SPECTRAL VARIABILITY OF QUASARS IN THE SLOAN DIGITAL SKY SURVEY. II. THE C IV LINE

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ABSTRACT

We examine the variability of the high-ionization C iv λ1549 line in a sample of 105 quasars observed at multiple epochs by the Sloan Digital Sky Survey. We find a strong correlation between the change in the C iv line flux and the change in the line width, but no correlations between the change in flux and changes in line center and skewness. The relation between line flux change and line width change is consistent with a model in which a broad line base varies with greater amplitude than the line core. The objects studied here are more luminous and at higher redshift than those normally studied for variability, ranging in redshift from 1.65 to 4.00 and in absolute r-band magnitude from roughly −24 to −28. Using moment analysis line-fitting techniques, we measure line fluxes, centers, widths, and skewnesses for the C iv line at two epochs for each object. The well-known Baldwin effect is seen for these objects, with a slope of β = −0.22. The sample has a median intrinsic Baldwin effect slope of βint = −0.85; the C iv lines in these high-luminosity quasars appear to be less responsive to continuum variations than those in lower luminosity AGNs. In addition, we find no evidence for variability of the well-known blueshift of the C iv line with respect to the low-ionization Mg ii λ2798 line in the highest flux objects, indicating that this blueshift might be useful as a measure of orientation.

Subject headings: galaxies: active — quasars: general — techniques: spectroscopic

Online material: machine-readable tables

1. INTRODUCTION

Quasar emission lines represent light reprocessed by high-velocity ionized gas surrounding a central continuum source. As the central source continuum varies, the emission lines vary in response. Quasar continuum variability is well studied. Long-known anticorrelations between variability amplitude and luminosity (e.g., Uomoto et al. 1976; Cristiani et al. 1997) and between variability amplitude and wavelength (e.g., Grieve et al. 1999; Trèvese et al. 2001; Wilhite et al. 2005), as well as the correlation between variability and time lag (e.g., Hook et al. 1994; Hawkins 2002; de Vries et al. 2003), were recently parameterized by Vanden Berk et al. (2004).

Variability of quasar emission lines is also well studied, but for a much smaller number of objects. Much of this work has come as a part of reverberation mapping efforts to determine black hole masses and study the structure of the broad-line region (BLR; e.g., Peterson 1993; Wandel et al. 1999) and has generally focused on line response to continuum variability. These emission-line variability studies have been critical in characterizing the structure of the BLR. By measuring the response delays of various emission lines with respect to the continuum, reverberation mapping has shown that the broad-line emitting region species are stratified by ionization potential (e.g., Peterson 1993) and that the size of the BLR is dependent on continuum luminosity (e.g., Wandel et al. 1999; Kaspi et al. 2005).

Until recently, C iv λ1549 had been monitored in only a few low-redshift, low-luminosity objects, such as NGC 5548, which has been monitored for years with both the International Ultraviolet Explorer (IUE) and the Hubble Space Telescope (HST; Clavel et al. 1991; Korista et al. 1995), and NGC 5141, which has been observed for short-term variability with IUE (Crenshaw et al. 1996). Kaspi et al. (2003) have begun a campaign to use C iv variability in reverberation mapping of high-redshift, high-luminosity quasars, but the results are not yet conclusive.

Profile variability of active galactic nucleus (AGN) emission lines has been studied (e.g., Wanders & Peterson 1996; Sergeev et al. 2001), but most of this has been done for nearby, low-luminosity Seyfert galaxies and has been limited to the rest-frame optical. The reasons for this are well motivated—low-luminosity objects are known to be more variable, and optical spectroscopy is more common—but this means there has been relatively little study of line variability in higher luminosity objects, or of rest-frame ultraviolet lines like C iv. Although not well studied in the time domain, the C iv line has demonstrated several intriguing properties at a single epoch that suggest that the study of C iv variability could prove useful in understanding the structure of the broad emission line region and of quasars as a whole.

