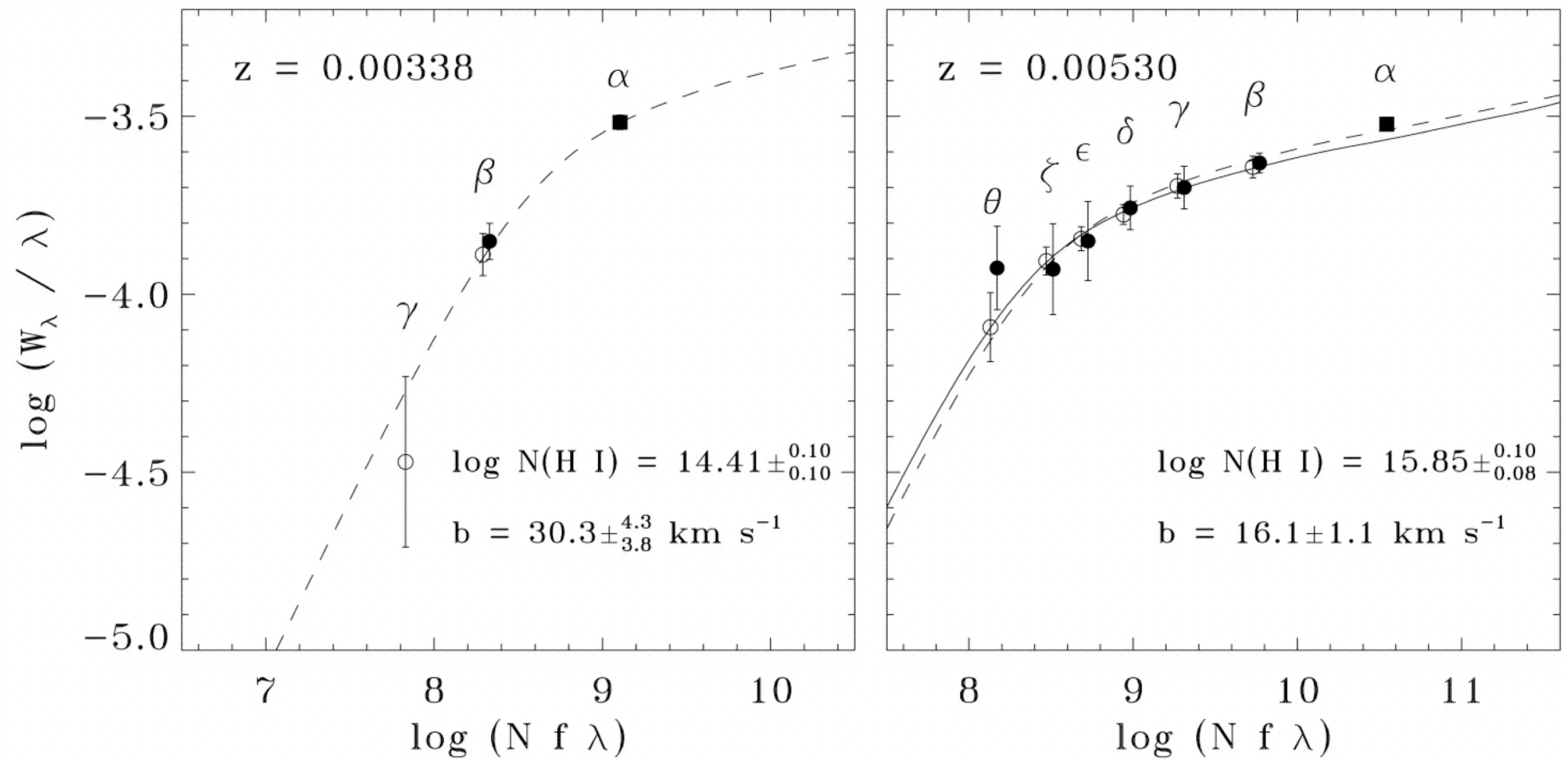


Tripp, Jenkins, Williger et al. (2002)

Ly α Clouds in the Outskirts of the Virgo Cluster

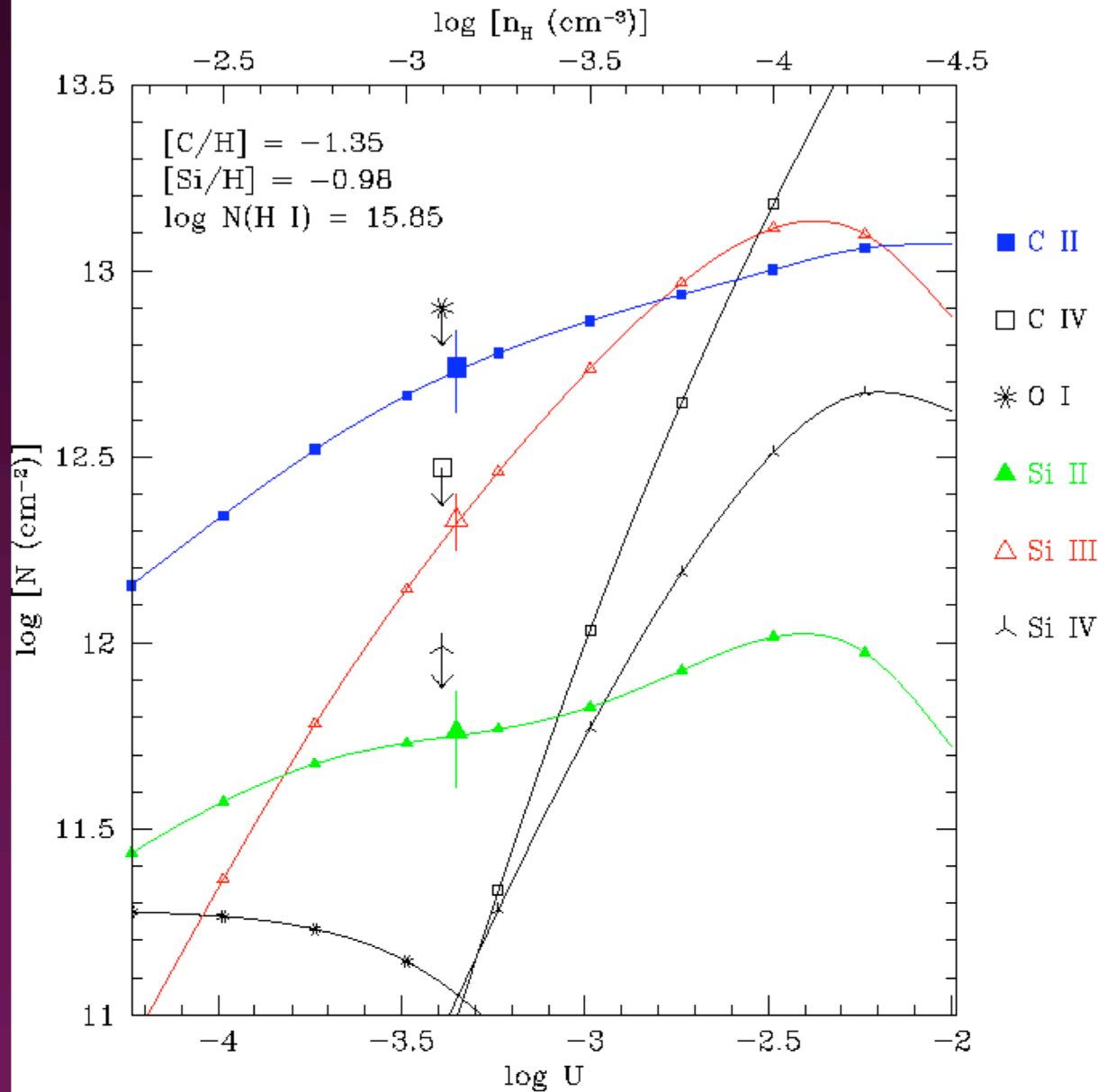


Tripp, Jenkins, Williger et al. (2002)



Sembach, Howk, Savage et al. (2001)

Model implication



- **Metallicity: 0.05-0.1 solar**
- **$\log n = -3.1$ to -2.8**
- **Pressure: 20-40 $\text{cm}^{-3} \text{ K}$**
- **size = 70 - 350 pc**

How is this tiny absorber confined?

Tripp, Jenkins, Williger et al. (2002)

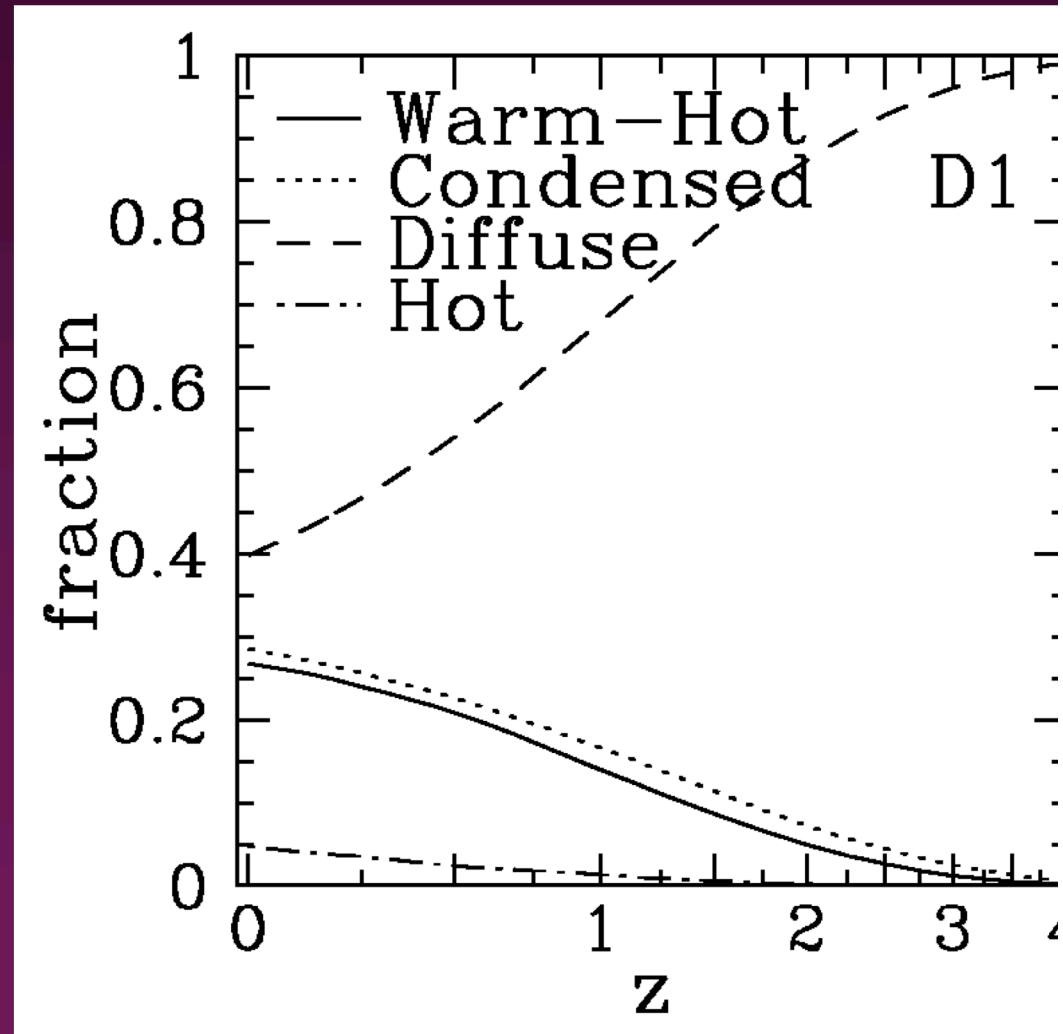
A High-Resolution Survey of Low-Redshift QSO Absorption Lines: Statistics and Physical Conditions of O VI Absorbers

Astro-ph 0706.1214 (Monday June 11)

Todd M. Tripp, Kenneth R. Sembach,
David V. Bowen, Blair D. Savage,
Edward B. Jenkins, Nicolas Lehner,
Philipp Richter

The Missing Baryons: Shock-Heated Intergalactic Gas?

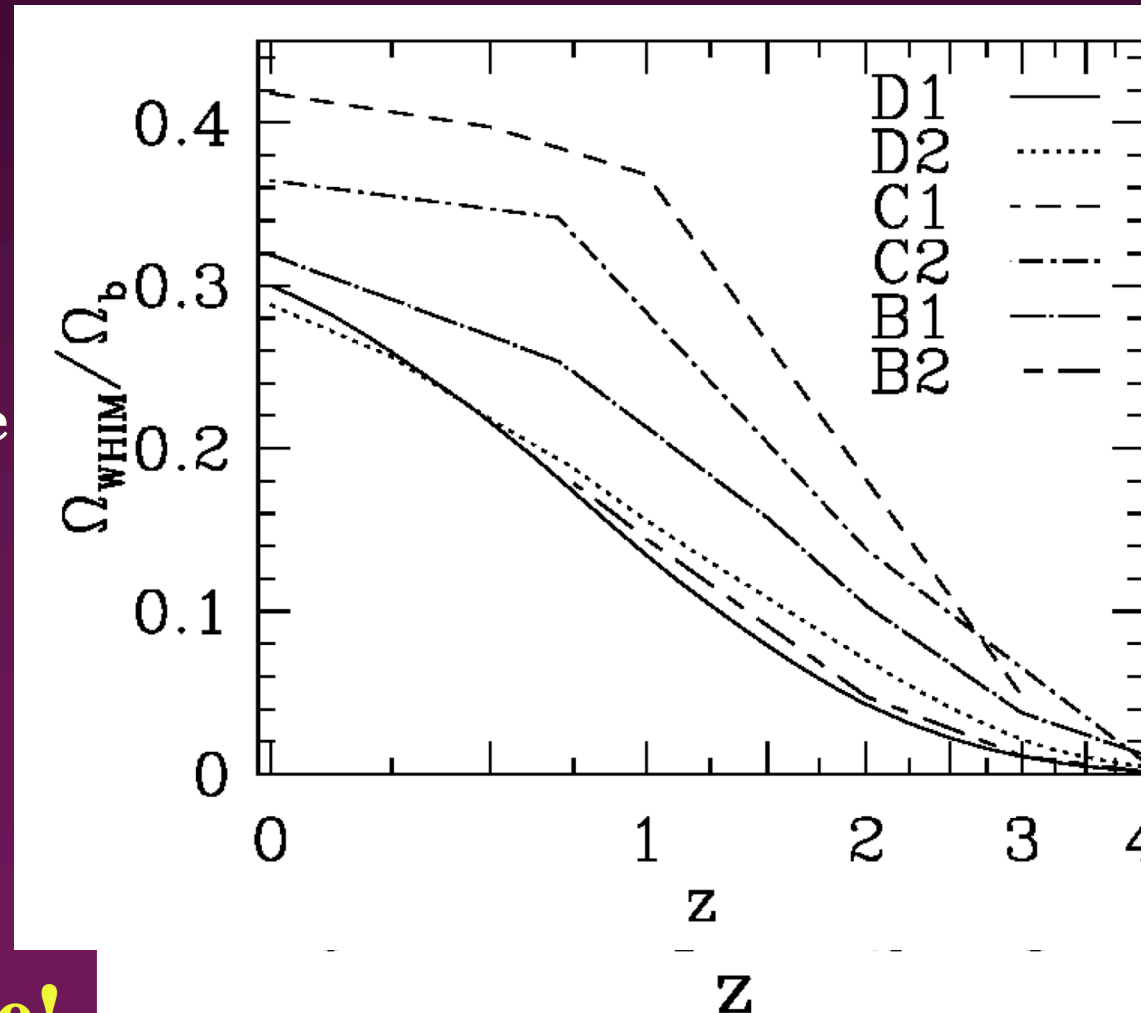
- Cen & Ostriker (1999)
- Dave et al. (1999)
- Hydrodynamic simulations of cosmological structure growth
- **30 - 50 % predicted to be in low-density, shock-heated gas at $10^5 - 10^6$ K**



Difficult to observe!

The Missing Baryons: Shock-Heated Intergalactic Gas?

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Difficult to observe!



Halo physical conditions and chemical enrichment constrain fundamental aspects of galaxy evolution.

For example, when gas accretes onto galaxies, is it shock heated to $\sim 10^6$ K (conventional model), or does it remain cool, (i.e., “cold mode” accretion, Keres et al. 2005)?

WIYN + HST image
of M82
(Gallagher et al.)

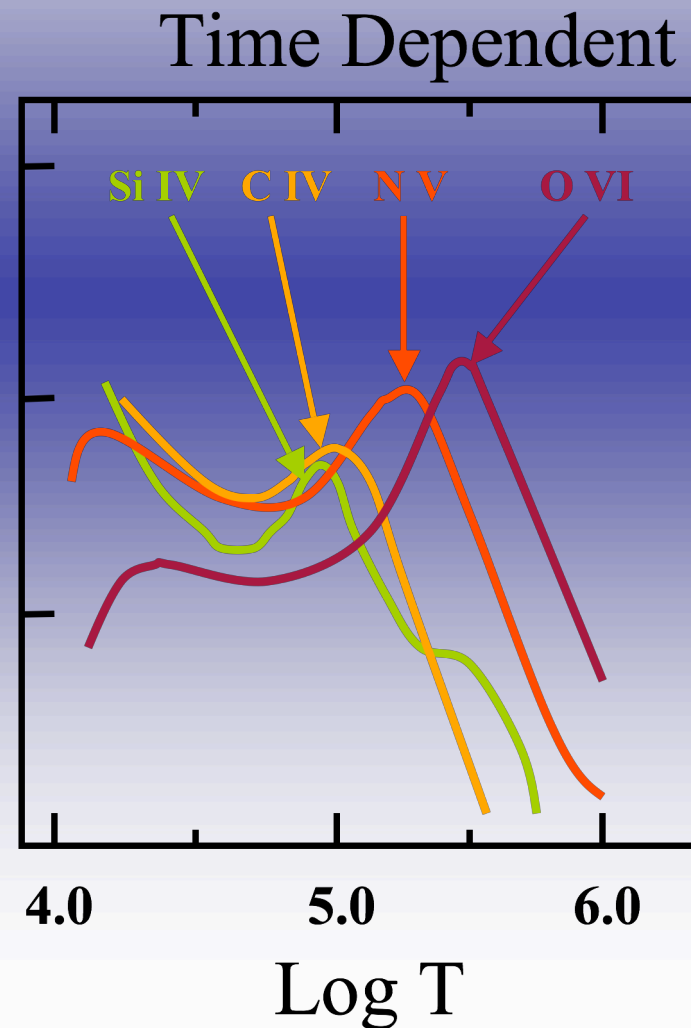
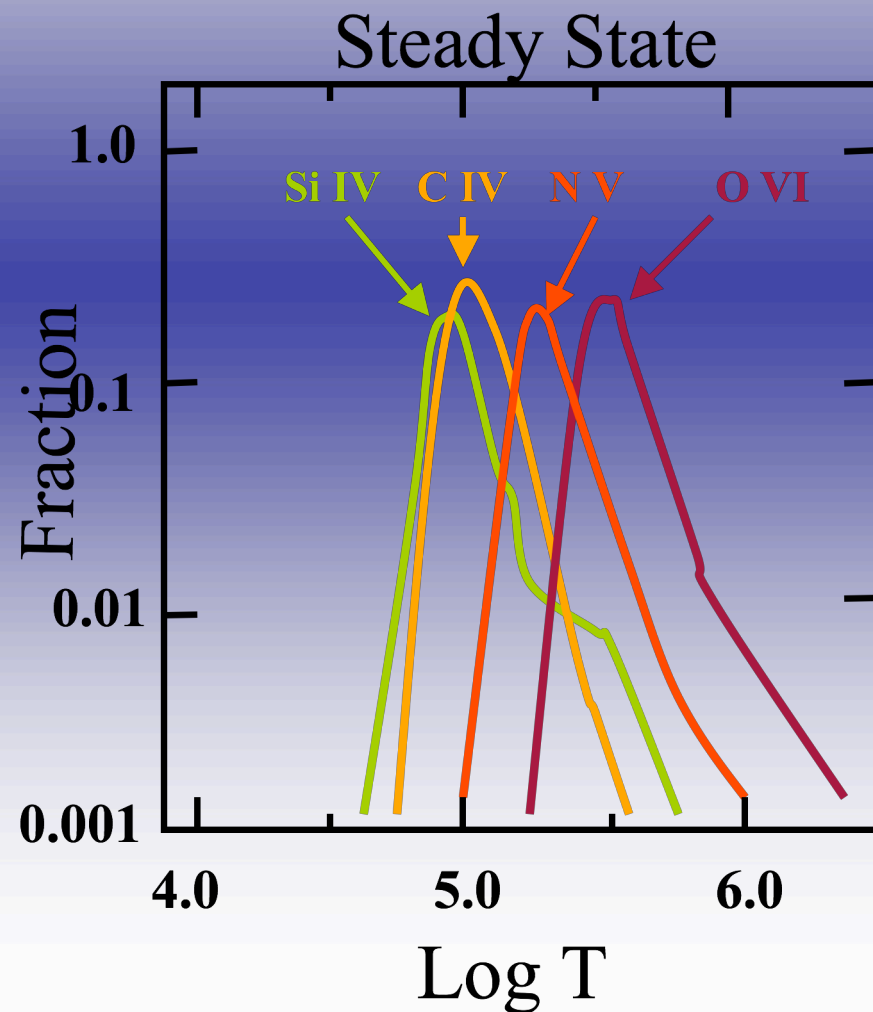
How do galactic superwinds affect galaxy
and large-scale structure evolution?

Searching for the Missing Baryons with UV and X-ray Absorption

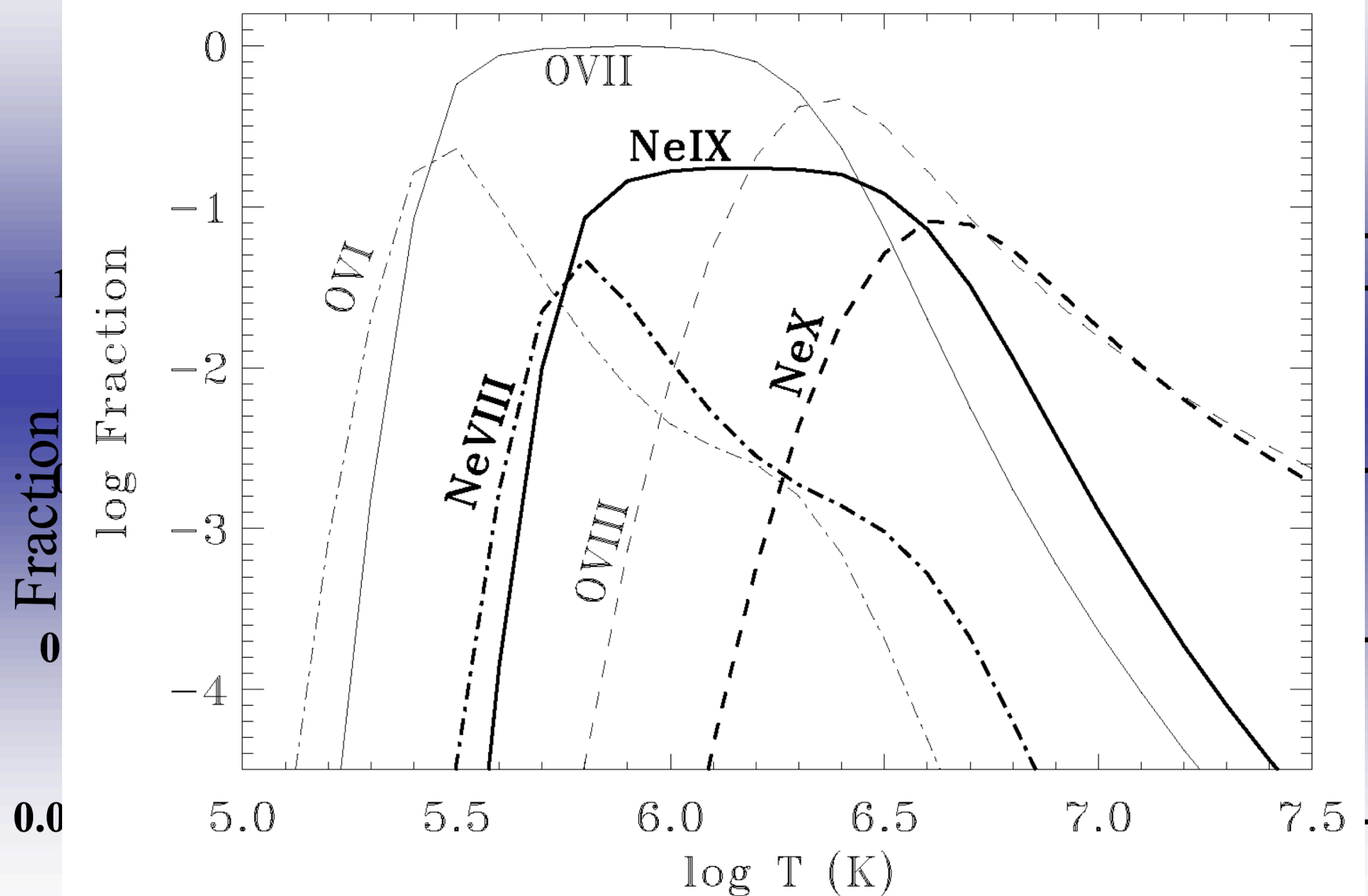
Ion fractions from Shapiro & Moore:

Searching for the Missing Baryons with UV and X-ray Absorption

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Searching for the Missing Baryons with UV and X-ray Absorption

