Quasar Outflow Properties from UV/Optical Spectroscopy

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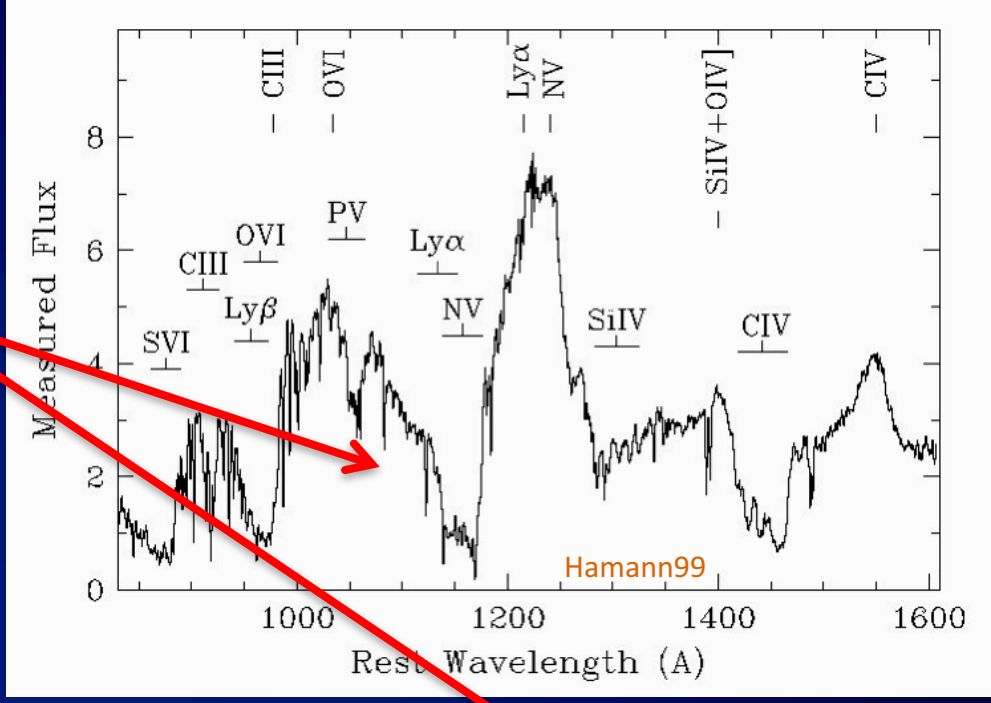
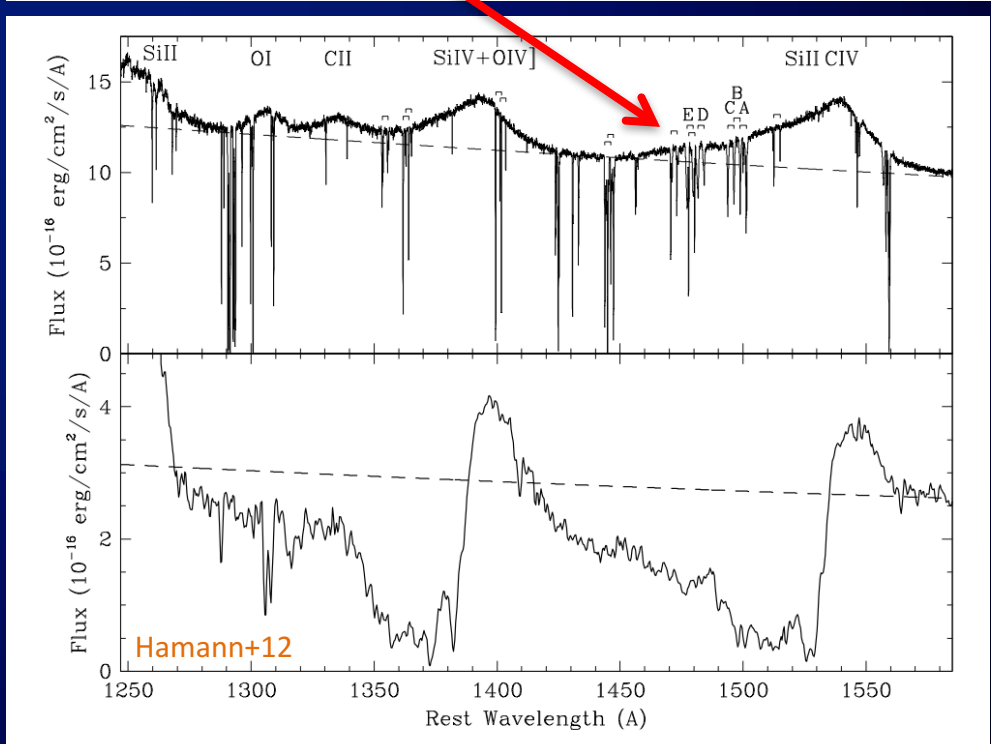
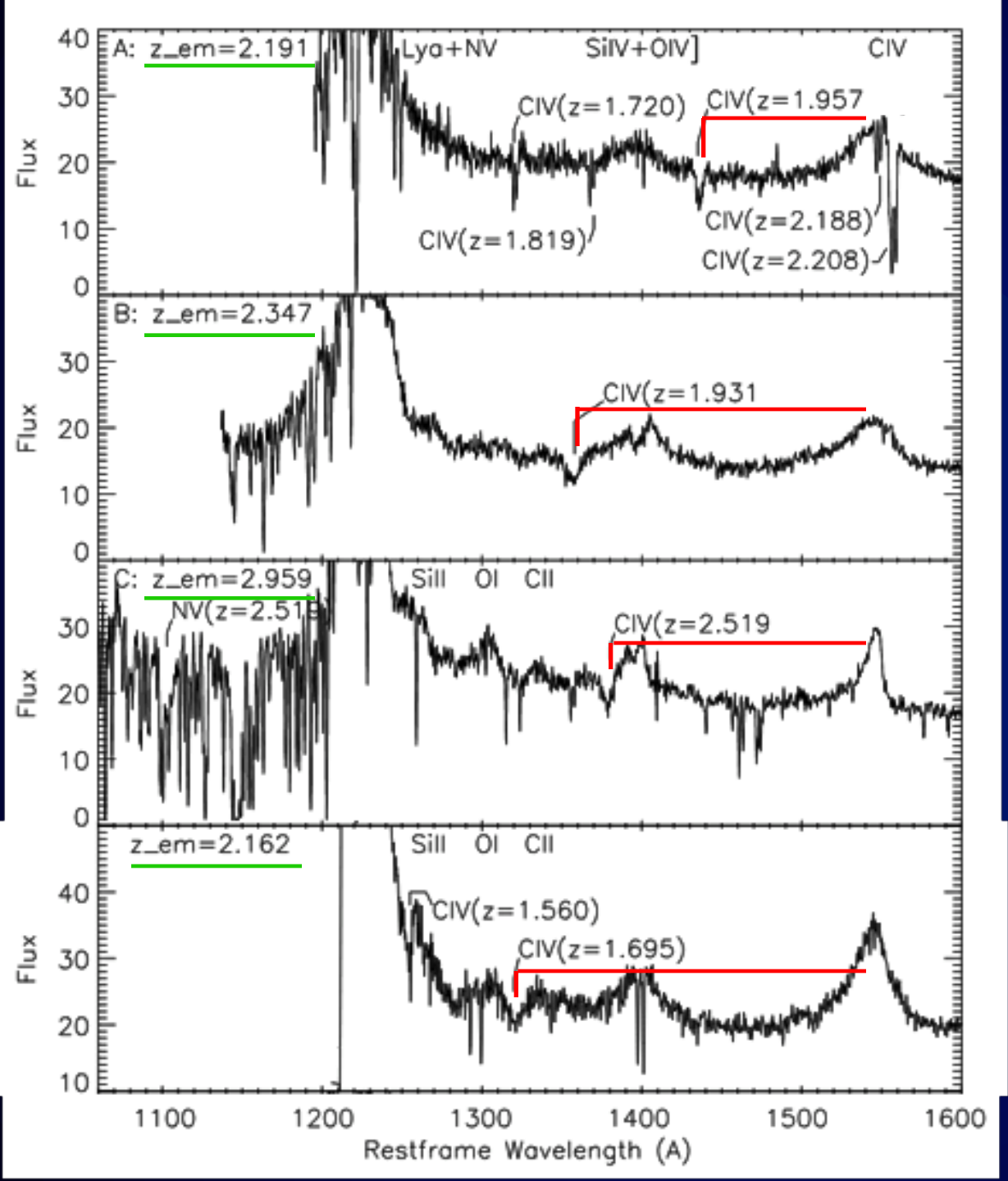
UV Outflows Questions:

- Diversity: BALs, mini-BALs, NALs, at a wide range of speeds
- Variability, X-ray UFOs, BELR blueshifts, …
- How do these things fit together?
- Orientation, evolution, other physics? (L, L/L_{edd}, metallicity, far-UV flux, X-ray shielding, …)
- Column densities & energetics
- Location (and spatial structure)