1.1. The C iv Line Profile

Wills et al. (1992) and Francis et al. (1992) found that C iv line width is anticorrelated with the equivalent width of the line, a result even more clearly demonstrated by Wills et al. (1993). The highest flux C iv lines tend to be the most narrow. Wills et al. (1993) suggested that this might be due to different relative importances of an intermediate-width line region (ILR) and the very broad line region (VBLR) from quasar to quasar. In this scenario, the narrow (~2000 km s⁻¹) line core is produced in the ILR, which lies near the outer edge of the BLR. The broad (~7000 km s⁻¹) line base is a product of the VBLR, which comprises the inner portion of the BLR. According to the ILR model, possible line core fluxes extend over a larger range in values than do the line base fluxes. Thus, the width of an individual line
is strongly dependent on the strength of the ILR line core. Strong C \textsc{iv} lines have dominant cores and are therefore narrow. Similarly, weak C \textsc{iv} lines have less dominant cores and thus relatively more important line bases and are preferentially broader as a result. Murray & Chiang (1997) found that the C \textsc{iv} profile could be reproduced with a continuous disk wind model and did not distinguish between intermediate-width and very broad line regions.

Wills et al. (1993) also found that the C \textsc{iv} line is typically asymmetric, in the sense that the C \textsc{iv} lines are generally skewed to shorter wavelengths. Richards et al. (2002a) found that this asymmetry tends to increase with increasing C \textsc{iv} blueshift; the most blueshifted lines also tend to be the most skewed toward the blue end of the spectrum.

1.2. The Baldwin Effect in the C \textsc{iv} Line

Baldwin (1977) and others later (Kinney et al. 1990; Baskin & Laor 2004) demonstrated that the equivalent width of the C \textsc{iv} line is anticorrelated with the luminosity of the nearby continuum for quasars observed at a single epoch:

$$W_{\text{C\textsc{iv}}} \propto L_{\text{b}}^{\beta}.$$  (1)

The initial fit to the slope was $\beta = -0.64$ (Baldwin et al. 1978). Kinney et al. (1990) found a lower value of $\beta = -0.17 \pm 0.04$, and later studies (e.g., Dietrich et al. 2002) have found similar results.

The Baldwin effect may also be recast in terms of line luminosity, giving the similar result

$$L_{\text{C\textsc{iv}}} \propto L_{\text{b}}^{\beta},$$  (2)

where $b = \beta + 1$. In this form, the relation is easier to understand. From quasar to quasar, as the continuum luminosity increases, the C \textsc{iv} line luminosity increases, but at a slower rate.

By using equivalent width as a proxy for luminosity, it had originally been hoped that the Baldwin effect could be used as a cosmological probe. Unfortunately, the roughly half-magnitude scatter about the original relation is too large to allow for precision cosmology.

Richards et al. (2002a) found that the Baldwin effect in C \textsc{iv} appears to be related to the blueshift of the line with respect to lower ionization lines, such as Mg \textsc{ii} (see §1.3). They separated almost 800 quasars into four equally populated bins, splitting by the size of the blueshift; from the quasars in each bin, they created a composite spectrum. They found a clear anticorrelation between the strength of the C \textsc{iv} line and the size of the blueshift. The bin with the largest C \textsc{iv}–Mg \textsc{ii} blueshift also had the lowest equivalent width composite C \textsc{iv} line, and vice versa.

It has been suggested that the C \textsc{iv} Baldwin effect could be largely reproduced by a softening of the continuum slope with increasing luminosity and luminosity-dependent quasar metallicity (Korista et al. 1998). Wang et al. (1998) found that the ultraviolet–to–X-ray spectral index is correlated with quasar luminosity: more luminous quasars have softer ionizing continua slopes. They also found that the UV–to–X-ray index is strongly correlated with C \textsc{iv} equivalent width. The combination of these effects leads directly to the Baldwin effect: quasars with high luminosity display low C \textsc{iv} equivalent width. Although these relations are consistent with the Baldwin effect, the physical driver itself is not yet understood.

Recently, Baskin & Laor (2004) found that the correlation with C \textsc{iv} equivalent width was much stronger with $L_{\text{b}}^{{1/2}}(\text{H}\beta \text{FWHM})^{-2}$, a proxy for $L/L_{\text{Edd}}$ [since the black hole mass scales as $L^{-1/2}(\text{H}\beta \text{FWHM})^2$] than it was with the simple continuum luminosity.

They have suggested that the Baldwin effect may in fact be a secondary effect spawned by a more fundamental relation between the C \textsc{iv} equivalent width and the relative accretion rate $L/L_{\text{Edd}}$. However, the potential physical mechanism driving the relation is unknown.