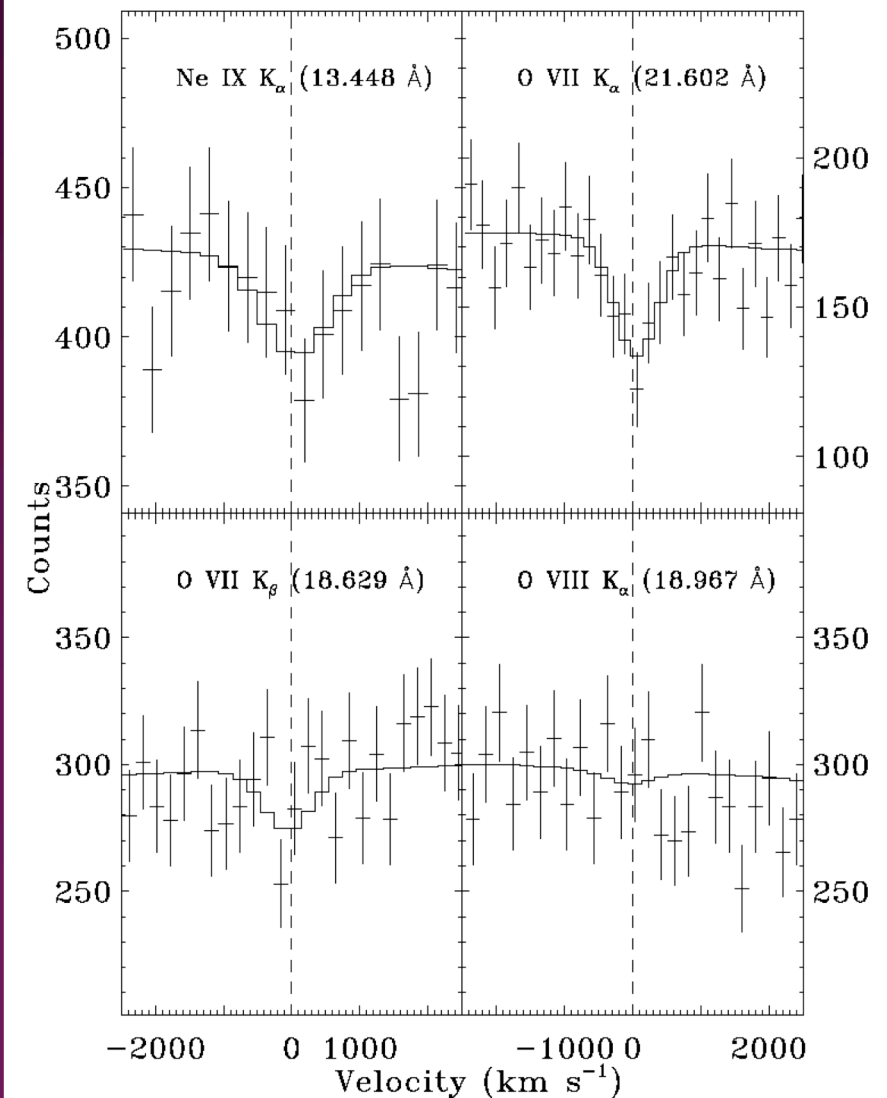
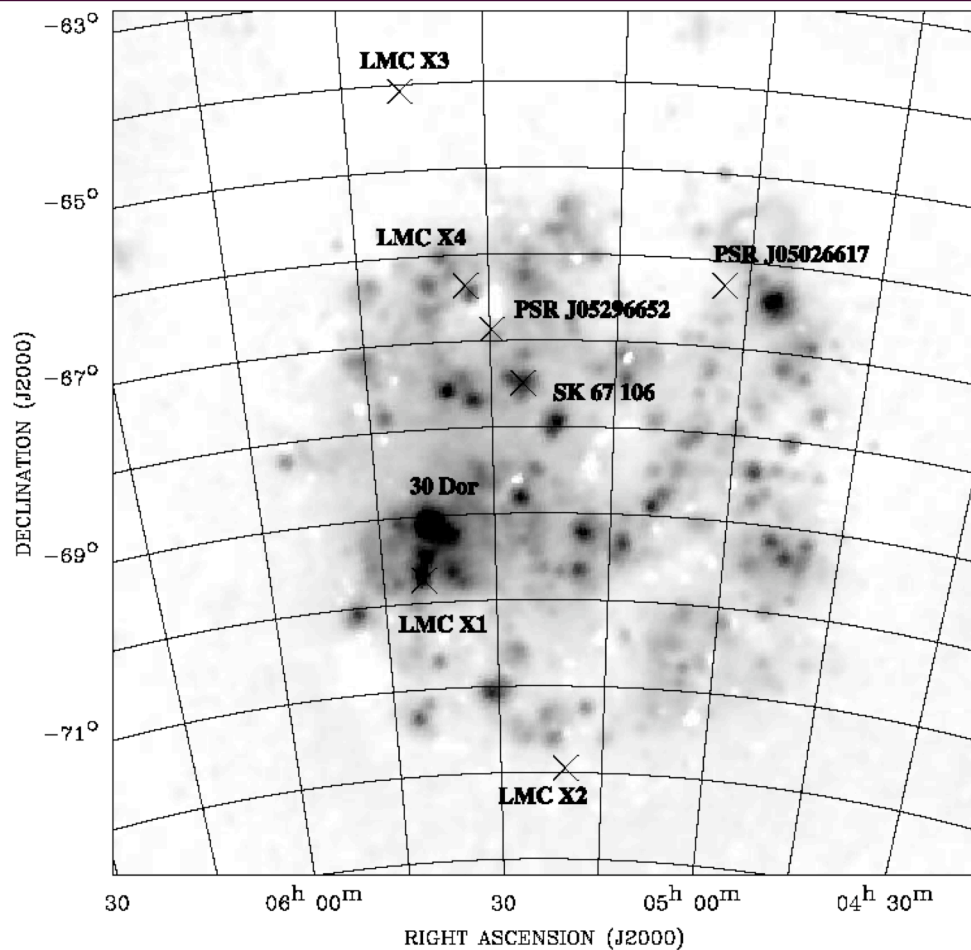


Log T

Log T

Reliable O VII detections: nearby gas

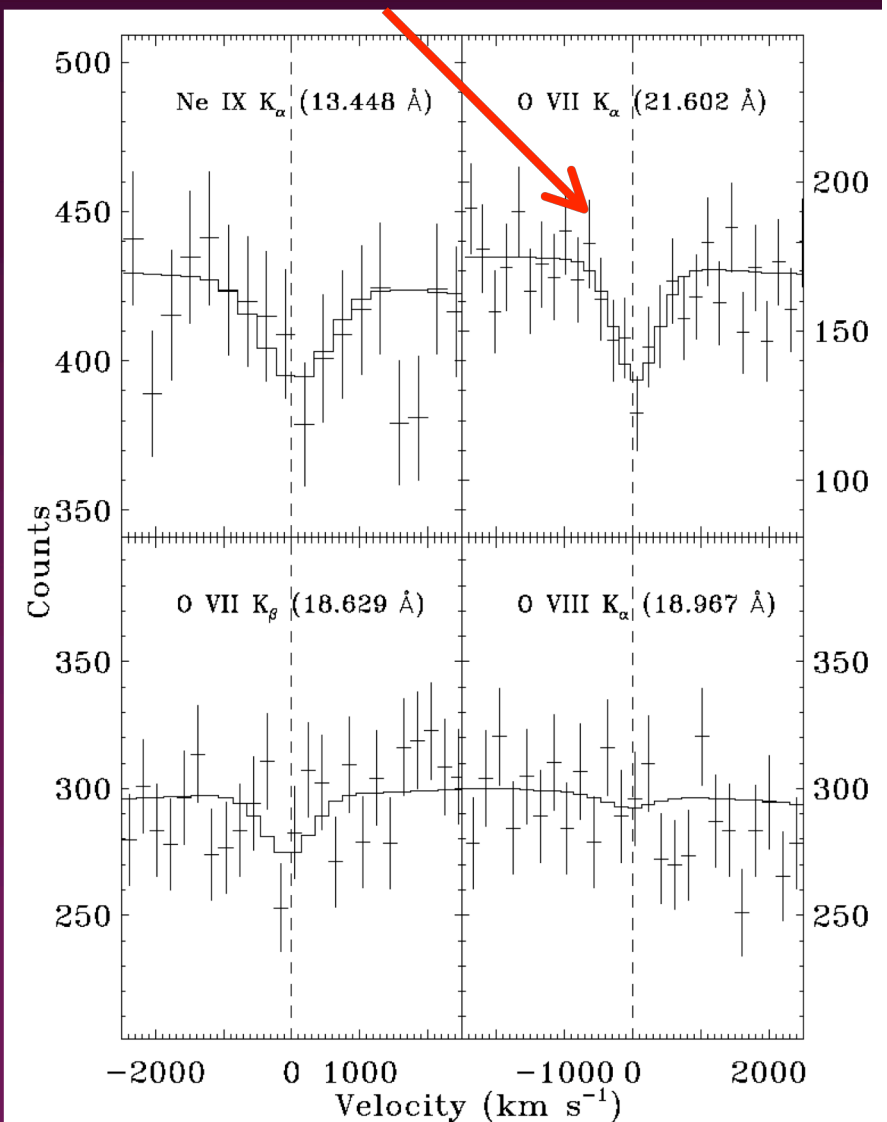
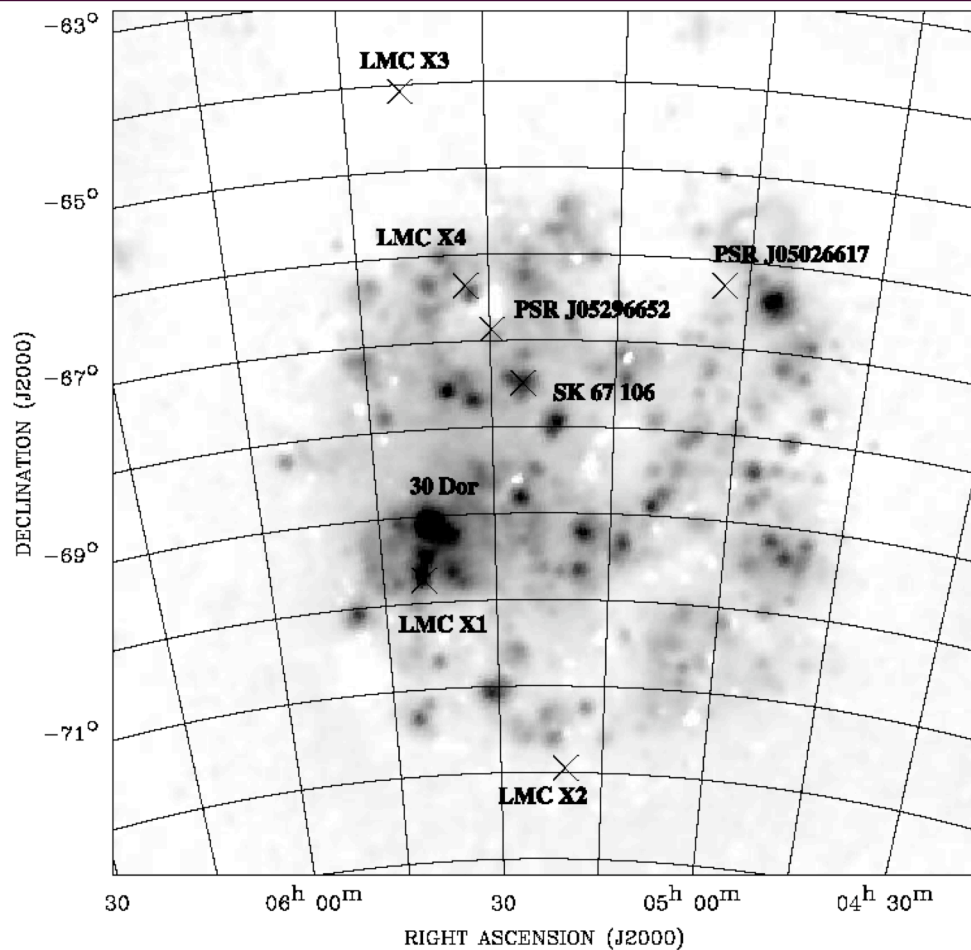
Wang, Yao, Tripp et al. (2005)



Reliable O VII detections: nearby gas

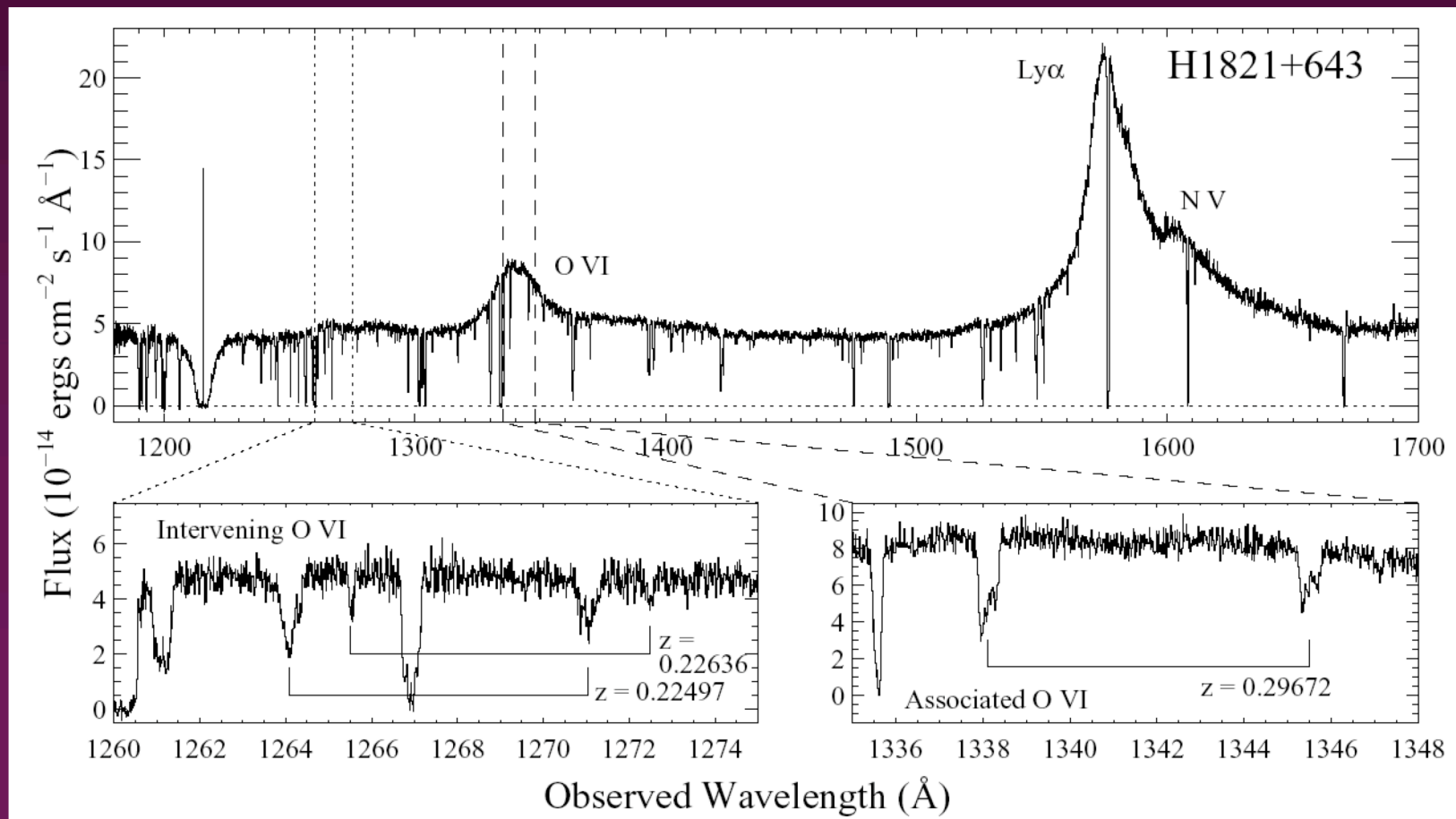
Wang, Yao, Tripp et al. (2005)

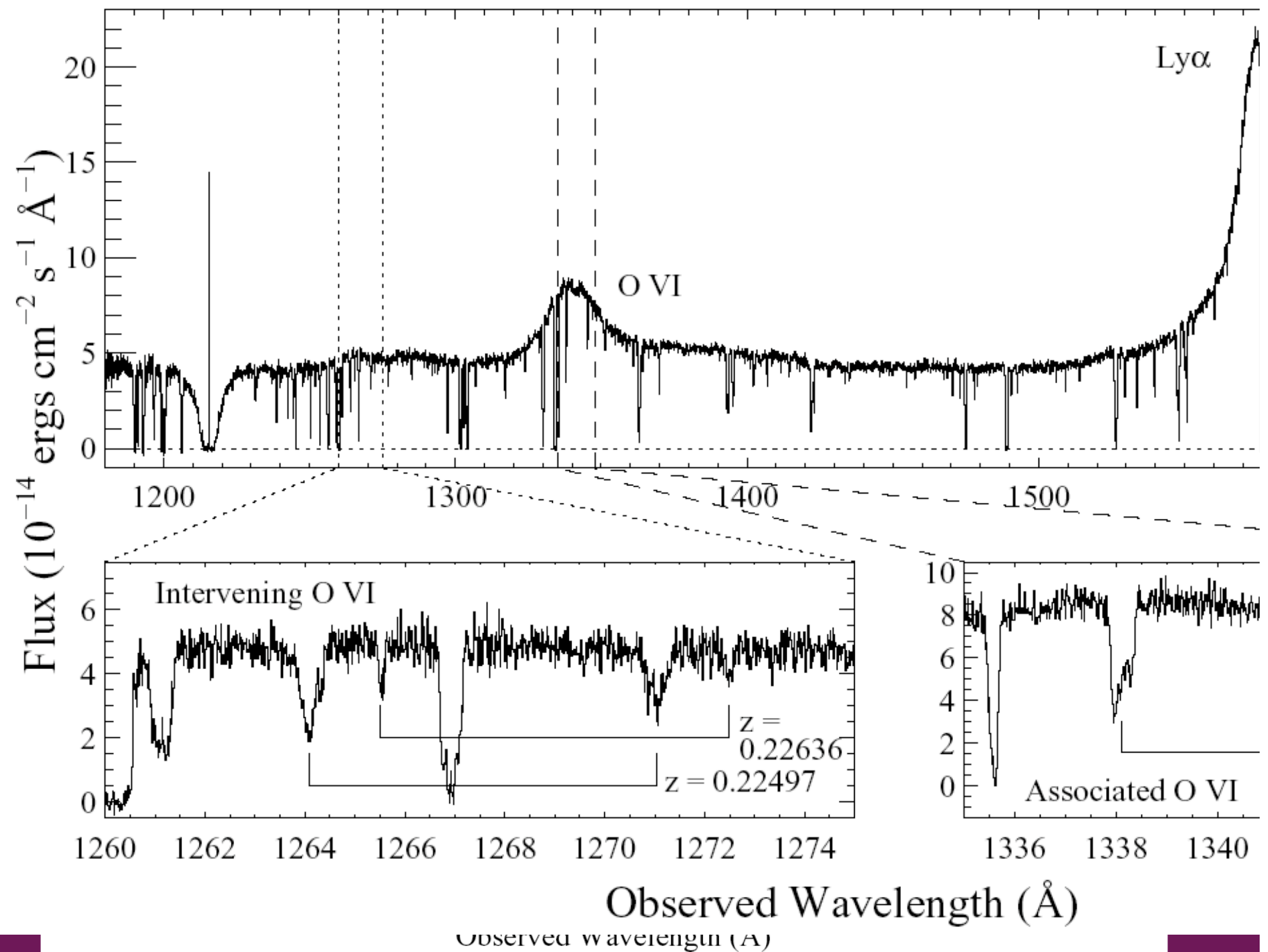
$$\log N(\text{O VII}) \approx 16.3$$



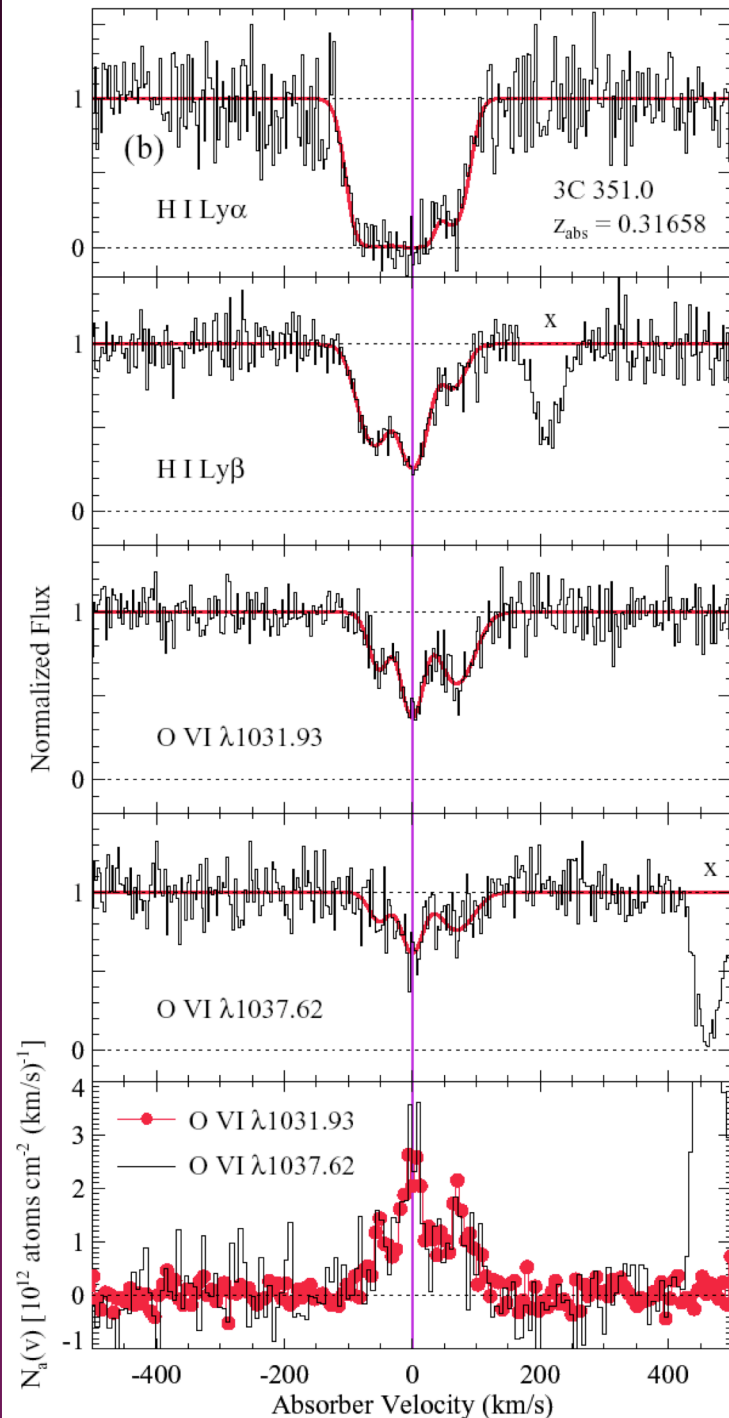
Low-Redshift QSO Absorption Lines: New Results on O VI Systems, the Warm-Hot IGM, and Feedback

Todd M. Tripp, University of Massachusetts





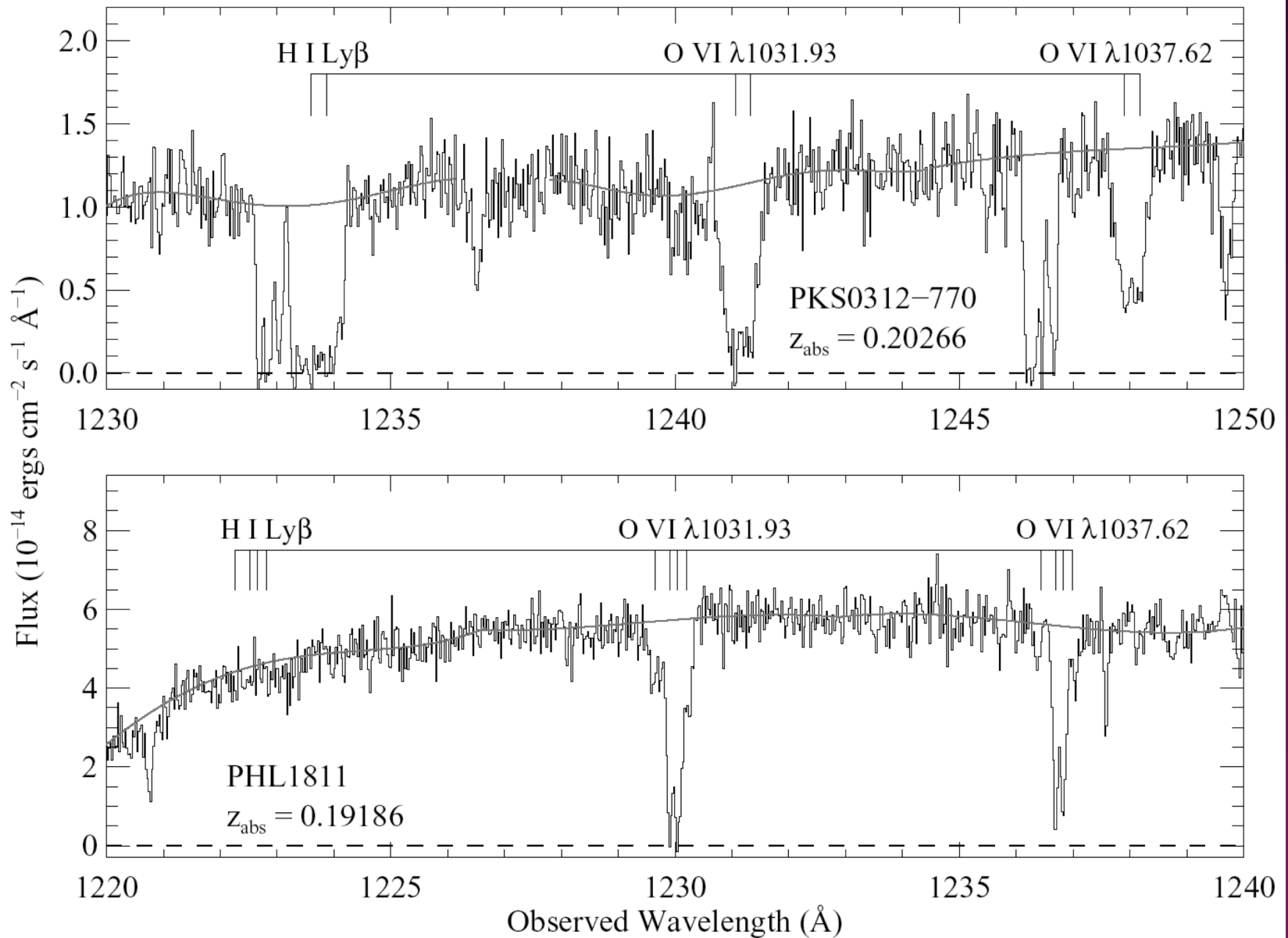
Two measurement techniques: Voigt-profile fitting and direct integration of apparent column densities



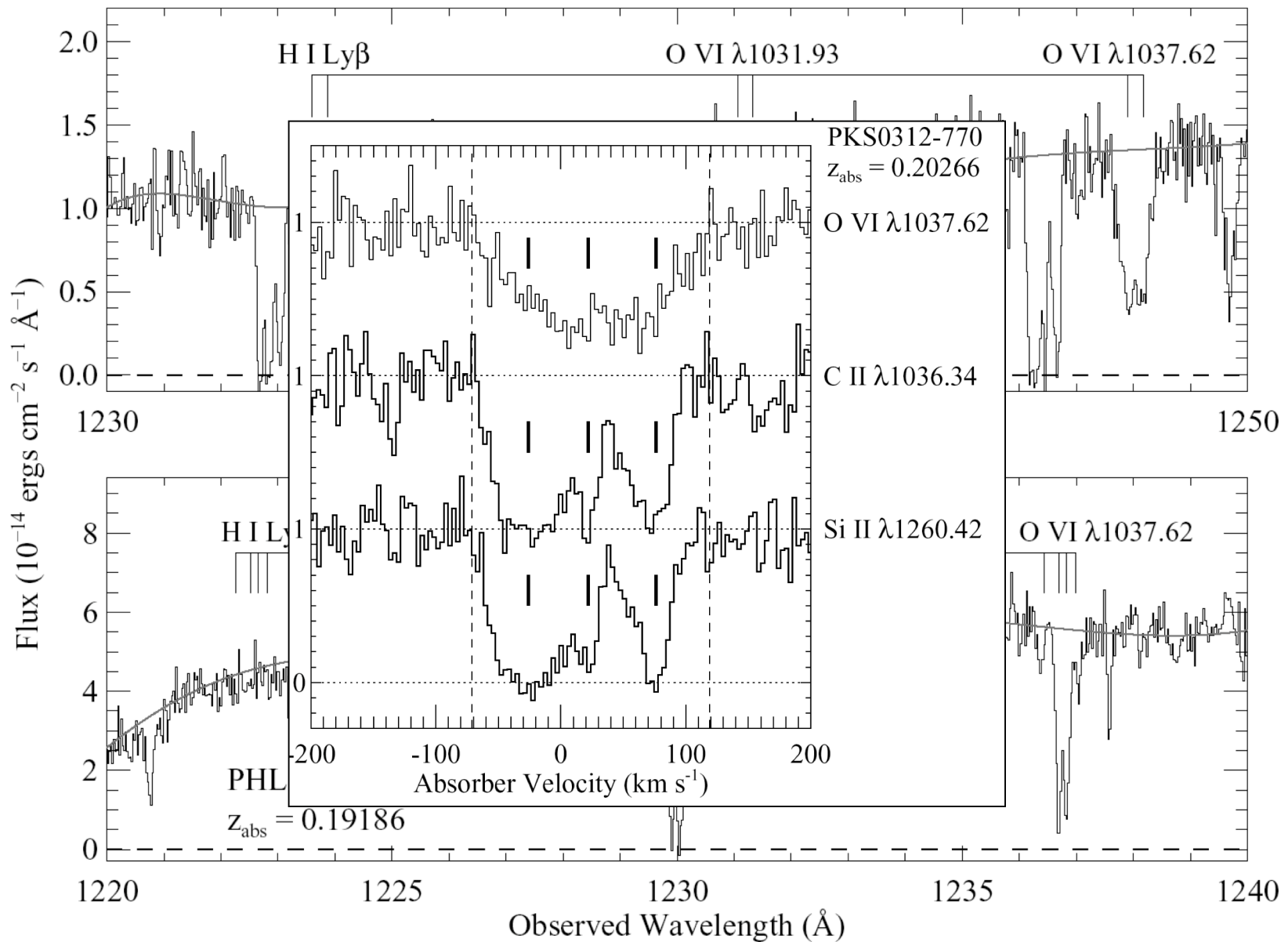
$$\tau_a(v) = \ln \left[\frac{I_c(v)}{I_{\text{ob}}(v)} \right]$$

