THE REDSHIFTED EXCESS IN QUASAR C IV BROAD EMISSION LINES

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ABSTRACT

In this paper, the Evans and Koratkar Atlas of Hubble Space Telescope Faint Object Spectrograph Spectra of Active Galactic Nuclei and Quasars is used to study the redward asymmetry in C IV broad emission lines (BELs). It is concluded that there is a highly significant correlation between the spectral index from 10 GHz to 1350 Å and the amount of excess luminosity in the red wing of the C IV BEL (>99.9999% significance level for the full sample and the radio-loud subsample independently, but no correlation is found for the radio-quiet subsample). This is interpreted as a correlation between radio core dominance and the strength of the C IV redward asymmetry. The data imply that within the quasar environment there is BEL gas with moderately blueshifted emission associated with the purely radio-quiet quasar (RQQ) phenomenon (the accretion disk), and the radio jet emission mechanism is associated with a redward BEL component that is most prominent for lines of sight along the jet axis. Thus, RQQs have C IV BELs that tend to show blueshifted excess, and radio-loud quasars show either a red or blue excess with the tendency for a dominant red excess increasing as the line-of-sight approaches the jet axis.

Key words: galaxies: active – quasars: emission lines – quasars: general

1. INTRODUCTION

About 10% of quasars possess powerful relativistic radio jets (known generically as radio-loud quasars (RLQs)). It is not clear if there are any differences between the accretion states of the central engines (accretion flow plus central supermassive black hole) in RLQs and radio-quiet quasars (RQQs) that are defined by “weak” jet power. The signature of the quasar phenomenon is the thermal continuum luminosity created by dissipation in the accretion flow that results in a large blue/UV excess in the spectrum (Sun & Malkan 1989). The most prominent features of quasar optical/UV spectra are the conspicuous broad emission lines (BELs). To first order, the continuum and BELs in RLQs and RQQs are remarkably similar (Corbin & Francis 1994; Zheng et al. 1997; Telfer et al. 2002). Systematic differences in the two families of spectra are only revealed by the study of subtle lower order spectral features (Corbin 1997b). The differences are so small that it is not clear if these features result from a difference in environment, or directly from emission induced (or suppressed) by the jet proper or actually a difference related to the accretion flow. In this paper, we concentrate on the properties of the C IV BEL in hopes of shedding light on the connection between radio jet propagation and the accretion state. The asymmetry of the C IV BEL has received significant attention in the past. Most efforts have centered on the blueshift seen in predominantly radio-quiet samples (see Wilkes 1984; Brotherton et al. 1994; Marziani et al. 1996; Baskin & Laor 2005; Sulentic et al. 2007, and references therein). There is also a more limited discussion of redward asymmetry in RLQs (Corbin 1991; Corbin & Boroson 1996; Marziani et al. 1996; Wills et al. 1995; Bachev et al. 2004). Not only is this topic of fundamental interest to the study of the quasar central engines, but more recently it has become a point of controversy in the field of central black hole mass estimates based on the assumption of the BEL gas being virialized in a gravitational potential (Baskin & Laor 2005). For high-redshift sources, C IV is one of the available BELs that can be used to estimate these virialized motions (Vestergaard & Peterson 2006). So, an important question is whether the gas that creates the emission in the asymmetric broad redwings represents virialized gas or some other gas flow that is driven by other forces.

This study is motivated by a few anecdotal comments indicating that very large redward asymmetries are found in the C IV BEL of some highly superluminal blazars (Marziani et al. 1996; Wills et al. 1995; Netzer et al. 1995; Corbin 1997a). It is of profound physical importance to determine whether these quasars are bizarre outliers or an extension of a trend within the quasar population. If they are an extension of a trend within the parent population then they are crucial evidence in the search for the source of the redward asymmetry. We explore this aspect through a large data set, the Hubble Space Telescope (HST) spectra from the Evans & Koratkar (2004) Atlas of HST Faint Object Spectrograph Spectra of Active Galactic Nuclei and Quasars.