The roughly half-magnitude scatter in the Baldwin effect was shown by Kinney et al. (1990) to be at least partially due to continuum and C \textsc{iv} line variability. As a quasar’s continuum luminosity increases or decreases, the C \textsc{iv} line luminosity (which consists largely of reprocessed continuum photons) increases or decreases in turn, with a small delay owing to the light-travel time. An intrinsic relationship between continuum and line luminosities may be written in forms identical to those for the global Baldwin relation ($W_{\text{C\textsc{iv}}} \propto L_{\text{b}}^{\beta}$ and $L_{\text{C\textsc{iv}}} \propto L_{\text{b}}^{\beta}$). Kinney et al. (1990) found that the so-called “intrinsic Baldwin effect” (IBE) slope ranged from $\beta_{\text{int}} = -0.4$ to $-0.9$ for six Seyfert galaxies and 3C 273, with an average of $\beta_{\text{int}} \approx -0.65$ ($\sigma_{\text{int}} \approx 0.35$).

The IBE is, for historical reasons, usually cast in terms of equivalent width, but it is more straightforward when expressed in terms of luminosity. As was the case with the global Baldwin effect, the slope of the IBE is between 0 and 1. This indicates that, for an individual quasar, the BLR reprocessing of the incident continuum light is not perfectly efficient. As the continuum luminosity of an individual quasar fluctuates, so too does the C \textsc{iv} line luminosity, but to a lesser degree. If an object had an IBE slope of 0.35, a doubling in a quasar’s continuum luminosity would only lead to a roughly 25% increase in C \textsc{iv} line luminosity (after allowing for the light-travel time delay).

The IBE slope itself has been found to vary. Over 13 yr of monitoring, the IBE slope of the H\beta line in the Seyfert I galaxy NGC 5548 ranged from $b = 0.4$ to 1.0 on timescales of roughly 1 yr (Goad et al. 2004). The slope was strongly anticorrelated with continuum flux, indicating a lower line responsivity at higher continuum flux levels, which is consistent with photoionization models (Korista & Goad 2004). Pogge & Peterson (1992) determined that the Baldwin effect scatter may be further reduced by accounting for the light-travel time, $\tau$, between the continuum source and the broad emission line region: $L_{\text{C\textsc{iv}}}(t) \propto L(t - \tau)^{\beta}$.

1.3. C \textsc{iv} Line Shifts

Gaskell (1982) first demonstrated that high-ionization quasar broad emission lines (such as C \textsc{iv}) are typically blueshifted by hundreds of km s$^{-1}$ with respect to the low-ionization lines, which are thought to represent the true systemic redshift of the quasar. This was verified in a number of later studies (Wilkes 1984; Espey et al. 1989; Corbin 1990; Tytler & Fan 1992; McIntosh et al. 1999; Sulentic et al. 2000). Recently, Richards et al. (2002a) measured the blueshift of the C \textsc{iv} line with respect to Mg \textsc{ii} for $\approx$800 quasars in the Sloan Digital Sky Survey (SDSS) Early Data Release Quasar Catalog (Schneider et al. 2002). A possible correlation between C \textsc{iv} blueshift and radio-determined orientation measures, as well as a similarity between the spectra of broad absorption line quasars and quasars with large C \textsc{iv} blueshifts, prompted Richards et al. (2002a) to suggest the possibility that the C \textsc{iv} blueshift could be used as a measure of quasar orientation, either internal (related to the disk wind opening angle) or external (related to the line of sight to the observer). They proposed that the blueshift might be a result of the obscuration or suppression of the C \textsc{iv} flux on the red side of the line. If the blueshift of the C \textsc{iv} line relative to low-ionization lines such as Mg \textsc{ii} is related to the observer’s viewing angle, it
could represent the first technique to measure orientation for radio-quiet quasars.