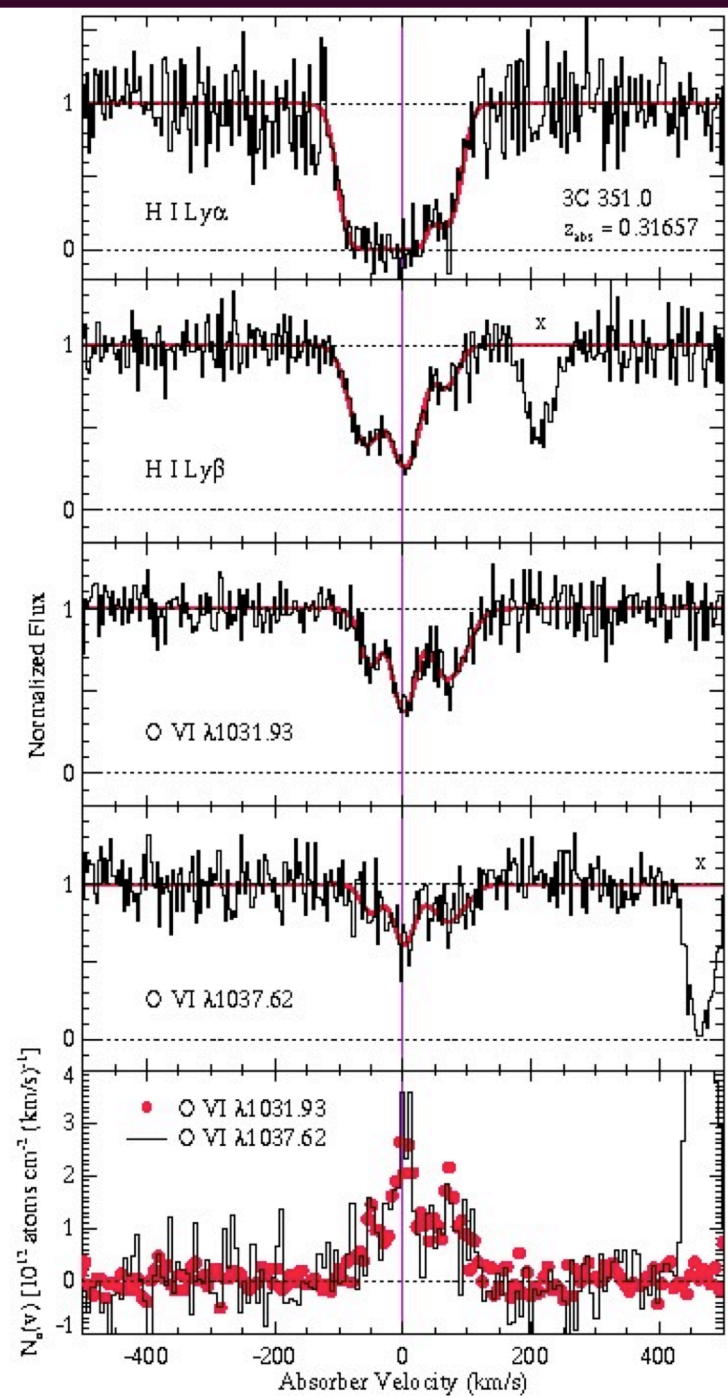
$$N_a(v) = \frac{m_e c}{\pi e^2} \frac{\tau_a(v)}{f \lambda} = 3.768 \times 10^{14} \frac{\tau_a(v)}{f \lambda}$$

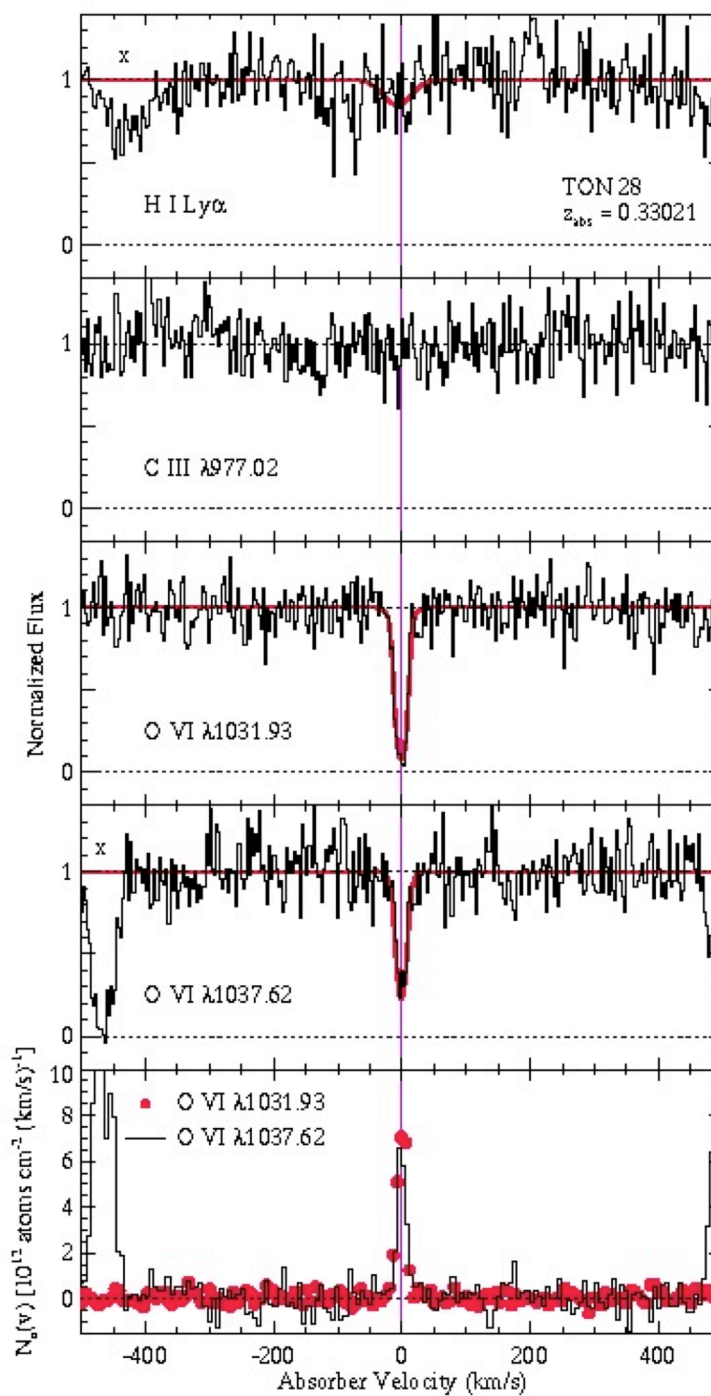
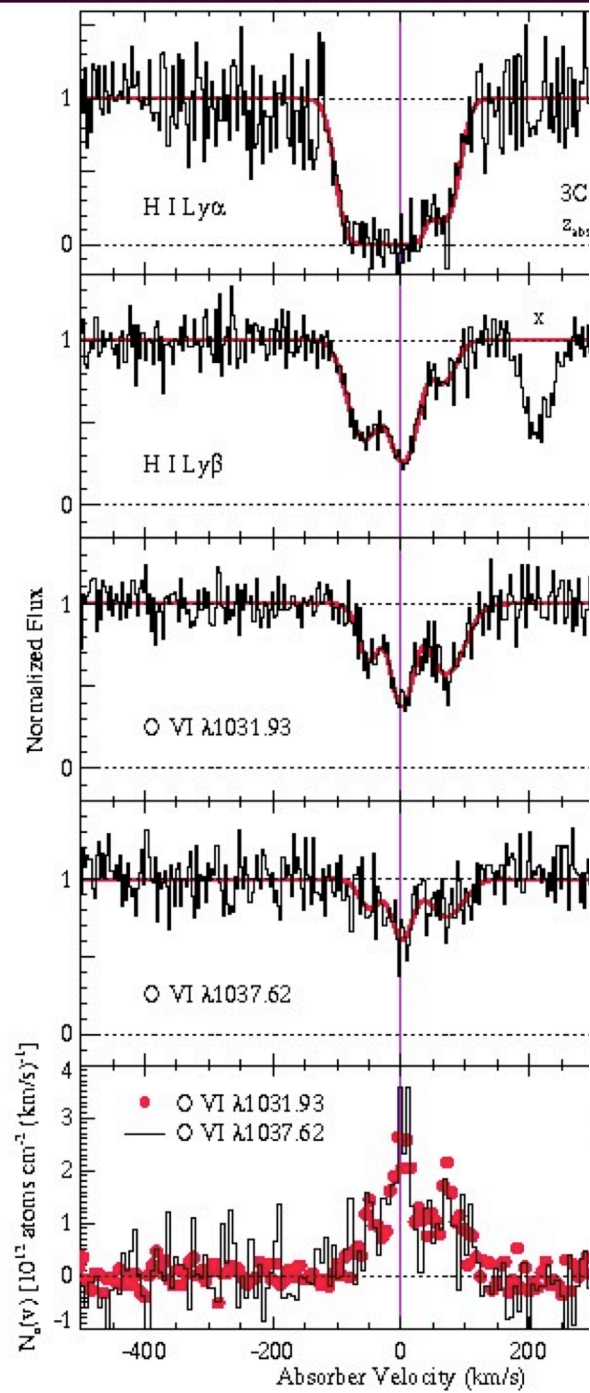
Multiphase O VI Absorbers

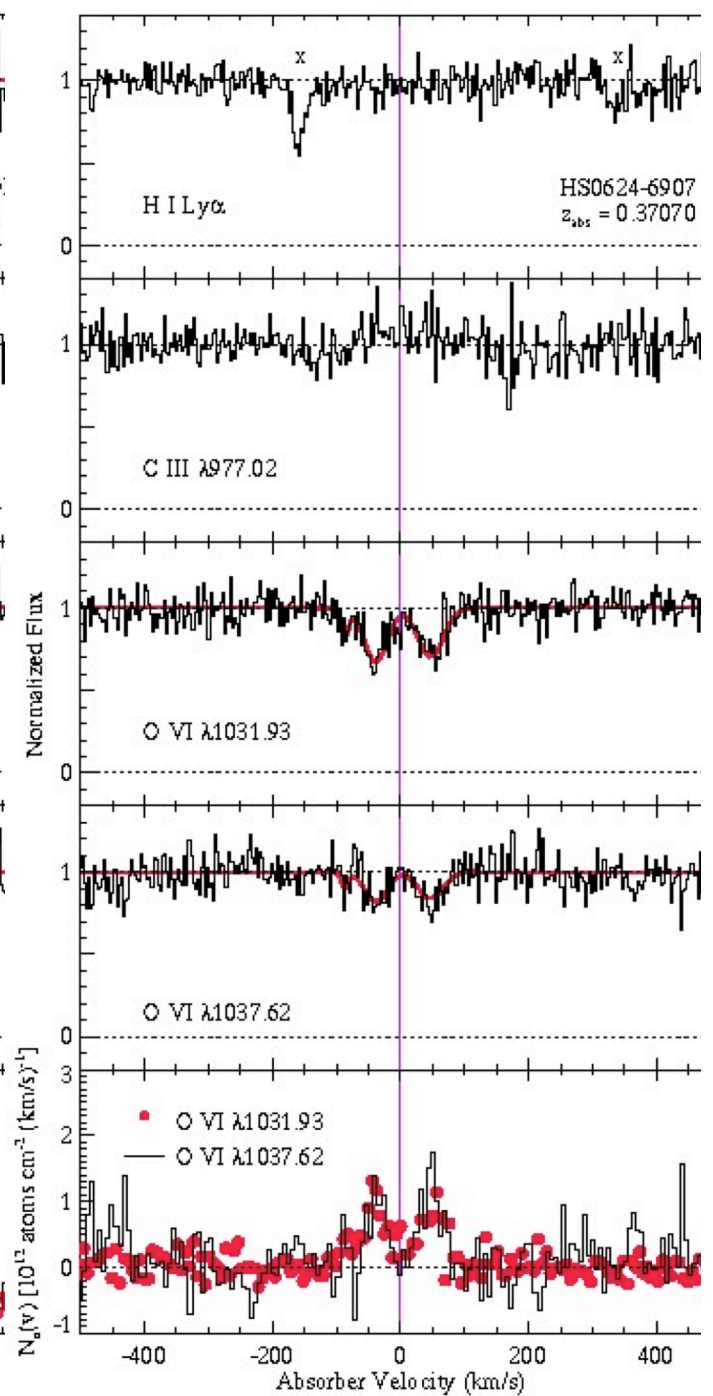
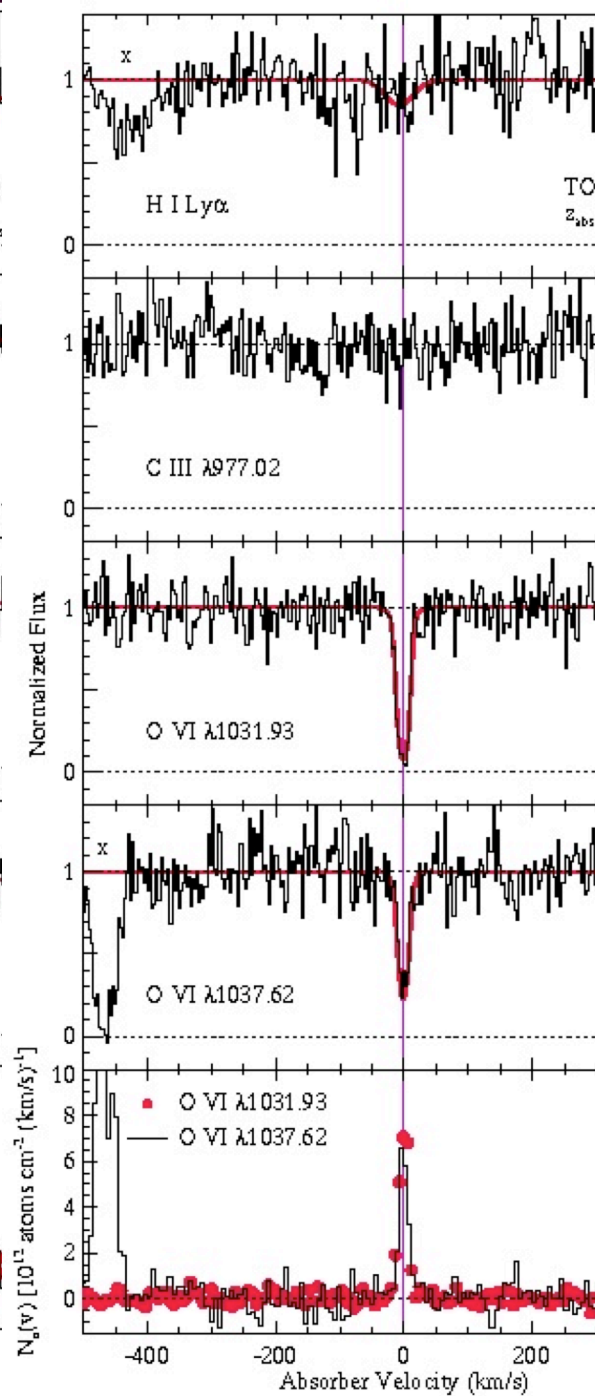
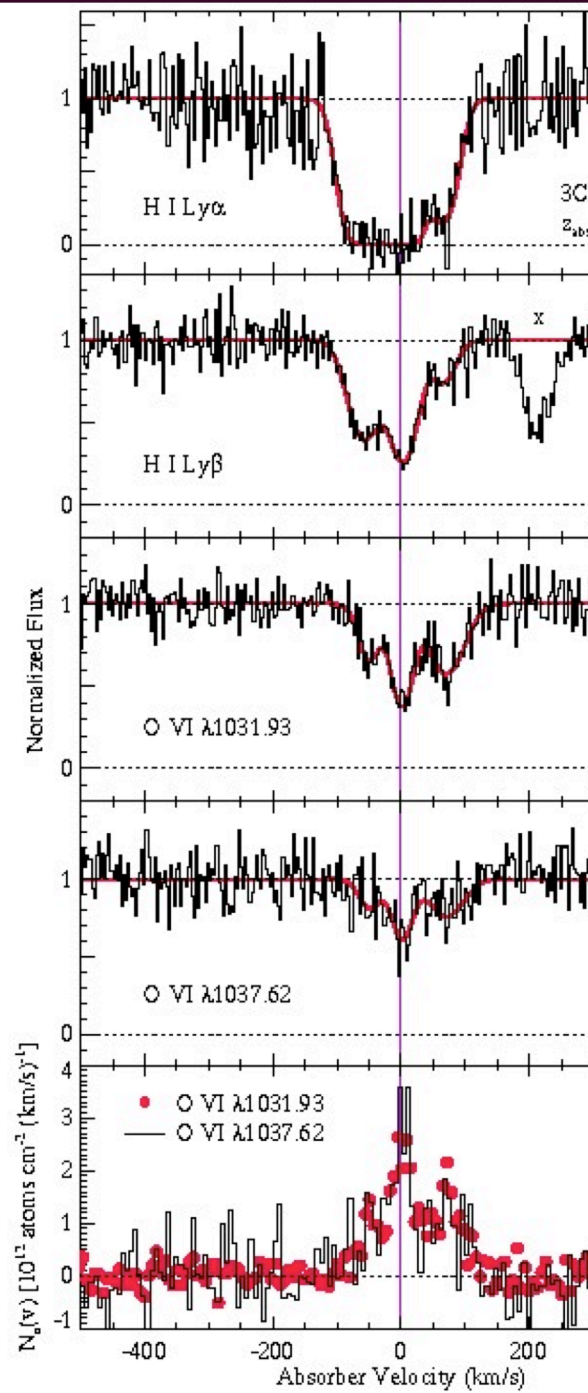


Multiphase O VI Absorbers

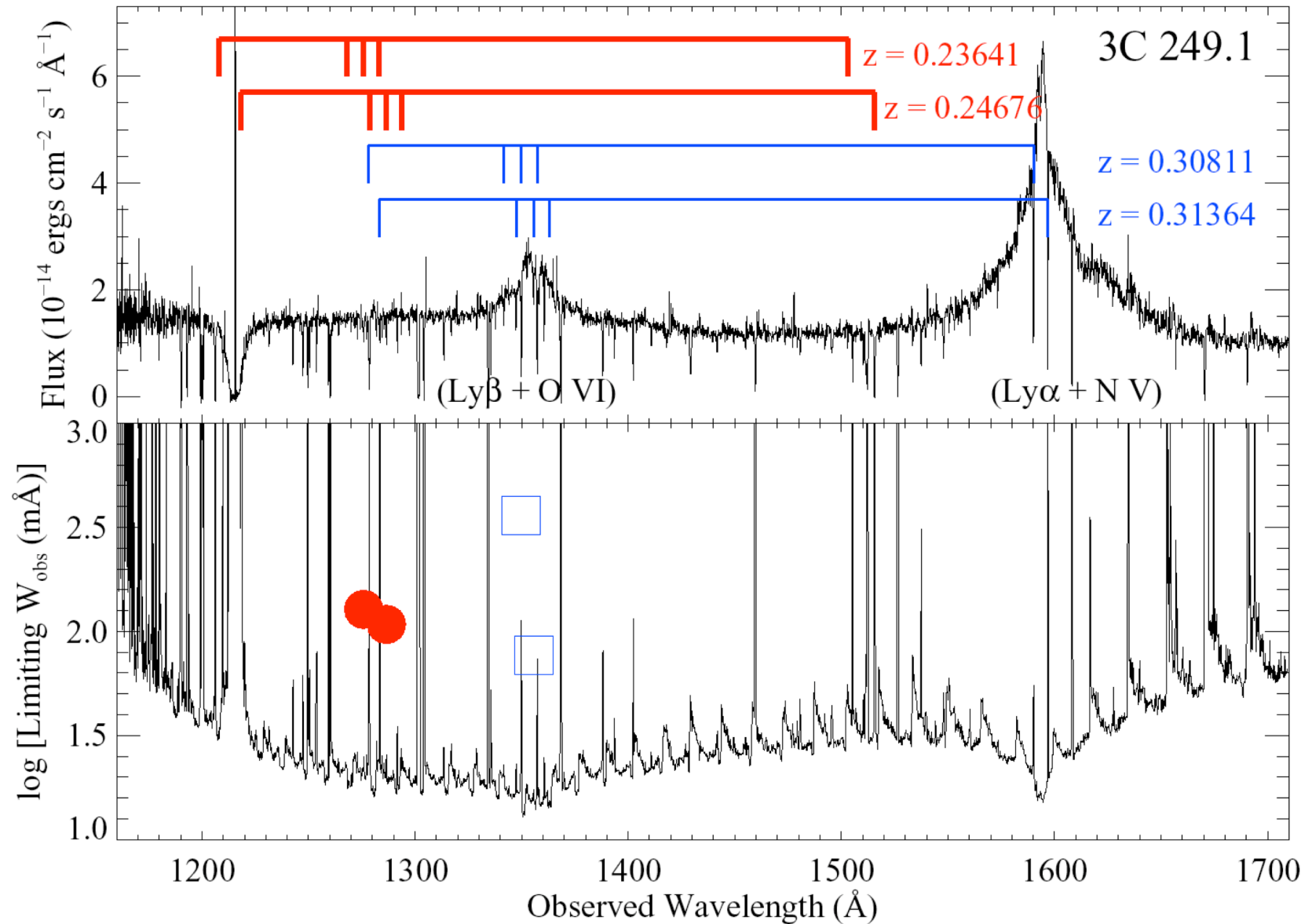








Intervening O VI dN/dz



Number of O VI Absorbers per Unit Redshift:

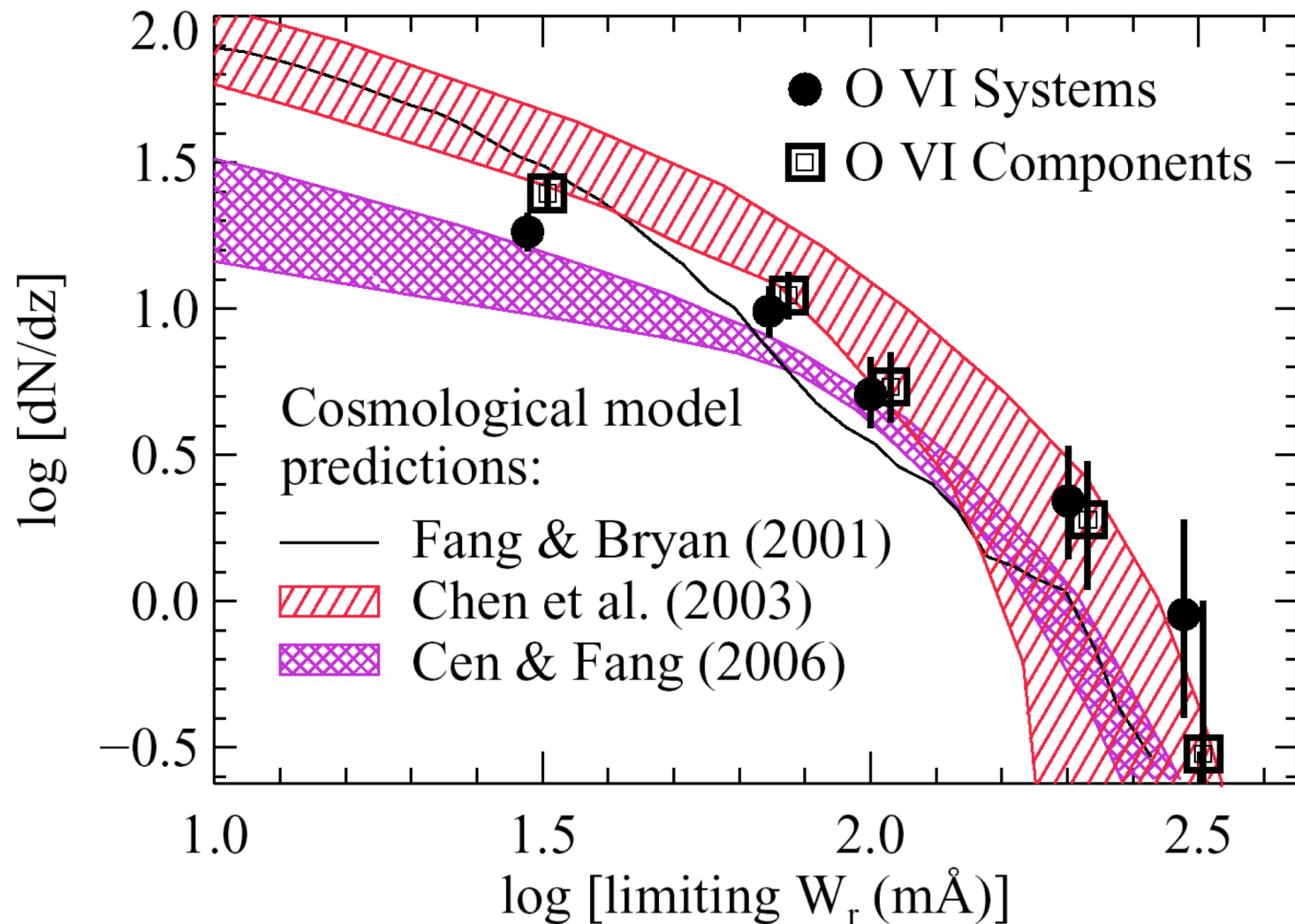
- Tripp et al. (2007): survey of extragalactic O VI absorbers in the spectra of 16 QSOs
- STIS echelle (E140M) and FUSE spectra
- 53 intervening O VI absorbers comprised of 78 individual components(excluding systems within 5000 km/s of the QSO redshift)
- 14 associated O VI systems (34 components)
- Absorber redshifts range from 0.002 to 0.495

Number of O VI Absorbers per Unit Redshift:

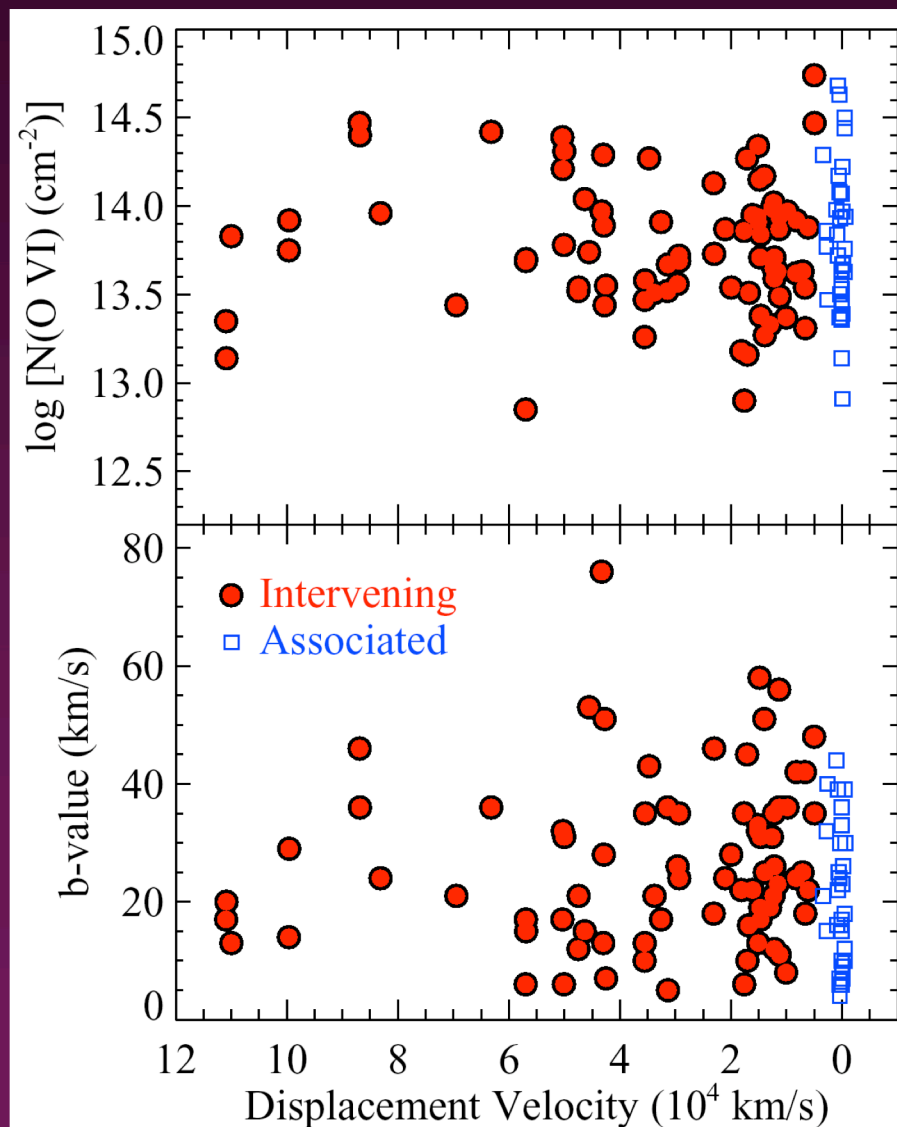
Table 4. Intervening O VI Absorbers: Number per Redshift Interval

Limiting W_r (mÅ) (1)	Number of O VI Systems (2)	Total Δz (3)	dN/dz (Systems) (4)	dN/dz (Components) (5)
30	48	2.623	$18.3^{+3.0}_{-2.6}$	$24.8^{+3.5}_{-3.1}$
70	30	3.063	$9.8^{+2.1}_{-1.8}$	$11.1^{+2.2}_{-1.9}$
100	16	3.121	$5.1^{+1.7}_{-1.2}$	$5.4^{+1.7}_{-1.3}$
200	7	3.177	$2.2^{+1.2}_{-0.8}$	$1.9^{+1.1}_{-0.8}$
300	3	3.179	$0.9^{+1.0}_{-0.5}$	$0.3^{+0.7}_{-0.3}$

Number of O VI Absorbers per Unit Redshift:

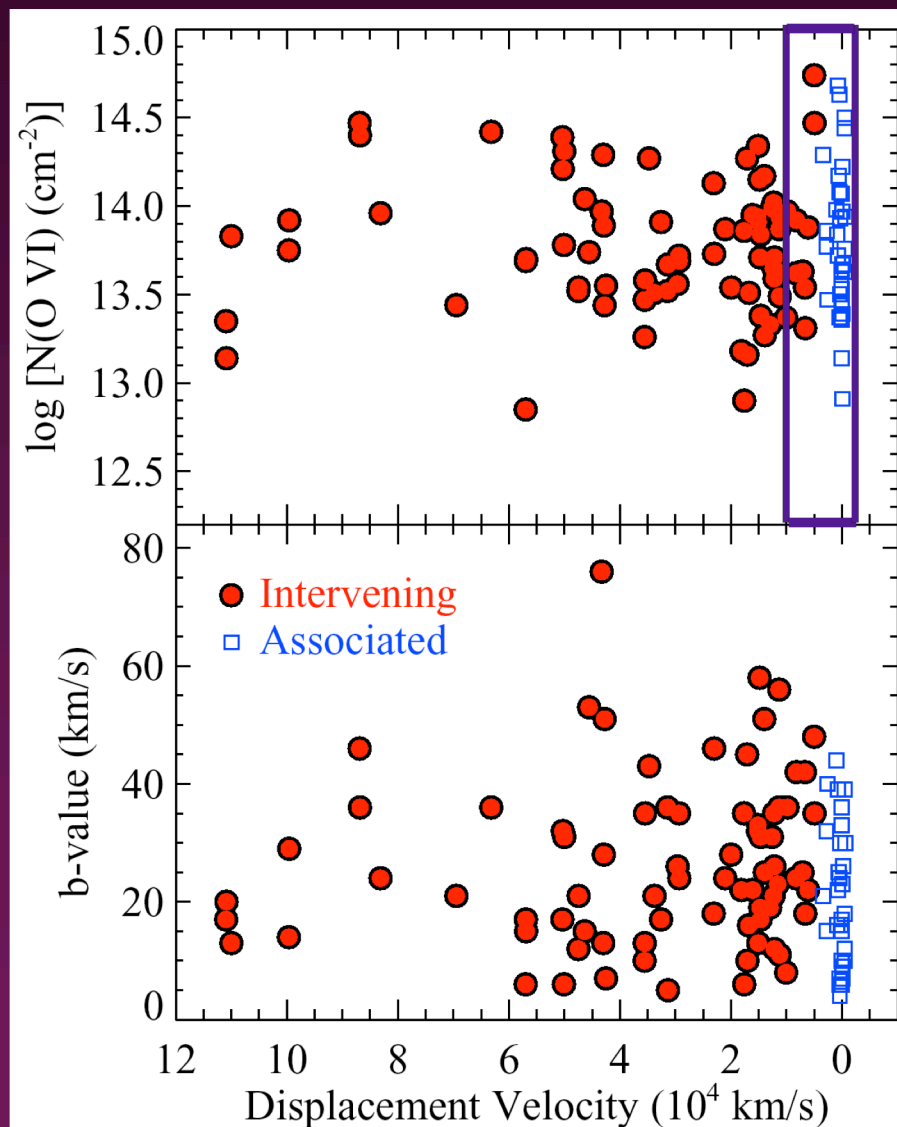


Intervening vs. Associated Absorbers



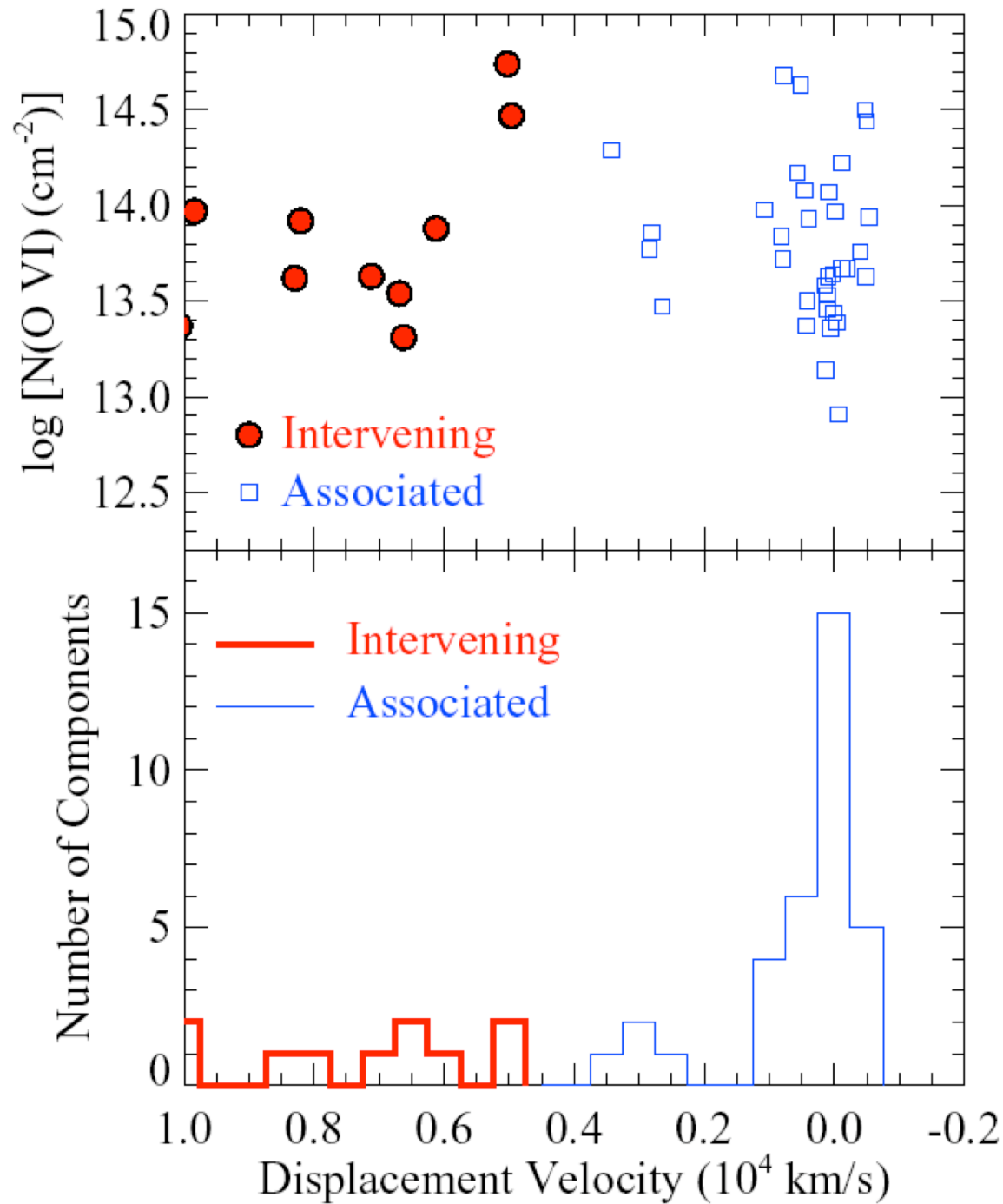
$$\beta = \frac{v_{\text{displ}}}{c} = \frac{(1 + z_{\text{QSO}})^2 - (1 + z_{\text{abs}})}{(1 + z_{\text{QSO}})^2 + (1 + z_{\text{abs}})}$$

Intervening vs. Associated Absorbers



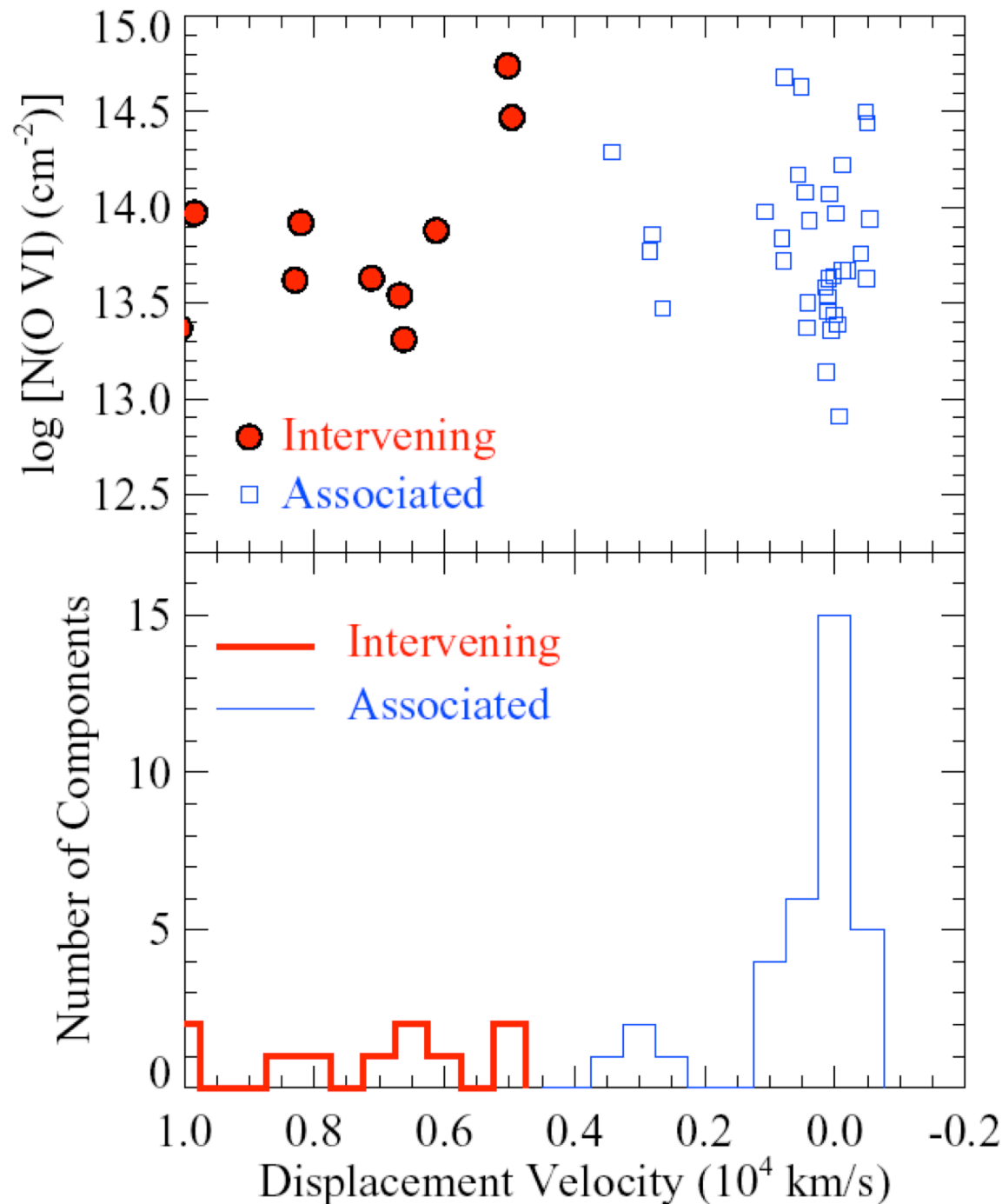
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ed Absorbers



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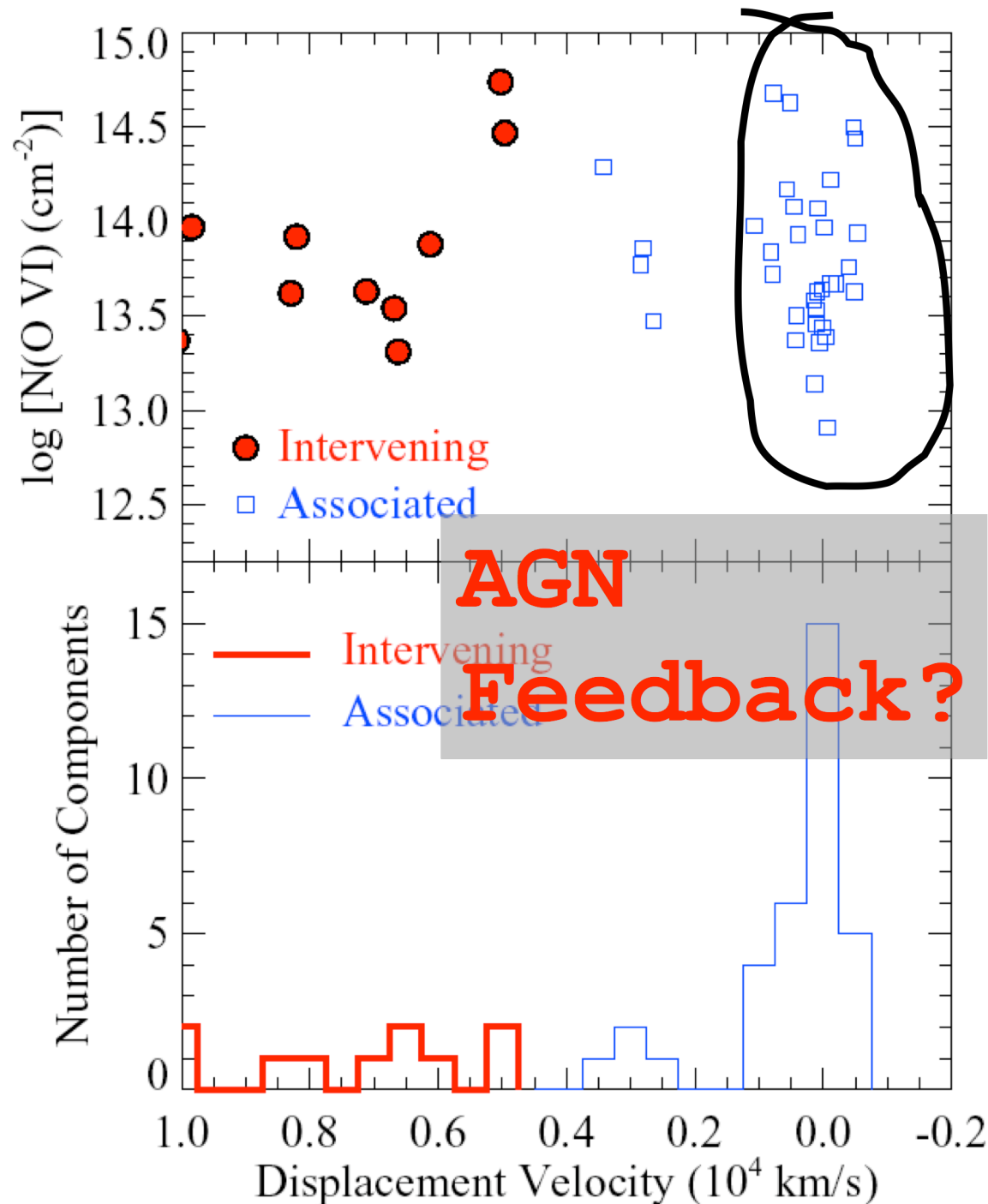
Associated Absorbers



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- For associated absorbers with $v_{\text{displ}} < 2500 \text{ km/s}$, dN/dz is 3 to 10 times higher than in intervening systems

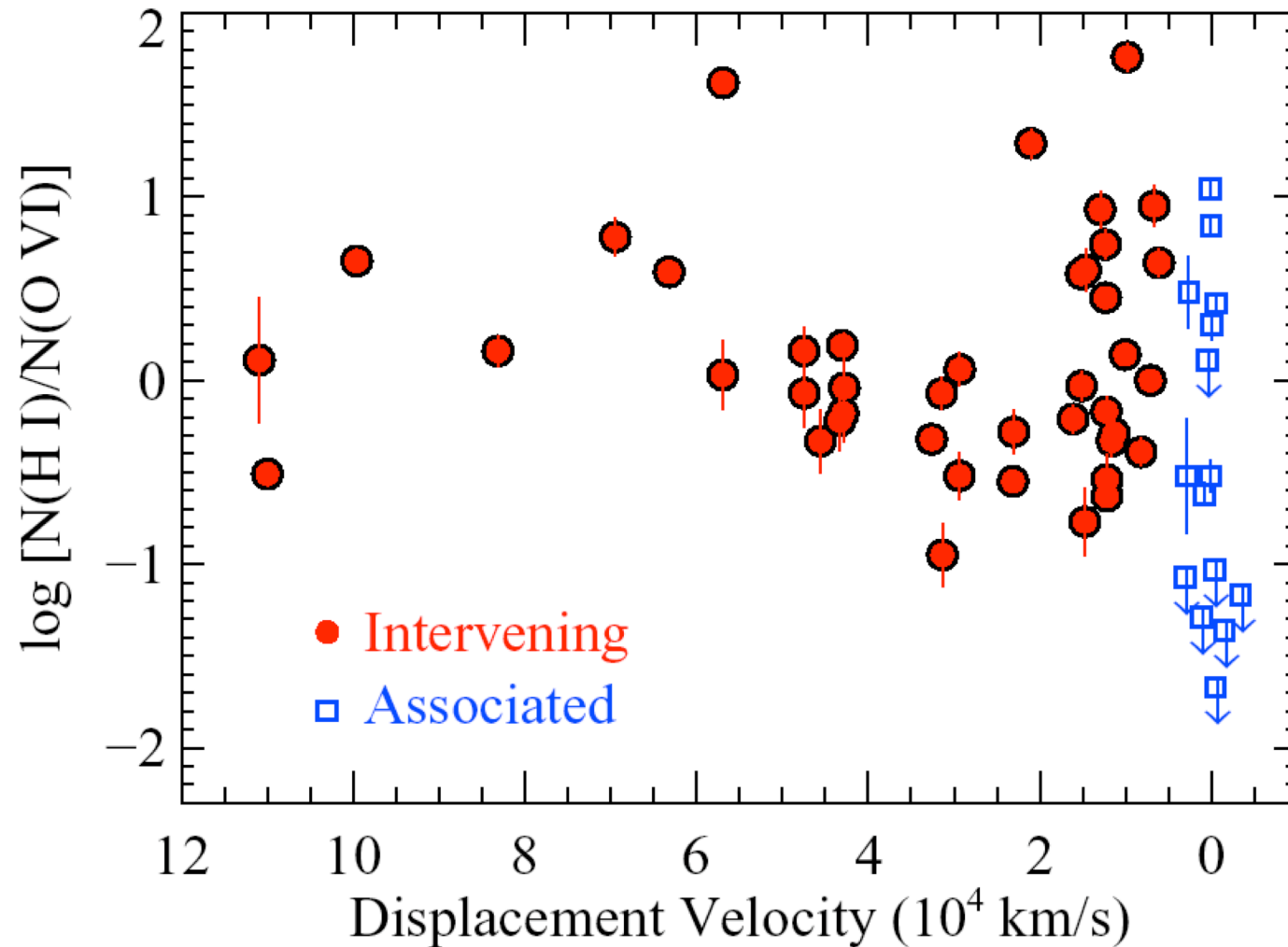
Associated Absorbers



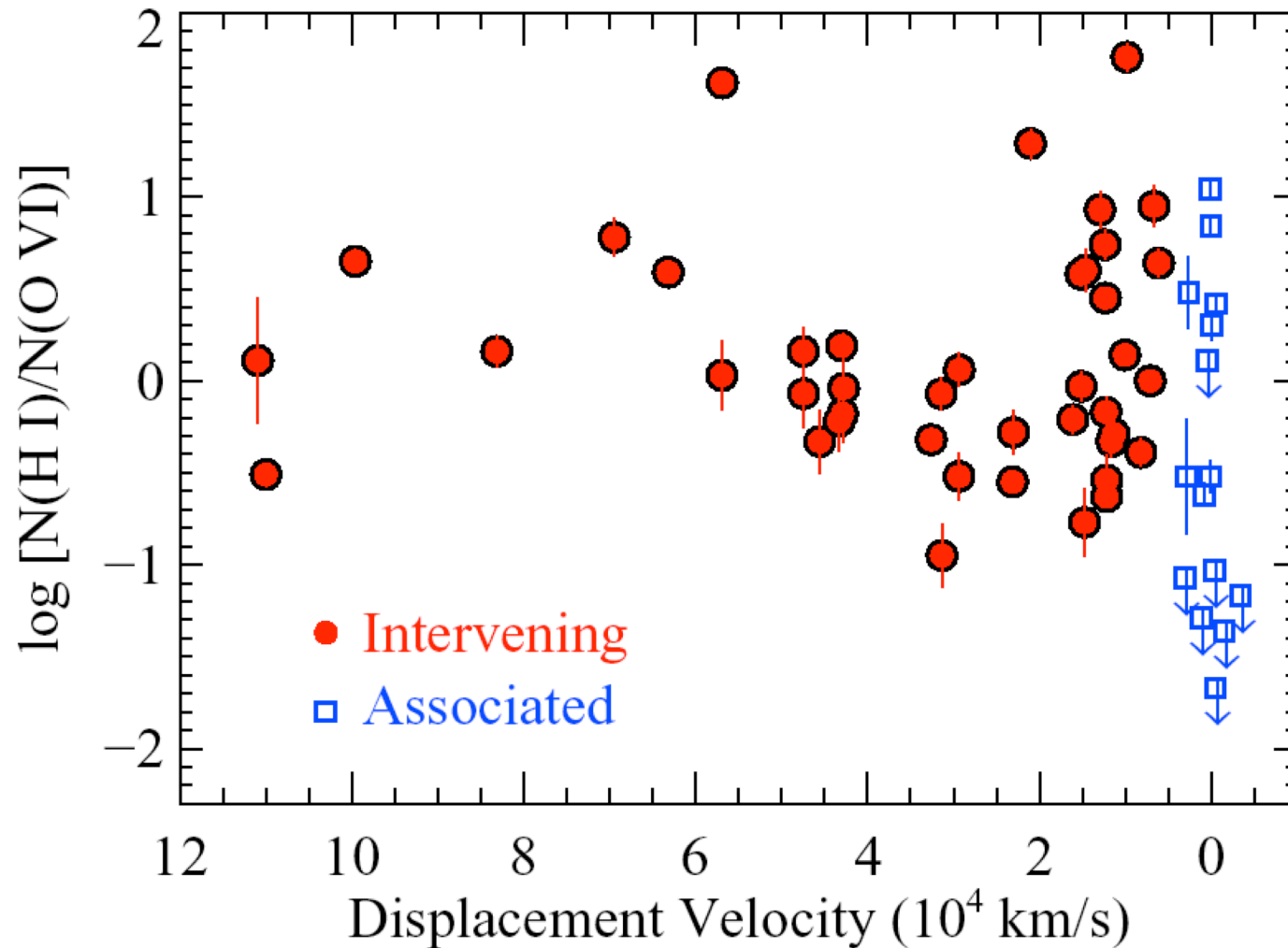
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Some associated systems have low H I/O VI ratios:

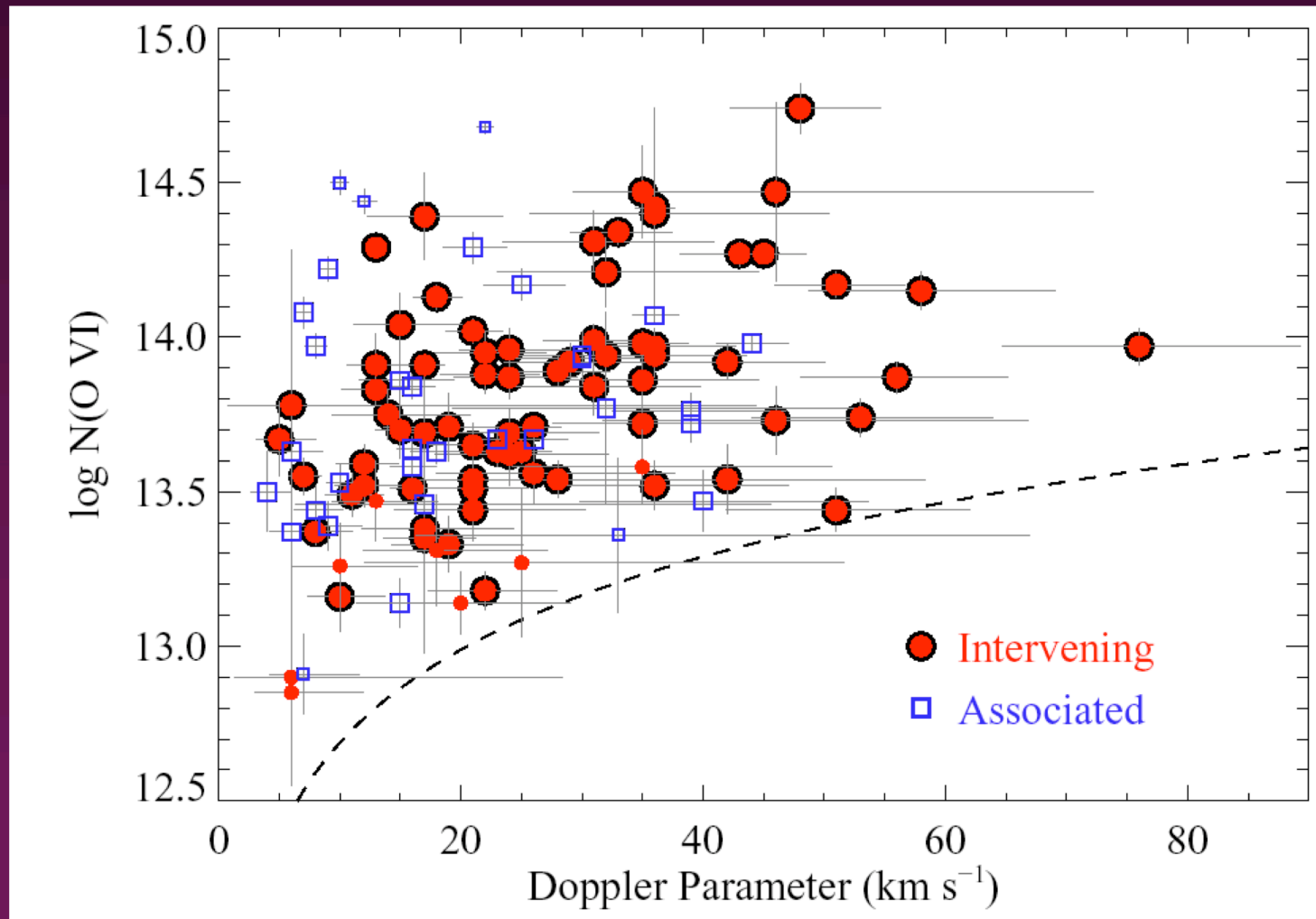


Question 1 for Joop:
Not ejected/intrinsic absorbers?

