Probing Quasar Outflows with Intrinsic Narrow Absorption Lines

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Abstract.
We present statistical and monitoring results of narrow absorption lines that are physically related to quasars (i.e., intrinsic NALs). We use Keck/HIRES spectra of 37 optically bright quasars at z=2–4, and identify 150 NAL systems that contain 124 C iv, 12 N v, and 50 Si iv doublets. Among them, 39 are classified as intrinsic systems based on partial coverage analysis. At least 50% of quasars host intrinsic NALs. We identify two families of intrinsic systems based on their ionization state. Some intrinsic systems have detectable low-ionization NALs at similar velocities as higher-ionization NALs, although such low-ionization lines are rare in broad absorption line (BAL) systems. We also have observed an optically bright quasar, HS1603+3820, eight times with Subaru/HDS and HET/MRS over an interval of 4.2 years (1.2 years in the quasar rest frame), for the purpose of monitoring a variable C iv mini-BAL system. We find that all the troughs of the system vary in concert. However, no other correlations are seen between the variations of different profile parameters. We propose that the observed variations are either (i) a result of rapid continuum fluctuations, caused by a clumpy screen of variable optical depth located between the continuum source and the mini-BAL gas, or (ii) a result of variable scattering of continuum photons around the absorber.

1. Introduction
Outflowing winds from the accretion disks around supermassive black holes provide a potential mechanism for extracting angular momentum from the accreting material, allowing accretion to proceed. They are also cosmologically impor-
tant because they provide energy and momentum feedback to the intergalactic medium (IGM). Traditionally, broad absorption lines (BALs; FWHM \( \geq 2,000 \) km s\(^{-1}\)) have been used to study such outflowing winds, because their large line widths and smooth line profiles suggest an association with the wind. Intrinsic narrow absorption lines (NALs; FWHM \( \leq 500 \) km s\(^{-1}\)) that are physically related to the quasars are an alternative and more promising tool for examining the physical conditions of the outflow than BALs for two important reasons: (i) NALs do not suffer from self-blending (i.e., a blend of blue and red members of doublets such as C\( ^{\text{iv}} \)\( \lambda \lambda 1548,1551 \)), and (ii) NALs are found in a wider variety of AGNs, while BALs are detected primarily in radio-quiet quasars.

In spite of their potential importance, NALs have not received as much attention as BALs, because it is difficult to distinguish intrinsic NALs from NALs that are not physically related to the quasars (i.e., intervening NALs), produced in intervening galaxies, the IGM, Milky Way gas, or gas in the quasar host galaxies. With the advent of high-dispersion spectroscopy of faint objects, it has become possible to identify intrinsic NALs, based primarily on one or both of the following indicators: (a) the dilution of absorption troughs by unocculted light (e.g., Hamann et al. 1997), and (b) time variability of line profiles (e.g., depth, equivalent width, and centroid), within a year in the absorber’s rest frame (e.g., Barlow & Sargent 1997).

2. Statistical Analysis with 37 Keck/HIRES Quasars

We have constructed a large, relatively unbiased, equivalent width limited sample of intrinsic NAL systems found in the high-resolutional \( (R = 37,500) \) spectra of \( z=2–4 \) quasars taken with Keck/HIRES. We identify 150 NAL systems that contain 124 C\( ^{\text{iv}} \), 12 N\( ^{\text{v}} \), and 50 Si\( ^{\text{iv}} \) doublets, of which 39 are identified as intrinsic NAL systems on the basis of their partial coverage signature. Using this sample, we study their demographics, the distribution of their physical properties, and any relations between them.

2.1. Fraction of Intrinsic NALs and Quasars with Intrinsic NALs

We separate intrinsic and intervening NAL systems using the partial coverage (PC) of doublets (e.g., Wampler, Chugai, & Petitjean 1995). Of the 124 C\( ^{\text{iv}} \) doublet, we find 19% show PC. Similarly, 18% of Si\( ^{\text{iv}} \) doublets and 75% of N\( ^{\text{v}} \) doublets show PC. If we focus on only systems near the quasar redshift (\( v_{\text{shift}} < 5000 \) km s\(^{-1}\); hereafter associated NALs), the fraction of C\( ^{\text{iv}} \) doublets showing PC increases to 33%. No associated Si\( ^{\text{iv}} \) doublet shows PC, while all N\( ^{\text{v}} \) doublets showing PC are associated. (For N\( ^{\text{v}} \), we can only probe associated systems due to severe Ly\( \alpha \) forest contamination at larger velocities). Richards (2001) estimate that as many as \(~36\%\) of C\( ^{\text{iv}} \) NALs may be intrinsic systems appearing at high ejection velocity. Taken at face value, this may imply that only \(~50\%) of intrinsic systems show PC.