1.4. The Present Work

This is the second paper reporting results of a quasar spectral variability program using data from the SDSS (York et al. 2000). The first paper (Wilhite et al. 2005, hereafter Paper I) examined the detailed wavelength dependence of quasar variability. This paper focuses on the high-ionization C IV λ1549 line. We briefly summarize the SDSS data acquisition, our previous spectrophotometric recalibration work, and the creation of the variable quasar sample in § 2. In § 3, we describe the line-fitting algorithm used here. The variability of the C IV line flux and profile is studied in § 4. Interesting individual objects are identified in § 5. The results are discussed in § 6, and we conclude in § 7. Throughout the paper we assume a flat, cosmological constant–dominated cosmology with parameter values ΩΛ = 0.7, ΩM = 0.3, and H0 = 70 km s⁻¹ Mpc⁻¹.

2. THE SLOAN DIGITAL SKY SURVEY

AND THE VARIABLE QUASAR SAMPLE

2.1. The Sloan Digital Sky Survey

Through the summer of 2004, the Sloan Digital Sky Survey (York et al. 2000) had imaged almost ~8200 deg² and obtained follow-up spectra for roughly 5 × 10⁶ galaxies and 5 × 10⁴ quasars. All imaging and spectroscopic observations are made with a dedicated 2.5 m telescope at the Apache Point Observatory in New Mexico. Imaging data are acquired by a 54 chip drift-scan camera (Gunn et al. 1998) equipped with the SDSS u, g, r, i, and z filters (Fukugita et al. 1996); they are then reduced and calibrated by the PHOTO software pipeline (Lupton et al. 2001). The photometric system is normalized such that SDSS magnitudes are on the AB system (Smith et al. 2002). A 0.5 m telescope monitors site photometricity and extinction (Hogg et al. 2001). Point-source astrometry for the survey is accurate to less than 100 mas (Pier et al. 2003). Ivezić et al. (2004) discuss imaging quality control.

Objects are targeted for follow-up spectroscopy as candidate galaxies (Strauss et al. 2002; Eisenstein et al. 2001), quasars (Richards et al. 2002b), or stars (Stoughton et al. 2002). Targeted objects are grouped in 3″ diameter “tiles” (Blanton et al. 2003), and aluminum plates are drilled with 640 holes whose locations on the plate correspond to the objects’ sky locations. Each plate is placed in the imaging plane of the telescope and plugged with optical fibers assigned to roughly 500 galaxies, 50 quasars, and 50 stars. Fibers run from the telescope to twin spectrographs.

SDSS spectra cover the observer-frame optical and near-infrared, from 3900 to 9100 Å. Spectra are obtained in three or four consecutive 15 minute observations until an average minimum signal-to-noise ratio (S/N) is met. The spectra are calibrated by observations of 32 sky fibers, 8 reddening standard stars, and 8 spectrophotometric standard stars. Spectra are flatfielded and flux-calibrated by the Spectro2d pipeline. Next, Spectro1d identifies spectral features and classifies objects by spectral type (Stoughton et al. 2002). Ninety-four percent of all SDSS quasars are identified spectroscopically by this automated calibration; the remaining quasars are identified through manual inspection. Quasars are defined to be those extragalactic objects with broad emission lines (FWHM velocity width of ≥1000 km s⁻¹), regardless of luminosity.

Through 2004 June, objects corresponding to 181 plates had been observed multiple times, with time lags between observation ranging from days to years. As discussed in Paper I, spectra from plates observed greater than 50 days apart have not been co-added and are more suitable for use in variability studies. There are 53 such large time lag plate pairs, containing almost 2200 quasars; 47 of these plate pairs are contained in the Third Data Release (DR3; Abazajian et al. 2005).

2.2. Refinement of Spectroscopic Calibration

Vanden Berk et al. (2004, hereafter VB04) and Paper I demonstrated that additional spectrophotometric calibration of SDSS spectra is necessary for variability studies. We summarize here the calibration methods used in Paper I; see that work for a complete discussion. The Spectro1d pipeline calculates three values of S/N for each spectrum by calculating the median S/N per pixel in the portions of the spectrum corresponding to the SDSS g, r, and i filter transmission curves. Hereafter, when referring to the two halves of a plate pair, we use the phrase “high-S/N epoch” to refer to the plate with the higher median r-band S/N. The plate with the lower median r-band S/N will be called the “low-S/N epoch.” It is worth emphasizing that this is a plate-wide designation; although most objects follow the plate-wide trend, this does not speak to the relative S/N values for any given individual object, nor does it correspond to an object’s relative line or continuum flux at a given epoch. The stars on a plate are used to resolve calibration differences between the high- and low-S/N epochs, under the assumption that the majority of stars are nonvariable (precautions are taken to remove the obviously variable stars from recalibration). For each plate pair, we create a recalibration spectrum equal to the ratio of the median stellar high-S/N epoch flux to the median stellar low-S/N flux as a function of wavelength. This recalibration spectrum is fitted with a fifth-order polynomial to preserve real wavelength dependences but remove pixel-to-pixel noise (see Fig. 5 of Paper I), leaving a smooth, relatively featureless curve as a function of wavelength. All low-S/N epoch spectra are then scaled by this “correction” spectrum.