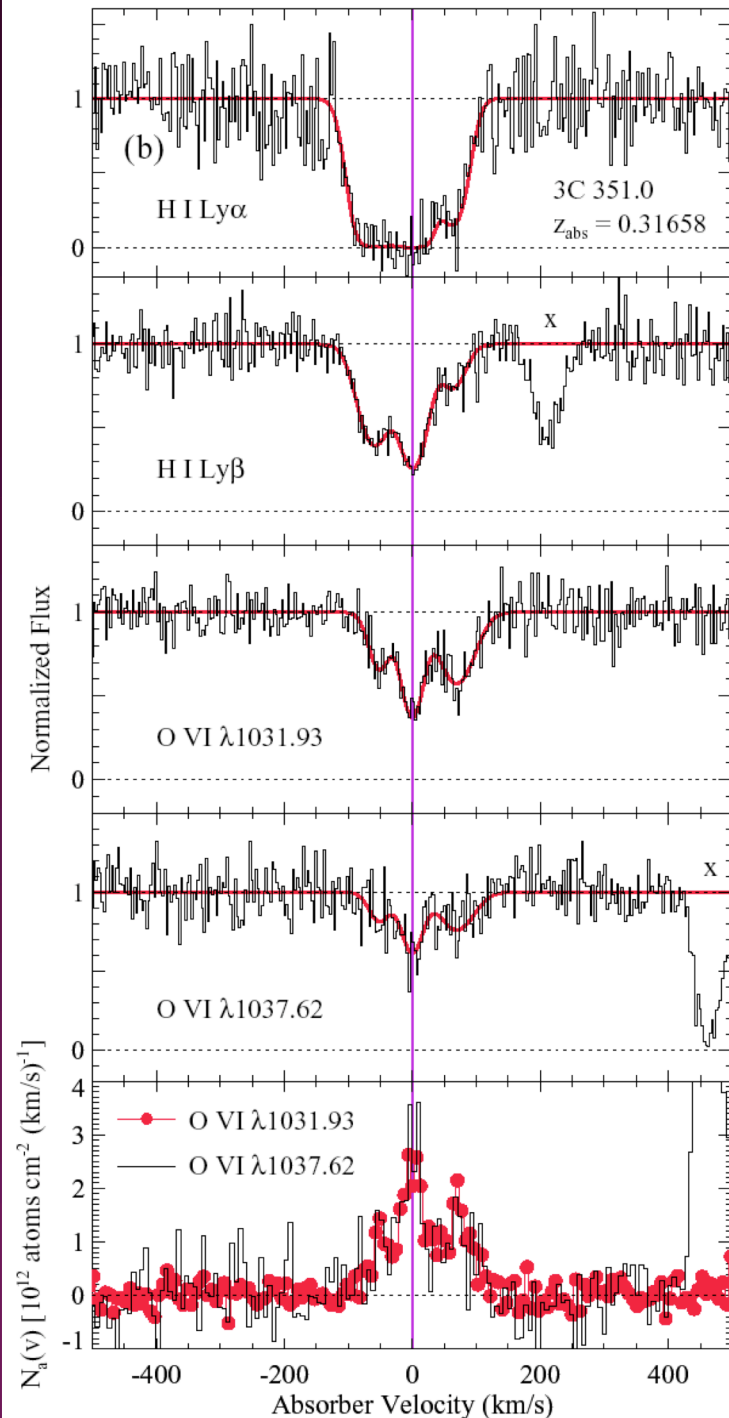


Correlation of N(O VI) with b(O VI)?

Not obvious.



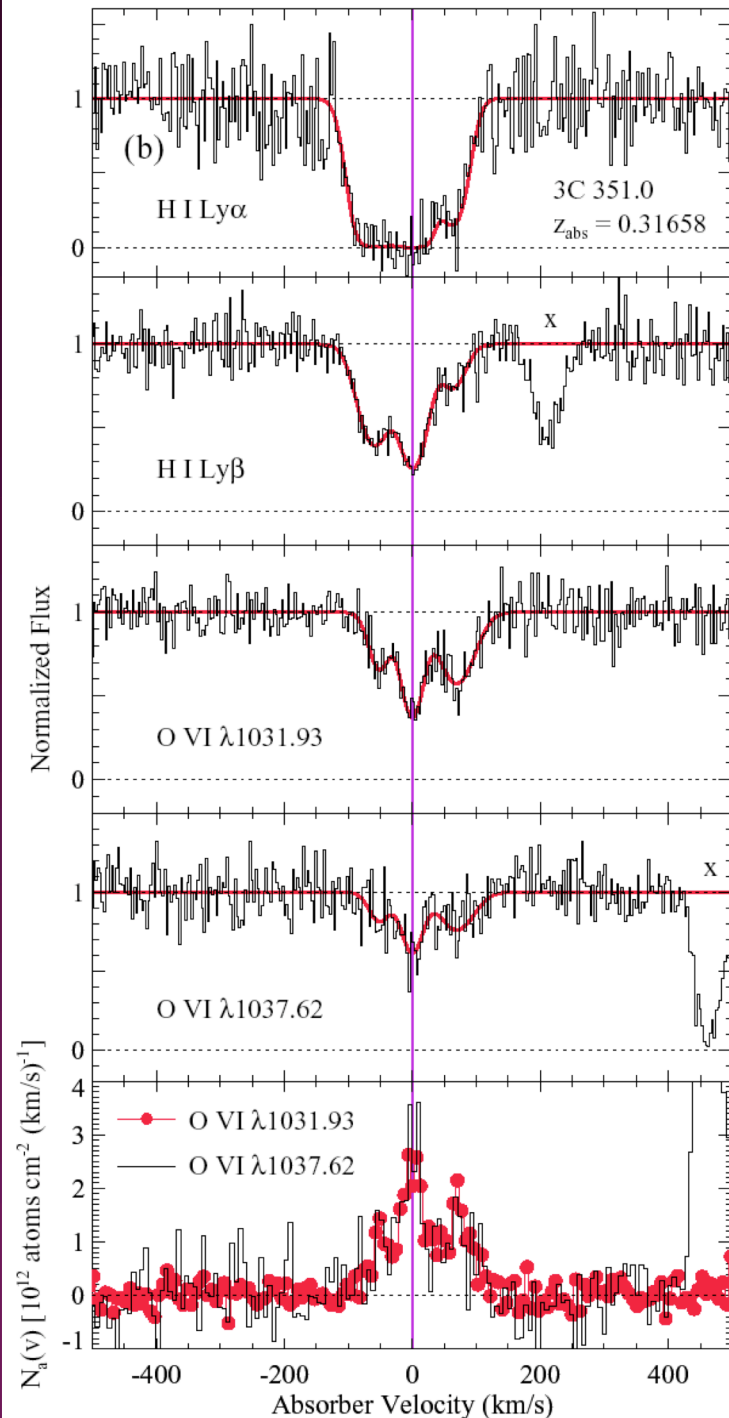
Line widths: an important clue



$$\tau_a(v) = \ln \left[\frac{I_c(v)}{I_{\text{ob}}(v)} \right]$$

$$N_a(v) = \frac{m_e c}{\pi e^2} \frac{\tau_a(v)}{f \lambda} = 3.768 \times 10^{14} \frac{\tau_a(v)}{f \lambda}$$

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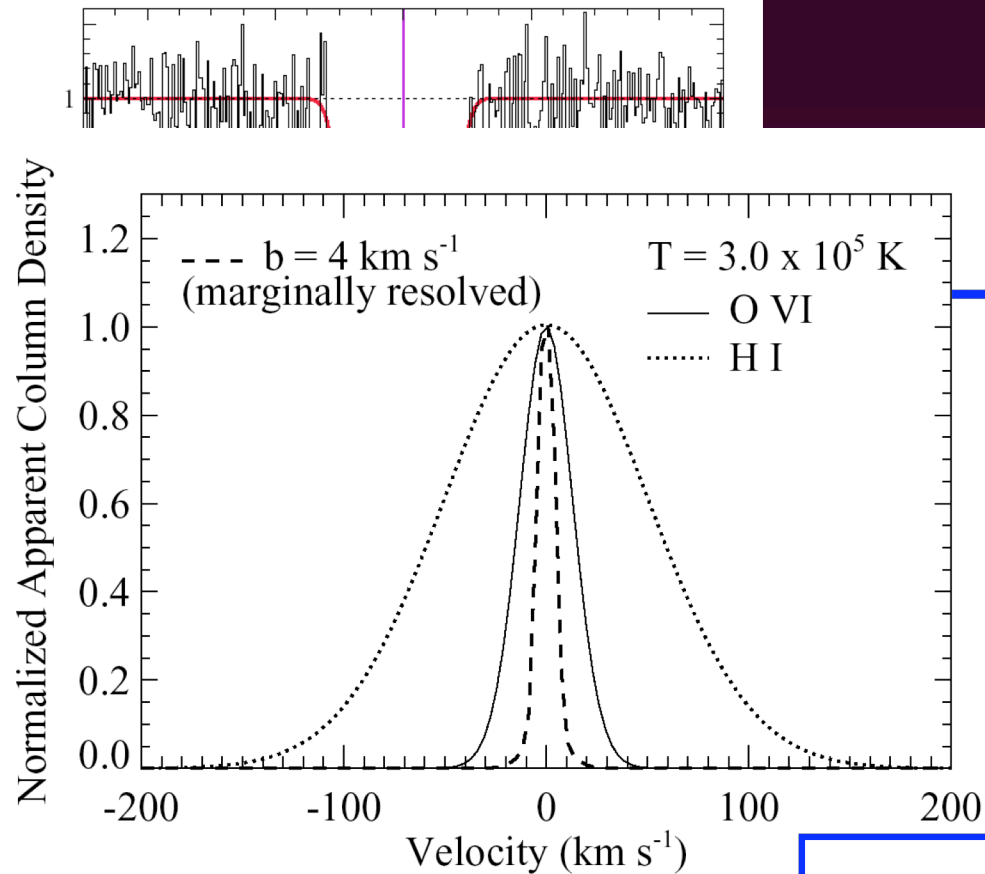


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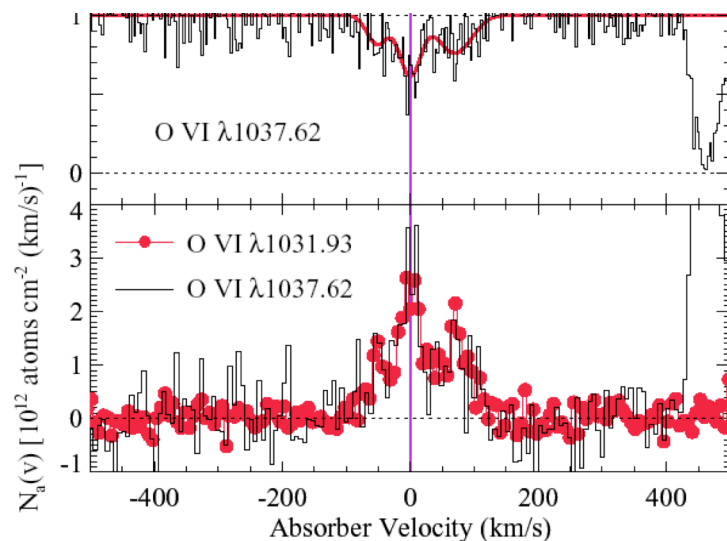
$$T = \frac{mb^2}{2k} = A \left(\frac{b}{0.129} \right)^2$$

Line widths: an important clue



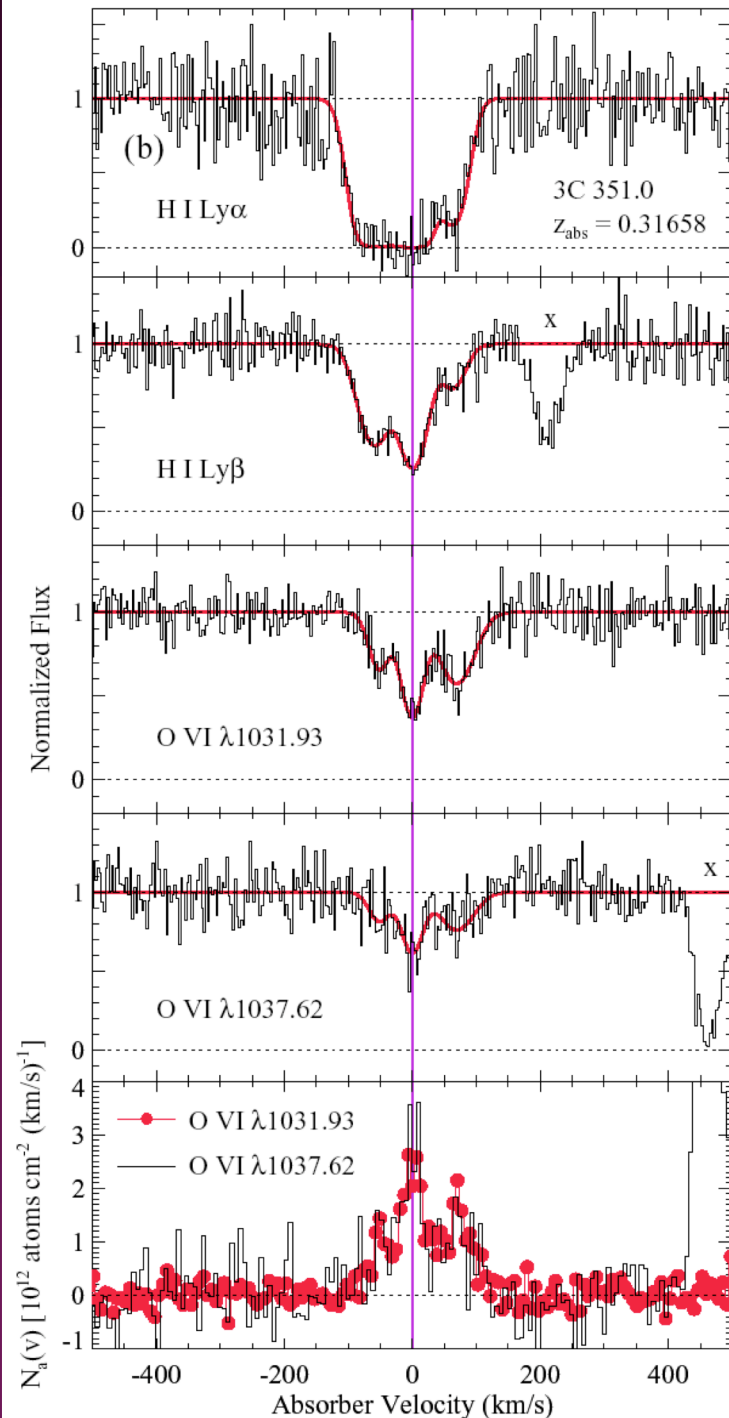
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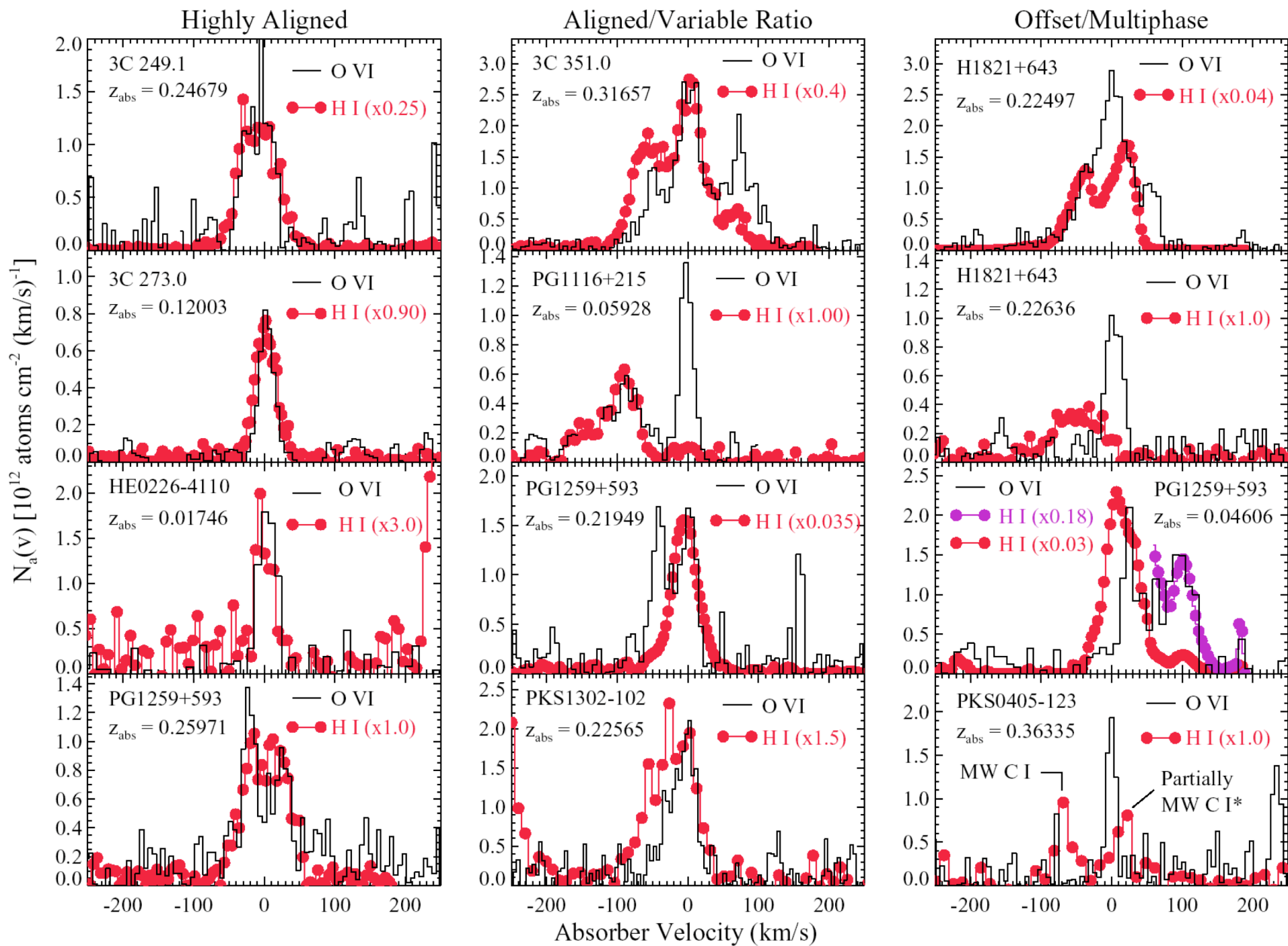
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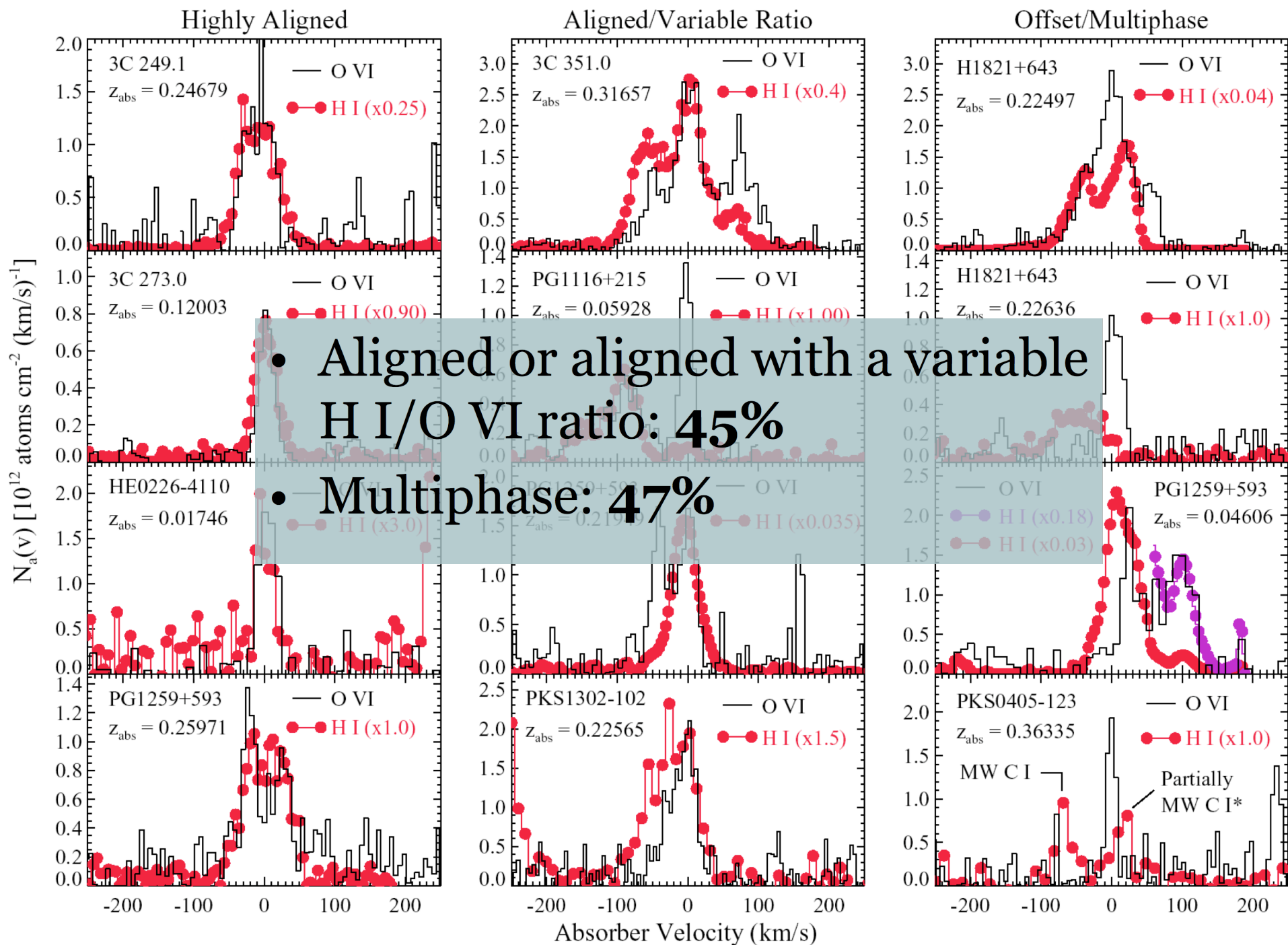