The history of the topic of the red and blue asymmetries in the C IV BEL of quasars is varied. Here, we list some of the known results.

1. In Corbin (1991) and Corbin & Francis (1994), a high-redshift sample was used to show that the C IV BELs in steep spectrum radio-quiet quasars (SSQs) were more redward asymmetric than those in flat spectrum radio-quiet quasars (FSQs).
2. In Wills et al. (1995), there was a brief comment that core-dominated quasars (CDQs) in a small sample of RLQs have larger C IV redward asymmetries contrary to result 1.
3. In Corbin (1992) and Corbin & Boroson (1996), it was found that the C IV redward asymmetry in quasars was correlated with the UV continuum luminosity.
4. In Corbin (1997a), it was noted that most redward asymmetric objects are RLQs, and he notes that the correlation with luminosity seen in Corbin & Boroson (1996) might be

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3 The radio loudness, R, is usually defined as a 5 GHz flux density at least 10 times larger than the 4400 Å flux density, R = S_{5 GHz}/S_{4400 Å} > 10 with R > 10 being a crude indication of a powerful radio jet (Kellermann et al. 1989).
a false correlation that arises because the highest luminosity objects in that sample tended to be radio loud.

5. Based on composite spectra from a large sample of Sloan Digital Sky Survey spectra, Richards et al. (2002) showed that RLQs have more redward emission in the C IV BEL relative to line center than RQQ quasars.

6. Using archived HST spectra, Bachev et al. (2004) showed that the composite C IV spectrum of RLQs showed a red excess relative to the RQQ composite spectrum.

7. It was mentioned in Marziani et al. (1996) that highly superluminal blazars (apparent velocity $\sim 10c$) showed redward asymmetry in the C IV BEL profile.

8. In Corbin & Boroson (1996), it was found that the C IV properties of RLQs showed a larger statistical spread than those for RQQs, including the asymmetry.

9. In Brotherton et al. (1994), Wilkes (1984), Marziani et al. (1996), Baskin & Laor (2005), and Corbin & Francis (1994), a blueward asymmetry was found in samples dominated by RQQs. In Baskin & Laor (2005), it was determined that the blueward asymmetry of their sample did not seem to correlate with any other spectral properties.

In this paper, based on an analysis of a large sample of HST spectra, a synthesis of most of the disparate claims noted above is achieved.

2. THE HST SAMPLE

A sample of 886 spectra from 221 sources are cataloged in Evans & Koratkar (2004) Atlas of HST Faint Object Spectrograph Spectra of Active Galactic Nuclei and Quasars. This sample was used to measure the redward asymmetry in C IV BELs. The formula that was used by Wills et al. (1995) was chosen to quantify this asymmetry, $A_{25-80}$, since we want to make contact with their subsample of “cleaner” HST spectra that were produced from meticulous calibration and careful continuum and line fitting. The reader is referred Wills et al. (1995) in order to find the details of how the raw data were processed. The quantity, $A_{25-80}$, is defined in terms of the full width at half-maximum (FWHM), in Å, the midpoint of an imaginary line connecting a point defined at $1/4$ of the peak flux density of the BEL on the red side of the BEL to $1/4$ of the peak flux density on the blue side of the BEL, $\lambda_{25}$, and a similar midpoint defined at $8/10$ of the flux density maximum, $\lambda_{80}$, as

$$A_{25-80} = \frac{\lambda_{25} - \lambda_{80}}{\text{FWHM}}.$$  \hspace{1cm} (1)

A positive value of $A_{25-80}$ means that there is excess flux in the red broad wing of the BEL. A negative value of $A_{25-80}$ indicates a blueward asymmetry of the BEL. In order to get a reliable measure of $A_{25-80}$, one needs sufficient signal to noise to make a meaningful measurement of $\lambda_{25}$. Also, there must not be deep intrinsic absorption features located in the BEL that inhibit the measurement of any of the quantities in Equation (1).