Mini-BALs & v > 0.1c

FWHM ~ 570 km/s

v ~ 22,000 km/s

FWHM ~ 2100 km/s

v ~ 40,000 km/s

FWHM ~ 1250 km/s

v ~ 35,000 km/s

FWHM ~ 2600 km/s

v ~ 48,000 km/s

Rodriguez Hidalgo+08

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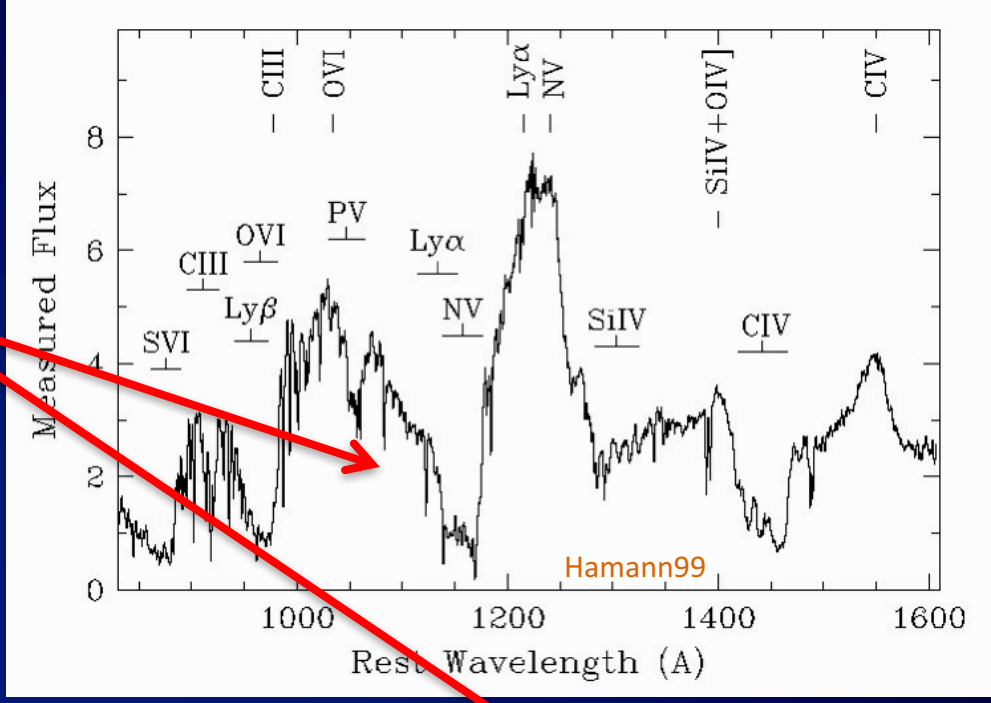
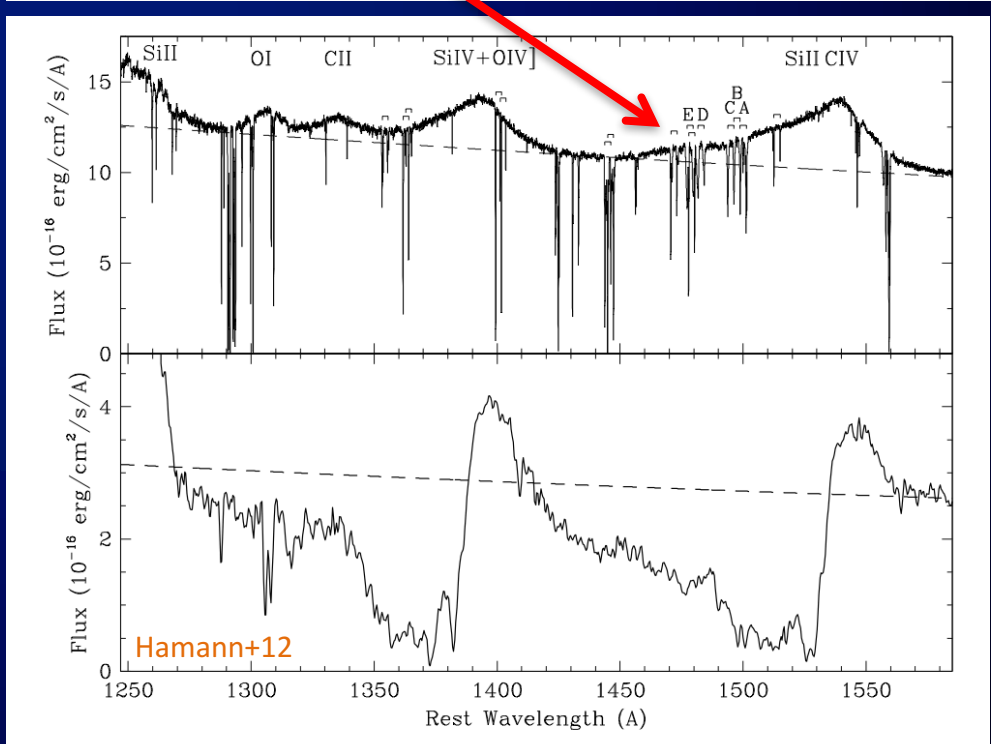
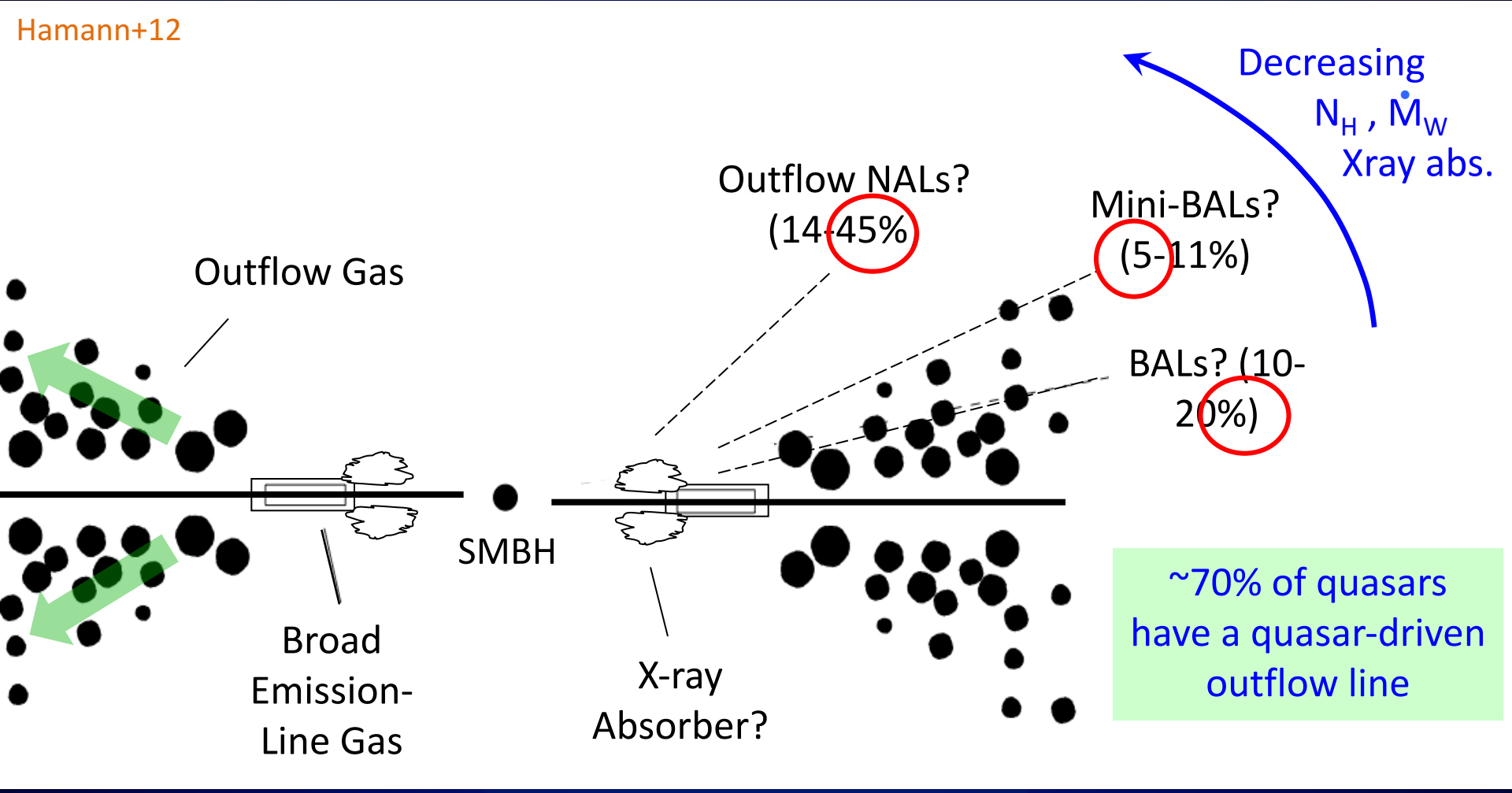




Hamann+12



~70% of quasars have a quasar-driven outflow line

Is this "unified" picture correct? (Do the detection %s = global covering fractions?)

