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Narrow C IV λ1549Å Absorption Lines in Moderate-Redshift Quasars

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Abstract. A large, high-quality spectral data base of well-selected, moderate-redshift quasars is used to characterize the incidence of narrow associated C IV λ1549 absorption, and how this may depend on some quasar properties. Preliminary results of this study are presented.

1. Introduction

Associated narrow absorption lines (NALs) in the spectra of active galaxies have widths less than a few hundred km s^{-1} and are located within 5000 km s^{-1} of the emission redshift (Weymann et al. 1979). They are likely physically connected to the active galactic nucleus. The working hypothesis in this study is that NALs are possibly the low-velocity equivalents to the more dramatic broad absorption features (BALs), with line widths reaching tens of thousands of km s^{-1}. The current, commonly adopted physical interpretation is that the line widths of both NALs and BALs trace the outflow velocity of the absorbing gas and that these outflows are somewhat equatorial. The exact solid angle extension of the NAL and BAL matter above the disk is unknown. BALs are predominantly found in the high-luminosity, radio-quiet quasars with a frequency of 10–12%. NALs appear present in 50–70% of the low-luminosity Seyfert galaxies (Hamann 2000), yet the frequency in quasars and how it may depend on source radio power and source axis inclination are not accurately known. The aim of this study is to address this issue with a large, high-quality, UV spectral data base of $z \approx 2$ radio-loud and radio-quiet quasars (hereafter RLQs and RQQs, respectively) for which the data are uniformly processed and analyzed (Vestergaard 2000; Vestergaard et al. 2001). The frequency of associated C IV NALs is studied and possible trends with quasar properties, such as luminosity, UV spectral slope, radio loudness, and source inclination are tested for. In particular, if there is a wind evaporating off the accretion disk, then one might naïvely expect this wind to be stronger in brighter, bluer objects, as the stronger radiation field will blow off more disk matter. If the associated NALs are somehow related to such a wind one would then expect a relationship between the strength of the NALs and the continuum characteristics: the continuum luminosity, $L_{\rm cont}$, the UV continuum slope, α_{UV}, and/or the absolute magnitude, M_V, of the object.

The first results of this study are presented here. An extended analysis, including a detailed comparison of the NAL properties of the RLQs and the RQQs, will be presented by Vestergaard (2001). First, the conclusions are summarized, then the data, measurements, and results are presented and briefly discussed.

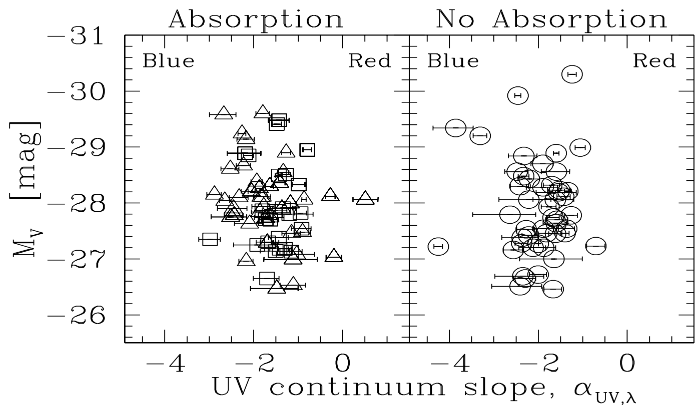

Figure 1. The distribution of M_V and $\alpha_{UV,\lambda}$ for the quasars with (triangles: RLQs; squares: RQQs) and without C IV NALs (circles).

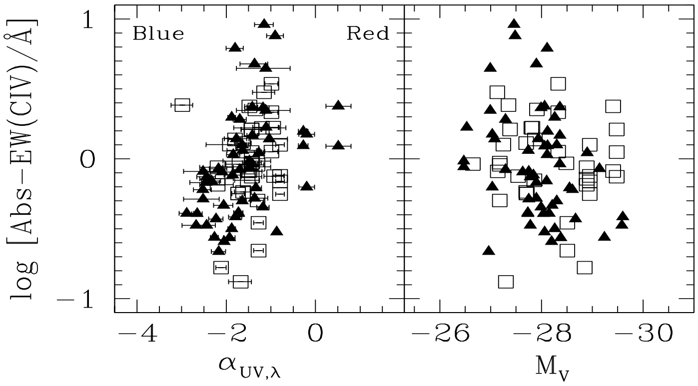

Figure 2. The distribution of the strength of the absorber relative to the UV continuum slope and the quasar luminosity.