The number of broad-line objects in the atlas with an observed C IV profile that also meet our minimum standards required to measure $A_{25-80}$ is only 95 out of the 221 sources in Evans & Koratkar (2004).

We used the HST spectral data downloaded from MAST except in the cases where higher quality spectra already existed in Wills et al. (1995). The continuum level was set with a local power-law fit between $\sim 1470$ Å and $\sim 1620$ Å. Figure 1 shows a plot of $A_{25-80}$ versus the spectral index from 10 GHz to 1350 Å in the quasar rest frame, $\alpha_{10}^{UV}$ (where the flux density two-point spectral index is defined by the convention $F_\nu \sim \nu^{-\alpha}$). The luminosity at 1350 Å is always available when C IV is being observed and it is a common measure of the UV continuum near the peak of the spectral energy distribution that is utilized in virial black hole mass estimates (Vestergaard & Peterson 2006). The radio data are compiled from the NASA Extragalactic Database, the FIRST and NVSS 1.4 GHz surveys, and the GB...
and PMNJ 5 GHz surveys. The physical interpretation of the two-point spectral index is closely related to the logarithmic ratio of core radio flux to continuum optical/UV flux that has been proposed as an “improved orientation indicator,” for RLQs. For the details of the justification of this claim (for $R_v$, which is the ratio of 5 GHz flux density of the core to the optical flux density) see Wills & Brotherton (1995). The basic idea is that the core radio flux is from a highly Doppler-enhanced relativistic jet and its value is very sensitive to the line of sight to the jet (Lind & Blandford 1985). Conversely, the optical emission represents the (almost) isotropic thermal emission from the accretion flow. Comparison of the two is a crude indicator of the angle that the line of sight makes to the radio jet (Wills & Brotherton 1995). Unfortunately, $R_v$ cannot be used directly since high-resolution radio images are not available for many of the sources in the sample, so the core flux density is not known. The two-point spectral index, $\alpha_{10}$, uses high-frequency radio flux as a surrogate for core flux density. Since large-scale radio flux is optically thin, steep spectrum emission and the unresolved radio core is often flat spectrum, the contribution of the core emission to the total flux density increases rapidly as the observing frequency increases. The higher the frequency that is used, the more accurate this surrogate will be. However, since many of the radio-quiet sources had measurements only at 1.4 GHz and 5 GHz, an extrapolation of the spectrum above 10 GHz in the rest frame is not justified. The use of the 10 GHz flux density surrogate makes the interpretation of $\alpha_{10}$ as an orientation indicator for RLQs inferior to $R_v$ for SSQs since the lobe flux density can still dominate the core flux density at 10 GHz in some lobe-dominated quasars with very weak cores. However, in some ways this broadband spectral index might be considered an improvement on the orientation indicator, $R_v$, since it implements the far UV flux density rather than the optical flux density, especially when considering blazars and FSQs. The amount of dilution of the observed, isotropic, thermal spectrum emitted by the quasar accretion flow by the steep spectrum, high-frequency tail of the jet synchrotron emission dies off rapidly as the frequency increases. Thus, for most broad-line blazars with a strong nonthermal optical component, the far UV luminosity is dominated by the thermal component and is representative of the accretion flow luminosity (Malkan & Moore 1986). For those objects where the thermal component is small and the synchrotron component is huge, the far UV luminosity can still be dominated by the nonthermal jet emission, but the inaccuracy of this estimate of the thermal component is reduced by an order of magnitude compared to the same estimate in the optical band.