Outflow NALs (excludes "environmental"): Simon+12, Nestor+08, Misawa+07

Mini-BALs: Rodriguez Hidalgo+08 BALs: Hewett+03, Knigge+08

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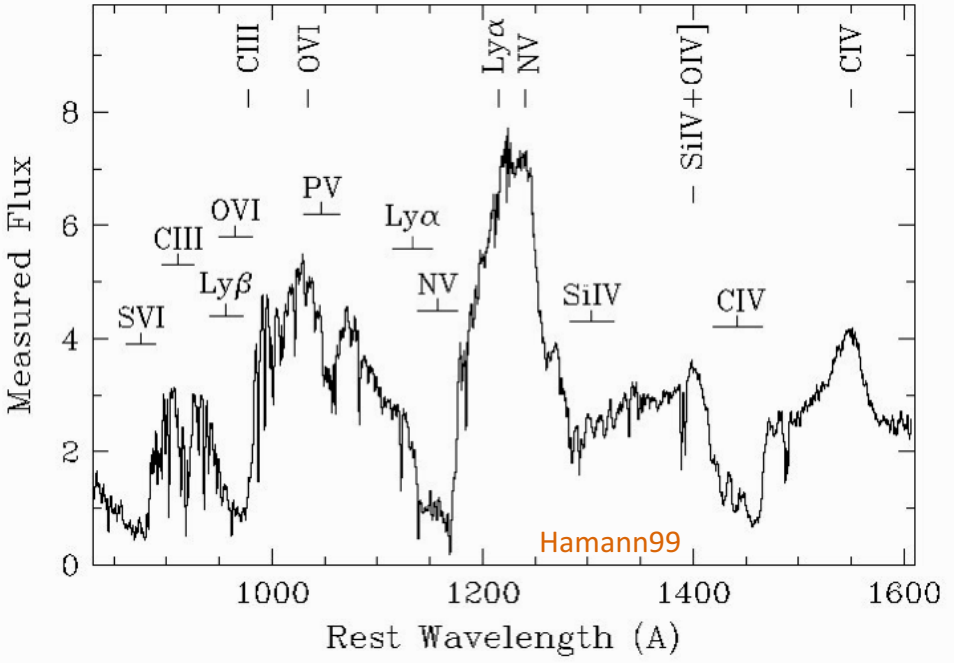
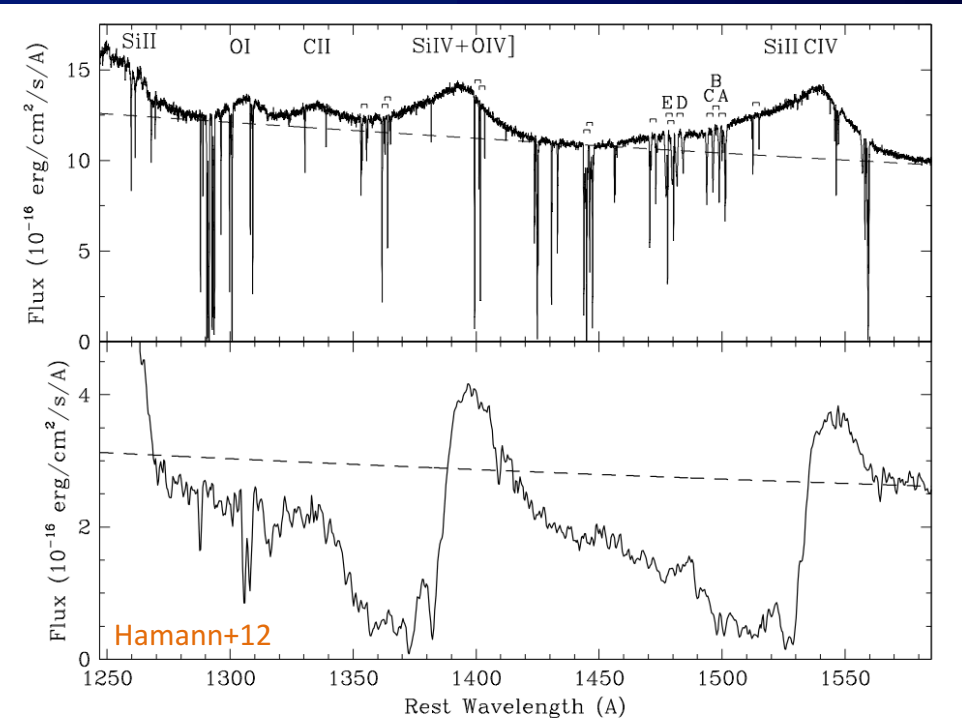
  - PV BALs & Energetics
  - CIV at ~0.3c in PDS 456 (?)

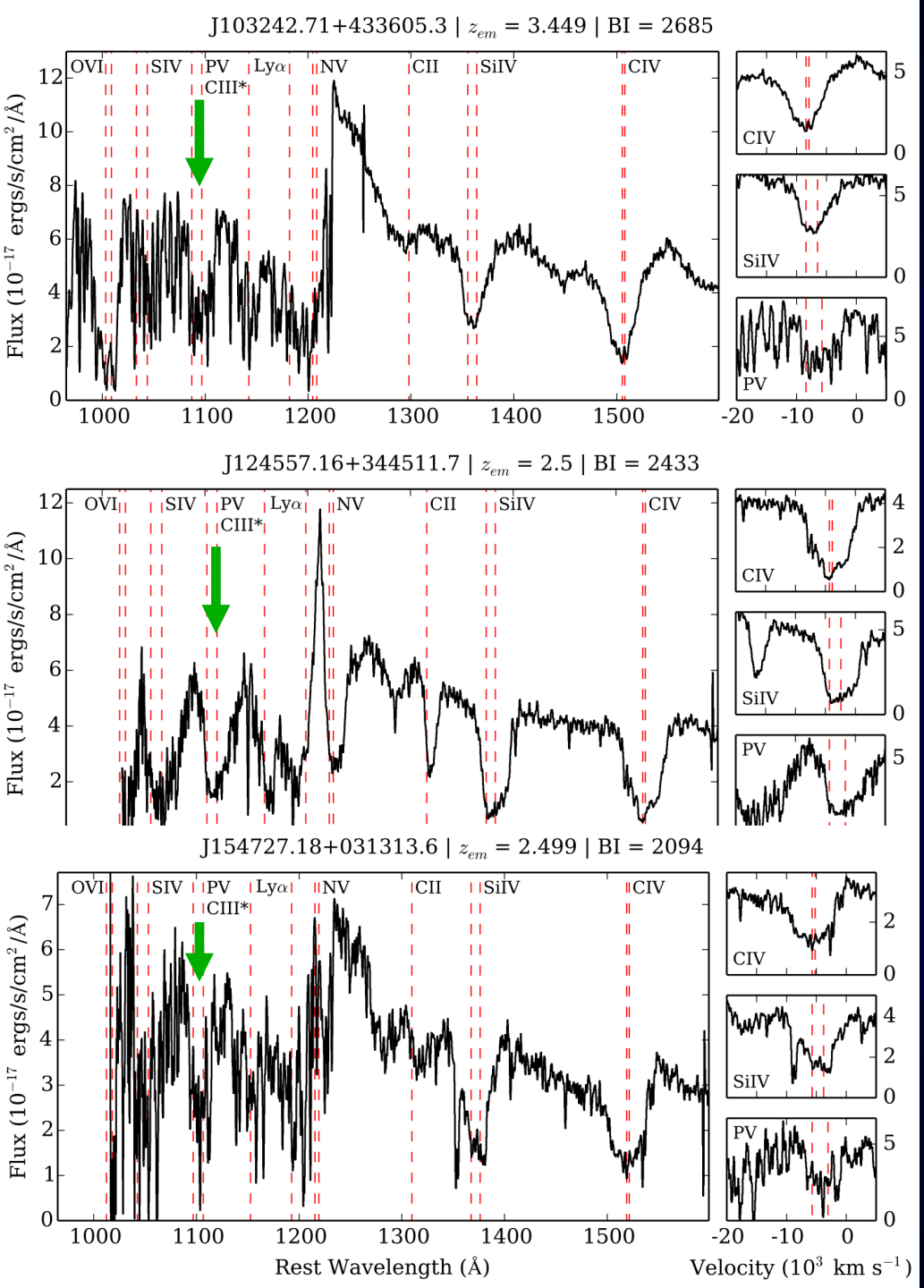




PV BAL Quasars

Low-abundance lines like PV 1118,1128 (Hamann 1998) & HeI* 3889,10830 (Leighly+11) require large N_H

Visual-inspection search in BOSS DR9 finds 167 BAL quasars with strong PV (Capellupo+17)