2.3. Variable Quasar Sample

In this study, we make use of the sample of variable quasars created in Paper I. Many quasars at low redshift appear as extended objects; due to the fiber nature of the spectrograph, these low-redshift objects are problematic for accurate relative spectrophotometry between epochs. To avoid such problems with extended objects, only quasars with z > 0.5 were used in Paper I. With respect to the assumed nonvariable stellar population, 315 quasars were determined to have varied significantly between epochs. These variable quasars have larger rest-frame time lags than the average for all SDSS quasars with multi-epoch spectroscopy, but are otherwise indistinguishable from the main sample. This sample was first used to study the detailed dependence of variability on wavelength; for more information, see Paper I.

3. FITTING THE C IV LINE

3.1. Region of Interest

Using moment analysis techniques, we fit the C IV line for all objects where the entire line has been observed by the SDSS spectrograph. Both epochs are fitted individually. Thus, for each object, we obtain flux, position, and profile information for the C IV line at two epochs.

The line-fitting techniques used are similar to those used by Vanden Berk et al. (2001) to fit composite spectra created from
the SDSS quasar survey, with a few modifications. Vanden Berk et al. (2001) fit the composite spectrum C iv over the rest-frame wavelength range 1494–1620 Å. However, the C iv line is typically flattened on the red side by He ii λ1640 and emission from other species, such as Fe ii, O ii, and Al ii, as well as having some unidentified flux above the continuum redward of 1600 Å (e.g., Wilkes 1984; Boyle 1990; Laor et al. 1994; Vanden Berk et al. 2001). However, over intervals centered on roughly 1480 and 1690 Å, quasar spectra are relatively free of emission, making these logical intervals to use in fitting the underlying continuum (see § 3.2).

Spectra are not deredshifted for fitting; the region of interest for each quasar is determined by scaling the [1472 Å, 1700 Å] interval by 1 + z for that quasar. Only those spectra containing this region in its entirety are used; quasars with redshifts between 1.65 and 4.35 are available for study. Table 1 lists these 105 objects, as well as their dates of observation (MJD), redshifts (z), rest-frame time lags (Δτ), absolute magnitudes (Mr), and both epochs’ S/N ratios. Absolute magnitudes are calculated assuming a power-law spectral energy distribution f(λ) ∝ λ^κ, with a slope of κ = -1.5.)

This leaves 105 objects with redshifts ranging from 1.65 to 4.00. The fitting procedures are explained in §§ 3.2–3.6. Results of the fits are in Tables 2 and 3.

### Table 1

| Number | SDSS J       | MJD | Δτ (days) | z | Mr, HSN | S/N, HSN | HSN | LSN |
|--------|--------------|-----|-----------|---|---------|----------|-----|-----|
| 1............. | 100013.37+011203.2 | 51,910 | 51,581 | 1.80 | 117.4 | 19.1 | –26.0 | 12.3 | 11.4 |
| 2............. | 100428.43+001825.6 | 51,910 | 51,581 | 3.04 | 81.3 | 18.7 | –27.6 | 16.4 | 11.2 |
| 3............. | 114211.59–005344.2 | 51,959 | 51,584 | 1.92 | 128.5 | 20.1 | –26.8 | 22.7 | 16.4 |
| 4............. | 114948.81+000855.8 | 51,959 | 51,584 | 1.97 | 126.3 | 19.4 | –26.2 | 12.9 | 10.9 |
| 5............. | 115154.83–005904.6 | 51,943 | 51,662 | 1.93 | 96.0 | 18.3 | –26.0 | 12.9 | 7.6 |
| 6............. | 115043.87–002354.0 | 51,943 | 51,662 | 1.98 | 94.4 | 19.7 | –27.8 | 40.0 | 27.2 |
| 7............. | 115213.55+001946.7 | 51,943 | 51,662 | 1.83 | 99.2 | 19.6 | –25.3 | 8.0 | 7.3 |
| 8............. | 124524.59–000937.9 | 51,928 | 51,660 | 2.08 | 86.9 | 19.5 | –27.3 | 29.7 | 20.8 |
| 9............. | 124356.22–000021.8 | 51,928 | 51,660 | 1.84 | 94.5 | 19.4 | –25.5 | 9.8 | 7.2 |
| 10............. | 124242.11+01157.9 | 51,928 | 51,660 | 2.16 | 84.8 | 18.4 | –26.3 | 14.2 | 9.4 |

