High Velocity Outflows in Narrow Absorption Line Quasars

G. Chartas, J. Charlton, M. Eracleous, M. Giustini, P. Rodriguez Hidalgo

Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, chartas@astro.psu.edu

R. Ganguly

Department of Computer Science, Engineering, & Physics, University of Michigan-Flint, Flint, MI 48502

F. Hamann

Department of Astronomy, University of Florida, 211 Bryant Space Science Center, Gainesville, FL 32611-2055

T. Misawa

Cosmic Radiation Laboratory, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198 Japan

D. Tytler

Center for Astrophysics and Space Sciences, University of California San Diego, La Jolla, CA 92093-0424, USA

Abstract

The current paradigm for the AGN phenomenon is a central engine that consists of an inflow of material accreting in the form of a disk onto a supermassive black hole. Observations in the UV and optical find high velocity ionized material outflowing from the black hole. We present results from Suzaku and XMM-Newton observations of a sample of intrinsic NAL quasars with high velocity outflows. Our derived values of the intrinsic column densities of the X-ray absorbers are consistent with an outflow scenario in which NAL quasars are viewed at smaller inclination angles than BAL quasars. We find that the distributions of $\alpha_{OX}$ and $\Delta\alpha_{OX}$ of the NAL quasars of our sample differ significantly from those of BAL quasars and SDSS radio-quiet
quasars. The NAL quasars are not significantly absorbed in the X-ray band
and the positive values of $\Delta \alpha_{OX}$ suggest absorption in the UV band. The
positive values of $\Delta \alpha_{OX}$ of the intrinsic NAL quasars can be explained in a
geometric scenario where our lines of sight towards the compact X-ray hot
coronae of NAL quasars do not traverse the absorbing wind whereas lines of
sight towards their UV emitting accretion disks do intercept the outflowing
absorbers.

Key words: Techniques:spectroscopic, quasars:general, Galaxies:active

1. Introduction

Optical and UV absorption lines in quasars are commonly classified by
their widths into “broad” (BALs; FWHM $> 2,000$ km s$^{-1}$), “narrow” (NALs;
FWHM $\lesssim 500$ km s$^{-1}$), and mini-BALs with absorption line widths ranging
between those of BALs and NALs. These class definitions are considered
somewhat arbitrary. The definition of NALs for example was chosen such
that the the C IV doublet can be resolved. Several models of quasar structure
indicate that the widths of intrinsic absorption lines may depend on the angle
between our line of sight and that of the outflowing absorbing stream, and
on the velocity gradient in the outflowing stream.

UV spectroscopic observations have revealed highly blueshifted narrow
and broad intrinsic absorption lines in quasars implying outflow velocities
of up to $\sim 60,000$ km s$^{-1}$ (e.g., Jannuzi et al. 1996; Hamann et al. 1997;
Narayanan et al. 2004). Intrinsic NALs are common in Type I AGN, occurring
in $\sim 50\%$ of of optically selected quasars (Misawa et al. 2007). They may
be present in all AGN but only detected in those cases where our line of sight
intersects the outflowing absorbing stream. Most of our current understand-
ing of the physical and kinematic structure of NALs and BALs stems from
studies of the velocity profiles of absorption lines that appear bluerward of
resonance UV emission lines. Little is presently known about the absorbing
and kinematic properties of these absorption line systems in the X-ray band.

In section §2 we describe the NAL Quasar sample selection, and in §3 the
observations, data analysis and results of the sample. Finally in section §4
we conclude by summarizing the results of our observations of NAL quasars.

Throughout this paper we adopt a $\Lambda$-dominated cosmology with $H_0 =
70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_\Lambda = 0.7$, and $\Omega_M = 0.3$. 
2. NAL Quasar Sample Selection