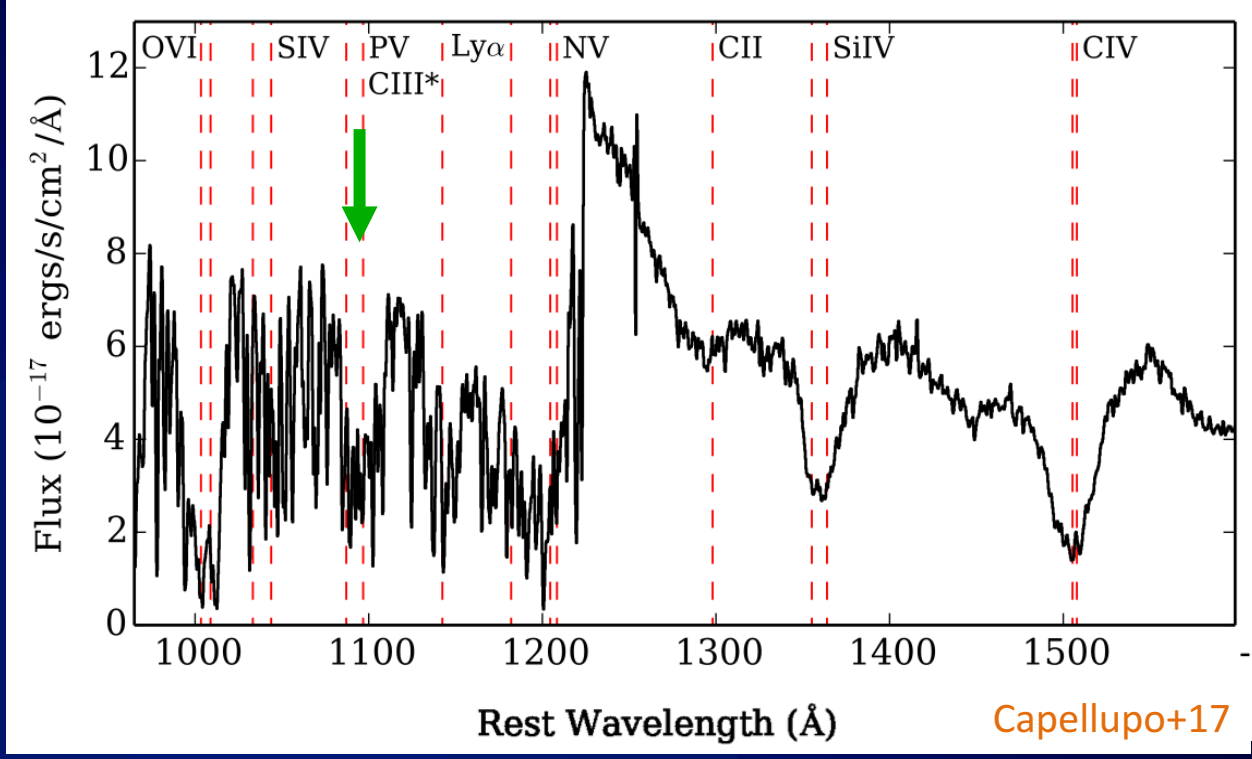


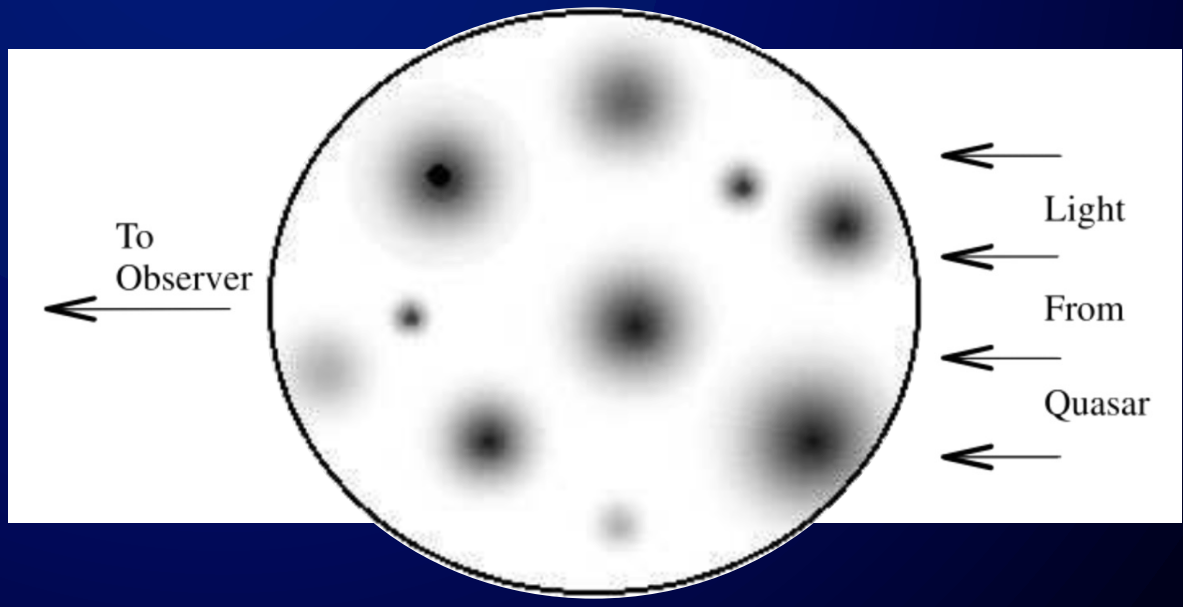
PV BAL Quasars

If P/C ~ solar, then
τ(CIV) >~ 1000 τ(PV) >> 1

Different depths in different lines, all with with τ >> 1

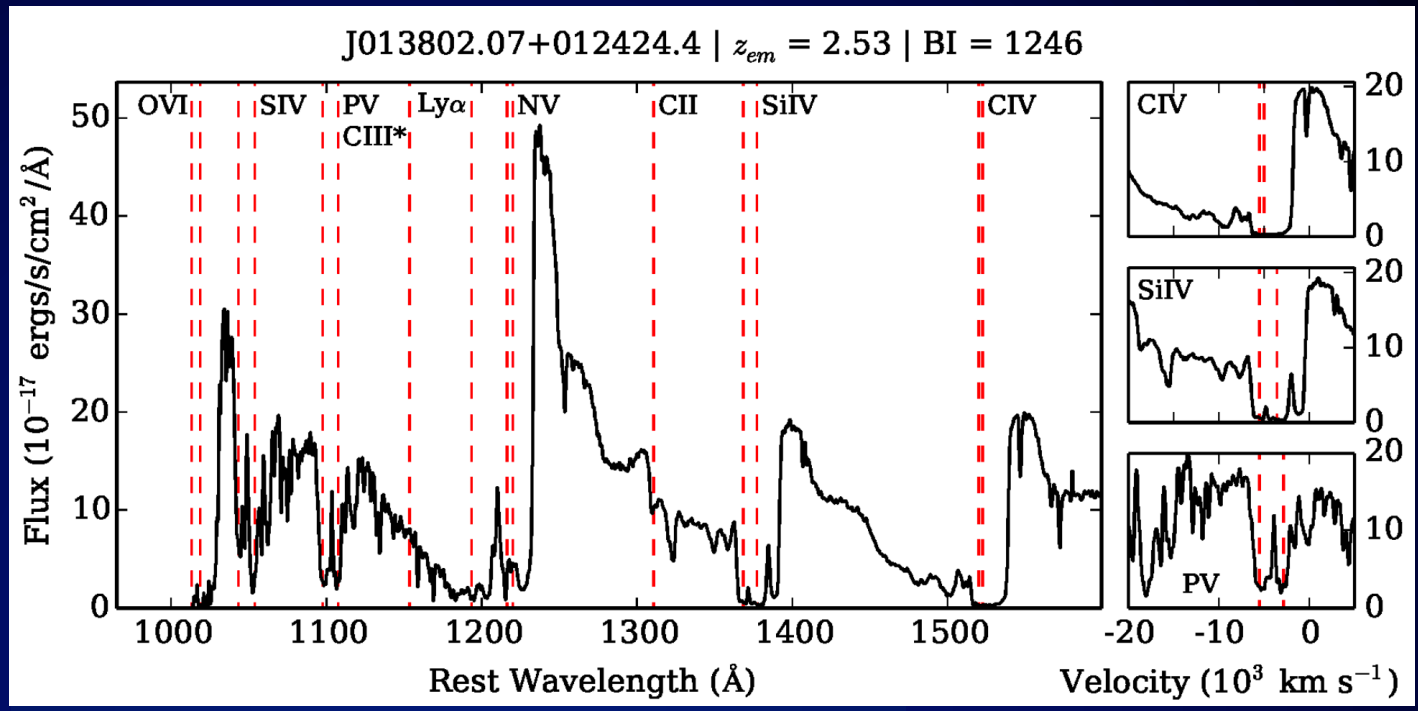
Inhomogeneous partial covering
(Hamann+01,04, Arav+05)





Column densities & Energetics:

Assume ~solar abundances for N_H constraints



Example: τ(PV) > 3 indicates $N_H > 4 \times 10^{22}$ cm^{-2} in ionized gas (Leighly+11).

Covering factor in PV: ~85%, Velocities: ~5000 km/s

If R ~ 3 pc (from variability with evidence for $\tau >> 1$) and Q ~ 15%
then dM/dt > 12 Mo/yr and $L_K > 4 \times 10^{44}$ ergs/s ~ 2% L_{bol}

➔ Is this common?