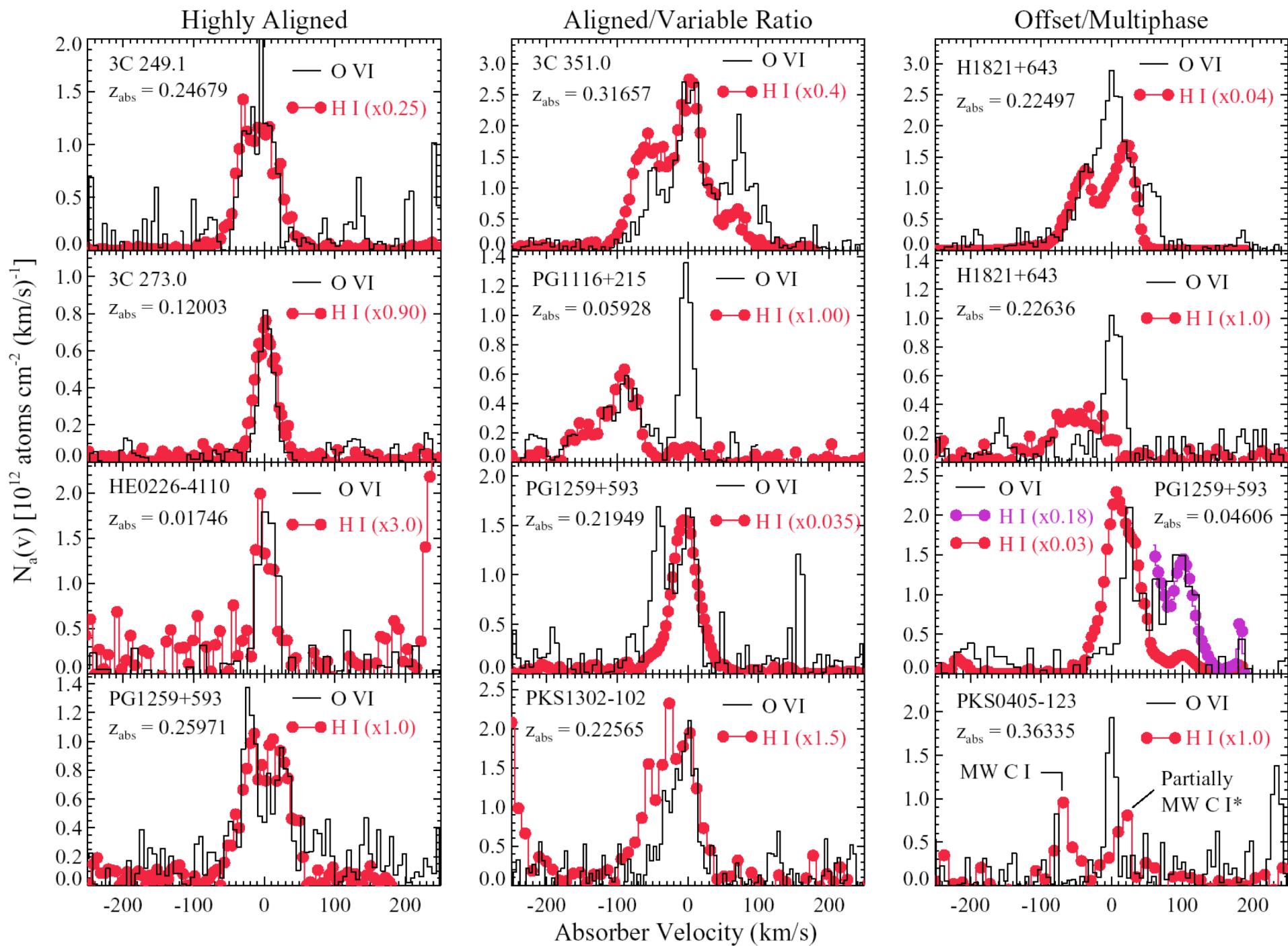
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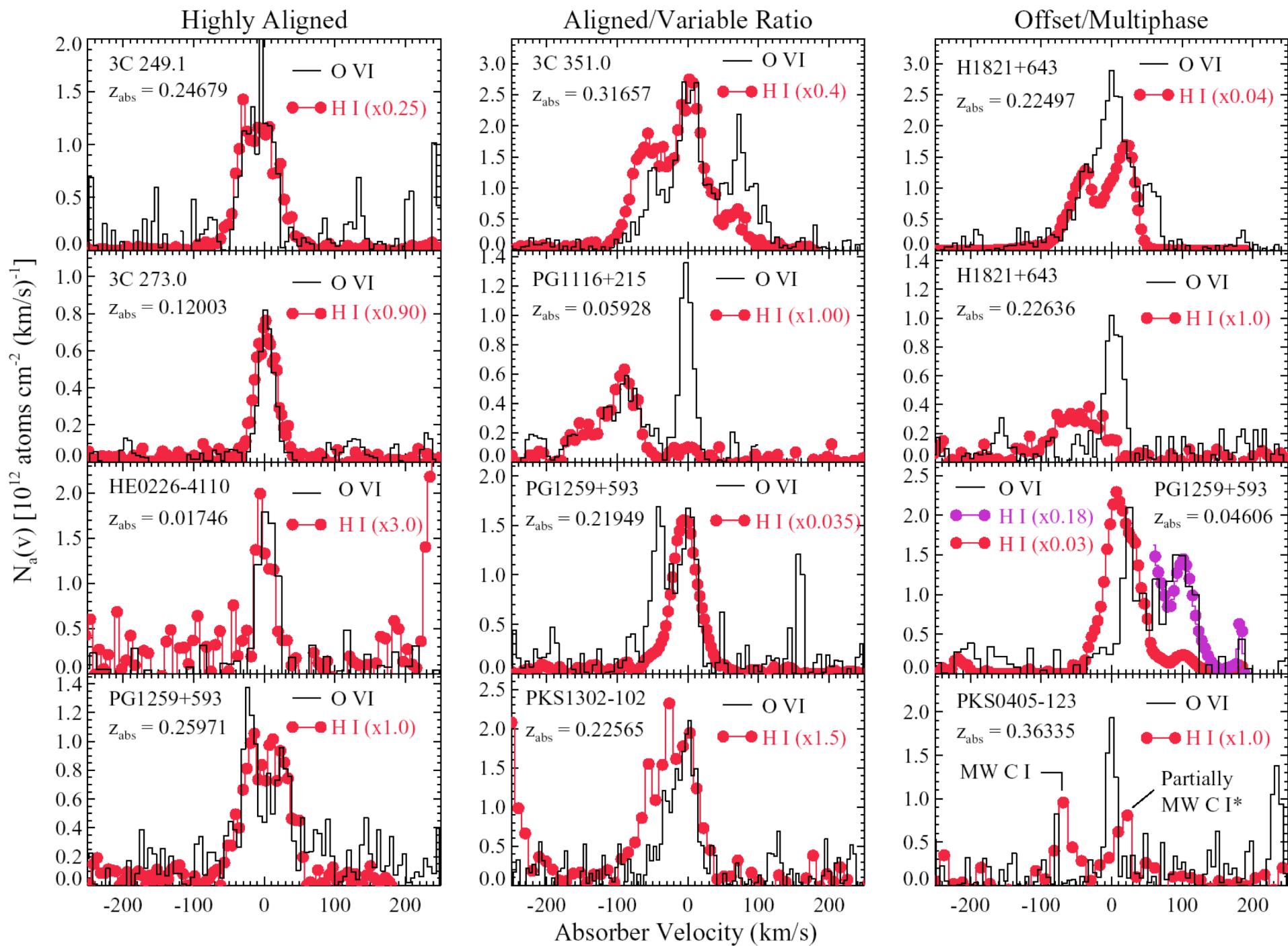
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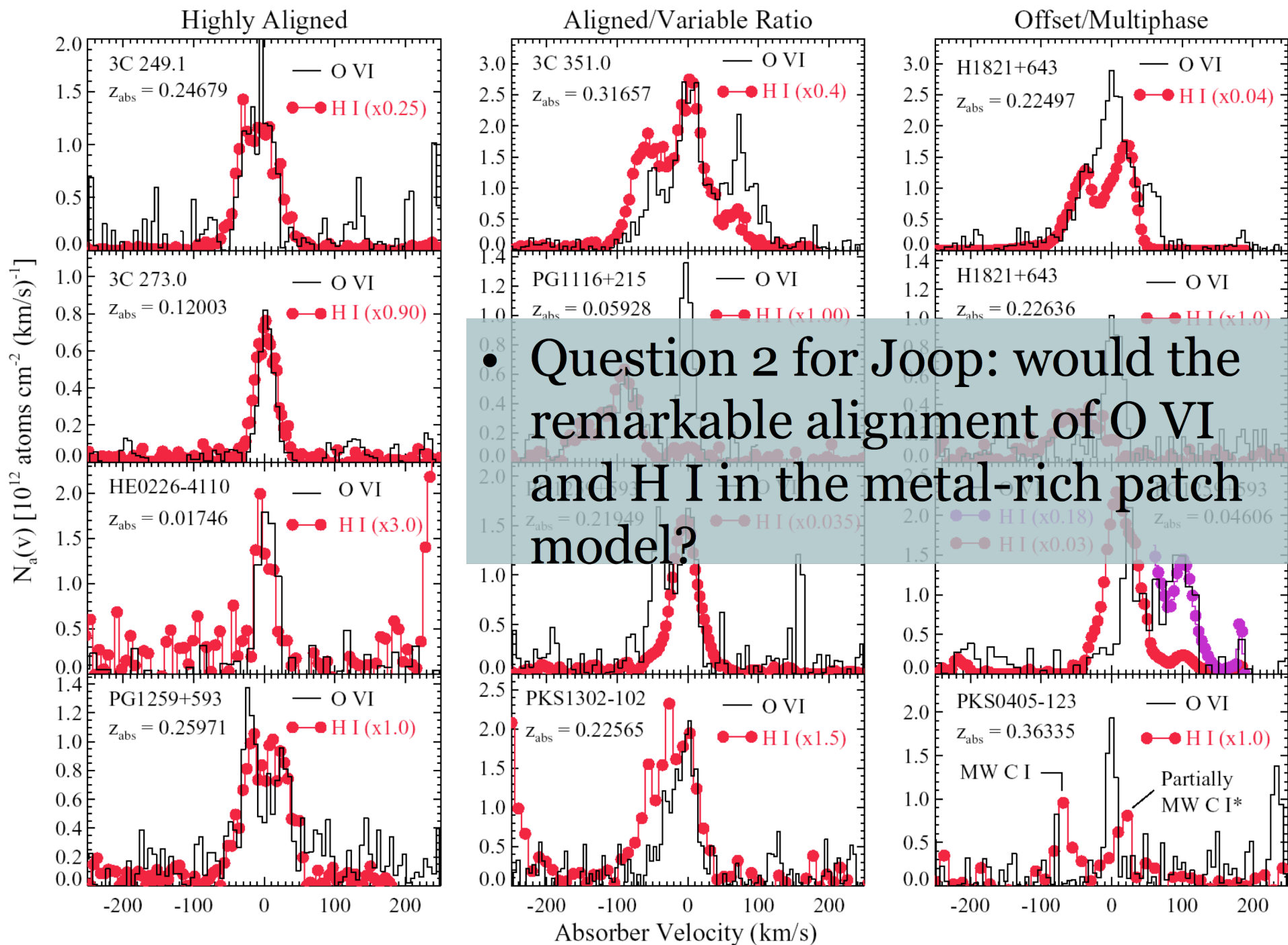
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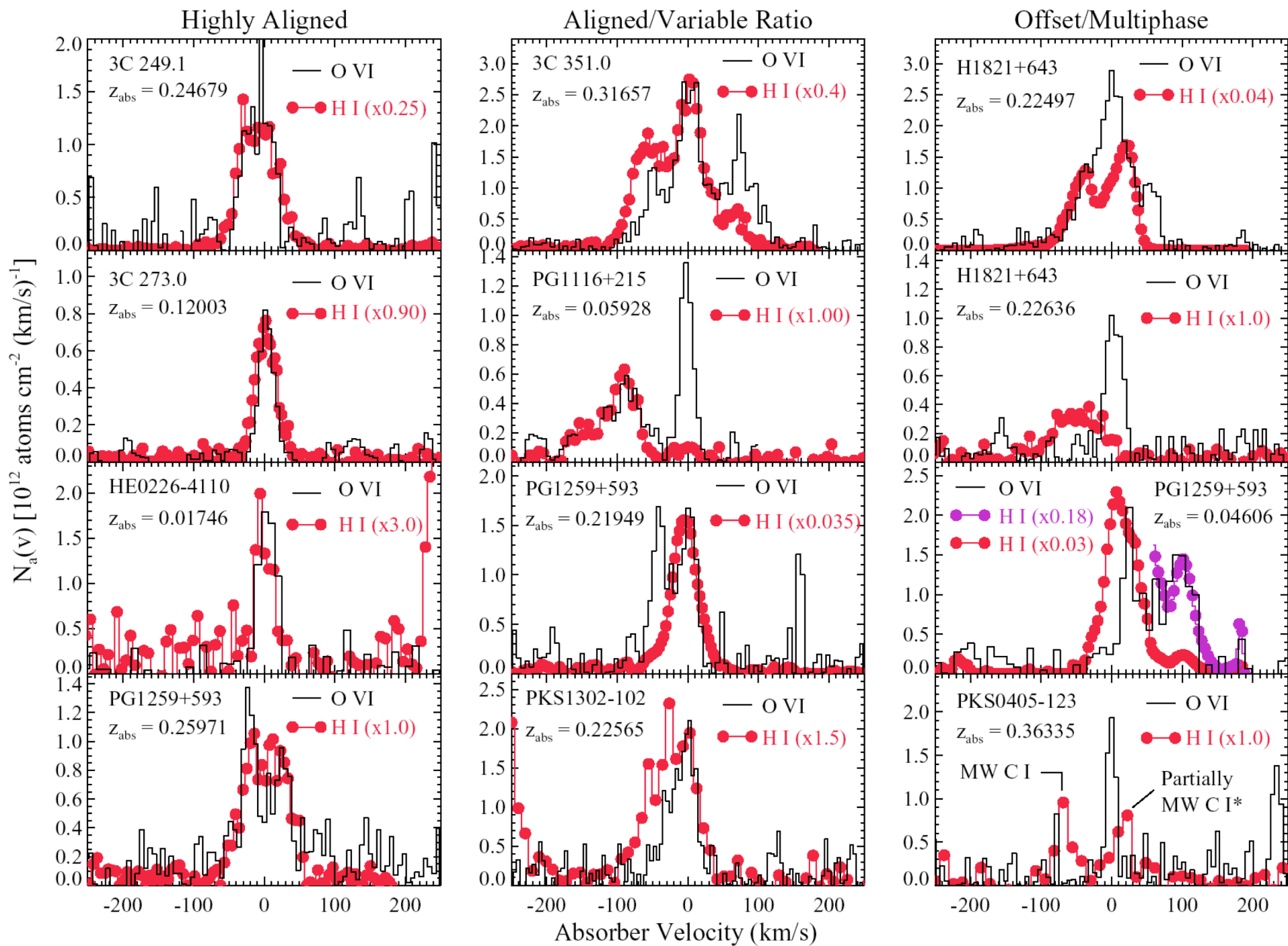


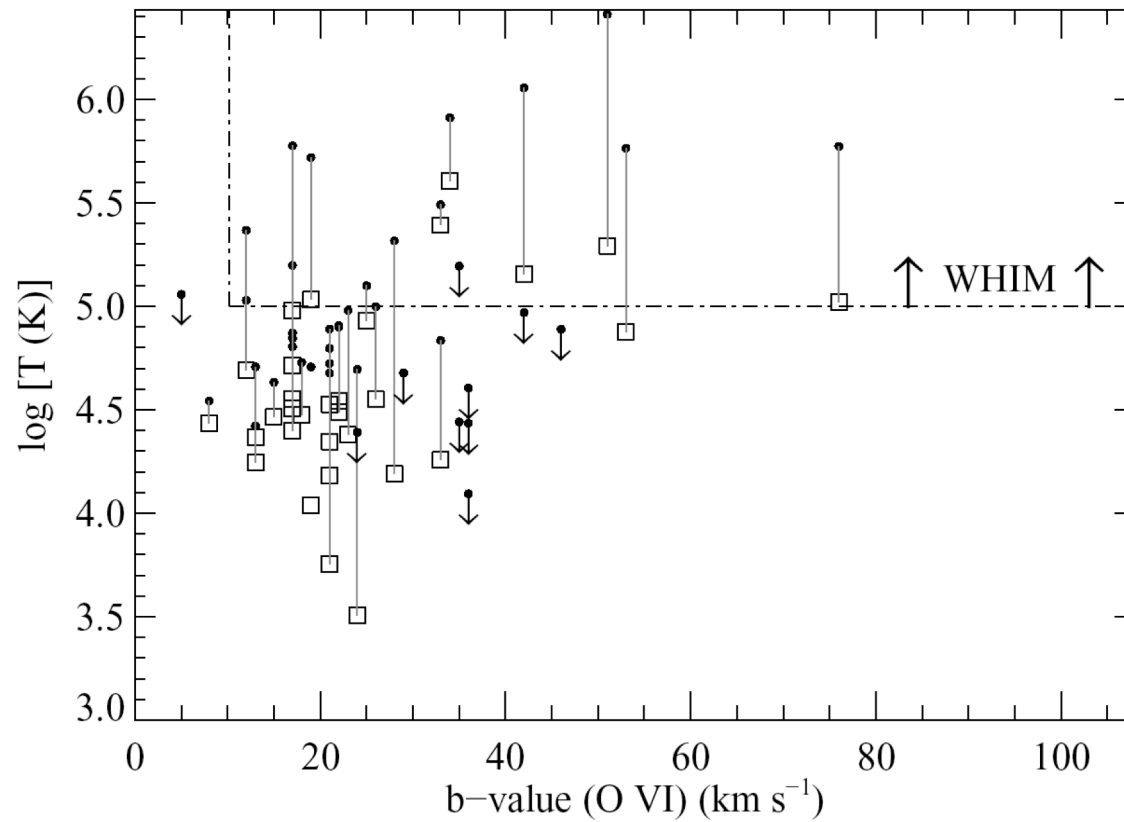






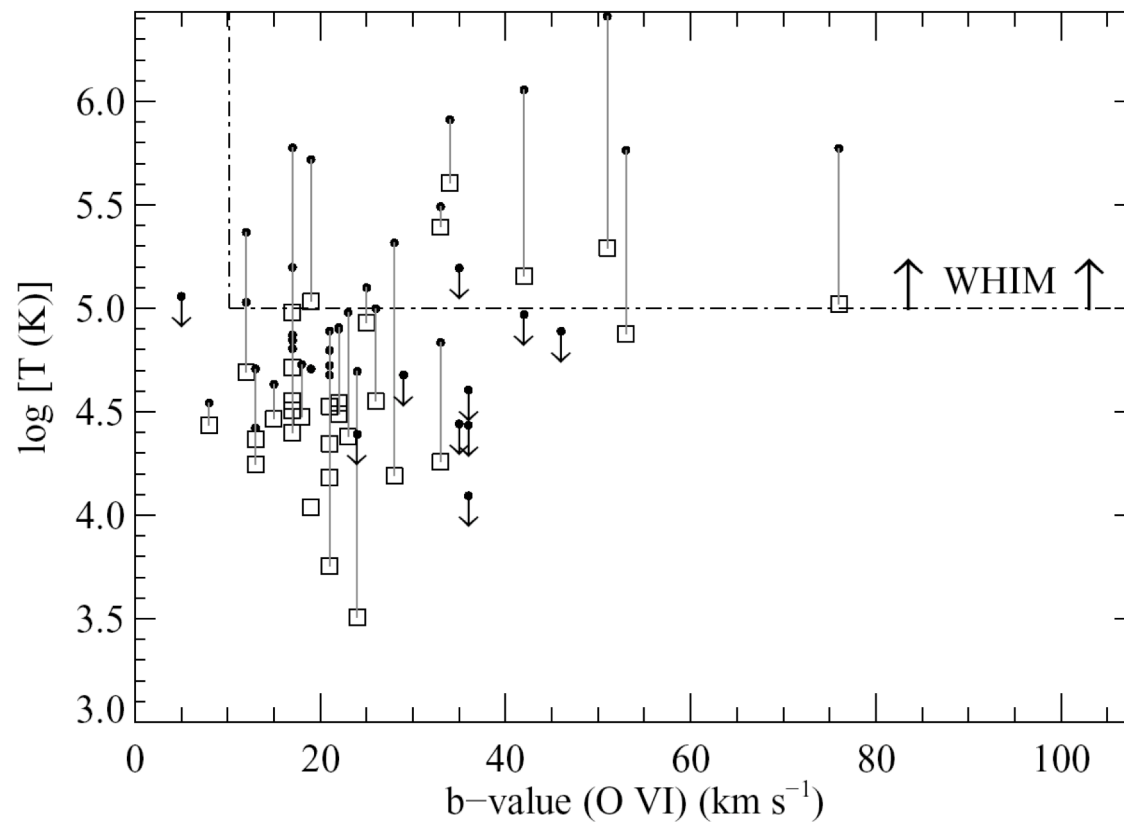






Consider the
intervening
components
that are well-
aligned

$$T = \frac{mb^2}{2k} = A \left(\frac{b}{0.129} \right)^2$$

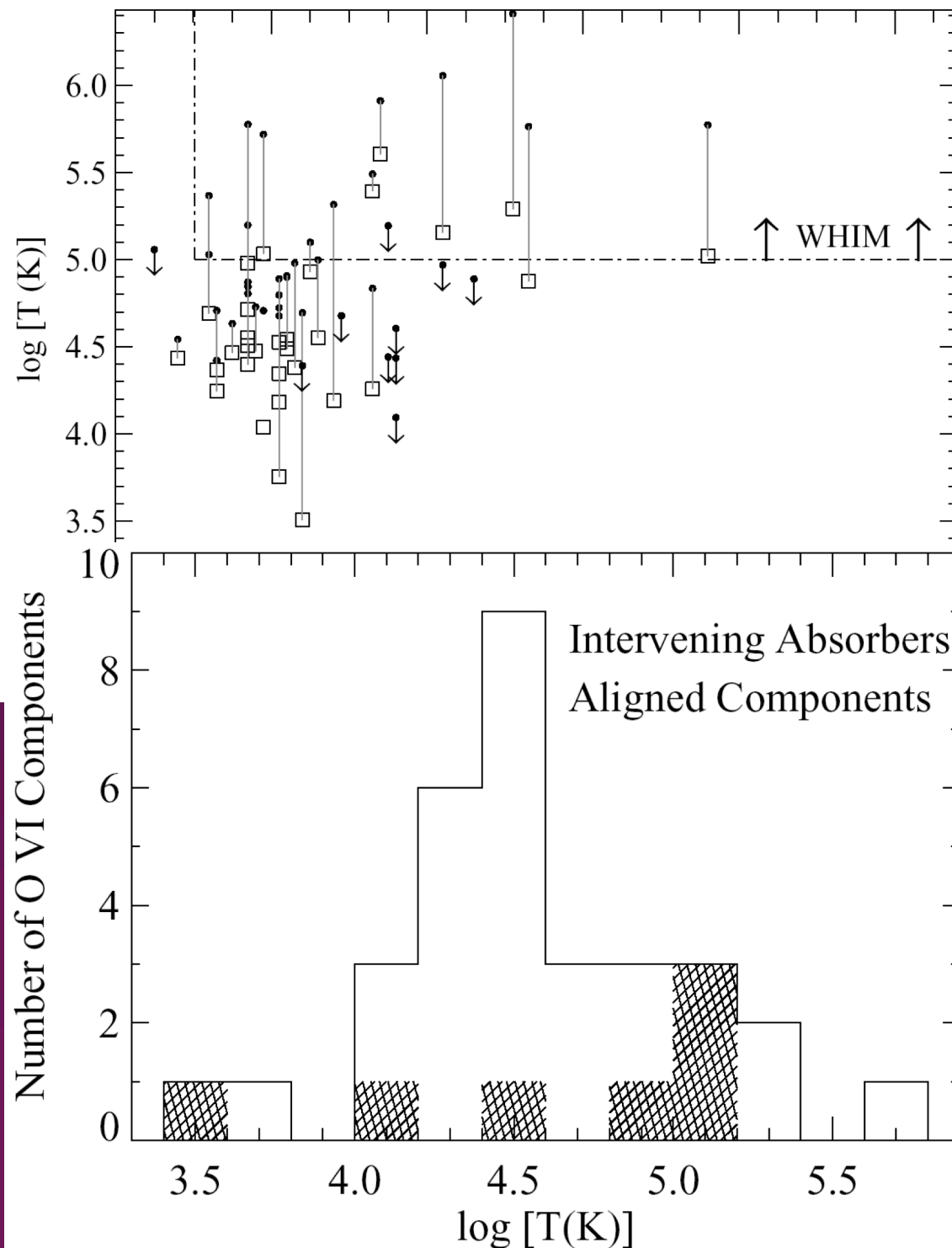


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$$b^2 = (0.129)^2 \frac{T}{A} + b_{\text{nt}}^2$$

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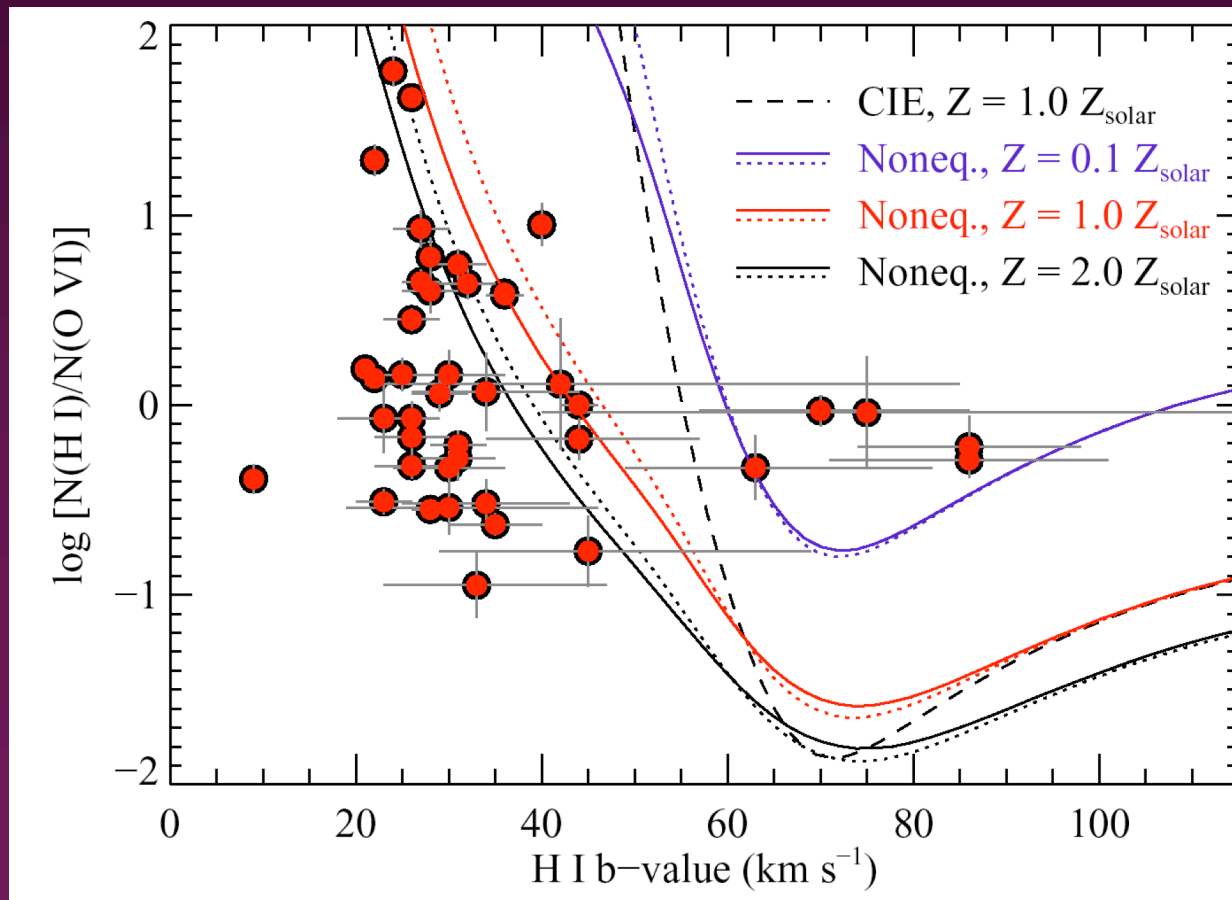


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Collisional ionization equilibrium fails (H I lines too narrow).

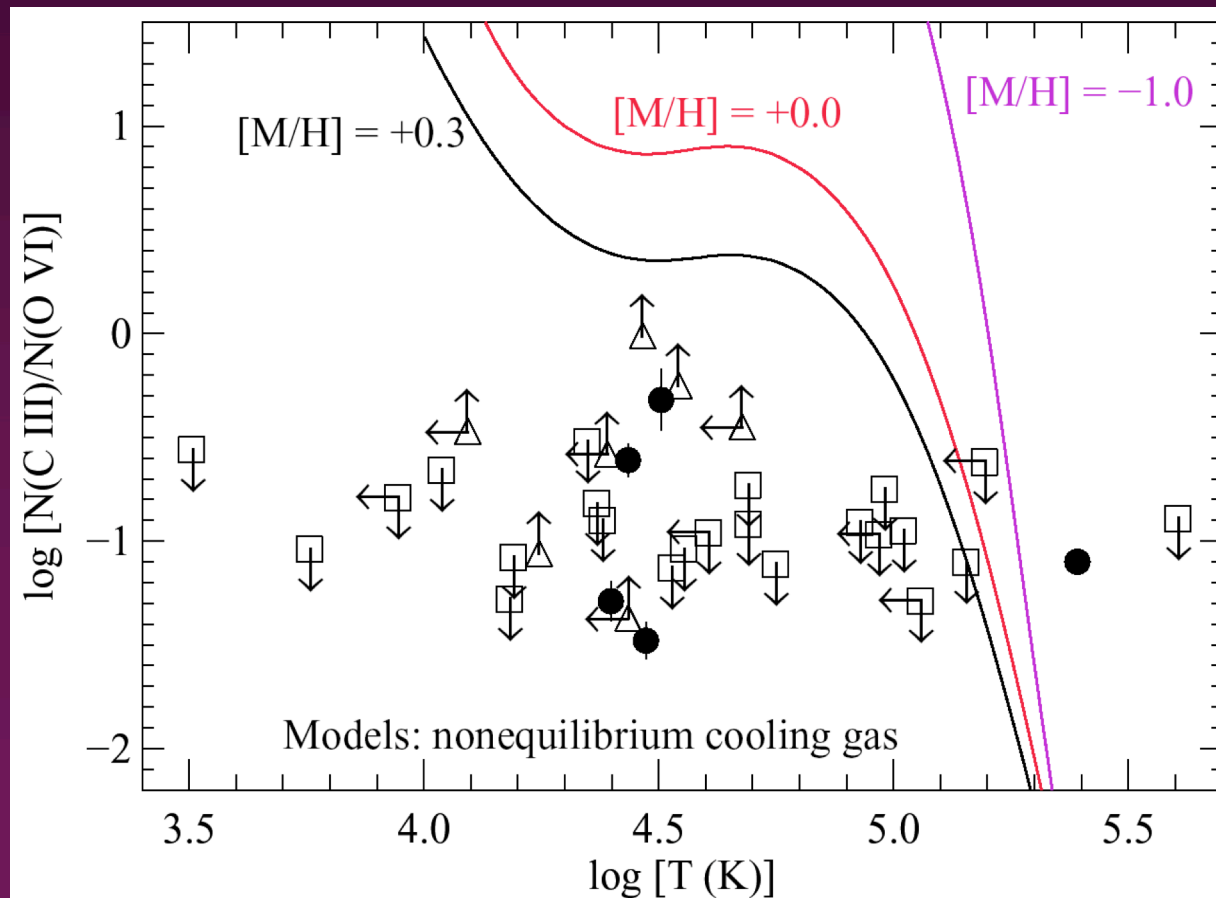
- What about non-equilibrium models?