Our initial NAL quasar sample consisted of \( z = 2–4 \) quasars observed with either the Keck telescope at high spectral resolution for the original purpose of studying intergalactic deuterium lines or quasars obtained from the VLT/UVES archive. The VLT/UVES observations were taken at high spectral resolution (\( R \sim 40,000 \)) for various scientific purposes. From this sample we identified intrinsic NALs by the partial coverage signature of their C IV, N V and S IV absorption doublets (Misawa et al. 2007). The X-ray sample used in this paper consists of 12 \( z = 2.2–3.1 \) quasars from the initial optical sample that contained intrinsic NALs. The X-ray NAL sample was selected from the initial NAL sample by choosing sources bright enough in the UV resulting in at least 100 counts in the Suzaku and/or XMM-Newton observations (see Table 1). We have also included in our analysis the 4 NAL quasars from the exploratory survey of Misawa et al. (2008). The X-ray sample does not contain any BAL quasars. Thus our sample consists of secure intrinsic NALs at high ejection velocities, \((63,000 \text{ km/s} \gtrsim v_{ej} \gtrsim 6,400 \text{ km/s})\). More importantly, the sample is unbiased, selected without regard to quasar properties. Thus it is representative of intrinsic NALs and lends itself to drawing general conclusions about the properties of the absorbers. We note a possible luminosity bias in the X-ray selected sample since we selected the brightest objects from the initial NAL quasar sample to obtain moderate S/N ratio X-ray spectra.

3. X-ray Observations of NAL Quasar Sample

A log of the observations that includes object, observation dates, observatory, observed count rates, total exposure times, and observational identification numbers is presented in Table 1.

In Table 2 we list the redshift, luminosity distance, Galactic column density, flux density at 2500Å, outflow velocity and the total rest-frame equivalent width (\( W_{\text{rest}} \)) of the C IV absorption line.

Eleven NAL quasars were observed with Suzaku and three with XMM-Newton. The Suzaku data were collected with the two front-illuminated (FI) CCDs XIS 0, 3 and one back illuminated CCD XIS 1. The XMM-Newton data were collected with the EPIC pn and MOS instruments. We used standard Suzaku and XMM-Newton processing pipeline to reduce the X-ray data.
The X-ray spectra were fitted simultaneously with two models employing XSPEC version 12 (Arnaud 1996). Specifically, the spectral models used in our analysis are the following: (a) A simple power-law, and (b) a simple power-law with intrinsic absorption. All models contain absorption due to our Galaxy.

In Figure 1 (left panels) we show the XIS spectra of three quasars of our sample (first three in Table 1) fit with a model consisting of a power law modified by intrinsic absorption (model b) together with $\chi^2$ residuals of the fits. The right panels of Figure 1 show 68%, 90% and 99% $\chi^2$ confidence contours of $N_H$ versus the photon index, $\Gamma$. We find that for all NAL quasars of our sample the $\chi^2$ confidence contours imply no significant intrinsic absorption with the possible exceptions for quasars Q0109-3518 and Q1158-1843 where there is a marginal detection of an intrinsic column density of $N_H \sim$ a few times $10^{22}$ cm$^{-2}$.

In Figure 2 we show the distribution of values of $\alpha_{ox}$ of NAL quasars without correction for intrinsic UV absorption, where, $\alpha_{ox}$ is the optical-to-X-ray slope $\alpha_{ox} =-0.384 \log(f_{2keV}/f_{2500} \AA)$ (Tananbaum et al. 1979). Twelve quasars...
Table 2: The NAL Quasar Sample.  

| Quasar     | z   | $D_L$ | $N_{\text{Gal}}^{\text{H}}$ | $f_2$ | $f_{2500\text{A}}$ | $v_{\text{shift}}$ | Rest EW |
|------------|-----|-------|-----------------|-------|----------------|------------------|---------|
|            |     | Gpc   | 10$^{20}$ cm$^{-2}$ | keV$^{-1}$ cm$^{-2}$ | mJy km s$^{-1}$ | km s$^{-1}$ | Å       |
| Q0109−3518 | 2.405 | 20.0  | 1.93            | $1.2 \times 10^{-13}$ | 0.261        | −62,990   | 0.064   |
| Q0122−380  | 2.2   | 18.0  | 1.77            | $4.3 \times 10^{-14}$ | 0.171        | −40,613   | 0.025   |
| Q0329−385  | 2.423 | 20.2  | 1.60            | $1.1 \times 10^{-13}$ | 0.154        | −58,879   |         |
| Q0450−1310 | 2.300 | 19.0  | 6.44            | $3.2 \times 10^{-14}$ | 0.185        | −6,369    | 0.17    |
| Q0551−3637 | 2.318 | 19.1  | 3.15            | $5.2 \times 10^{-13}$ | 0.165        | −51,179   | 0.3     |
| Q0940−1050 | 3.080 | 27.1  | 4.17            | $8.5 \times 10^{-14}$ | 0.203        | −18,576   | 0.14    |
| Q1009+2956 | 2.644 | 22.5  | 2.40            | $1.5 \times 10^{-13}$ | 0.277        | −33,879   | 0.1     |
| Q1017+1055 | 3.156 | 27.9  | 3.66            | $1.4 \times 10^{-13}$ | 0.083        | −47,660   | 4.92    |
| Q1158−1843 | 2.448 | 20.5  | 3.80            | $3.0 \times 10^{-13}$ | 0.167        | −15,745   | 0.86    |
| Q1334−0033 | 2.801 | 24.1  | 2.02            | $3.9 \times 10^{-13}$ | 0.122        | −51,040   | 0.36    |
| Q1548+0917 | 2.749 | 23.6  | 3.43            | $6.2 \times 10^{-14}$ | 0.057        | −36,296   | 0.32    |
| Q1946+7658 | 3.051 | 26.8  | 7.58            | $1.4 \times 10^{-13}$ | 0.197        | −11,940   | 0.1     |