2. Summary and Conclusions

The main results of this study are as follows:

- The frequency of high-velocity NALs in RQQs and RLQs is similar.
- RLQs show a small excess of associated NALs with respect to RQQs.
- Relatively fewer *core-dominated* RLQs show associated NALs than lobe-dominated RLQs do.
- The strongest associated NALs ($\gtrsim$ 3Å) are mostly in RLQs.
- The data are consistent with the associated absorption being stronger in more inclined objects where reddening effects may play a larger role. Do these effects dominate radiation pressure effects?
- About 8% (5/66) of the RLQs show strong (EW >3Å) absorption at relatively low velocities, which is not seen in the RQQs here. While RQQs can accelerate the central outflow to high velocities (in BALs), the RLQs are perhaps not capable thereof to the same extent. This is consistent with predictions of disk outflow models. Are RLQ NALs the low-velocity equivalents to the BAL phenomenon seen mostly in RQQs?

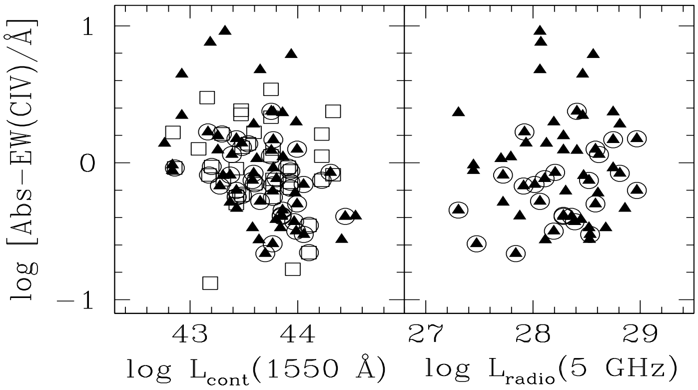

Figure 3. The absorption strength versus continuum luminosities.

Table 1. **Frequency of Absorbed Objects and of C IV NALs**

Sample	**N**	**Absorbed QSOs (All Abs. Vel's)**	**Velocity ≤ 5000 km s^{-1}**	**5000 < Velocity 15000 km s^{-1}**
All QSOs	114	66 = 58%	41 = 36%	36 = 32%
RQQs	48	25 = 52%	14 = 29%	14 = 29%
RLQs	66	41 = 62%	27 = 41%	22 = 33%
CDQs	20	12 = 60%	7 = 35%	7 = 35%
LDQs	46	29 = 63%	20 = 43%	15 = 33%
Absorber Frequency Among Absorbed Quasars Only				
LDQs	–	29/66 = 44%	20/41 = 49%	15/36 = 42%
CDQs	–	12/66 = 18%	7/41 = 17%	7/36 = 19%

3. The Sample, the Data, and the Measurements

The sample of 114 quasars (66 radio-loud and 48 radio-quiet) was selected for a study of the emission lines (Vestergaard 2000; Vestergaard, Wilkes, & Barthel 2000; Vestergaard et al. 2001). The spectra cover a minimum range from ∼1000 to ∼2100 Å with a spectral resolution of ∼ 5 Å or better. High quality VLA radio maps at 1.4, 5, and 15 GHz are available for most of the RLQs (Barthel et al. 1988; Lonsdale, Barthel, & Miley 1993; Barthel, Vestergaard, & Lonsdale 2000). Vestergaard et al. (2001) provide details on all the data.

The RLQs are further subclassified as lobe-dominated quasars, LDQs (i.e., $R_{5GHz} = S_{5GHz,core}/S_{5GHz,total} < 0.5$), or as core-dominated quasars, CDQs ($R_{5GHz} \geq 0.5$). The quasars were selected such that the RLQs and RQQs have similar z and luminosity, M_V, distributions (e.g., Fig. 1).

A cosmology of $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$ is used throughout.