It is desirable to verify the interpretation of $\alpha_{10}$ as an orientation indicator for RLQs. The fundamental consistency check of interpreting $\alpha_{10}$ as an orientation indicator is that SSQs should have lower values (weaker cores) than FSQs since they are believed to be viewed with a line of sight more inclined from the jet axis than FSQs (Antonucci 1993; Barthel 1989; Lind & Blandford 1985). A Kolmogorov–Smirnov (K–S) test indicates that FSQs have larger values of $\alpha_{10}$ (mean of 0.735 ± 0.142) than SSQs (mean of 0.629 ± 0.106) at the 99.5% significance level. Similarly, a Wilcoxon rank sum tests indicate that the ranks of the $\alpha_{10}$ values for FSQs are larger than the ranks of the $\alpha_{10}$ values for SSQs at the 99.8% significance level. These statistical tests lend credence to the orientation indicator interpretation of $A_{25–80}$ for RLQs.

The errors in $A_{25–80}$ in Figure 1 arise primarily from the uncertainty in $\lambda_{25}$ since the signal-to-noise ratio is the smallest in the broad wings. The error in each quantity in Equation (1) was individually estimated and the results were added in quadrature. The error in $\lambda_{25}$, for example, was achieved by approximating the region near the 1/4 maximum point of the line profile by a local polynomial fit. The error in $\lambda_{25}$ was determined to be slope of this polynomial ($\partial \lambda / \partial F_\lambda$) at the 1/4 maximum point times the rms noise level. This naturally produces larger errors in $A_{25–80}$ for sources with very broad wings, i.e., the more horizontal the spectrum in the wings, the larger the slope ($\partial \lambda / \partial F_\lambda$) will be. The error bars in Figure 1 are very conservative estimates of the 1σ errors in the sense that these errors would be greatly reduced by smoothing the data. The polynomial fit to the noisy data minimizes residuals, so it should also be close to a fit that would minimize residuals in smoothed wings as well, but the rms noise (the driver of the large errors in Figure 1) would be considerably less. The errors in $\alpha_{10}$ arise primarily from uncertainty in the 10 GHz flux density from either variability (blazars) or lack of high-frequency data (RQQs).

The sample plotted in Figure 1 includes 28 RQQs, 27 SSQs defined by a spectral index greater than 0.5 (based on the convention $F_\nu \sim \nu^{-\alpha}$) from 2.7 GHz to 5 GHz (or 1.4 GHz to 5 GHz if 2.7 GHz data were not available) and 40 FSQs (which will be used interchangeably with the term blazar in the following). The sample decomposition in Figure 1 also segregates out the blazars that are known Fermi or EGRET gamma-ray loud sources (Abdo et al. 2009). Although the gamma-ray loud subsample of FSQs is too small for meaningful statistical analysis, it is an intriguing subsample because these sources tend to have higher apparent superluminal velocities as measured by very long baseline interferometry than other FSQs and this has been interpreted as a more polar line of sight to the jet (Lister et al. 2009; Kellermann et al. 2004).

As a check of our measurement technique, we note that previously published $A_{25–80}$ estimates in Wills et al. (1995), Baskin & Laor (2005), and Corbin & Boroson (1996) for roughly half the sources in our sample are within the error bars that are shown in Figure 1. Thus, we do not expect that there are any significant systematic differences between the measurement techniques employed here and those of other research teams for the remaining sources in Figure 1 that have not been previously published. Note that Marziani et al. (1996), Bachev et al. (2004), and Sulentic et al. (2007) subtract out a narrow-line component to compute asymmetry of the broad component, so it is difficult to make a quantitative comparison to the data presented here.

