Quasar Outflow Properties from UV/Optical Spectroscopy

Fred Hamann
University of California, Riverside

Hanna Herbst
Dan Capellupo
Emily Moravec
Paola Rodriguez Hidalgo

Isabelle Paris
George Chartas
James Reeves
Emanuele Nardini
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 $\sim$ 570 km/s
$v \sim$ 22,000 km/s

FWHM $\sim$ 2100 km/s
$v \sim$ 40,000 km/s

FWHM $\sim$ 1250 km/s
$v \sim$ 35,000 km/s

FWHM $\sim$ 2600 km/s
$v \sim$ 48,000 km/s

Rodriguez Hidalgo+08
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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 \sim 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 \( P/C \sim \) solar, then
\[ \tau(CIV) > \sim 1000 \, \tau(PV) \gg 1 \]

Different depths in different lines, all with \( \tau \gg 1 \)

Inhomogeneous partial covering

(Hamann+01,04, Arav+05)

Capellupo+17


**Column densities & Energetics:**

Assume ~solar abundances for \( N_H \) constraints

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

Covering factor in PV: \( \sim 85\% \), Velocities: \( \sim 5000 \text{ km/s} \)

If \( R \sim 3 \text{ pc} \) (from variability with evidence for \( \tau >> 1 \)) and \( Q \sim 15\% \)

then \( \frac{dM}{dt} > 12 \text{ Mo/yr} \) and \( L_K > 4 \times 10^{44} \text{ ergs/s} \sim 2\% L_{\text{bol}} \)

\( \Rightarrow \) Is this common?  

Capellupo+17
BALs to mini-BALs
Moravec+17

OVI $\geq$ 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:

\[
\begin{align*}
\nu &= 16230 \text{ km/s}, \\
\beta &= 600 \text{ km/s}, \\
\tau &> 3, \\
C_0 &= 0.27
\end{align*}
\]

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

Range in covering factors: \( 0.27 < C_0 < 0.8 \)

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

If \( R \sim 2 \text{ pc} \) (from variability) \( \Rightarrow L_K \sim 0.7\% L_{\text{bol}} \)
Herbst+17: BOSS DR12 median spectra sorted by $\text{BI} = \text{`balnicity'}$
(see also Baskin+13, Baskin+15)
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:

\[
M \approx 4100 \left( \frac{Q}{15 \text{ per cent}} \right) \left( \frac{N_H}{2 \times 10^{22} \text{ cm}^{-2}} \right) \left( \frac{R}{3.5 \text{ pc}} \right)^2 M_\odot,
\]

\[
K \approx 4 \times 10^{54} \left( \frac{M}{4100 M_\odot} \right) \left( \frac{\nu}{10000 \text{ km s}^{-1}} \right)^2 \text{ erg}.
\]

Bottom line from PV analysis:

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

Even at “small” pc-scale distances: \(0.2\% < L_K < 2\% L_{\text{bol}}\) for BAL outflows with PV.
PDS 456

\[ z = 0.184 \]
\[ L \sim 10^{47} \text{ ergs/s} \]

**X-ray UFO (Reeves+16):**
\[ v \sim 0.25-0.31c \]
\[ \log N_H (\text{cm}^{-2}) > 23 \]
\[ \log \xi > 5 \]

UV BAL identified as Ly\(\alpha\) at
\[ v \sim 18,000 \text{ km/s} \]
...is probably CIV at \(\sim 0.3c\)

**Problems with Ly\(\alpha\):**
- Ly\(\alpha\)-only is unprecedented
  known BALs have
  OVI \(\geq\) CIV \(\geq\) Ly\(\alpha\)
- Where is CIV at
  \[ v \sim 18000 \text{ km/s} \]
Predicted BAL tau’s (Cloudy) for clouds with \( \log N_{\text{HI}} \) (cm\(^{-2}\)) = 15.2

Ly\(\alpha\)-only BAL would require unusually low \( U \) and \( N \) and \( H \)

Cloudy13
(Ferland+13)
PDS 456: 2000 (red) vs 2014 (black)