3.1. The Measurements

The C IV emission line profile was reproduced with a smooth fit [see Vestergaard et al. (2001) for details]. This smooth profile fit acts as the local "continuum" for the absorption lines. No Galactic extinction correction is performed on the spectra. The measured absorption lines were defined as C IV doublet absorption based on the following criteria ($\Delta\lambda_{doublet} = 1550.77 - 1548.20Å = 2.57Å$):

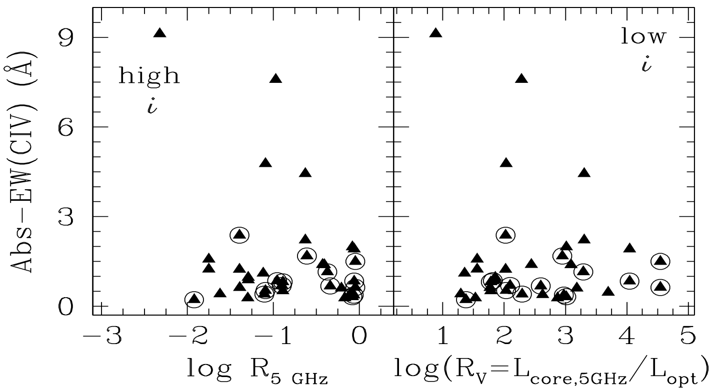

Figure 4. The absorber EW versus source inclination (i) estimators.

- The observed equivalent width, EW_{obs}, $\geq$ 0.5Å of each system/blend
- The measured $\Delta\lambda_{separation,rest} = \Delta\lambda_{doublet} \pm \frac{1}{2}$ resolution element
- Rest EW doublet ratio: 0.8 − 2.2 (allows for blending/resolution effects)
- The doublet FWHMs match within the resolution ($\sim$200−300 km s^{-1})
- Rest EW of each transition $\geq 3\sigma$ detection limit

4. Results and Brief Discussion

The results are presented in Table 1 and in the figures. RLQs are shown as triangles, while RQQs are shown as open squares. Encircled symbols are high velocity (>5000 km s^{-1}) absorbers.

The quasars with NALs (Fig. 1) have an average UV slope, $< \alpha_{UV} > = -1.54$ (median $= -1.48$), while unabsorbed quasars have $< \alpha_{UV} > = -1.99$ (median $=$ -1.89). However, a K-S test shows no statistically significant differences at the 99.95% confidence level. Both groups have $<M_V> \approx -27.9$ mag. The strength (equivalent width, EW) of the C IV NALs correlates strongly with α_{UV} (Spearman's rank, r = 0.43) with a P <0.1% probability of occuring by chance (Fig. 2, left). A slightly weaker correlation (r = 0.21, P = 3.95%) exists with quasar luminosity (Fig. 2, right) such that the EW tends to decrease in brighter objects. A stronger trend is seen with UV continuum luminosity (r = −0.32, P = 0.19%; Fig. 3, left). This is contrary to the naïve expectation (§ 1) that brighter, bluer objects more easily generate stronger disk-winds. As will be clear later, what is encountered is a complication due most likely to inclination and/or reddening effects. No relation is seen with radio luminosity (Fig. 3, right).

Table 1 lists the frequency of narrow C IV absorbers among various quasar subgroups. The main results were listed in the summary. Not only do LDQs have a higher NAL frequency than CDQs, but they also tend to be more strongly absorbed (Fig. 4; also e.g., Foltz et al. 1988; Barthel, Tytler, & Vestergaard 1997, who used almost the same RLQ sample studied here). LDQs are believed to be intrinsically similar to CDQs, just viewed at a higher inclination, i, of the radio axis relative to our line of sight. In this study the i-dependence of the NAL strengths is tested on a more well-suited sub-sample of the RLQs, which is important if the NALs are associated with the quasars. To avoid possible selection biases the LDQs and CDQs were selected to cover the same range in L_{ext} (Fig. 5; Vestergaard et al. 2000). Also, no L_{ext} dependence is seen for the EWs. Both

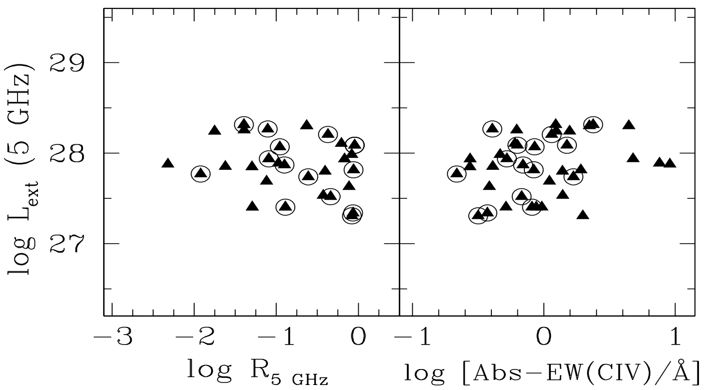

Figure 5. The EW inclination dependence is *not* due to L_{ext} biases.