Figure 2 shows a scatter plot of the UV luminosity, $L_{UV} = \lambda L_\lambda$, at 1350 Å versus $A_{25–80}$. We do not see any significant correlation of $A_{25–80}$ and $L_{UV}$ as claimed in Corbin & Boroson (1996). The strength of various correlations (computed by means of the Spearman rank correlation coefficient) with $A_{25–80}$ is tabulated in Table 1. The Spearman rank correlation coefficient, $r_s$, is listed adjacent to the probability of the null hypothesis that there is no correlation between the parameters, labeled “P(Null).” The correlation of $A_{25–80}$ with $\alpha_{10}$ is statistically significant in the total sample and in the radio-loud subsample. The lack of a statistically significant correlation within the SSQ subsample is likely due to considerable masking of the core flux density by the often dominant steep spectrum lobe flux at 10 GHz (e.g., $P(Null)$ is reduced to 0.089 if 50 GHz flux density is used as a surrogate instead of 10 GHz). Since there is a large proportion of upper limits on $\alpha_{10}$ (~1/3) in the RQQ subsample there is no rigorous way of performing a correlation analysis. In order to deal with this, the correlation was computed by means of three distinct models of the data. The first choice in Table 1 was the correlation with all 28 sources in row 5 using the upper...
limits on the 10 GHz flux density as an approximation to the measured values. Second, the uncertainty associated with these upper limits was removed by just considering the 18 sources without upper limits in row 6. In row 7, it was assumed that the radio flux density was half of the upper limit. All three models of the RQQ data showed no evidence of a correlation of $A_{25–80}$ with other parameters. Thus, it is concluded that Table 1 indicates no evidence of a statistically significant Spearman rank correlation within the RQQ subpopulation. Since the RQQs are randomly clustered in a disjoint region of Figure 1, in the same general direction as the RLQ linear fit (extrapolating toward the lower left corner), they statistically act as one very heavily weighted point at the far end of the correlation, thereby enhancing the statistical significance of the correlation within the total sample in Table 1.

### 3. INTERPRETATION OF THE ASYMMETRY

In the previous section, the correlation between the $A_{25–80}$ and $\alpha_{10}^{UV}$ was established on a statistical basis in Table 1. There is a vast literature on blueward asymmetries in the CIV in RQQs. By contrast, this analysis has been directed toward redward asymmetry. In this section, we incorporate previous discussions of blueward asymmetry into this correlation analysis.

#### 3.1. The Distribution is Bimodal

It is shown that there are two disjoint pieces of information contained within the scatter of the data in Figure 1. First, we consider the distributions of asymmetry in Figure 3 for each quasar subclass represented in Table 1. There is a clear distinction in the asymmetry of the RQQs with that of the RLQs as well as with the radio loud subpopulations FSQ and SSQ, individually, as evidenced by a K–S test. The maximum difference $D$ and the K–S probability that the pairs of samples are drawn from the same population are listed in Table 2. The K–S test results in Table 2 indicate that $A_{25–80}$ is a measurable difference between RLQs and RQQs with high statistical significance. This bimodality is mirrored in the radio sector, these sources are bimodal in the power of the radio jet. The bimodality is manifest in Figure 1 as RQQs have $\alpha_{10}^{UV}$ < 0.3 and RLQs have $\alpha_{10}^{UV}$ > 0.3.

#### 3.2. Redward Asymmetry is Associated with a Strong Radio Jet

The Spearman rank correlation for the RQQs in Table 1 strongly supports the notion that there is no correlation between $A_{25–80}$ and other parameters. This might be expected since Baskin & Laor (2005) found that the asymmetry did not correlate with any other measured property in a sample of predominantly...
RQQs. The lack of signs of correlation in the RQQs and the strong correlation of the RLQs with $a_{10}^{UV}$ in Table 1 is another aspect of the bimodality of the two populations noted in the previous subsection. In terms of the correlation in Figure 1, the RQQs are essentially objects with virtually no 10 GHz flux density to first order and they are therefore clustered in the far left-hand bottom corner of the scatter plot. This clustering in the lower left-hand bottom corner is most naturally explained by the fact that redward asymmetry in the C iv BEL profile is associated with the presence of a radio jet, a feature that is weak in RQQs by definition.