Curves: non-eq.
radiatively cooling
plasma models of
Gnat & Sternberg
(2007)

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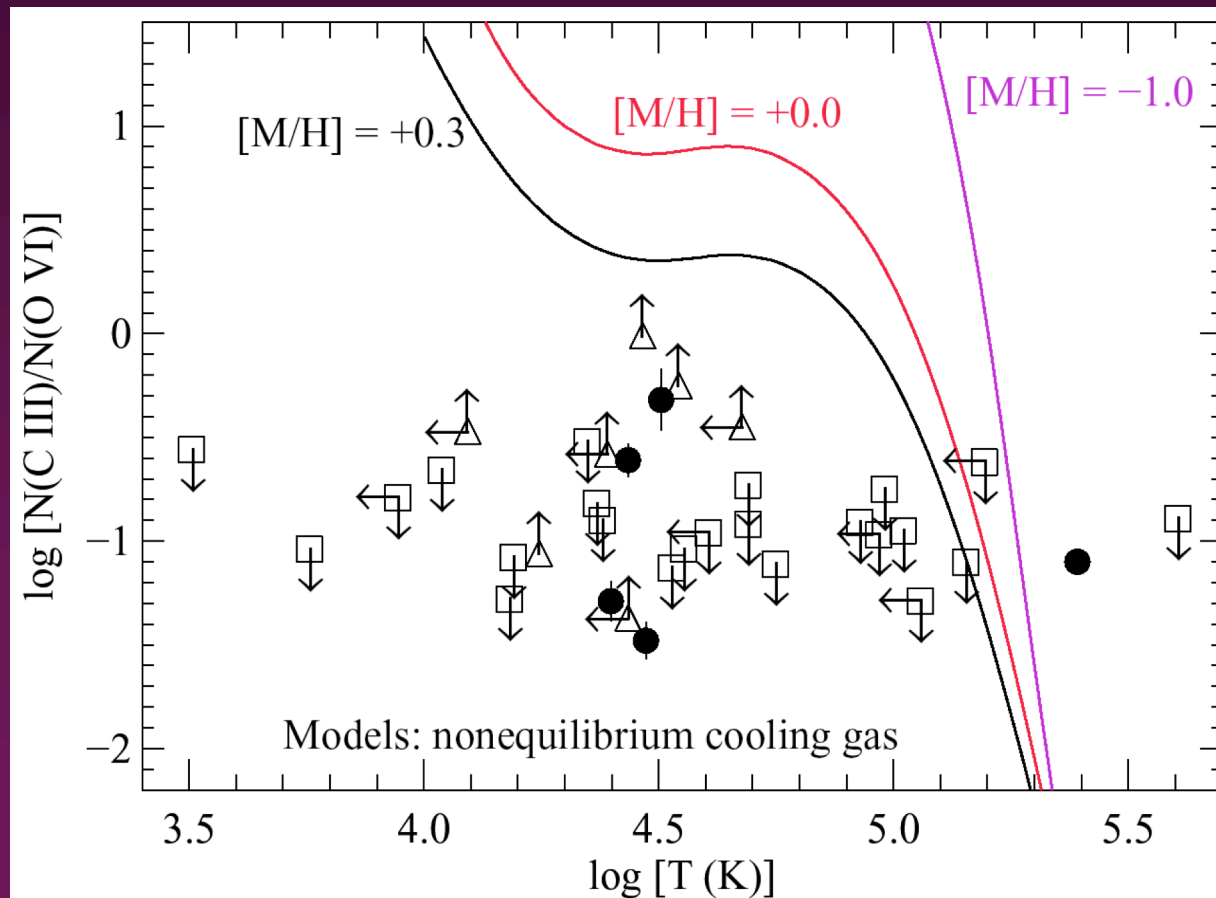
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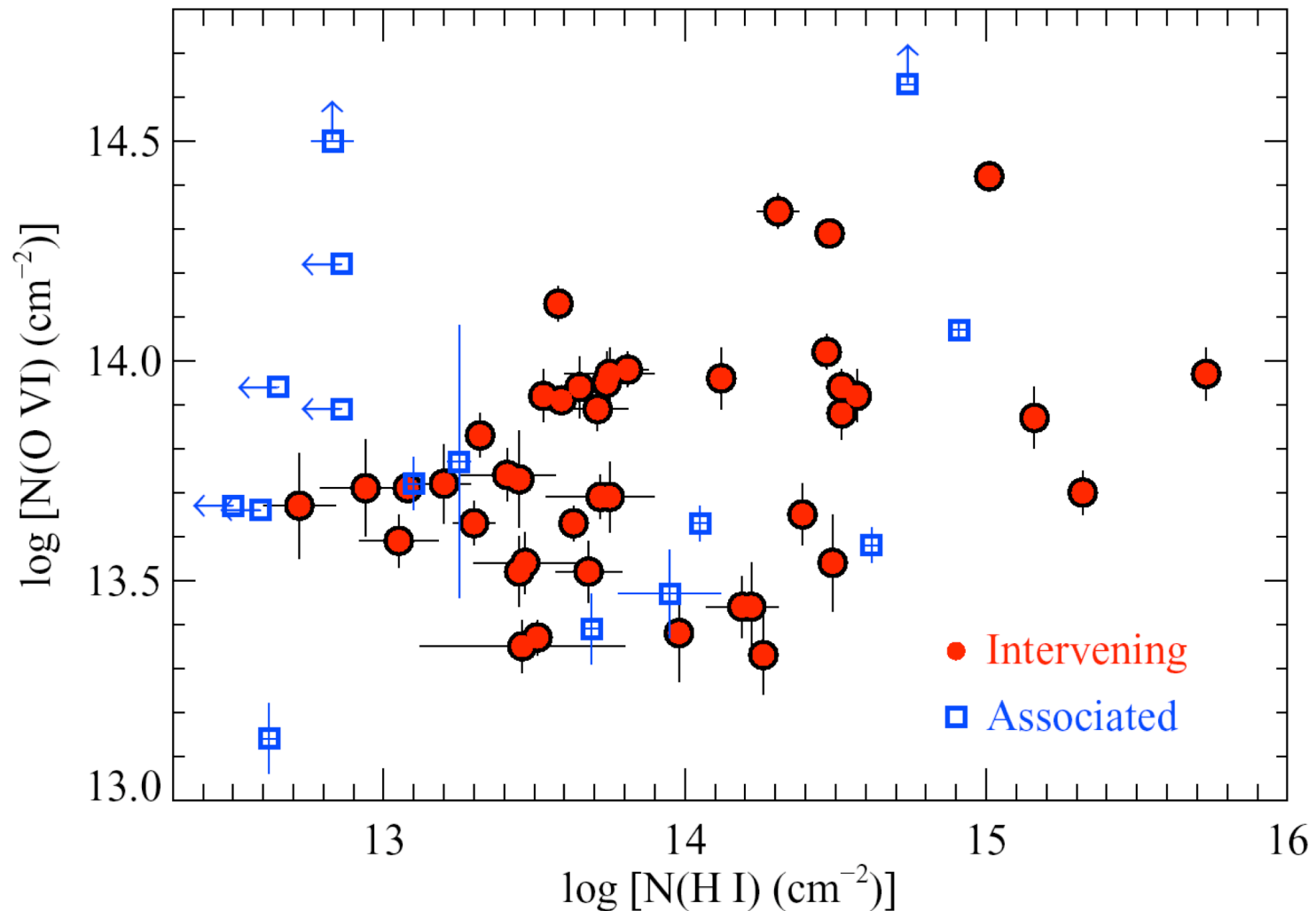


Curves: non-eq.
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Caveat: Gnat &
Sternberg neglect
photoionization
by the UV bkg.

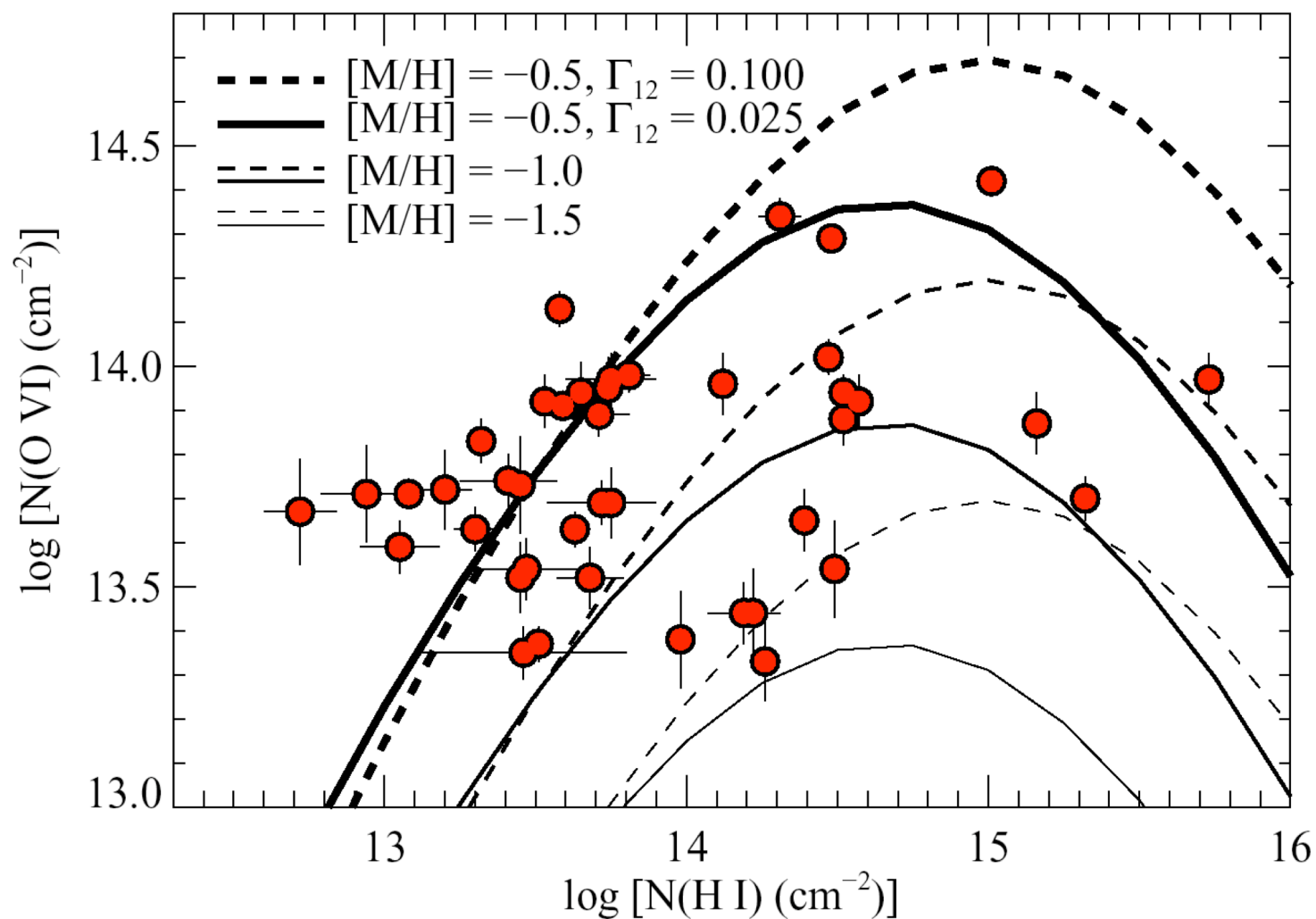
Pure photoionization?

$$n_{\text{H}} \approx 10^{-5} \left[\frac{N(\text{H I})}{2.3 \times 10^{13}} \right]^{2/3} T_4^{0.17} \Gamma_{12}^{2/3} \left(\frac{f_g}{0.16} \right)^{-1/3} \quad (\text{Schaye 2001})$$

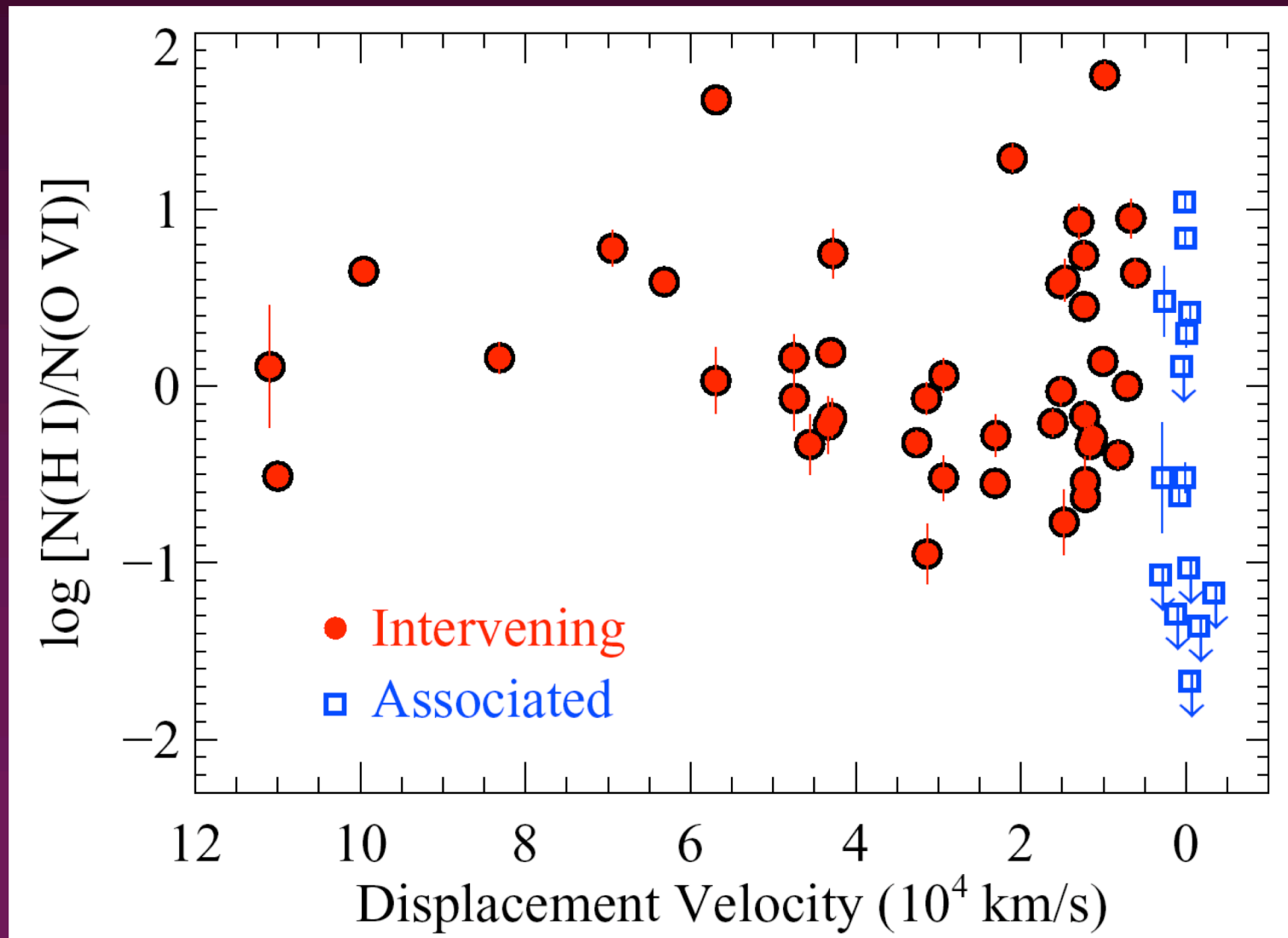


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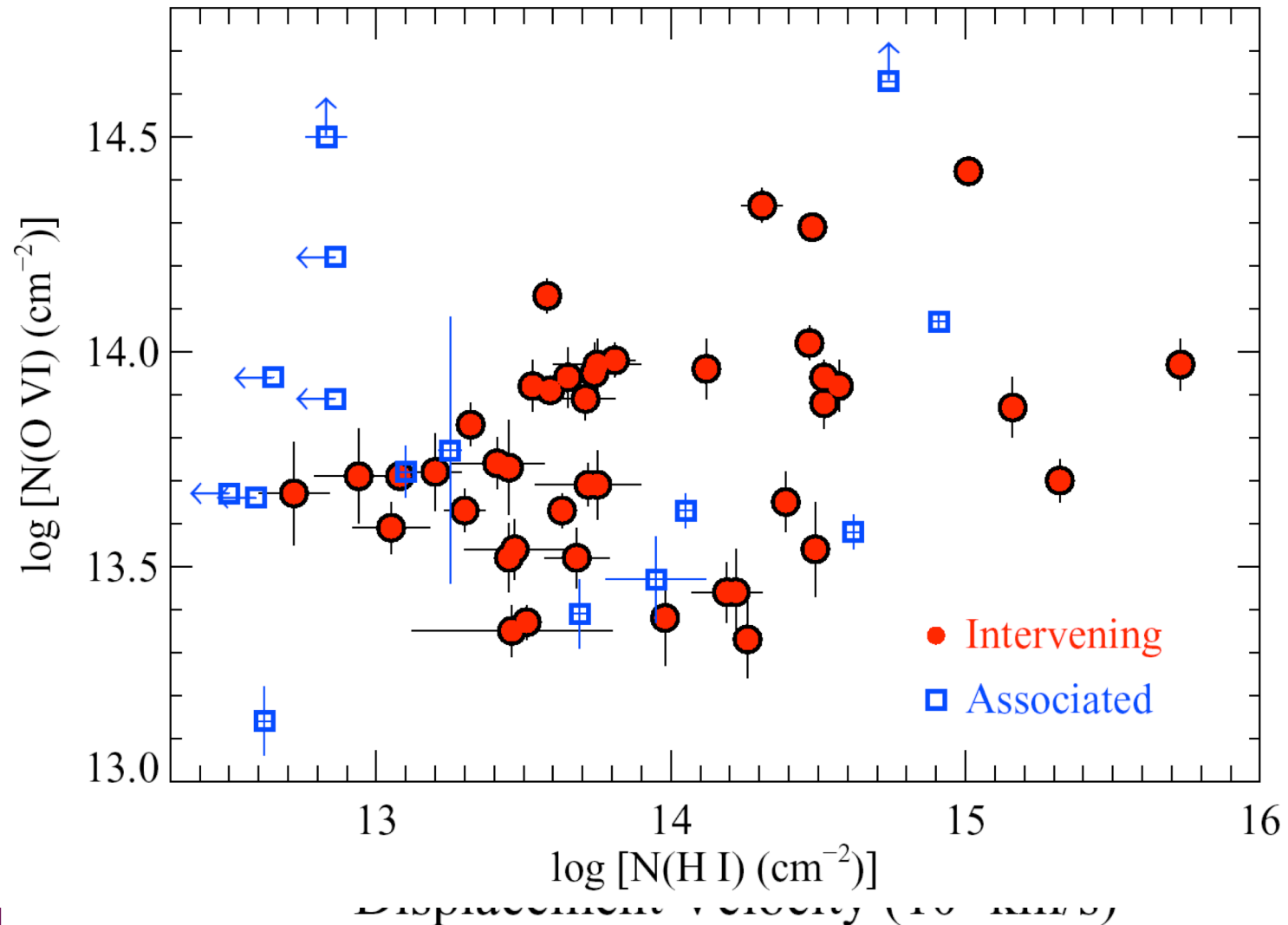
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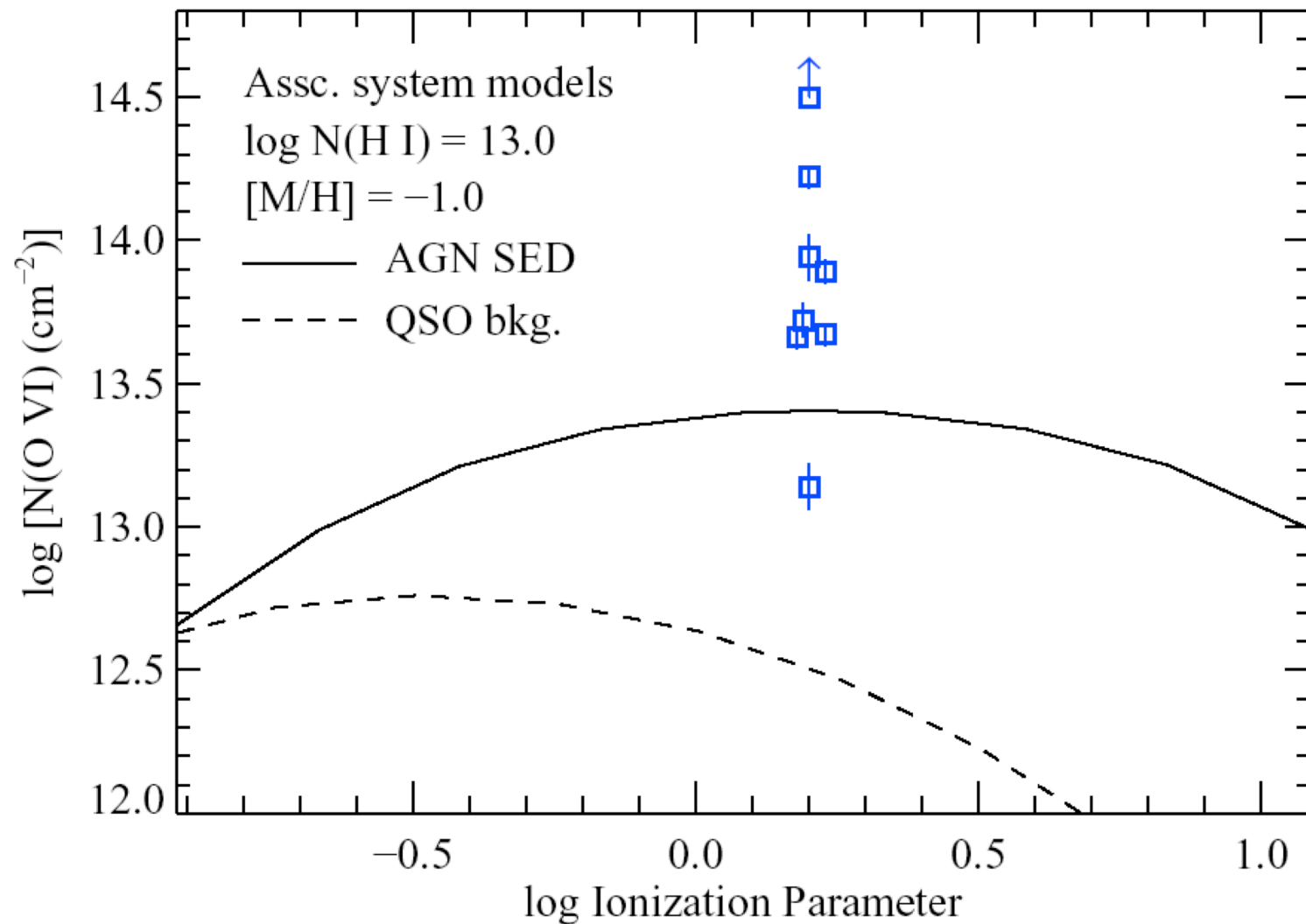
Ionization & Metallicity of Associated Absorbers



Ionization & Metallicity of Associated Absorbers

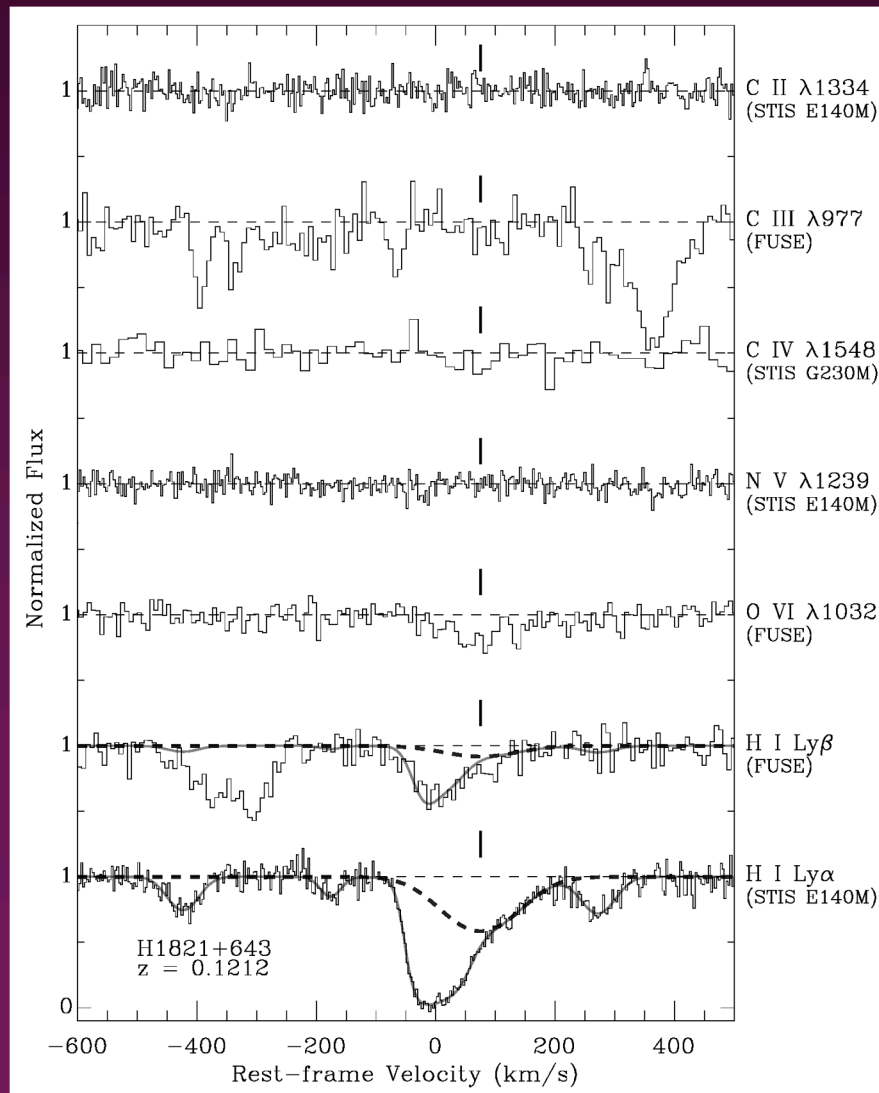


Ionization & Metallicity of Associated Absorbers

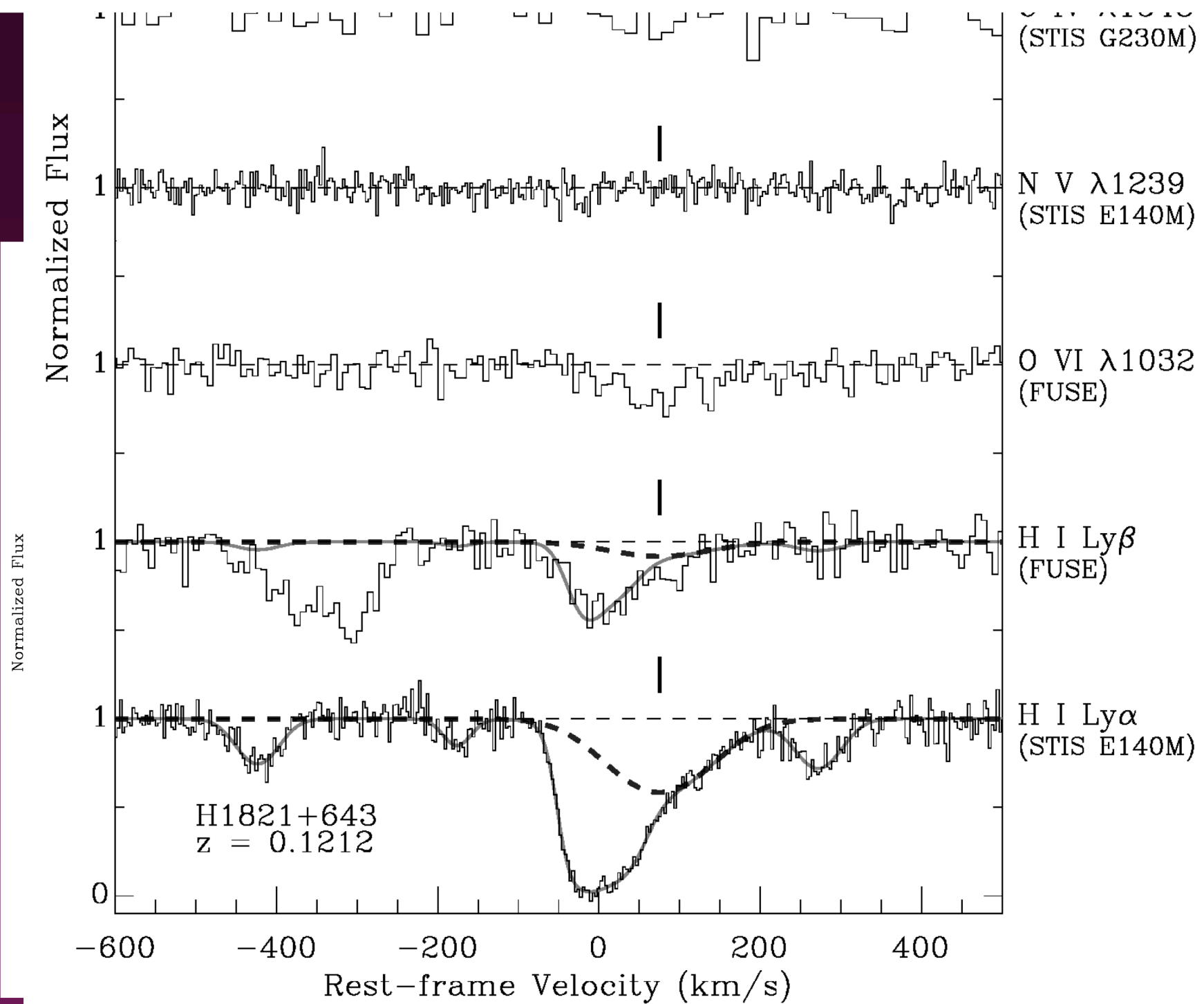


Multiphase O VI Absorbers

H1821+643, $z = 0.12120$ (Tripp et al. 2001)