Capellupo+17

BALs to mini-BALs

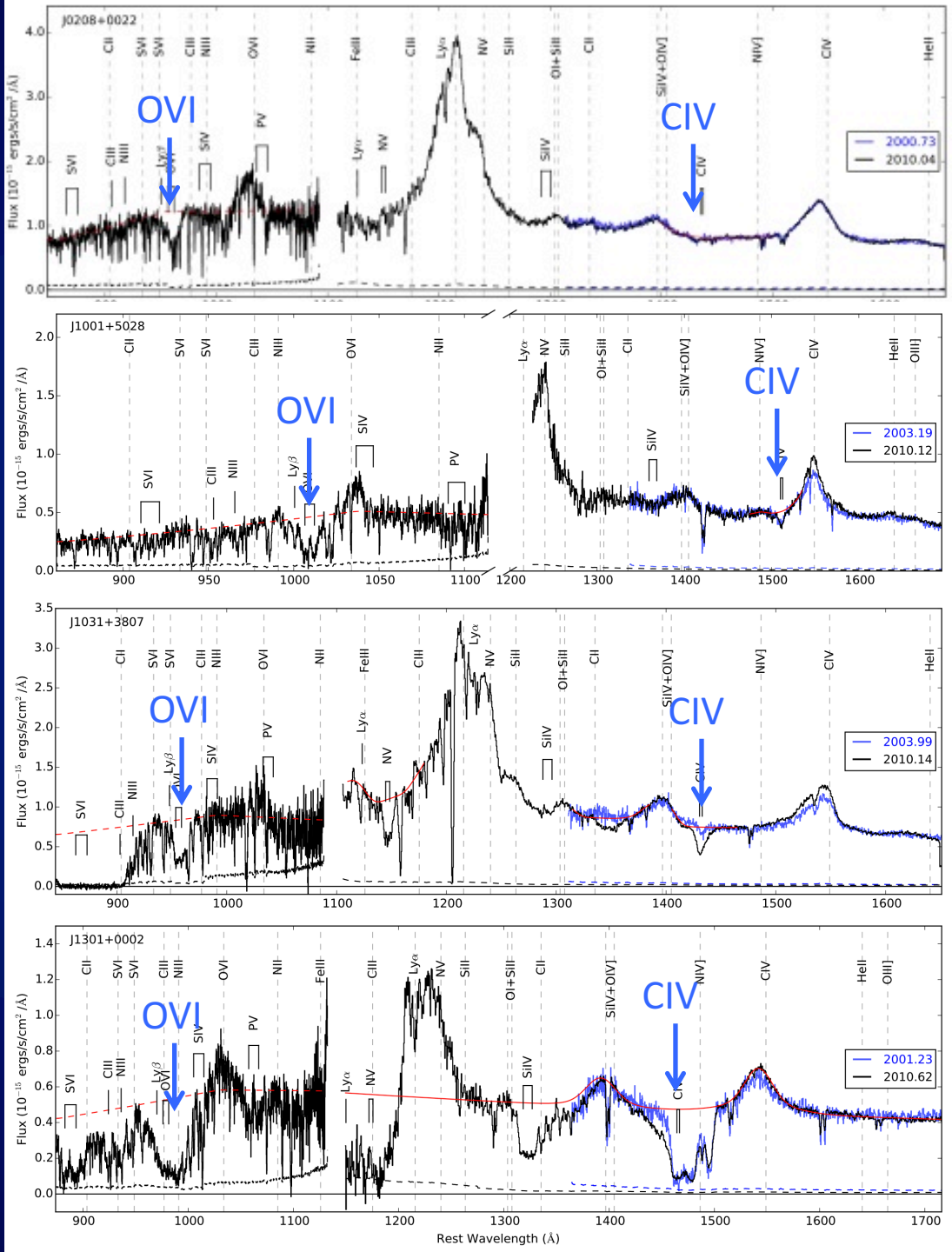
Moravec+17

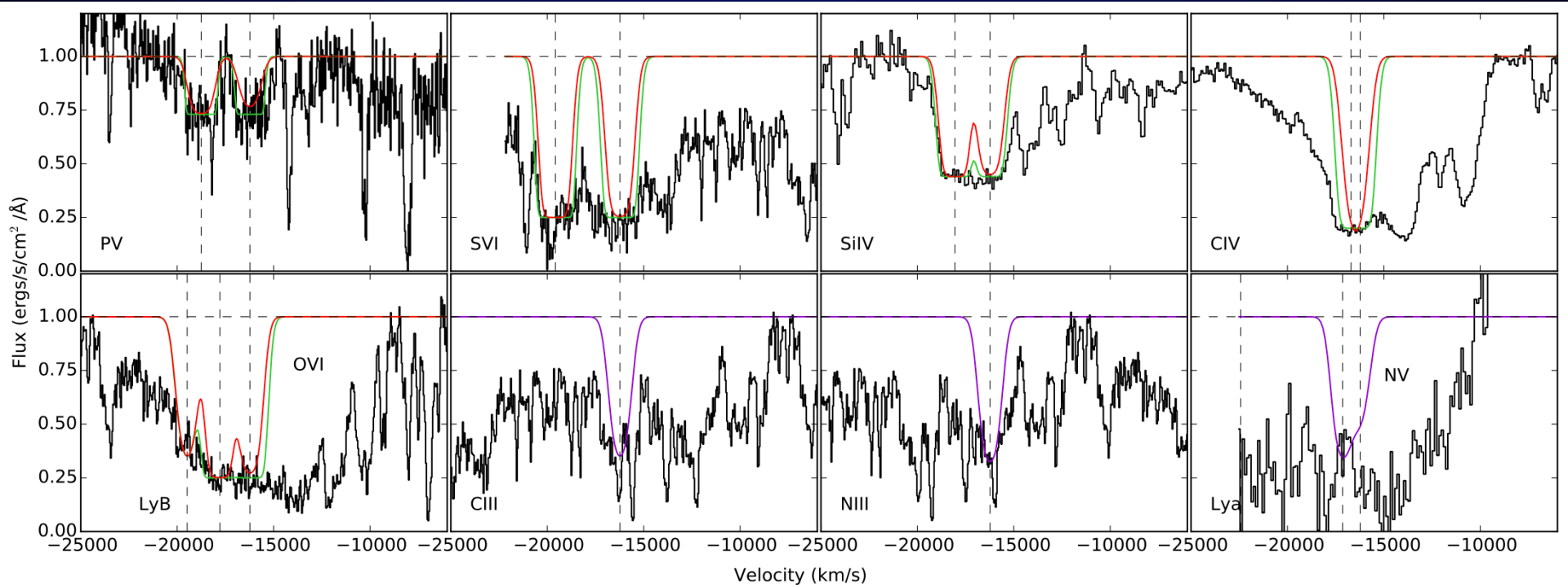
OVI >= CIV

1:1 ratios in OVI

All varied in < 1.9 yrs

PV mini-BAL
embedded in a BAL



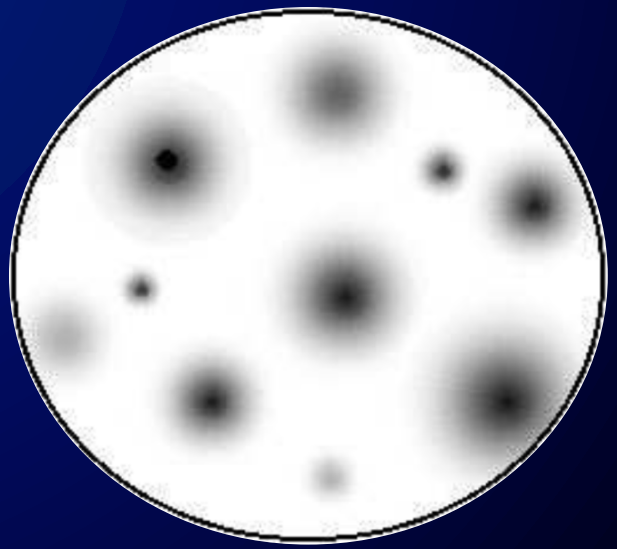


PV mini-BAL in a BAL outflow:

v = 16230 km/s, b = 600 km/s, $\tau > 3$, $C_0 = 0.27$

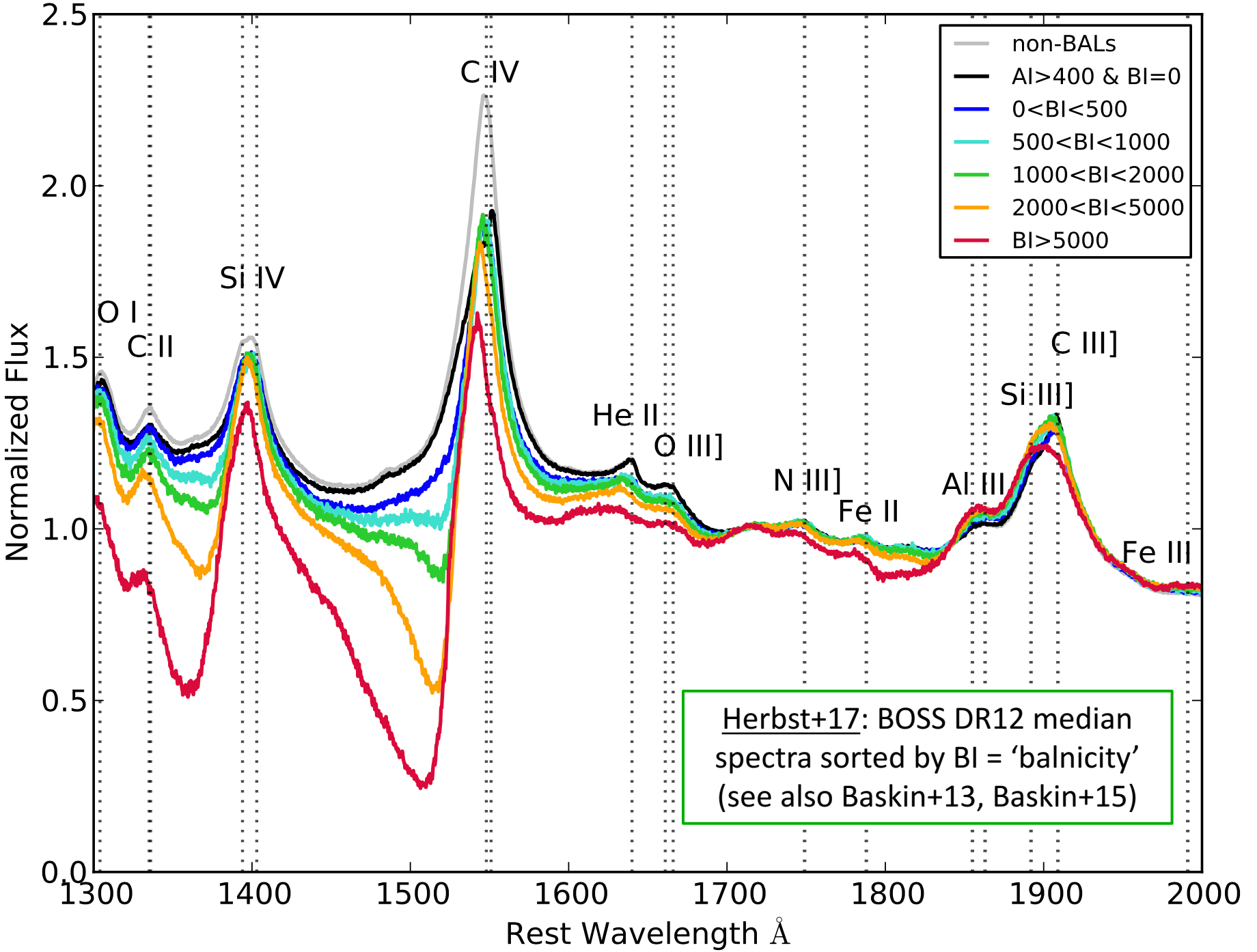
Move this fit to other lines to identify $\tau >> 1$ gas

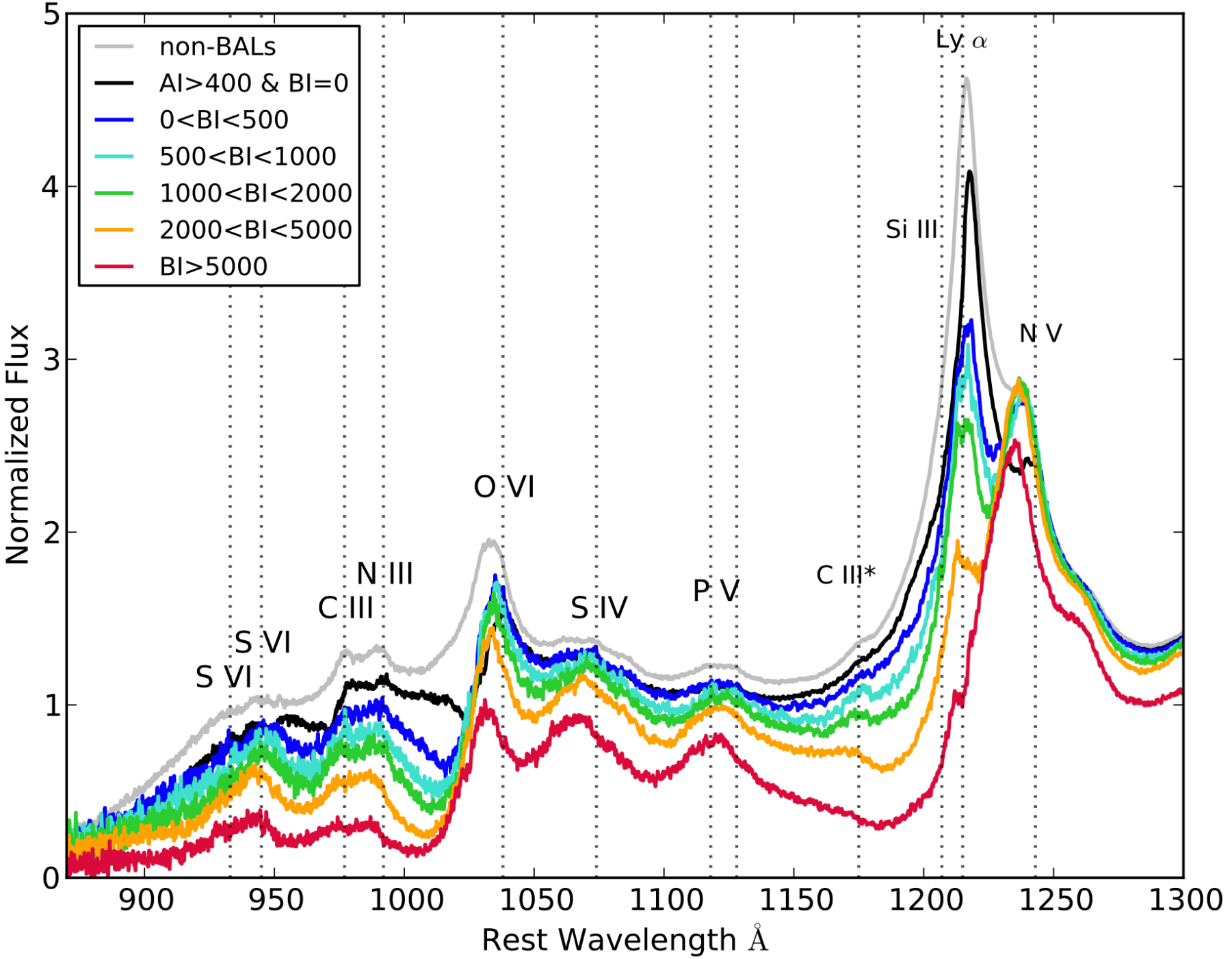
Range in covering factors: $0.27 < C_0 < 0.8$

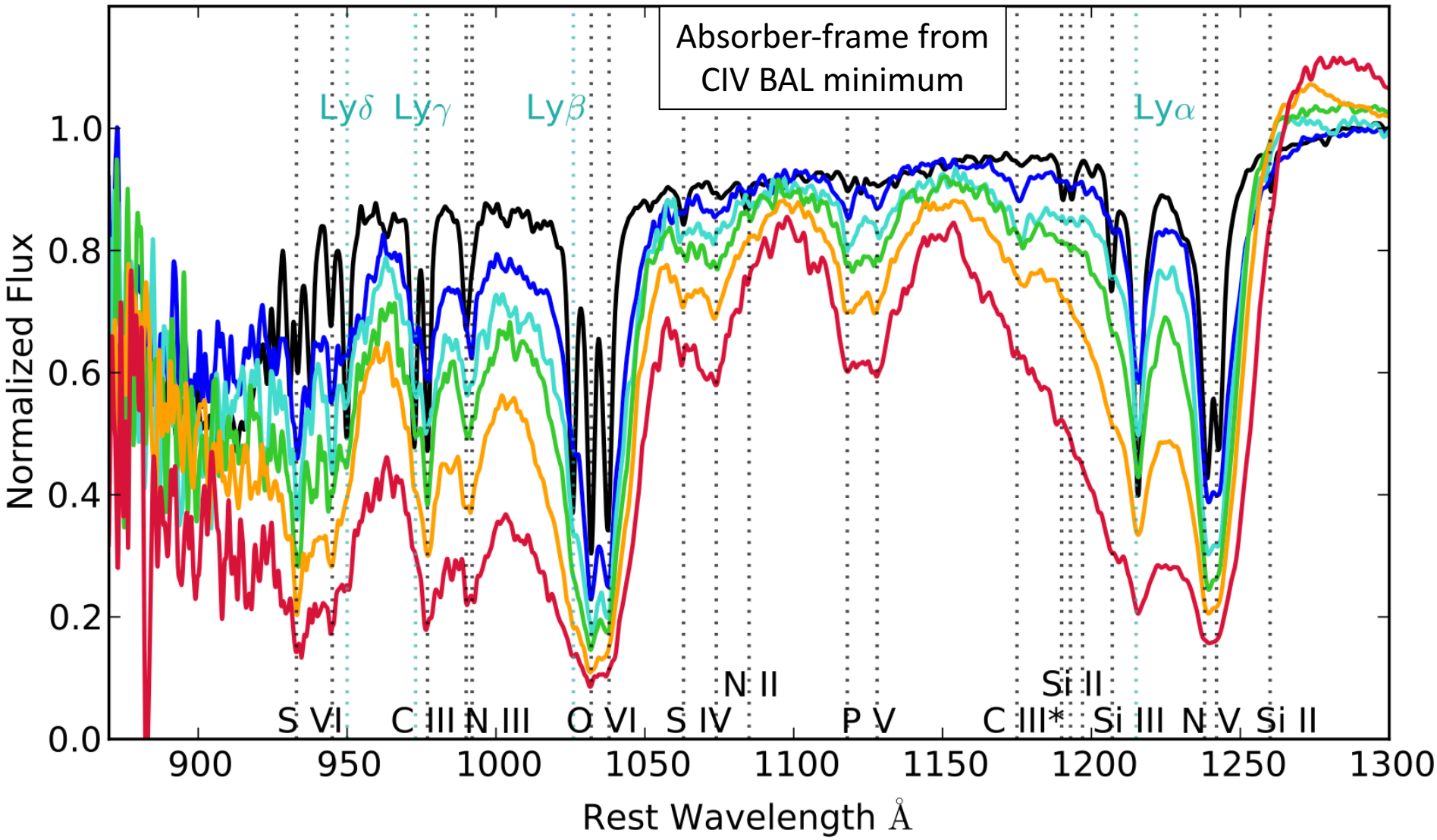


$N_H > 2 \times 10^{22}$ cm^{-2} (based on PV, solar P/H, Leighly+11)