3.3. Blueward Asymmetry is Associated with the Accretion Disk

Consider the vast literature demonstrating a blueward asymmetry in RQQ C iv BELs (Wilkes 1984; Brotherton et al. 1994; Marziani et al. 1996; Baskin & Laor 2005; Sulentic et al. 2007). Our data in Figure 3 agree with this notion, the distribution of $A_{25–60}$ for RQQ is heavily skewed toward negative values. The physics of the RQQ phenomenon typically induces a blueward asymmetry (through an unknown mechanism). The physics creating RQQs is generally believed to be the thermal luminosity resulting from dissipation in an accretion flow onto a supermassive black hole (Sun & Malkan 1989). Furthermore, in this standard model, the BELs represent reprocessed thermal emission in gas that is photo-ionized by the accretion flow emissivity. It follows that the blueward asymmetry of the C iv BELs is empirically determined to arise in the combined dynamical system of the accretion flow, the resultant radiation field and the BEL gas. It has been suggested that the blue excess in the C iv BEL is evidence of an outflowing wind from the accretion disk in RQQs (Marziani et al. 2006).

Now consider the dynamical environment of RLQs for which there are two central engines. The first one is associated with the accretion flow and its powerful thermal radiation, i.e., the same as the RQQs. In addition, there is a second central engine with similar power that drives a radio jet. The accretion disk is associated with an excess of C iv BEL gas that is blueshifted relative to the C iv peak. Based on the correlations in Table 1 and Figure 1, the radio jet central engine is associated with an excess of C iv BEL gas that is redshifted relative to the C iv peak. A RLQ has both central engines and there are competing effects. The first is related to the accretion disk and has a propensity to be associated with excess blueshifted emission in the C iv BEL. The other is related to the radio jet and is associated with excess redshifted emission in the C iv BEL. This has been demonstrated

| Sample 1/Number | Sample 2/Number | Maximum Difference, $D$ | Probability |
|-----------------|-----------------|-------------------------|-------------|
| RQQ/28          | RLQ/67          | 0.5917                  | < 0.001     |
| RQQ/28          | FSQ/40          | 0.6607                  | < 0.001     |
| RQQ/28          | SSQ/27          | 0.4907                  | 0.002       |
| FSQ/40          | SSQ/27          | 0.2718                  | 0.138       |
empirically, so we do not know the exact mechanism which causes the accretion disk (radio jet) to produce blueshifted (redshifted) C iv emission. These are competing effects that can show up in different relative strengths in principle. The statistical evidence in Table 1 that there are competing effects is that A_{25–80} is more strongly correlated with the logarithmic ratio of the radio luminosities (loosely associated with jet power) to the UV luminosity (accretion induced thermal luminosity) than to either of the luminosities (UV or 10 GHz) in RLQs. It is the relative strength of the jet to the accretion disk, not just the strength of the jet that produces the strongest correlation. Physically speaking, each central engine can be extant with a wide spread of strength independent of the other central engine’s strength and by some mechanism each induces broad wing emission in the BEL gas that exists in a myriad of possible enveloping environments—this is undoubtedly a complicated dynamical system. This is very different than what is the case for RQQs. The extra degree of freedom for creating emission in the C iv broad wings should result in both blue asymmetries and red asymmetries in RLQ C iv BELs and much larger cosmic scatter in the RLQ asymmetry properties than for RQQs. Evidence for the first of these conditions is indicated by the distribution of A_{25–80} in the RLQ histogram in Figure 3. The second condition is supported by the comparison of the histograms for RQQs and RLQs in Figure 3, the RLQ distribution is much wider. The scatter of the data is consistent with two competing sources of BEL wing gas.

