Narrow (UV) Absorption Line
Outflows from Quasars

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Outflow Features:

Broad Absorption Lines (BALs)

Observed in 10-23% of optically-selected quasars

Probably present in all quasars (with ~10-23% covering)

Measured flow speeds: a few to >30,000 km/s

$\text{FHWM} / v \sim 1$

Possibly large mass loss rates
Narrow Absorption Lines (NALs):

1) Quasar outflows
2) Intervening gas or galaxies
3) Mass-loaded quasar flows
4) Starburst-driven winds
5) Ambient halo gas
6) Merger remnants

Where do NALs form?

At \( v < 1000 \text{ km/s} \):

- 3) Mass-loaded quasar flows
- 4) Starburst-driven winds
- 5) Ambient halo gas
- 6) Merger remnants

How can we find NALs in quasar-driven outflows??
Measure all NALs in ~2200 SDSS quasars

Huge excess at low v.

NALs at v < 1000 might be “environmental” (host halos, starburst-driven winds)

Assume all lines at very high v are unrelated/intervening

Others must be quasar outflows!

>50% of NALS from 2000-8000 km/s are outflows

14% of quasars have at least one narrow outflow line

How can we identify individual outflow NALs?

But strong lines only, some higher v NALs are in outflows (Simon talk):

⇒ True outflow fractions are larger
Outflow NALs at 9700-14,000 km/s (in R~70,000 to 100,000 spectra, Keck, VLT)

These 5 CIV doublets (A-E) form in a quasar outflow,

Surrounded here by (probably) unrelated intervening lines

QSO: z ~ 2.3, L ~ 8x10^{47} ergs/s, L/L_E ~ 0.4

Hamann et al. 2011
Formation in a quasar-driven outflow confirmed by:

1) Line variability

2) Smooth “broad” (very super-sonic) line profiles

3) Partial covering of the continuum source

→ “Intrinsic” at speeds much too high for “environmental” gas.

Hamann et al. 2011
NAL outflow properties:
- Outflow speeds ~ 9700 – 14,000 km/s
- FWHMs ~ 62 – 164 km/s
- Coordinated variability in 5 distinct systems (<0.63 yr rest)
- NAL strength changes commensurate with covering factor changes (~0.35 to 0.2 in CIV)

Hamann et al. 2011
Partial Covering

Lines can be saturated (1:1 doublet ratios) but not “black” if the absorber only partially covers the background light source.

Requires *small* structures: < 0.01 pc for partial covering of the continuum source.

*Suggests* a location near the continuum source.

Often goes with line variability and smooth “broad” profiles.

→ Quasar outflows
OVI stronger and broader than CIV, and less variable, in all 5 systems.

Lower ions not detected.
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Lower ions not detected

Altogether:

Five distinct flow structures with similar:
kinematics, sizes, ionizations, locations?
Coordinated changes suggest global changing ionization

No acceleration, < 3 km/s/yr → coasting freely >~ 5 pc from SMBH

Short survival times → within ~5 pc of origin (quasar)

Max distance ~1 kpc (recombination time)

Line-lock in A-B-C → driven by radiation pressure, moving directly toward us (w/in 16°)

Hamann et al. 2011
Changing ionization can change the covering fraction, without motion, if the absorber is inhomogeneous.
Observed wavelength (Å)

- Total $N_H \sim 5 \times 10^{19}$ cm$^{-2}$ in all 5 systems
- Kinetic energy too small by $\geq 100x$ for “feedback”
- Metallicity $\sim 2x$ solar $\rightarrow$ consistent with merger-starburst-quasar evolution sequence

NAL outflow properties:

Hamann et al. 2011
These outflow NALs are \(~100\times\) narrower and weaker than BALs, but with the same speeds, same ionization.

Also negligible X-ray absorption

(Just et al. 2007; also Chartas et al. 2009, Gibson et al. 2010)

BALs come with \textit{strong} X-ray absorption

(Gallagher et al. 2002, 2006)

Possibly enough to “shield” UV absorber downstream

Possibly \textit{needed} to moderate ionization and radiatively drive BAL gas
Is this geometry correct?

The radiative (x-ray) shield might be necessary to moderate the ionization and allow radiative acceleration of BAL gas…

But what about the NAL and mini-BAL outflows?
How are NAL flows driven without a radiative (x-ray) shield?

Curved trajectories? But what is the vertical force? And why do NAL clouds keep moderate BAL-like ionizations after leaving the shielded BAL environment?

(Radiative shielding is difficult, and maybe not important.)
1-D radiative shields will produce strong absorption lines (at $\nu \sim 0$) unless they are highly ionized, but then they are not useful shields!

Opaque shields in stratified geometries need spatial tuning.
In any case, no x-ray absorption in NAL and mini-BAL outflows.

In our luminous quasar, moderate ionization at $r \sim 5$ pc requires $n_H \sim 10^8$ cm$^{-3}$

Which means the flow is in *tiny* sub-structures with size $\Delta r \sim N_H/n_H \sim 10^{11}$ cm!

Even at $r \sim 1$ kpc, $\Delta r < 10^{15}$ cm and $\Delta r/r < < 10^{-6}$
Is this geometry correct? (Are these global covering fractions?)

NALs: Simon et al. 2011, Nestor et al. 2008, Misawa et al. 2007
Mini-BALs: Rodriguez Hidalgo 2008
BALs: Hewett et al. 2003

~72% of quasars have a quasar-driven outflow line

Decreasing $N_H$, $M_W$ xray abs.
Is this geometry correct?

Is there evolution: FeLoBAL $\rightarrow$ BAL $\rightarrow$ mini-BAL $\rightarrow$ NAL ??

Low $\rightarrow$ High ionization (more $\rightarrow$ less reddening) ??

What about extended & multi-component flows (diff. structures, same los)?
This mini-BAL with FHWM $\sim 1200$ km/s is accompanied by NALs with FWHM $\sim 150$ km/s.

The whole complex is variable.

Simon et al. 2011

Plot above shows 9 CIV doublets, likely to be an outflow complex (partial covering, broad smooth profiles)
Outflow complexes like this (CIV – partial covering in red) might form on galaxy scales.

High speeds → launch near the quasar, not the mass loaded galaxy-wide “blowout”…

Maybe quasar ejecta mixed with “shreds” from ISM clouds

In this simulation (Hopkins & Elvis 2010) a hot fast flow creates pressure dips and instabilities that shred a cool dense ISM cloud
Conclusions:

- Quasar-driven NAL (and mini-BAL) flows appear at same speeds and ionizations as BAL flows, but ~100 times weaker/narrower.

- NAL flows are a common/important part of the outflow phenomenon (43% of quasars compared to ~23% for BALs, 6% for mini-BALs)

- Wide range in kinematic properties (Simon talk), possibly locations: rich narrow complexes, single lines, FWHMs merging with “mini-BALs”

- Probably not (or less) energetically important (for feedback)

- What is the geometry/relationship to BAL and mini-BAL flows?

- Moderate ionizations near the quasar, without a shield, require high densities and tiny sub-structures ($\Delta r/r < < 1$)

- Shielding not needed for radiative acceleration.