High-Velocity Narrow-Line Absorbers in QSOs

F. Hamann, T. Barlow, R.D. Cohen, V. Junkkarinen & E.M. Burbidge
Center for Astrophysics & Space Sciences, University of California –
San Diego, La Jolla, CA, 92093-0424

Abstract. We discuss the identification and kinematics of intrinsic narrow-
line absorbers in three QSOs. The line-of-sight ejection velocities in the
confirmed intrinsic systems range from \( \sim 1500 \text{ km s}^{-1} \) to \( \sim 51,000 \text{ km s}^{-1} \).
The ratio of ejection velocity to line width, \( V/\Delta V \), in these systems
ranges from \( \sim 3 \) to \( \sim 60 \), in marked contrast to the BALs where typically
\( V/\Delta V \sim 1 \). We speculate on the possible relationship between the BAL
and narrow-line absorbers. Like the BALs, intrinsic narrow-line systems
appear to be rare, but the outflows that cause them might be common if
they cover a small fraction of the sky as seen from the QSO.

1. Introduction

We are involved in a program to identify and study the intrinsic absorption-line
systems in QSOs using spectra from the Hubble Space Telescope (HST) and the
Keck and Lick Observatories. The well-known broad absorption lines (BALs)
detected in roughly 10–15% of QSO spectra clearly form in high-velocity outflows
from the QSOs. However, the location of narrow-line absorbers in QSO spectra
must be examined on a case-by-case basis. Narrow-line systems could form (1)
in ejecta or infall very near the QSO engine, (2) in the extended host galaxy of
the QSO, (3) in a nearby cluster galaxy, or (4) in cosmologically intervening gas.
We will refer to the category (1) systems (which include the BALs) as intrinsic
and all others as intervening. In this proceedings we discuss the identification
and kinematics of intrinsic narrow-line absorbers in three radio-quiet QSOs:
PG 0935+417 (\( z_s = 1.966 \)), UM 675 (\( z_s = 2.150 \)) and Q 2343+125 (\( z_s = 2.515 \)).
Some results on the ionization and metal abundances in these and other intrinsic
systems are presented in our accompanying paper (by Hamann et al.) in this
volume.

2. Observational Results

Figure 1 compares two spectra of PG 0935+417 obtained at Lick in 1993 and
1996 with roughly 220 km s\(^{-1}\) resolution. Both observations show strong \( z_d \approx z_e \)
lines plus a relatively broad absorption feature near 3870 Å. The broad feature
varied significantly between the two measurements. We attribute the \( \sim 3870 \text{ Å} \)
feature to extremely high-velocity C IV based on probable detections of corre-
sponding N V and O VI absorption in HST spectra (not shown) and because
Figure 1. Lick-KAST spectra of PG 0935+417. The $z_a \approx z_e$ lines are labeled above and the high-velocity C IV feature is labeled below. The 1996 data are scaled to match the 1993 flux (in $10^{-15}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$) at 4200–4400 Å.

Figure 2. Keck-HIRES spectra of PG 0935+417 (from Feb. 1996) showing C IV lines in the $z_a \approx z_e$ (top panel) and high-velocity systems (lower) on velocity scales relative to the emission redshift for 1548.20 Å. The lower panel also shows the 1993 Lick data for comparison.
an identification with blueshifted Si iv is ruled out by the absence of C iv absorption at \( \sim 4300 \) Å. Figure 2 shows Keck observatory spectra at \( \sim 7 \) km s\(^{-1}\) resolution of C iv in the \( z_a \approx z_e \) and broad high-velocity systems. The Keck data (from Feb. 1996) show that the \( z_a \approx z_e \) absorber (upper panel in Fig. 2) can be regarded as two systems with dramatically different line profiles and at least three components in each system. The high-velocity C iv absorber (lower panel) is shifted \( \sim 51,000 \) km s\(^{-1}\) from the emission redshift and maintains a smooth profile at high resolution. (The high-velocity feature spans more than one Keck-HIRES echelle order and its profile is forced to match the March 1996 Lick data in this plot.)

Figure 3 shows Keck and other spectra of intrinsic lines in UM 675 and Q 2343+125 (see also Hamann et al. 1995, 1997a and 1997b). Both systems are dominated by relatively broad components (FWHM \( \sim 450 \) km s\(^{-1}\)) that varied considerably between observations and are well-resolved at the 7–9 km s\(^{-1}\) resolution of these Keck data. Much narrower lines (labeled in the figure) are also present in both systems. For UM 675, the figure compares Keck-HIRES spectra of several \( z_a \approx z_e \) lines measured in September 1994 to observations by Sargent, Boksenberg & Steidel (1988) obtained at Palomar observatory in November 1981. For Q 2343+125, the figure compares two Keck observations (September 1994 and October 1995) of high-velocity C iv lines with data obtained at Palomar by Sargent et al. (1988) in October 1984. N v, Si iv and possibly Ly\( \alpha \) are also detected in this system (see Hamann et al. 1997b). The absence of narrow lines in the ratio of the two Keck spectra of Q 2343+125 shows that these components did not vary.