We can test this idea of two competing effects by looking at the two outliers in detail. The FSQ PG 1718+481 with A = −0.33 and the RQQ E1821+643 with A = 0.26. If the interpretation given is correct, then there should be evidence that PG 1718+481 has strong accretion disk radiation and E1821+643 has a powerful jet. The primary indicator that a luminous accretion flow (a quasar) is present in a galactic nucleus is the detection of a large UV peak in the spectral energy distribution (Sun & Malkan 1989). Thus, this first prediction seems to be verified by the fact that \lambda L_{\lambda}(1350 Å) = 2 \times 10^{47} \text{erg s}^{-1} for PG 1718+481, by far the largest value in Figure 2. This large UV flux accounts for the small value of \alpha_{10}^{UV} = 0.424, one of the lowest in the RLQ sample. The continuum flux is almost certainly from the accretion disk and not the high-frequency tail of the synchrotron emission from the jet based on the following four facts. First, the spectral index is too flat from 3350 Å to 1650 Å, \alpha_v = 0.76 to be a blazar synchrotron emission and the EWs of the BELs are too large for the continuum to be dominated by synchrotron emission (Steidel & Sargent 1991; Wills et al. 1995). Also, the NASA Extragalactic Database notes that it is not optically variable and the optical polarization is low, both inconsistent with a synchrotron interpretation of the continuum. Within the two-component model, the accretion disk luminosity is so strong that it induces (through a yet to be determined physical process) a large blueward excess which swamps any redwing contributions induced by the relativistic jet (through a yet to be determined process).

The case for E1821+643 is not as strong, but still highly compelling. This quasar is a powerful radio source with a 151 MHz luminosity intermediate between that of a very strong FR I and an FR II radio source (Blundell & Rawlings 2001). Physically, the 151 MHz luminosity is believed to be a measure of the long-term time-averaged kinetic power delivered by the jet to the distant radio lobes (Willott et al. 1999). The methods of Willott et al. (1999) indicate a jet kinetic luminosity of \approx 2 \times 10^{44} \text{erg s}^{-1}. Very Large Array observations indicate that the source is core dominated and flat spectrum (Blundell et al. 1996). The core spectrum is highly inverted between 5 GHz and 15 GHz with \alpha = −0.94 with a 15 GHz flux density of 25 mJy (Blundell & Lacy 1995; Blundell et al. 1996). The peak of the spectral energy distribution of the core is unknown. Very Long Baseline Array observations show that the core size is less than 1 pc which bounds the brightness temperature >1.4 \times 10^9 \text{K} (Blundell et al. 1996). The flat spectrum nature of the jet and its large high-frequency luminosity are consistent with a powerful jet viewed close to the line of sight. The very large high frequency flux of the core might be indicative of a current episode of increased jet power. Within the two-component model described above, the dominant flat spectrum core is the manifestation of a powerful FR II jet viewed near the line of sight. This dynamics and geometry of the current episode of jet ejection are inducing a redward asymmetry that swamps the blueward asymmetry produced by the powerful accretion disk.

It is interesting that the outlier, E1821+643, in the scatter plot in Figure 1 is also a well-studied outlier in the quasar literature. Despite the radio characteristics just described, it is formally radio quiet (with R \approx 1.5) as per the standard definition of radio loudness defined in footnote 3 (Blundell et al. 1996). The reason that it is always classified as radio quiet in spite of a powerful radio jet is that the optical/UV luminosity is extremely large, L_{UV} = 1.3 \times 10^{46} \text{erg s}^{-1} (see Figure 2), making it one of the most luminous quasars at z < 0.5 (Lacy et al. 1999). This circumstance results in E1821+643 lying within the range (at the high end) of \alpha_{10}^{UV} of the RQQs in Figure 1, \alpha_{10}^{UV} = 0.200, even though it has a powerful jet. It is a rare case of a quasar that lies in a giant elliptical galaxy at the center of a cluster, but is not a RLQ (Lacy et al. 1992). This object has observational properties that are typical of both RQQs and RLQs, hence it has properties typical of both RLQs (large A_{25–80} and RQQs (small \alpha_{10}^{UV}) in the scatter plot in Figure 1. A major advantage of the use of \alpha_{10}^{UV} in the analysis in this paper is that is independent of the classification of a quasar as a RLQ or a RQQ.