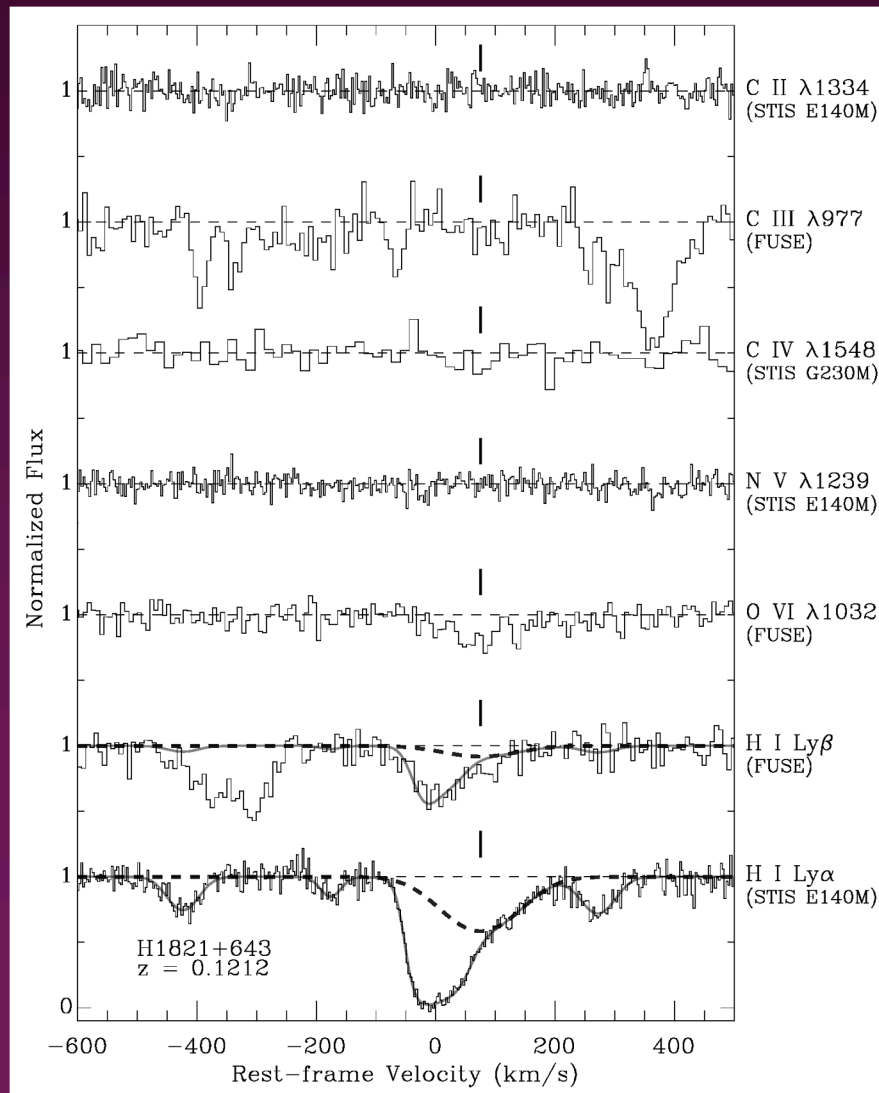


- Ly α profile contains a smooth, broad profile spread over many resolution elements
- The broad component is aligned with O VI
- H I + O VI b-values imply $T = 2.5 \times 10^5$ K



Multiphase O VI Absorbers

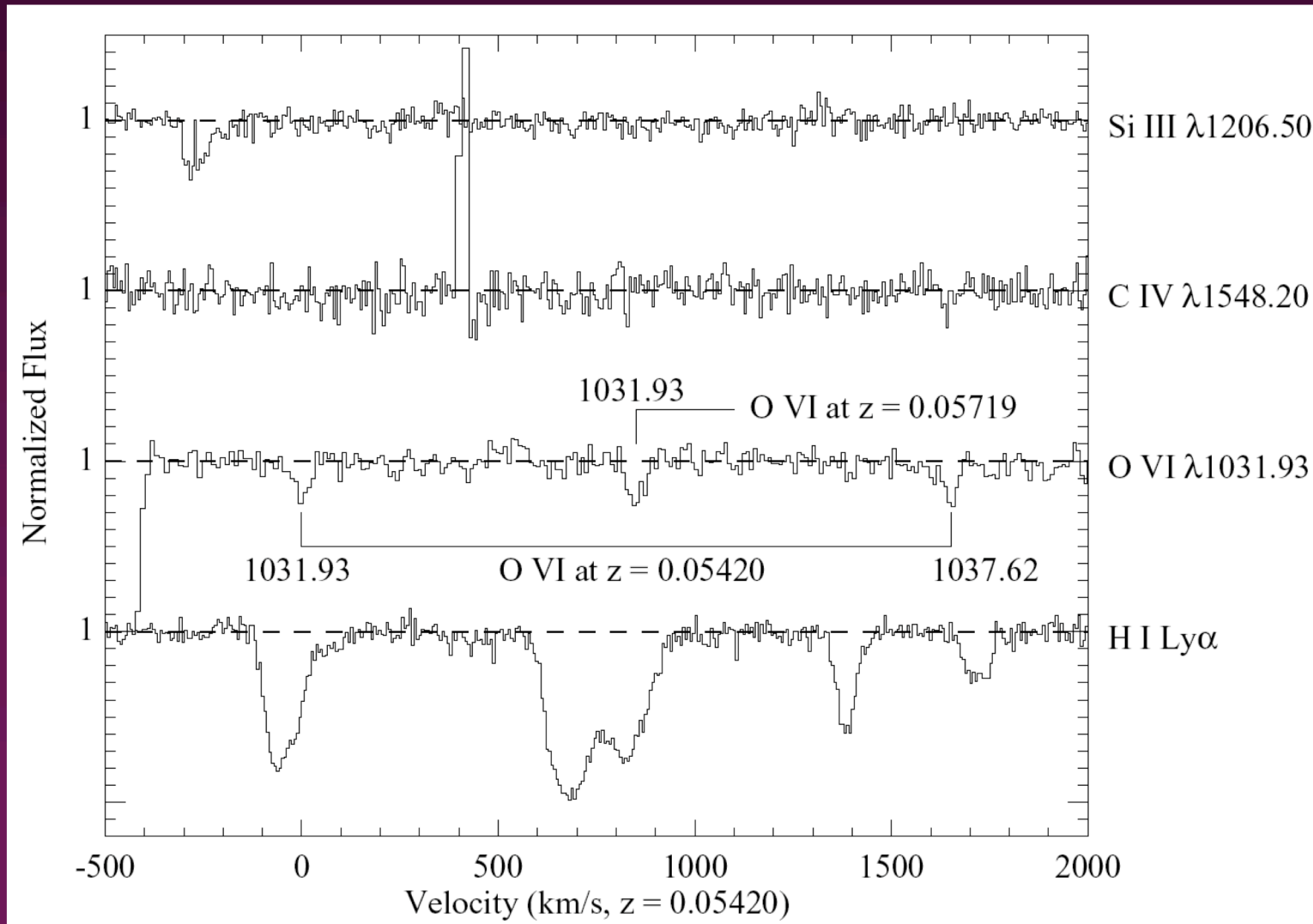
H1821+643, $z = 0.12120$ (Tripp et al. 2001)



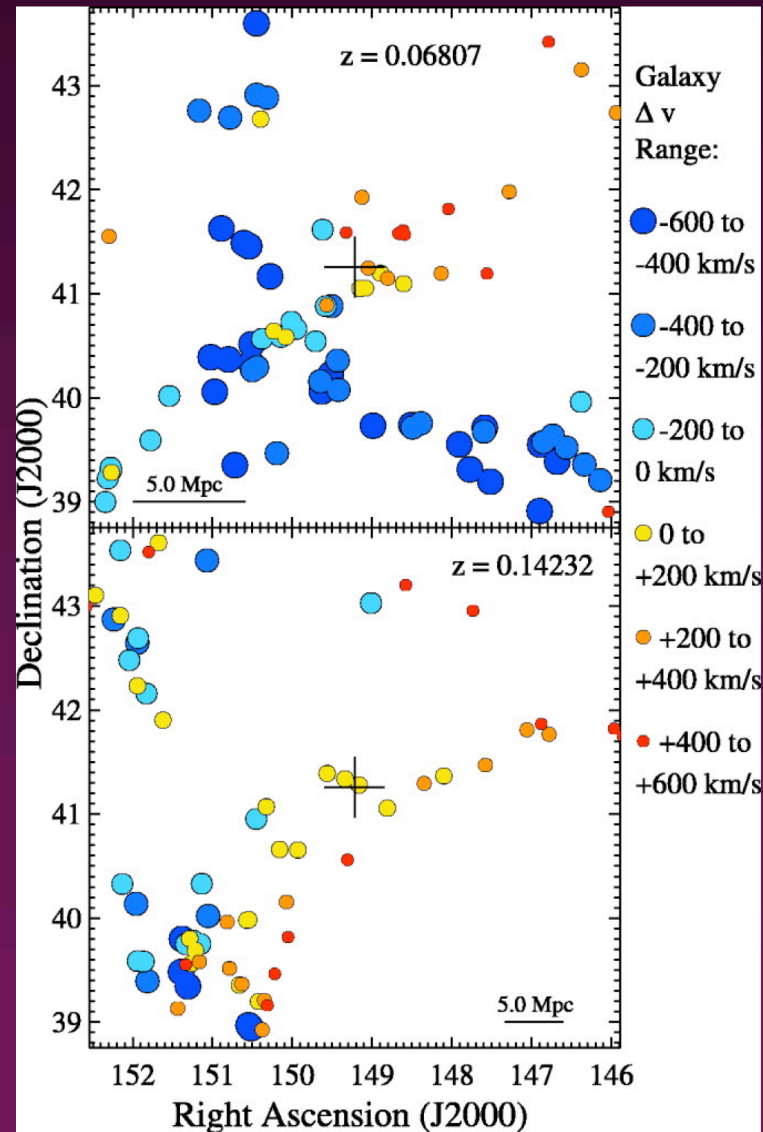
- Ly α profile contains a smooth, broad profile spread over many resolution elements
- The broad component is aligned with O VI
- H I + O VI b-values imply $T = 2.5 \times 10^5$ K

Multiphase O VI Absorbers

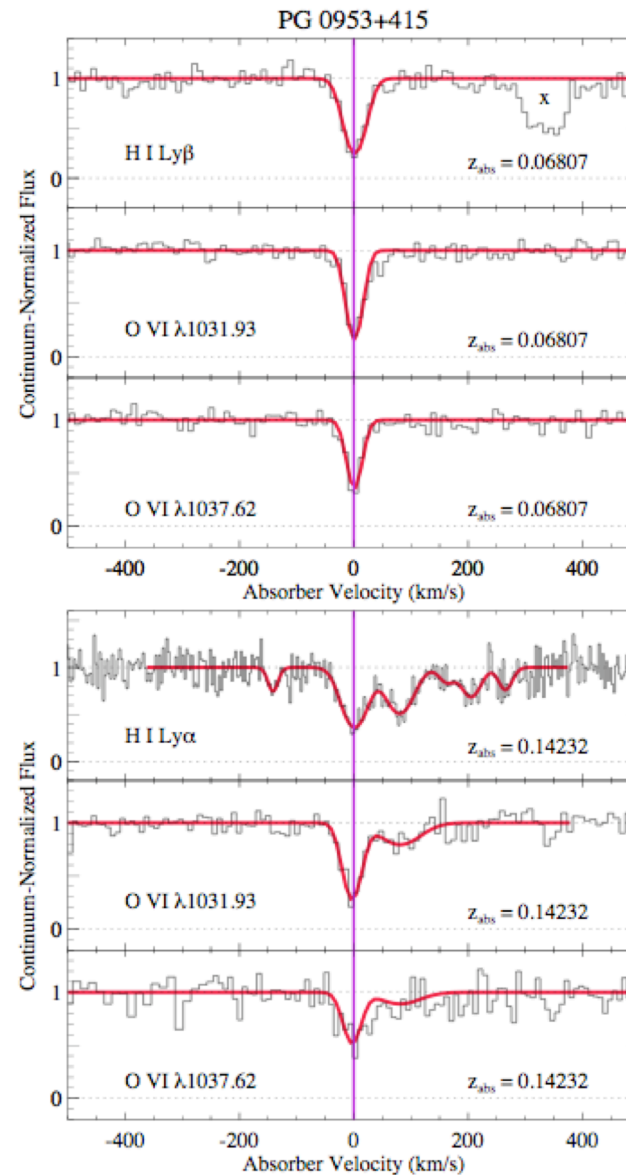
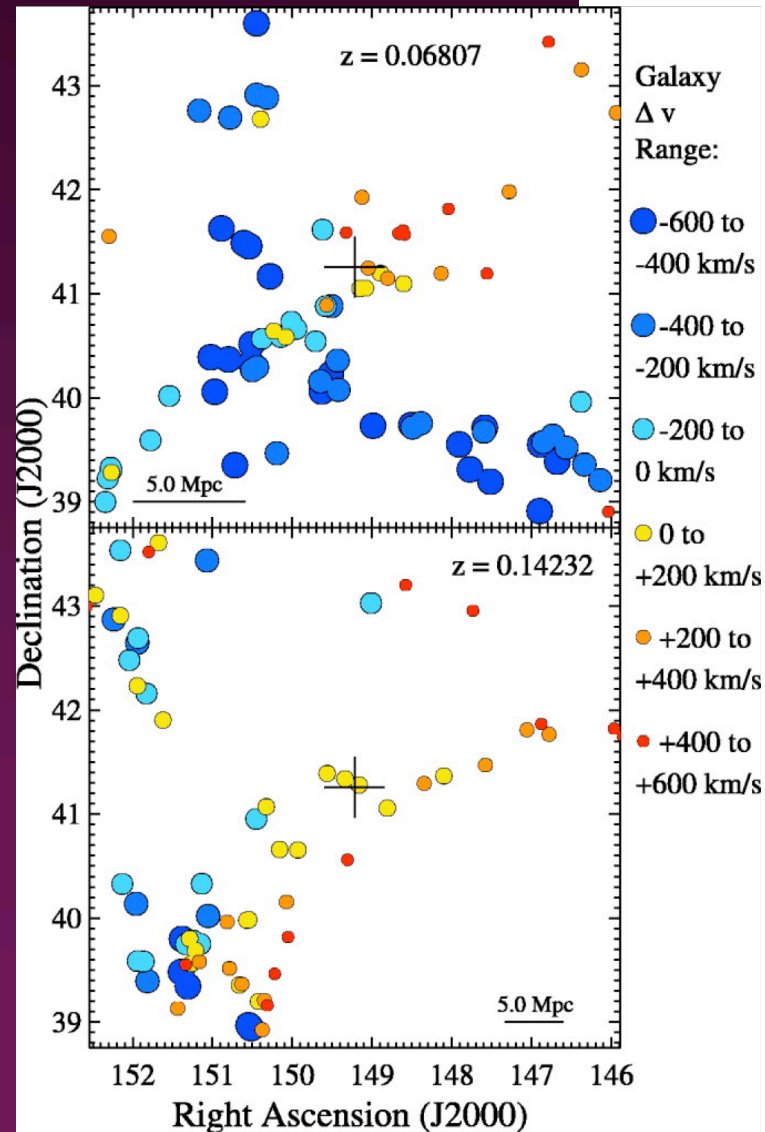
PKS 2155-304



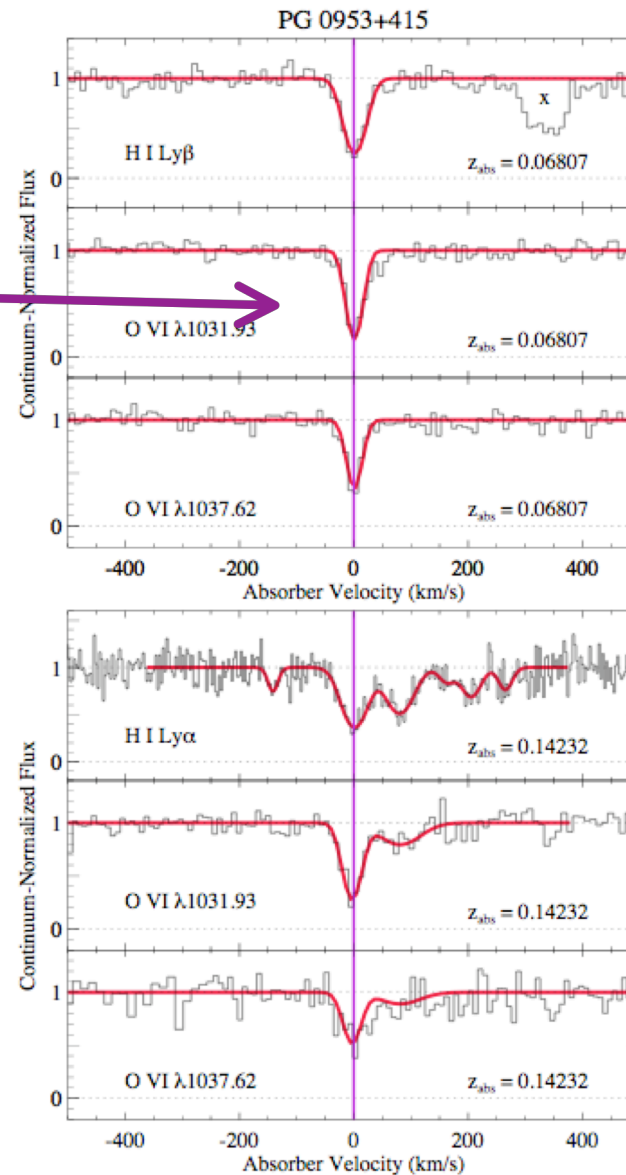
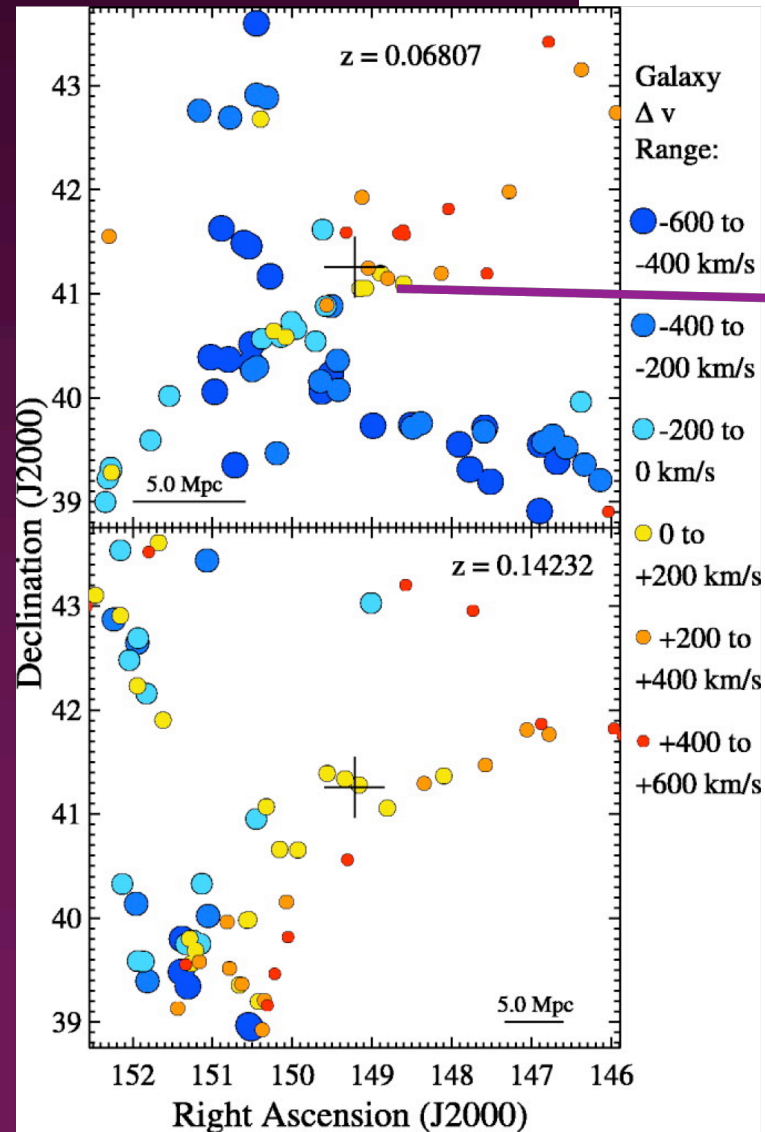
Low- z O VI Absorbers Toward PG0953+415 (Tripp et al. 2006)



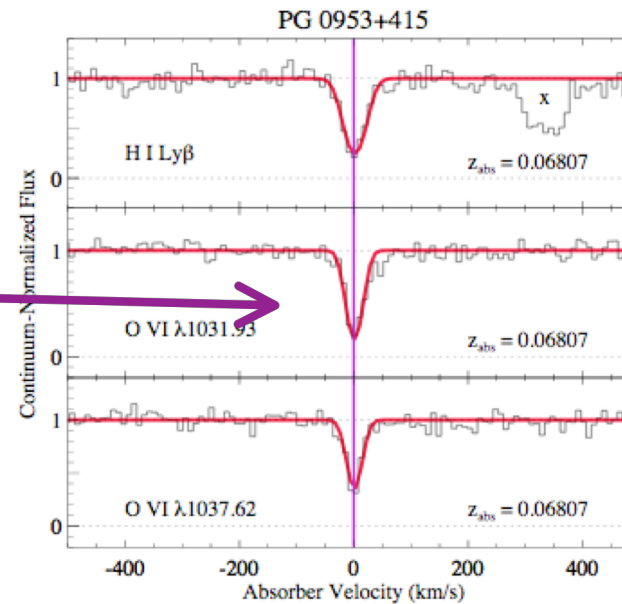
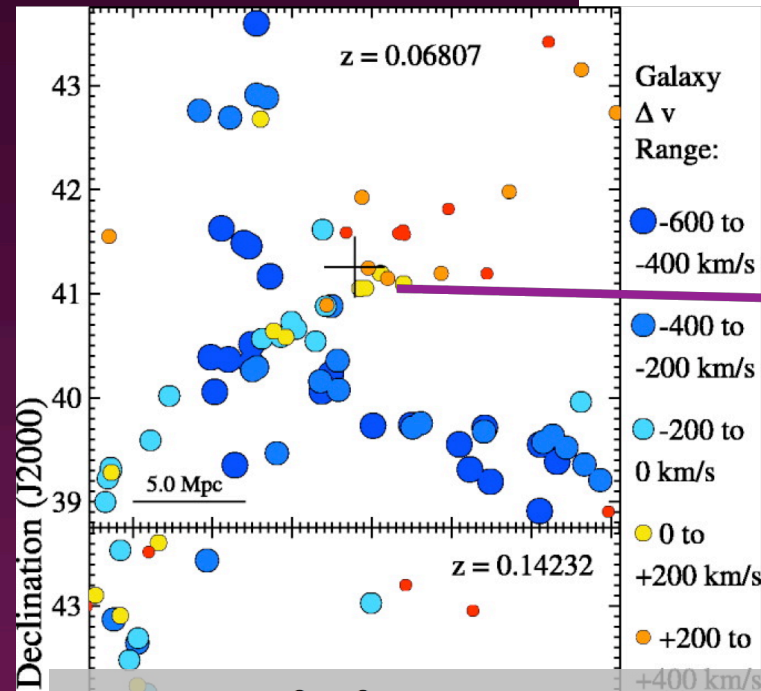
Low- z O VI Absorbers Toward PG0953+415 (Tripp et al. 2006)



Low- z O VI Absorbers Toward PG0953+415 (Tripp et al. 2006)



Low-z O VI Absorbers Toward PG0953+415 (Tripp et al. 2006)



- $z = 0.06807$
Nearest galaxy
>195 kpc away or
 $L < 0.04 L^*$
(nearest known
galaxy: 736 kpc)
- $z = 0.14232$
Nearest galaxy ρ
= 155 kpc

Surprising result: the $z = 0.06807$ absorber has a high metallicity: $Z = 0.5 Z(\text{solar})$. How did such high-metallicity gas end up so far from luminous galaxies? **But, is this a fluke?? Where are the O VI systems typically found in a larger sample?**

Some closing comments

- Low- z O VI absorbers are ubiquitous
- However, many are cold and probably photoionized
- The multiphase absorbers might be the hot, collisionally ionized cases
- $dN/dz(\text{O VI})$ increases sharply as $z(\text{abs})$ approaches the QSO redshift
- Associated absorbers are distinguished by a low H I/O VI ratios
- The low H I/O VI ratios in the associated systems could be partially due to ionization, but they also have substantially higher metallicities