We also find that the fraction of quasars that have one or more intrinsic NAL systems is about 50%, although this is a lower limit because our spectra do not have full offset velocity coverage and because some intrinsic absorbers may not exhibit the signature of partial coverage. One possible interpretation
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Figure 1. Velocity plots of various transitions in the system at $z_{\text{abs}} = 1.8919$ of HS1103+6416 (strong C iv system) and the system at $z_{\text{abs}} = 2.7125$ of HS1700+6416 (strong N v system). We classify 39 intrinsic NAL systems into 28 strong C iv and 11 strong N v systems.

2.2. Ionization Conditions of Intrinsic NAL Systems

Considering the ionization structure of the 39 intrinsic NAL systems in our sample, we find the following two major categories, which may represent absorbers of different densities and/or at different distances from the ionizing source.

**Strong C iv Systems** — These are characterized by strong (i.e., large equivalent width), partially covered C iv NALs, strong Lyα lines, and relatively weak or undetectable N v NALs. Of the 28 systems in this category, 25 have intermediate ionization lines (such as Si iii and C iii) and 15 have low ionization absorption lines (such as Si ii and C ii) (see Figure 1).

**Strong N v Systems** — These are characterized by strong N v NALs, and relatively weak, non-black Lyα lines. C iv and O vi NALs may also be detected in these systems, and in some cases O vi may be stronger than N v. We find 11 systems in this category, of which 5 have detected intermediate ionization transitions, and only 1 has detected low ionization transitions (see Figure 1).

In the 15 strong C iv systems with low ionization transitions detected, the line profiles of the C iv NALs and the low ionization lines are similar. Moreover, the low ionization lines are usually detected at the same velocities as the partially covered C iv NALs, implying that both families of lines arise in the same parcels of gas. About 50% of intrinsic NAL systems include low-ionization lines, while the fraction of BAL systems with low-ionization lines (i.e., LoBALs) among all BAL systems is only 13–17% (e.g., Sprayberry & Foltz 1992; Reichard et al. 2003). The different ionization conditions of intrinsic NALs and BALs suggest that they may be located in different regions around the accretion disk.
3. Monitoring of C IV Mini-BAL in HS1603+3820

We have obtained six Subaru/HDS and two HET/MRS spectra of the quasar HS1603+3820 \((z_{em} = 2.542)\) spanning an interval of approximately 1.2 years in the quasar rest frame, for the purpose of monitoring intrinsic systems. Among the 9 C IV systems, only the mini-BAL system at \(z_{abs} \sim 2.43\) (\(v_{shift} \sim 9,500 \, \text{km s}^{-1}\) from the quasar emission redshift) shows both time variability and partial coverage. We fit models only to the bluest portion of the C IV mini-BAL profile where self-blending is not severe. All fit parameters (i.e., column density, Doppler parameter, coverage fraction, and shift velocity) as well as the total equivalent width of the system vary significantly with time, even on short time scales. However, the profile parameters do not correlate with each other, with one exception: the equivalent widths of all the troughs in this system vary together. We have examined a number of ways of explaining the above variations of the C IV mini-BAL and we have found two viable possibilities.

**Scattering of Continuum Photons** — The observed partial coverage signature is the result of continuum photons scattering around the absorber and into our cylinder of sight. The observed changes in mini-BAL equivalent widths are thus produced by variations in the scattered continuum that dilutes the absorption troughs. This idea can be tested observationally through spectropolarimetry (e.g., Brotherton et al. 1997).

**Screening of Variable Optical Depth** — The illumination of the UV absorber fluctuates on short time scales. We suggest that these fluctuations are caused by a screen of variable optical depth between the mini-BAL gas and the continuum source. This screen might be identified with the shielding gas invoked or predicted in some outflow models. Moreover, it could be analogous to the “warm” absorbers observed in the X-ray spectra of Seyfert galaxies and some quasars (Crenshaw et al. 1999). This picture can also explain the variations in the coverage fraction, which appear to be unrelated to the ionic column density changes.

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