### 3. Evidence for Intrinsic Absorption

Barlow & Sargent (1997) and Hamann et al. (1997a) recently summarized observational signatures that can distinguish intrinsic from intervening absorption-line systems (also Barlow et al. this volume). These signatures include (1) time-variable line strengths, (2) partial line-of-sight coverage of the background light source(s), and (3) absorption-line profiles that are broader and smoother than intervening systems when measured at high spectral resolutions (cf. Blades 1988). The line-of-sight coverage fraction can be derived from multiplet ratios whose relative optical depths (proportional to \( f\lambda \)) are known from atomic physics. Partial coverage weakens the absorption troughs and leads to multiplet ratios closer to unity than expected from the measured depths of the lines. For doublets with \( f\lambda \) ratios of \( \sim 2 \), such as C iv and N v, the coverage fraction, \( C_f \) (0 \( \leq C_f \leq 1 \)), at any velocity in the profiles is given by,

\[
C_f = \frac{I_2^1 - 2I_1^1 + 1}{I_2^2 - 2I_1^2 + 1}
\]

where \( I_1 \) and \( I_2 \) are the residual intensities in the weaker and stronger doublet lines, respectively, normalized by the continuum intensity (also Hamann et al. 1997a; Barlow & Sargent 1997). Note that the coverage fraction includes both direct and scattered sources of radiation; values of \( C_f < 1 \) might result from complete coverage along direct lines-of-sight but zero coverage of the scattered flux (see papers on polarization in this volume).
Figure 3. Multi-epoch observations of intrinsic absorption lines in UM 675 (left panels) and Q 2343+125 (right) on velocity scales relative to the emission redshifts (appropriate for 1548.20 Å in C IV, etc.).

The dominant broad line components in UM 675 and Q 2343+125 are clearly intrinsic because they meet all three criteria above. Their time-variability and broad and smooth profiles are evident from Figure 3. We estimate coverage fractions at the center of the broad C IV profiles of $\sim 50\%$ in UM 675 and $\leq 20\%$ in Q 2343+125 (also Hamann et al. 1995, Hamann et al. 1997a and 1997b). The status of the much narrower lines in these QSOs is unknown. In Q 2343+125, the fact that the narrow C IV lines did not vary with the broad components indicates that the narrow features form in a physically distinct region. In UM 675, the narrow systems blended with the broad lines are probably intrinsic and related to the broad-component gas because (1) their profiles are still broader than typical intervening systems and (2) the doublet ratio in the strongest narrow-line system (labeled ‘A’ in Figure 3) indicates partial coverage ($C_f < 50\%$).

We also identify 2 of the 3 systems mentioned above for PG 0935+417 (Figs. 1 and 2) as intrinsic. The high-velocity C IV feature (at $\sim 51,000$ km $s^{-1}$) is time-variable and has a much broader and smoother profile than “known” intervening absorbers. We cannot estimate the coverage fraction for this system because the absorption feature is much wider than the doublet separation. The $z_a \approx z_e$ system at roughly $-2800$ km $s^{-1}$ is also intrinsic based on its relatively broad profiles, partial line-of-sight coverage, and a possible change in the absorption depth near $\sim 3000$ km $s^{-1}$ (from a second Keck-HIRES spectrum not shown). We estimate $C_f \leq 75\%$ near the line centers of the 3 components in this system. The origin of the narrower $z_a \approx z_e$ lines at roughly $-1600$ km $s^{-1}$ in PG 0935+417 is uncertain; they showed no evidence for variability, their coverage fractions are
consistent with unity, and the narrow profiles are consistent with intervening absorption.

4. **Outflow Kinematics and Morphologies**

The line-of-sight ejection velocities in the systems discussed here range from roughly 1500 km s\(^{-1}\) in UM 675 to 51,000 km s\(^{-1}\) in PG 0935+417. These outflow velocities span the same range as BALs measured in other spectra, but in BALs the ratio of line centroid velocity to line width \(V/\Delta V\) is typically of order unity (Weymann \textit{et al.} 1991). Here we find \(V/\Delta V\) ranging from \(\sim 3\) in UM 675 to \(\sim 60\) in Q 2343+125. The system at \(-51,000\) km s\(^{-1}\) in PG 0935+417 has \(V/\Delta V \sim 34\). These large \(V/\Delta V\) ratios require either (1) a highly-collimated steady flow that crosses our line-of-sight to the emission source(s) and thereby reveals only part of its full velocity extent, or (2) discrete “blobs” that might arise, for example, from episodic ejection events. The line widths, while much narrower than BALs, are still many times larger than the thermal speeds (\(<5\) km s\(^{-1}\) for carbon at a temperature of \(<20,000\) K). Therefore the absorbers have a range of non-thermal line-of-sight velocities and they cannot be single, coherently moving clouds. For any geometry where the absorbers are moving along our line-of-sight to the continuum source(s), the finite line widths imply that the absorbing regions are radially expanding or contracting or have some other large internal motion such as turbulence.