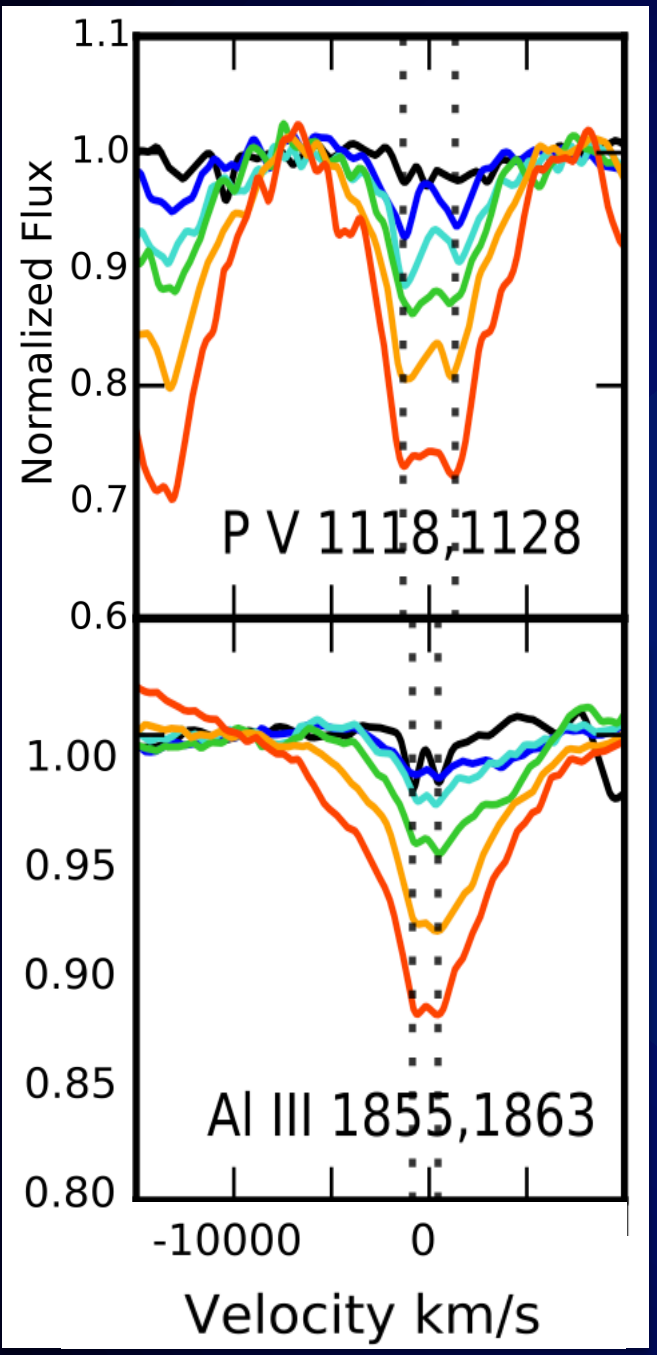
If R ~ 2 pc (from variability) -> L_K ~ 0.7% L_{bol}


non-BALs
AI>400 & BI=0
0<BI<500
500<BI<1000
1000<BI<2000
2000<BI<5000
BI>5000
O I
C II
Si IV
C IV
He II
O III]
N III]
Fe II
Al III
Si III]
C III]
Fe III
Herbst+17: BOSS DR12 median spectra sorted by BI = 'balnicity' (see also Baskin+13, Baskin+15)
Normalized Flux
Rest Wavelength Å
0.0
0.5
1.0
1.5
2.0
2.5
1300
1400
1500
1600
1700
1800
1900
2000


non-BALs
AI>400 & BI=0
0<BI<500
500<BI<1000
1000<BI<2000
2000<BI<5000
BI>5000
Normalized Flux
Rest Wavelength Å
Ly α
Si III
N V
O VI
N III
C III
S VI
S VI
S IV
P V
C III*
0
1
2
3
4
5
900
950
1000
1050
1100
1150
1200
1250
1300


Absorber-frame from
CIV BAL minimum
Lyδ
Lyγ
Lyβ
Lyα
S VI
C III
N III
O VI
S IV
N II
P V
C III*
Si II
Si III
N V
Si II
Normalized Flux
Rest Wavelength Å
0.0
0.2
0.4
0.6
0.8
1.0
900
950
1000
1050
1100
1150
1200
1250
1300

Herbst+17

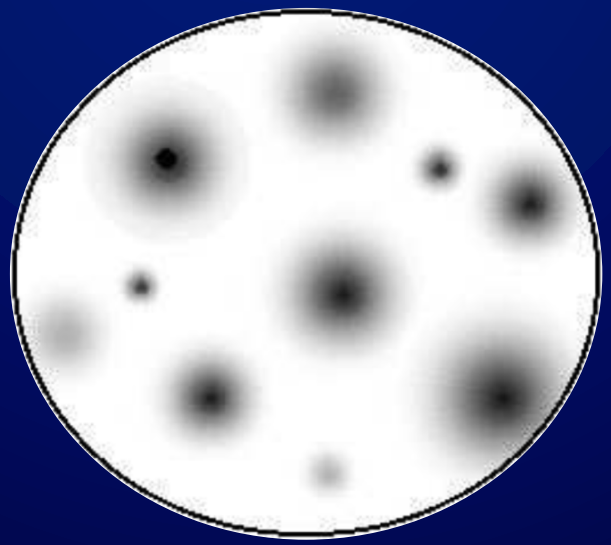


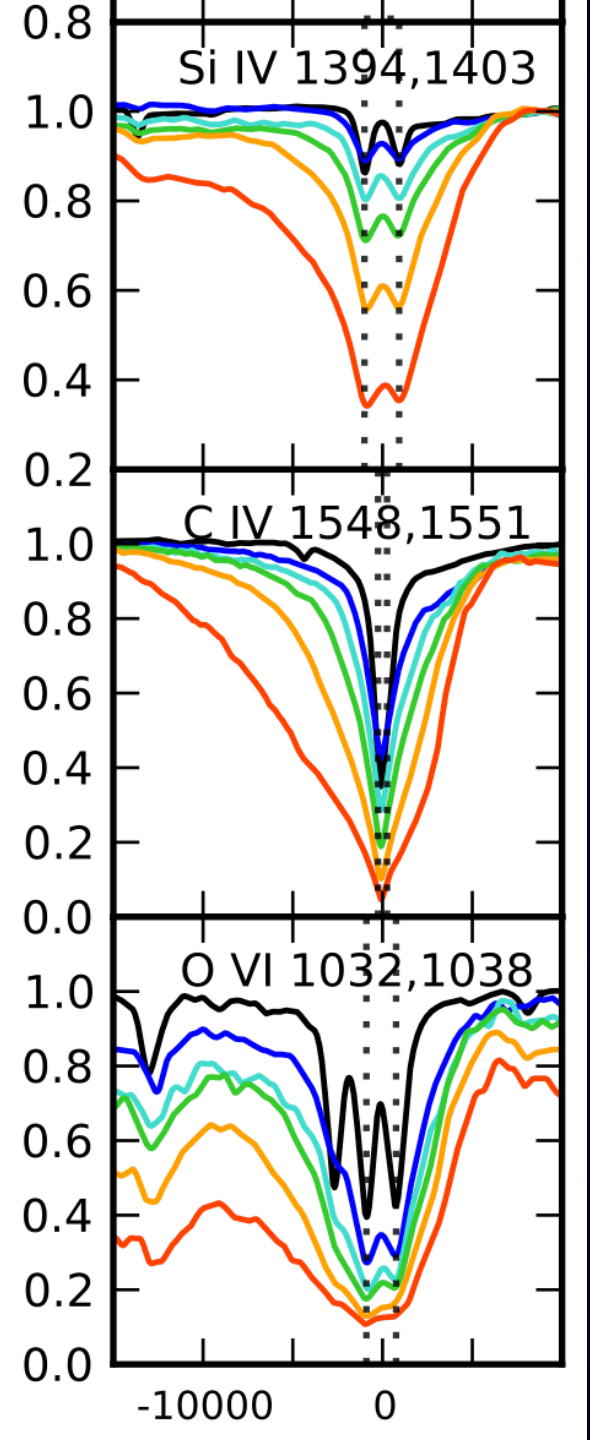
PV is present in all BAL (BI > 0) composites

Median 1:1 doublet ratios regardless of BAL strength

$\tau >> 1$

BAL strength is mostly LOS covering fraction (projected area with $\tau > 1$) not column density