in this sample are from this study and four are from the Misawa et al. (2008) study. The dashed line shows the distribution of type 1 radio-quiet quasars with $l_{2500}$ values similar to those of our sample (see Table 5 of Steffen et al. 2006). We notice a significant shift of the $\alpha_{\text{ox}}$ distribution of NAL quasars with respect to the optical-selected type 1 SDSS quasars. One possible interpretation of this shift is that on average NAL quasars may be more UV absorbed than type 1 SDSS quasars.

Since $\alpha_{\text{ox}}$ is known to correlate with UV luminosity (e.g., Avni-Tananbaum 1986) we also calculate the parameter $\Delta \alpha_{\text{ox}} = \alpha_{\text{ox}} - \alpha_{\text{ox}}(l_{2500\text{A}})$, where $\alpha_{\text{ox}}(l_{2500\text{A}})$ is the expected $\alpha_{\text{ox}}$ for the monochromatic luminosity at 2500Å (Eq. 6 of Strateva et al. 2005). $\Delta \alpha_{\text{ox}}$ is a proxy of X-ray weakness corrected for the dependence of $\alpha_{\text{ox}}$ on UV luminosity.

In Figure 3 we show the distribution of $\Delta \alpha_{\text{ox}}$ for our current NAL sample, the Steffen et al. 2006 SDSS quasar sample, the Giustini et al. (2008) BAL quasar sample and the Gallagher et al. (2006) LBQS BAL quasar sample. Interestingly our preliminary results hint towards positive values of $\Delta \alpha_{\text{ox}}$ for
NAL quasars.

The positive values of $\Delta \alpha_{OX}$ of the intrinsic NAL quasars can be explained in a geometric scenario where NAL quasars are viewed at low inclination angles. A possible geometric configuration that can explain this is shown in Figure 4. In this scenario, lines of sight towards the compact X-ray hot coronae of NAL quasars do not traverse the absorbing wind whereas lines of sight towards their UV emitting accretion disks do intercept the outflowing absorbers. Objects that are viewed along lines-of-sight that transverse a substantial portion of the outflowing wind will appear to be Compton thick.

In Figure 5 we show the total rest-frame CIV equivalent width, $W_{\text{rest}}$ (top panel), and the maximum NAL velocities of intrinsic CIV NALs of quasars (bottom panel) in our sample (filled circles) and the Misawa et al. (2008) sample (open circles) plotted against $\alpha_{OX}$ (evaluated without corrections for intrinsic absorption). $W_{\text{rest}}$ vs. $\alpha_{OX}$ in intrinsic NAL quasars appears to follow the trend of $W_{\text{rest}}$ vs. $\alpha_{OX}$ found by Brandt (2000) in low-redshift quasars. It is interesting to point out that the only object from our sample that does not appear to follow this trend is Q1017+1055 that contains both a NAL and a mini-BAL. We finally note that the maximum outflow velocities of the UV absorbers of intrinsic NAL quasars do not appear to be correlated with their X-ray weakness in contrast to what has been reported for BAL quasars (i.e., Gallagher et al. 2006).