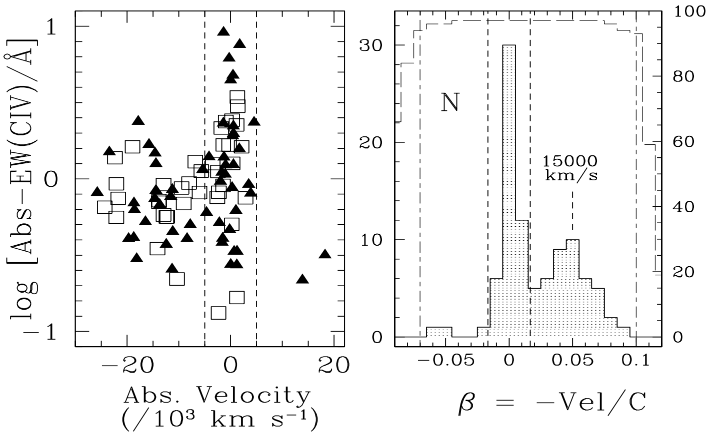

Figure 6. The distribution of absorber strength on the absorber velocity relative to the emission redshift (left). *Right:* The number distribution of the absorbers (shaded; left axis) compared with the spectra measured (dashed curve; right axis) show both peaks are real; see text.

$\log R_{5\rm GHz}$ and $\log R_{\rm V}$ estimate i (e.g., Wills & Brotherton 1995). Also for this subsample are the strongest NALs seen in LDQs and the strength increases with i (Fig. 4). If indeed LDQs are highly inclined, then the correlations of NAL EW with $\alpha_{\rm UV}$, $M_{\rm V}$, $L_{\rm cont}$, $\log R_{5\rm GHz}$, and $\log R_{\rm V}$ (Figs. 2, 3, 4) can be explained as a combination of inclination and reddening effects, which thus seem to dominate possible radiation pressure effects on disk outflows. It is worth noting that Ganguly et al. (2001) do *not* find an enhanced frequency of C IV NALs for the few LDQs among 59, $z \lesssim 1.2$ quasars from the *HST* Quasar Absorption Line Key Project. Furthermore, their measured NAL strengths are significantly lower indicating a clear redshift evolution of the NALs. And Richards et al. (2001) find a small excess of high-velocity NALs in CDQs relative to LDQs. These issues will be addressed in forthcoming work.

The strongest NALs are furthermore *associated* with the quasars. Fig. 6 shows the distribution of EW with absorber velocity relative to the quasar restframe. With exception of the usual five strongest RLQ NALs, there is a similar velocity distribution for RLQs and RQQs (Fig. 6, left). Fig. 6 (right) shows the distribution of the β parameter [$\beta = (r^2-1)/(r^2+1)$, $r = (1+z_{\rm em})/(1+z_{\rm abs})$; e.g., Peterson 1997]. The enhancement of NALs within 5000 km s^{-1} (between the vertical, short-dashed lines) is clear. The long-dashed curve shows the number of spectra available for measurement at a given β bin. The vertical, dot-dashed lines denote the range where at least 95% (92/96) of the spectra are present. The high fraction of spectra across the entire second bump shows that the 15,000 km s^{-1} peak is real. The increased EW around 18,000 km s^{-1} (Fig. 6, left) is also quite possibly real. These two peaks are intringuingly close to the terminal velocities typically seen in BALs ($\sim$20,000 km s^{-1}); this may potentially be important.

The fact that RQQs tend to show modest NAL EWs, while RLQs have quite strong NALs is consistent with disk-wind models (e.g., Murray & Chiang 1995) which predict that RLQs are not capable of accelerating the high density outflows to relativistic velocities because the stronger X-ray flux strips the electrons off the atoms, thereby decreasing the radiation pressure on the outflowing gas. The moderately strong, high-velocity NALs seen in the RLQs ($\sim$18,000 km s^{-1} peak, Fig. 6, left) adds an interesting twist to this scenario. Perhaps the NALs are a separate subset of the equatorial absorbers as they are seen independently of radio-type. This and the two peaks of high-velocity absorbers will be further addressed by Vestergaard (2001).

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