Column densities & energetics:

$$M \approx 4100 \left(\frac{Q}{15\,\text{per cent}}\right)\left(\frac{N_H}{2\times10^{22}\,\text{cm}^{-2}}\right)\left(\frac{R}{3.5\,\text{pc}}\right)^2 \text{M}_\odot,$$

$$K \approx 4\times10^{54}\left(\frac{M}{4100\,\text{M}_\odot}\right)\left(\frac{v}{10\,000\,\text{km s}^{-1}}\right)^2 \text{erg.}$$

$L_K \propto R * v^3$

Bottom line from PV analysis:

N_H > few x 10^{22} cm^{-2} (in ionized gas) is typical, even for weak BALs

Even at "small" pc-scale distances: 0.2% < L_K < 2% L_{bol} for BAL outflows with PV

Herbst+17

PDS 456

z = 0.184
L ~ 10^{47} ergs/s

X-ray UFO (Reeves+16):
v ~ 0.25-0.31c
log $N_H(cm^{-2})$ > 23
log ξ > 5

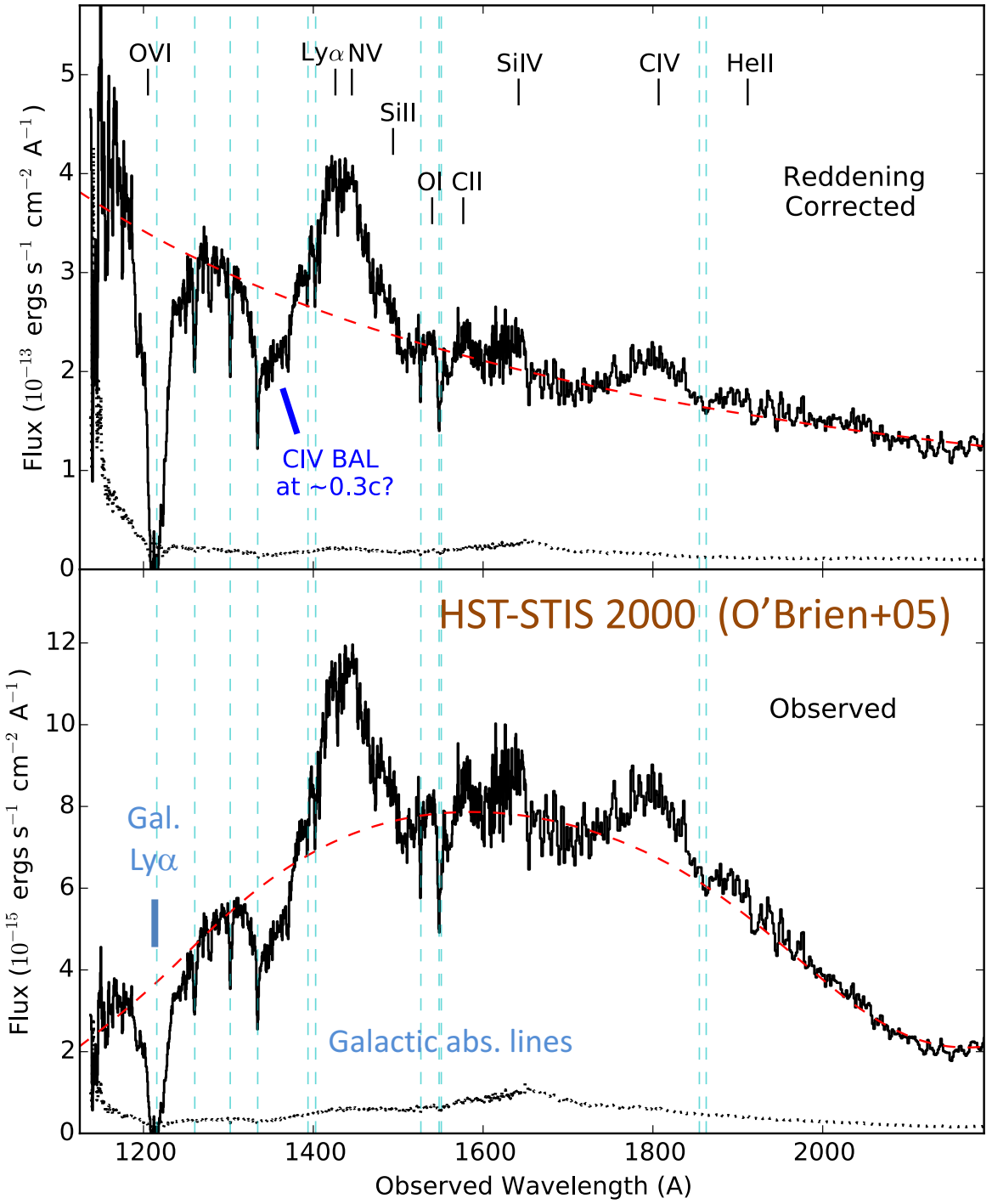
UV BAL identified as Lyα at
v ~ 18,000 km/s

…is probably CIV at ~0.3c

Problems with Lyα:

- Lyα-only is unprecedented
known BALs have
OVI >= CIV > Lyα

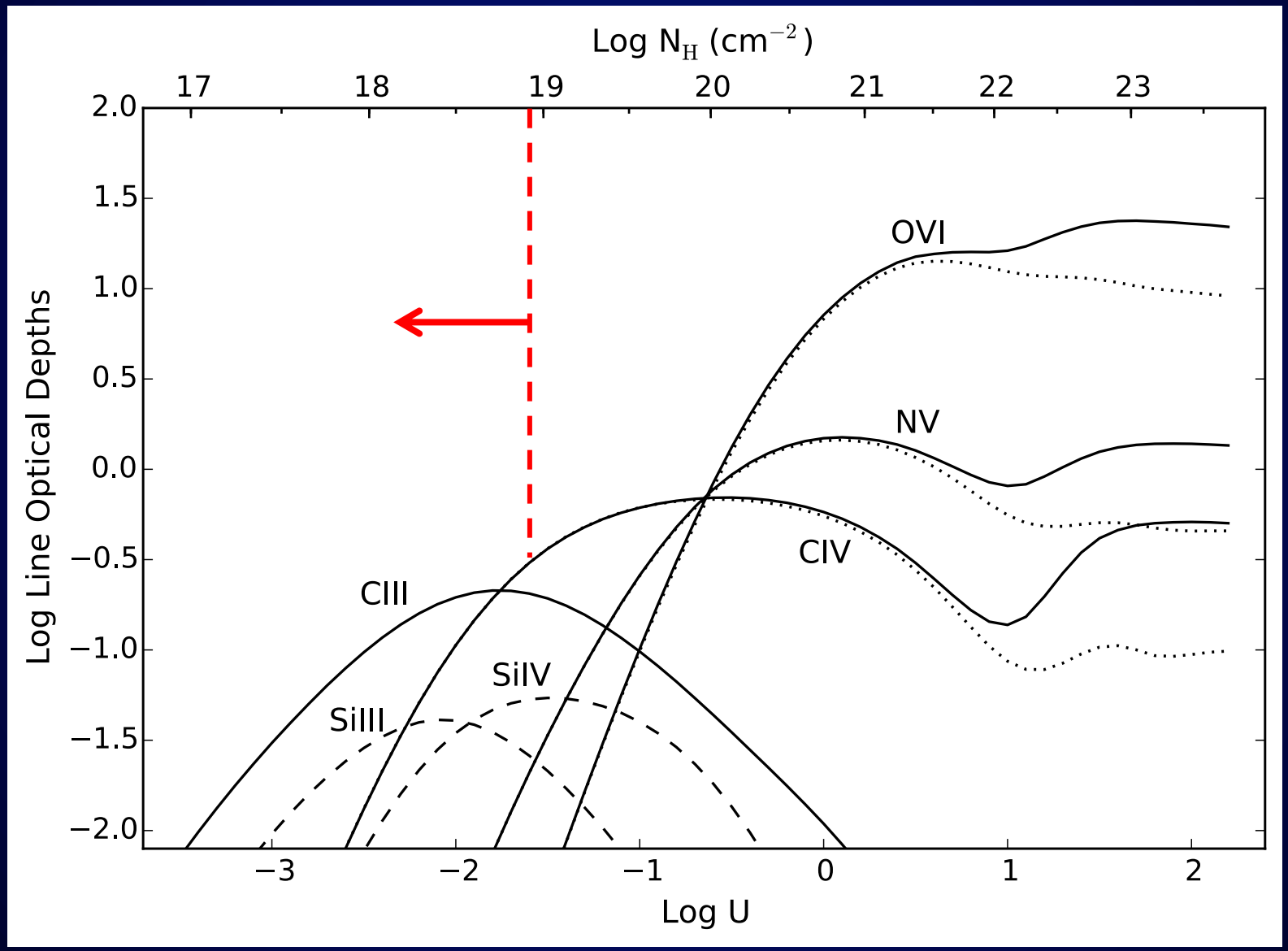
- Where is CIV at
v ~ 18000 km/s?



Predicted BAL tau's (Cloudy) for clouds with log N_{HI} (cm^{-2}) = 15.2

Lyα-only BAL would require unusually low U and N_H

Cloudy13
(Ferland+13)



PDS 456: 2000 (red) vs 2014 (black)