MULTI-EPOCH OBSERVATIONS OF THE RED WING EXCESS IN THE SPECTRUM OF 3C 279

BRIAN PUNSLY
1415 Granvia Altamira, Palos Verdes Estates, CA 90274, USA

ICRANet, Piazza della Repubblica 10, I-65100 Pescara, Italy; brian.punsly@verizon.net, brian.punsly@comdev-usa.com

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ABSTRACT

It has been previously determined 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 quasar C IV λ1549 broad emission lines (BELs). Ostensibly, the prominence of the red excess is associated with the radio jet emission mechanism and is most pronounced for lines of sight close to the jet axis. Studying the scant significant differences in the UV spectra of radio-loud and radio-quiet quasars might provide vital clues to the origin of the unknown process that creates powerful relativistic jets that appear in only about 10% of quasars. In this study, the phenomenon is explored with multi-epoch observations of the Mg ii λ2798 broad line in 3C 279 which has one of the largest known red wing excesses in a quasar spectrum. The amount of excess that is detected appears to be independent of all directly observed optical continuum, radio, or submillimeter properties (fluxes or polarizations). The only trend that occurs in this sparse data is: the stronger the BEL, the larger the fraction of flux that resides in the red wing. It is concluded that more monitoring is needed and spectropolarimetry with a large telescope is essential during low states to understand more.

Key words: galaxies: active – quasars: emission lines – quasars: general – quasars: individual (3C 279)

1. INTRODUCTION

Perhaps the greatest mystery of the quasar phenomenon is that ~10% of the quasar population possess powerful relativistic radio jets (known generically as radio-loud quasars, RLQs). These are dramatic features that can transport $\gtrsim 10^{40}$ W hundreds of kiloparsecs into the intracluster medium (Willott et al. 1999). Yet, the majority of quasars are radio-quiet quasars (RQQs) that are defined by “weak” jet power. In spite of this most conspicuous property, the optical/UV continuum and broad emission lines (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; Richards et al 2002). Perhaps the most extreme difference in the spectra of these two classes of objects 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 quasar C IV λ1549 BELs, at $\sim 99.9999\%$ statistical significance (Punsly 2010). The prominence of the redward excess is apparently associated with the radio jet emission mechanism and is most pronounced for lines of sight close to the jet axis.1 In some blazars (core-dominated radio sources), the asymmetry is so extreme that the line shape becomes similar to a right triangle, the emission is dominated by the red, gently sloping side (“the hypotenuse”). In this Letter, we explore why this effect is so pronounced in some radio-loud active galactic nuclei that are viewed along the jet axis.

The red excess in the BELs has been noted in anecdotal examples of blazar spectra including the first case to be studied in detail, Hα in 4C 34.47 in Corbin (1997a). The origin of the red wing excess is unknown and explanations have ranged from gravitational and transverse redshift within 200 M (gravitational radii) from the central black hole, reflection off optically thick, out-flowing clouds on the far side of the accretion disk, or transmission through inflowing gas on the near side of the accretion disk (Larsson et al. 2012; Lister et al. 2009; Jorstad et al. 2011). 3C 279 also has a spectrum with some of the most redward asymmetric BELs ever observed. As a consequence of the extraordinary nature of this blazar, there is a wealth of simultaneous long-term monitoring data from radio waves to gamma rays, which facilitate multi-epoch comparisons. Since the effect is most pronounced in blazars, one is often forced to deal with the huge amount of dilution from the optical, high-frequency tail of the Doppler-enhanced synchrotron emission from the relativistic jet (Lind & Blandford 1985). Thus, in 3C 279, for example, it is difficult to extricate the BELs from the continuum unless the jet emission is weak (a low state).

2. SPECTRA FROM THREE EPOCHS

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Figure 1. Optical spectra at three different epochs.

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imaginary line connecting a point defined at one-fourth of the peak flux density of the BEL on the red side of the BEL to one-fourth of the peak flux density on the blue side of the BEL, \( \lambda_{25} \), and a similar midpoint defined at eight-tenths of the flux density maximum, \( \lambda_{80} \), as

\[
A_{25-80} = \frac{\lambda_{25} - \lambda_{80}}{\text{FWHM}}.
\]

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 calculate \( A_{25-80} \) in the presence of the random noise that is superimposed on the line profiles in Figure 2, one can proceed as in Wills et al. (1995). Using the continuum fit described in the last section, the lines are fit by two or three Gaussians profiles that interpolate between the fluctuations of the random noise. The values for each epoch are listed in Column 5 of Table 1.

The errors associated with estimating \( A_{25-80} \) 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 one-fourth maximum point of the line profile by the composite Gaussian fit. The error in \( \lambda_{25} \) was determined to be the slope of this composite Gaussian fit (\( \partial \lambda / \partial F_\lambda \)) at the one-fourth maximum point times the rms noise level. This naturally produces larger errors in \( A_{25-80} \) for epochs 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. These uncertainties are listed in Column 5 of Table 1.