4. DISCUSSION

In this paper, we analyzed the line asymmetries in a large sample of quasar C iv BELs. The following results were shown to be statistically significant.

A-I. A_{25–80} is correlated with \alpha_{10}^{UV} in the total QSO sample, the RLQ subsample and the FSQ subsample (see Figure 1 and Table 1).

A-II. A_{25–80} is not correlated with \alpha_{10}^{UV} in the RQQ subsample (see Figure 1 and Table 1).

A-III. The distribution of A_{25–80} is bimodally split in the radio sector of QSO parameter space: RQQs have smaller, usually negative A_{25–80} values (i.e., RQQs generally have blue asymmetric C iv BEL profiles), in contrast to the RLQs that have A_{25–80} values that are more broadly distributed with a tendency toward red asymmetric C iv BEL profiles (see Figures 1 and 3). Furthermore, the RQQ A_{25–80} values are not correlated with \alpha_{10}^{UV} while the RLQ A_{25–80} values are correlated with \alpha_{10}^{UV} (see Table 1).

These results are mathematically robust. More speculatively, we physically interpret these facts as arising from a two-component model with the following properties (with the justifying information in parenthesis).

B-I. The blue asymmetry in the C iv BEL, A_{25–80} < 0, is associated with accretion disk physics and its interaction with
the enveloping gaseous environment. (The RQQ histogram in Figure 3 and the standard RQQ model (Sun & Malkan 1989).)

B-II. The red asymmetry in the C iv BEL, $A_{25-80} > 0$, is associated with the central engine of a powerful relativistic jet and its interaction with the enveloping gaseous environment. (The majority of RLQs in the histogram in Figure 3 have $A_{25-80} > 0$, almost no RQQs have $A_{25-80} > 0$ in the histogram. The largest $A_{25-80} > 0$ RQQ source has a powerful jet, see Section 3.3.)

B-III. The red asymmetry in the C iv BEL, $A_{25-80} > 0$, is associated with the central engine of a powerful relativistic jet and its interaction with the enveloping gaseous environment. (The majority of RLQs in the histogram in Figure 3 have $A_{25-80} > 0$, almost no RQQs have $A_{25-80} > 0$ in the histogram. The largest $A_{25-80} > 0$ RQQ source has a powerful jet, see Section 3.3.)

B-IV. The red asymmetry in the C iv BEL, $A_{25-80} > 0$, is associated with the central engine of a powerful relativistic jet and its interaction with the enveloping gaseous environment. (The majority of RLQs in the histogram in Figure 3 have $A_{25-80} > 0$, almost no RQQs have $A_{25-80} > 0$ in the histogram. The largest $A_{25-80} > 0$ RQQ source has a powerful jet, see Section 3.3.)

Finally, the results above are cast in the light of the nine historical findings that were noted in the introduction. The result A-I above incorporates the findings (CDQs have larger $A_{25-80}$ than other RLQs), 4 (the largest $A_{25-80}$ is in RLQs), 5 (RLQs have redder C iv BELs than RQQs), 6 (composite C iv has redder wings for RLQs than RQQs), and 7 (some superluminal quasars have large red wing excess) from Section 1. The finding 8 (RLQs have a larger spread in $A_{25-80}$ than RQQs) is verified by the relative spread in the histograms in Figure 3 and is explained by B-IV of the consequences of the physical interpretation that are noted above. Historical finding 9 (RQQs tend to have $A_{25-80}$ < 0) is consistently described by results A-II and A-III noted at the beginning of this section. Figure 2 shows that the conclusion of study 3 ($A_{25-80}$ correlated with $L_{4UV}$) was an artifact of a sample in which the most luminous sources were often RLQs, as suggested in Corbin (1997a). There is no support for the conclusion found in study 1 (SSQs have larger $A_{25-80}$ than FSQs) in agreement with Wills & Brotherton (1996) who note that the result in study 1 was only marginally significant.

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