Partial Coverage and Time Variability of Narrow-Line Intrinsic QSO Absorption Systems

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Abstract.

It is possible to distinguish “intrinsic” absorption systems (gas clouds within the quasar environment) from “intervening” systems (gas clouds unrelated to the quasar phenomenon) by considering certain observational properties. We find that the most direct determinations of the intrinsic nature of a system are time variability and partial coverage of the background light source by the absorption region. Both of these conditions are unlikely to occur in intervening systems. We present Keck and HIRES data which demonstrate both these phenomena. We also summarize a list of several other observational properties which appear to be indicative of “intrinsic” systems.

1. Introduction

It is now clear that at least some of the narrow-line QSO absorption systems are caused by gas related to the quasar environment. We expect the majority of these systems to have absorption redshifts ($z_a$) close to the systemic redshift of the quasar (as determined from the quasar emission-line redshift, $z_e$), although intrinsic narrow lines have been found at outflow velocities ranging from near zero to more than 30,000 km s$^{-1}$. (e.g. Hamann et al. this volume.)

We can classify quasar absorption lines into three general categories: (1) “Intervening” systems which are due to gas clouds unrelated to the quasar that coincidentally fall along our line-of-sight to the quasar. These may be associated with the disks or haloes of galaxies or exist independent of galaxies in intergalactic space. (2) “Intrinsic” systems which are caused by gas related to the quasar environment and probably ejected outward from the quasar central engine. And (3) systems which are due to gaseous regions within the host galaxy of the quasar or within a galaxy cluster which contains the quasar. These latter absorbers may not be ejected from the quasar, but are still affected by the quasar luminosity and environment. Since such regions are within the gravitational well of the quasar galaxy, there is a bias for these clouds to intercept our line-of-sight as compared to intervening systems which are much more distant from the quasar.
The most obvious intervening systems are those with much smaller redshifts than the quasar \((z_a \ll z_e)\) where emission from a galaxy has also been detected near the same line-of-sight and is at the same redshift as the absorber. In contrast, the most obvious intrinsic systems are the so-called broad absorption-lines (BALs) in BALQSOs, which have large velocity widths \((\gtrsim 1,000 \text{ km s}^{-1})\) and always appear within 50,000 km s\(^{-1}\) of the emission line redshift. However, we require additional criteria in order to classify narrow absorption lines (less than a few hundred km s\(^{-1}\)) which have no identified galactic counterpart. Statistically, we know that most of these narrow line systems are intervening because the systems are distributed between \(z=0\) and \(z=z_e\) indicating that the majority of systems are cosmologically distributed between us and the quasar \((\text{e.g. Steidel 1990.})\) In this paper, we discuss criteria for distinguishing the intrinsic narrow line systems from the intervening systems and present examples demonstrating some of the observational properties of categories (2) and (3).

2. Intrinsic vs. Intervening Indicators

Recent studies of metallicity, ionization, time variability, and velocity structure of narrow \(z_a \sim z_e\) systems have shown that certain properties appear to distinguish narrow intrinsic systems from the more ubiquitous intervening systems. In order of how reliably they indicate an intrinsic system, these properties include: (1) time variability \((\text{Hamann et al. 1995})\), (2) partial coverage of the background light source along our line-of-sight by the absorption-line region \((\text{cf. Wampler et al. 1995; Hamann et al. 1997; Barlow & Sargent 1997})\), (3) high electron density as derived from fine structure lines as a distance indicator when combined with an ionization level estimate \((\text{cf. Morris et al. 1986})\), (4) spectropolarimetry revealing increased fractional polarization in the lines relative to the continuum \((\text{so far only observed in BALs, cf. Goodrich et al. 1995, Cohen et al. 1995})\), (5) velocity structure, \(\text{e.g. a “correlated” or “smooth” line profile shape across many components when observed at spectral resolutions of} \lesssim 10 \text{ km s}^{-1} \text{ FWHM (in contrast, intervening systems often show several apparently independent components), (6) high metallicities (e.g. Petitjean et al. 1994), (7) high ionization levels, (8) proximity to BALs, and (9) redshifts close to the emission line redshift (e.g. Anderson et al. 1987.)}\)

We consider the first few properties as strong indicators of the intrinsic nature of the system, and the last few properties as very weak indicators. For example, we expect some intervening systems to occur close to the emission-line redshift and close to BALs, to have high ionization lines, and possibly to have high metallicities \(\sim \text{solar.})\) Conversely, we do not expect all intrinsic systems to lie close to the emission redshift or close to BALs.

Time variability is perhaps the most conclusive indicator. If the intrinsic absorber is photoionized by the quasar continuum source, and the quasar source is known to vary, we expect the absorption line optical depths to also vary. (Intervening C IV systems, on the other hand, are probably ionized by a stable flux which permeates the intergalactic-medium.) It is also possible for intrinsic absorption to vary due to the motion of the region across our line-of-sight. The two variability effects can be distinguished by observing two lines with different ionization levels.
Unfortunately, detecting time variability requires two observations separated by \( \gtrsim 1 \) year during which the quasar happens to vary. A more direct approach (requiring only one epoch) is to determine the line-of-sight coverage fraction \((C_f)\) of the background light source by the absorption region. High signal-to-noise \((S/N \gtrsim 30\) per resolution element\) and high resolution \((\lesssim 10 \text{ km} \text{s}^{-1} \text{FWHM})\) spectra can be used to measure the apparent \(C_f\) of the absorbing clouds as determined by the residual intensities of a resolved and separated doublet such as \(	ext{C IV} \lambda \lambda 1548,1550\) (see Hamann et al. this volume.)