Whatever flow geometry obtains, the measured ions (from H\(^i\) and Si\(^{iv}\) to C\(^{iv}\), N\(^v\) and O\(^{vi}\) in different sources) always appear at the same velocity (within the uncertainties). Evidently, the ionization structures are not highly stratified in velocity. Another constraint is the lack of acceleration in the Q 2343+125 absorber. Figure 3 shows that this system shifted by \(<100\) km s\(^{-1}\) in 3.1 yrs in the QSO rest frame (11 years observed). In contrast, the centroid of the extreme high-velocity absorber in PG 0935+417 shifted by roughly +900 km s\(^{-1}\) in 1 yr in the QSO rest frame. However, the complex variation in that absorption profile suggests that the apparent shift was caused by changes in the optical depth structure rather than acceleration of the gas.

5. **Discussion**

We have not (yet) conducted a systematic survey for intrinsic narrow-line absorbers in QSOs, but one is clearly needed to understand the frequency of these systems, the range of their kinematics and physical conditions, and their possible relationship to the BALs and other QSO properties such as radio loudness and soft X-ray absorption. It is important to keep in mind that narrow metal-line systems that do not show any of the signatures of intrinsic absorption (§3) might be intrinsic nonetheless. It is our experience from inspection of moderate-resolution absorption-line survey spectra, such as Sargent \textit{et al.} (1988), that high-velocity systems with line widths above a few hundred km s\(^{-1}\) (as in PG 0935+417 and Q 2343+125) do not occur in more than a few percent of QSOs. Nonetheless, these absorbers might be ubiquitous in QSOs if, like the BAL gas, they cover only a small fraction of the sky as seen from the central QSO. It is also our experience, based on PG 0935+417, Q 2343+125, and one other QSO not shown
here (Q 0151+048), that the broader high-velocity systems are extremely variable; we detected substantial changes in our first two observations of each of these systems. Jannuzi et al. (1996) reported HST observations of a system that appears similar to the high-velocity absorber in PG 0935+417 – at roughly −56,000 km s\(^{-1}\) in the low-redshift QSO PG 2302+029. We expect that follow-up observations will show line-strength changes and confirm the intrinsic nature of that system. Since velocities above 50,000 km s\(^{-1}\) are extremely rare among BALs, the existing data suggest that narrow-line intrinsic absorbers can reach these speeds much more readily.

Many narrow-line \(z_a \approx z_e\) systems are known in radio-loud quasars, but the three QSOs discussed here, plus Q 0151+048 and PG 2302+029 mentioned above, are all radio-quiet. Perhaps it is only systems with high velocities and/or relatively broad and smooth line profiles (i.e. “mini-BALs”) that are like the BALs in avoiding radio-loud sources. Are these systems related either physically or in an evolutionary sense to the BAL outflows? A physical connection is suggested by the several known cases where narrow-line intrinsic absorbers appear in the same spectrum as conventional BALs (e.g. Barlow et al. 1994; Wampler et al. 1995). There is evidence that some of the narrow-line \(z_a \approx z_e\) absorbers in radio-loud QSOs are also intrinsic (Barlow & Sargent 1997; Aldcroft et al. in this volume). How are those systems related to the BALs and intrinsic narrow-line systems in radio-quiet QSOs? Also, how are any of the intrinsic QSO absorbers related to the \(z_a \approx z_e\) systems in Seyfert 1 galaxies (see Crenshaw et al. this volume)? A better understanding will require more observations to test whether narrow-line intrinsic systems are characteristically different in QSOs/active galaxies with different redshifts, luminosities and radio properties.

Acknowledgments. This work was supported by NASA grants NAG 5-1630 and NAG 5-3234.

References

Barlow, T. A. & Sargent, W. L. W. 1997, AJ, 113, 136
Barlow, T. A. & Junkkarinen, V. T. 1994, BAAS, 26, 1339
Blades, J. C. 1988, in QSO Absorption Lines: Probing the Universe, eds. J.C. Blades, C. Norman, & D.A. Turnshek, (Cambridge: Cambridge Univ. Press), p. 147
Hamann, F., Barlow, T. A., Beaver, E. A., Burbidge, E. M., Cohen, R. D., Junkkarinen, V., & Lyons, R. 1995, ApJ, 443, 606
Hamann, F., Barlow, T. A., Junkkarinen, V. T. & Burbidge, E. M. 1997a, ApJ, 478, 80
Hamann, F., Barlow, T. A., & Junkkarinen, V. T. 1997b, ApJ, 478, 87
Jannuzi, B. T., et al. 1996, ApJ, L11
Sargent, W. L. W., Boksenberg, A., & Steidel, C. C. 1988, ApJS, 68, 539
Wampler, E.J., Chugal, N.N., Petitjean, P. 1995, ApJ, 443, 586
Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23