4. CONCLUSIONS

Our results are summarized as follows:

(a) The intrinsic column densities of the X-ray absorbers in our sample of NAL quasars are constrained to be less than a few $\times 10^{22}$ cm$^{-2}$. These values of $N_{\text{H}}$ are consistent with an outflow scenario in which NAL quasars are viewed at smaller inclination angles than BAL quasars.

(b) The distributions of $\alpha_{OX}$ and $\Delta \alpha_{OX}$ of the NAL quasars of our sample differ from those of type 1 SDSS radio-quiet quasars and BAL quasars (Figures 2 and 3). The NAL quasars are not significantly absorbed in the X-ray band and the positive values of $\Delta \alpha_{OX}$ suggest absorption in the UV band.

(c) The positive values of $\Delta \alpha_{OX}$ of the intrinsic NAL quasars can be explained in a geometric scenario where NAL quasars are viewed at low inclination angles (Figure 4). In this scenario, lines of sight towards a compact X-ray hot coronae of NAL quasars do not traverse the absorbing wind
whereas lines of sight towards their UV emitting accretion disks do intercept the outflowing absorbers.

(d) We find that the maximum outflow velocities of the UV absorbers of NAL quasars are not correlated with their X-ray weakness in contrast to what has been reported for BAL quasars (i.e., Gallagher et al. 2006).

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Figure 1: In the left panels we present the XIS spectra of three quasars of our sample fit with a model consisting of a power-law modified by intrinsic absorption (model b) together with $\chi^2$ residuals of the fits. The right panels show the 68%, 90% and 99% $\chi^2$ confidence contours of the intrinsic column density, $N_H$, versus the photon index, $\Gamma$. 
Figure 2: The distribution of values of $\alpha_{\text{ox}}$ of NAL quasars without correction for intrinsic UV absorption. Twelve quasars in this sample are from this study and four are from the Misawa et al. (2008) study. The dashed line shows the distribution of type 1 SDSS radio-quiet quasars with $I_{2500}$ values similar to those of our sample (Steffen et al. 2006). A significant shift of the $\alpha_{\text{ox}}$ distribution of NAL quasars with respect to the type 1 SDSS radio-quiet quasars may indicate that on average NAL quasars are more UV absorbed than the SDSS quasars.
Figure 3: Distribution of $\Delta \alpha_{\text{ox}}$, the difference between the observed value of $\alpha_{\text{ox}}$ and the value predicted for that monochromatic UV luminosity by the correlation of Steffen et al. (2006). Negative values of $\Delta \alpha_{\text{ox}}$ indicate a steeper slope than expected. Histograms drawn as dotted lines indicate upper limits. (a): The distribution of $\Delta \alpha_{\text{ox}}$ among quasars in our sample and the Misawa et al. (2008) (without corrections for intrinsic absorption). (b): The distribution of $\Delta \alpha_{\text{ox}}$ among SDSS quasars from Steffen et al. (2006). (c): The distribution of $\Delta \alpha_{\text{ox}}$ among the Giustini et al. (2008) BAL quasar sample. (d): The distribution of $\Delta \alpha_{\text{ox}}$ among BAL quasars from the LBQS (from Gallagher et al. 2006).
Figure 4: Schematic diagram of a proposed geometry for the accretion disk and associated outflow in quasars. For large inclination angles X-ray emission from the near side of the accretion disk and the central continuum source is blocked by the Compton thick absorbing wind. X-ray lines of sight originating from the corona are indicated with solid lines and UV lines of sight originating from the accretion disk are indicated with dashed lines. Scattered and fluorescent emission from the far side of the accretion disk and outflow may reach the observer. Light rays that originate near the black hole will be slightly bent due to GR effects.
Figure 5: Properties of intrinsic CIV NALs of quasars in our sample (filled circles) and the Misawa et al. (2008) sample (open circles) plotted against $\alpha_{\text{OX}}$ (evaluated without corrections for intrinsic absorption). Top Panel: Variation of rest frame equivalent width with $\alpha_{\text{OX}}$. Their rest frame equivalent width is the sum of equivalent widths of all intrinsic NALs in the same quasar. The crosses represent the associated CIV NALs measured in low-redshift quasars by Brandt (2000). Bottom Panel: Variation of the maximum NAL velocity with $\alpha_{\text{OX}}$. The triangles are from the Giustini et al. (2008) BAL quasar sample.