The line luminosities in Table 1 are computed using the Galactic extinction from Schlafly & Finkbeiner (2011) as posted in the NASA Extragalactic Database and a cosmological model defined by \( H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_\Lambda = 0.7 \), and \( \Omega_m = 0.3 \). The first thing to note is that the 2009 and 2010 line profiles are virtually identical in Figure 2 and Table 1 even though the optical polarization is an order of magnitude larger in 2009. The line was decomposed into two empirical components, a blue side (with negative velocity in Figure 2) and a red side based on a redshift, \( z = 0.5356 \). Column 2 of Table 1 is the total line luminosity, \( L(\text{Mg} \, \text{II}) \), and Column 3 is the ratio of red side luminosity, \( L(\text{Mg} \, \text{II})_{\text{red}} \), to the blue side luminosity, \( L(\text{Mg} \, \text{II})_{\text{blue}} \). Column 4 is the red excess that is defined by reflecting the blue side about the zero velocity axis and computing the red residuals. This quantity is then normalized by \( L(\text{Mg} \, \text{II}) \),

\[
\text{Red Excess} \equiv \frac{L(\text{Mg} \, \text{II})_{\text{red}} - 2L(\text{Mg} \, \text{II})_{\text{blue}}}{L(\text{Mg} \, \text{II})}.
\]

The next column is the asymmetry parameter, \( A_{25-80} \), defined in Equation (1). The last two columns depict the strength and polarization of the optical continuum.

The errors in Column 2 of Table 1 represent the luminosity of the rms of the residuals (noise level) to the composite Gaussian fit that is obtained by integrating the residual luminosity over the
entire line profile from $-5000$ km s$^{-1}$ (blue) to 13,000 km s$^{-1}$ (red). Similarly, one computes the uncertainty in the blue (red) side of the line decomposition as the integrated luminosity of the rms residual noise level (note that the rms residual noise level is always positive, by definition, even when the residual luminosity is negative) over the blue (red) portion of the line profile from $-5000$ km s$^{-1}$ to 0 km s$^{-1}$ (0 km s$^{-1}$ to 13,000 km s$^{-1}$). The errors in the blue and red sides propagate through quadratures in order to generate the error estimates in Columns 3 and 4.

The intent of presenting Table 1 is to demonstrate that the variation in the red wing excess over an 18 year time span exists independent of how it is defined. The last two rows show that a virtually unchanged line profile can still be clearly detected even when the synchrotron background triples in strength. Thus, the Steward Observatory monitoring can detect a well-defined asymmetric profile over a wide range of continuum luminosity and should provide a wealth of epochs with asymmetric profiles in the coming years. The preliminary trend in the data is that when the line strength is elevated, the degree of asymmetry increases.

4. DISCUSSION

The purpose of this Letter is not to make strong claims as to the physical origin of red wing excess in blazars. The purpose is to show that it is possible to see changes in the red wing excess in blazars.

The primary result of Table 1 is that the Mg $\text{ii}$ red wing excess does not vary in consort with the rest of the broadband emission. Considering the conspicuous jet viewed in a nearly pole-on orientation, it seems likely that the red excess is associated with the jet and not the virialized gas responsible for the core and blue wing of the emission line. This seems to favor the optically thick outflow scenario described in Section 1. The phenomenon might be related to the outflow that is responsible for the broad absorption lines seen in some polar orientation broad absorption line quasars (Zhou et al. 2006; Ghosh & Punsly 2007; Punsly & Zhang 2010).

Temporal variations in line properties can then be compared to contemporaneous variations of jet properties on subparsec scales that can be detected during the extensive monitoring from millimeter wavelengths to gamma rays of many FERMI-selected blazars and high-frequency (43 GHz) Very Long Baseline Array images (Ataraski et al. 2011; Bonning et al. 2012; Jorstad et al. 2011; Larsson et al. 2012). In principle, any such causal connections can be used as a probe of possible relationships between jet propagation/formation and the gaseous environment on subparsec scales, the broad-line region. In one way, this comment attempts to minimize the complexities introduced by large Doppler enhancement of the emission which can make it extremely difficult to determine the intrinsic properties of the jet.

The data presented here, from three epochs observed with modest apertures, are insufficient to properly explore the possibilities noted above. To improve our understanding requires more optical data with larger telescopes and long-term monitoring. Future long-term monitoring (since the timescale for variation is longer than one year from Table 1) of the FWHM and the luminosity using the decompositions into red, blue, and core components can be used as a crude surrogate for reverberation mapping of the red wing (since the optical continuum is hidden by the synchrotron emission). It would be important to find time lags (if any) between the blue wing, the line core, and the red excess. This would yield information on the relative locations of the gas producing the line core and the gas responsible for the red excess. Perhaps of more interest, it is proposed that the Steward Observatory monitoring be used as a trigger for a large telescope observation. If a broad line is clearly displayed in the Steward Observatory data, this would trigger a large (8 m) telescope to observe 3C 279 with high-resolution spectropolarimetry the purpose being the same as in the study of broad absorption line quasars—to look for signs of scattered emission in the red wing, namely position angle rotation or a change in the polarization level (Smith et al. 1995; Ogle 1997). These data could be used as a probe of the geometry in scenarios where the red wing is scattered emission that was resonantly absorbed in an out-flowing wind or it is scattered light from an optically thick “moving mirror” that is created by a stream of clouds in motion.

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