Direct density limits from excited-state fine structure lines are also useful. Intervening systems are expected to have low density \(( \lesssim 1 \text{ cm}^{-3})\), while at least some intrinsic systems appear to have higher density \(( \gtrsim 1000 \text{ cm}^{-3})\) from time variability (Hamann et al. 1995.) Unfortunately, the high ionization level of most intrinsic systems mean that the most readily observed fine structure lines such as \(	ext{C II}^* \lambda 1335\) generally are not observable.

Ionization and metallicity are subject to uncertainties in the photoionization model and the shape of the ionizing continuum. An observational feature which may result from both high ionization and high metallicity is the unusually high \(N(\text{N V})/N(\text{H I})\) ratio (as compared to intervening systems) seen in many intrinsic systems.

3. Observations and Discussion

We present HIRES data on two quasars with narrow \(z_a \sim z_e\) absorption which show partial coverage \((Q0449-13, z_e=3.09)\) and time variability \((Q1700+64, z_e=2.72)\). These systems also show high ionization lines, possible high metallicity, and line profiles that are broader and less structured than lines seen at high resolution in intervening systems.
Figure 1 shows the N V $\lambda\lambda 1238,1242$ doublet in the QSO 0449–13. This system might be considered a “mini-BAL”, since the width (600 km s$^{-1}$) and outflow (3,000 km s$^{-1}$) are smaller than BALs in other QSOs, but the smooth structure and width is significantly different than intervening systems. Note that both N V lines appear to be saturated but do not reach zero intensity. This effect indicates that the absorption region does not completely cover the background light source. Since these lines occur near the Ly$\alpha$ and N V broad emission lines (BELs), it is possible that the continuum is completely covered while the broad emission-line region (BELR) is only partially occulted. The ambiguity of BEL and continuum coverage occurs in many $z_a \sim z_e$ systems, however by studying various ions it is possible to distinguish the two effects (Barlow & Sargent 1997.)

Figure 2 shows both lines of the Si IV doublet in Q 0449–13 on a velocity scale. The crosses indicate the amount of the light which must be subtracted to obtain a 2:1 optical depth ratio. In other words, these values indicate the apparent fraction of the background light source not covered by the absorption region. The weakness of the Si IV BEL means that at least some of the continuum source is not obscured by the Si IV absorption. Note that $C_f$ varies from $\sim 0.8$ to $\sim 0.5$ across the Si IV line profile. This effect of a velocity dependent coverage fraction has been seen in at least one BALQSO (CSO 755, cf. Barlow & Junkkarinen 1994.)

Partial coverage by an absorption region creates a difficulty in determining the true column density of a given ion. In principle, it is possible to determine the true optical depth if $C_f$ can be measured. However, this measurement is complicated by the fact that $C_f$ can vary between ions and with velocity, and can depend upon the underlying BEL strength (Barlow & Sargent 1997.)
Figure 3. Keck HIRES Spectra of Q 1700+64 showing time variability and partial coverage by the C IV $\lambda\lambda\lambda\lambda_{1548,1550}$ doublet. The emission-line plus continuum flux has been normalized. The heliocentric, vacuum wavelengths are in Angstroms.

Figure 4. Keck HIRES Spectra of Q 1159+12 showing the fine structure line C II $\lambda1335$.

Figure 3, shows time variability in the C IV doublet for the $z_a \sim z_e$ system in 1700+64 for two epochs separated by two years. The outflow velocity, using $z_e = 2.722$, is 770 km s$^{-1}$. The apparent optical depth of the C IV lines decreased by about 25%. The N V doublet also varied by a similar amount during the same period. This system yields $C_f < 1$ in both C IV and N V. The line width (FWHM$\sim30$ km s$^{-1}$) is well within the range of intervening systems, but the gas is clearly intrinsic to the quasar.

Variability similar to the case in Q1700+64 can be detected in $\sim30\%$ of intrinsic narrow-line systems with data of comparable resolution and S/N (Barlow et al. 1997, in preparation.) Variations on a $\sim1$ year timescale indicate electron densities $\gtrsim 1000$ cm$^{-3}$, since the recombination time ($\propto 1/n_e$) must be short enough for the ionization levels to reach equilibrium.

Figure 4 shows Keck HIRES data of the QSO 1159+12 ($z_e=3.50$) which contains an absorption system at $z_a = 3.5266$ with a velocity width of 60 km
s$^{-1}$ and an apparent infall velocity of about 1700 km$^{-1}$ relative to the C IV BEL. This system includes the low-ionization line C II $\lambda$1334 and the fine structure line C II$^*$ $\lambda$1335, as well as C IV and N V. From the ratio N(C II)/N(C II$^*$), we compute an electron density of about 6 cm$^{-3}$. By estimating an ionization parameter of $\approx$0.06 from Si II, Si III, and Si IV, we obtain a distance from the quasar of 800 kpc. Although this system has $z_a > z_e$ and high ionization lines, it is clearly outside the near quasar environment and not included in the class of ejected intrinsic absorbers. However, since it is ionized by the quasar and may reside in the galaxy cluster of the quasar, we place this system in the third category of absorber listed in the introduction.

With the aid of high resolution, high signal-to-noise data, narrow intrinsic absorption systems can be distinguished from intervening systems unrelated to quasar. By classifying these systems and studying their correlated properties such as density and metallicity, we can study the evolution of the quasar environment and determine the effects on the quasar host galaxy and galaxy cluster.

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