### Table 2

| NUMBER | C IV Flux Variability |
|--------|-----------------------|
|        | f_cont (10^-17 ergs s^-1 cm^-2 Å^-1) | f_line (10^-17 ergs s^-1 cm^-2) |
| 1............. | 11.2 | 20.3 | 1205.1 | 1099.3 |
| 2............. | 8.0 | 6.4 | 1248.3 | 1165.5 |
| 3............. | 19.6 | 27.5 | 1458.3 | 1644.1 |
| 4............. | 9.7 | 13.5 | 746.4 | 654.4 |
| 5............. | 10.1 | 7.1 | 614.6 | 479.6 |
| 6............. | 50.3 | 44.9 | 4691.5 | 3729.1 |
| 7............. | 5.8 | 8.7 | 712.1 | 853.0 |
| 8............. | 20.7 | 17.3 | 1991.0 | 2013.4 |
| 9............. | 7.6 | 4.8 | 760.7 | 702.2 |
| 10............. | 8.9 | 6.3 | 784.8 | 925.1 |

### Notes

Table 2 is presented in its entirety in the electronic edition of the Astrophysical Journal. A portion is shown here for guidance regarding its form and content.

3.2. Continuum Fitting and Total Line Flux

Accurately fitting the underlying continuum near a line is critical. Too low or high a continuum fit will lead to an overestimate or underestimate of the line flux. An incorrectly fitted local continuum slope could introduce an apparent asymmetry not inherent to the line itself. Despite its importance, there is no widely accepted method of continuum fitting. The fits to quasar continua in Wills et al. (1993) employed either a power law or a low-order polynomial. Vanden Berk et al. (2001) fitted the local continuum with a straight line. Over such a small wavelength range (~ 150 Å), it appears that any reasonable function will work, provided that care is taken.

For simplicity, we employ a straight-line local continuum fit. To ensure that the fits were well behaved, numerous visual checks were done. We varied the size of the region of interest and the size of the region used to fit the continuum. We use here those values that appeared to give the most accurate and stable fits to the continuum and the line center.

Before fitting the continuum, the region of interest in each spectrum is manually inspected for poor night-sky subtraction or absorption lines. In the case of poor subtraction of a night-sky line (most commonly O i 5577), we interpolate over the affected region, using the pixels within 25 Å on either side. Night-sky lines were removed from eight spectra. There are no cases where poor night-sky subtraction occurs near the peak of a line. Absorption lines are only removed in the cases where they affect the fit to the continuum; they are not removed if they lie on top of the C iv emission line itself. Only four absorption lines are removed.

To fit the continuum, a single straight line is fitted to pixels at either end of the region of interest. This corresponds roughly to fitting the continuum with those pixels with rest-frame wavelengths between 1472 and 1487 Å or between 1685 and 1700 Å. This linear continuum fit is then subtracted from every pixel in the region of interest to isolate the line flux:

$$ F_{\text{line}}(\lambda) = F_{\text{total}}(\lambda) - F_{\text{cont}}(\lambda). $$

To avoid inclusion of emission flux from other sources, measurements are made over the range corresponding to a 100 Å interval centered on 1546 Å in the quasar’s rest frame. (Although 1549 Å is the laboratory wavelength of C iv, the line is blueshifted in quasars such that the mean rest wavelength position is actually 1546 Å; Richards et al. 2002a; Vanden Berk et al. 2001.)
The total flux for the line is simply the integral of the continuum-subtracted line flux density \([F_\lambda = F_\text{line}(\lambda)]\) over this measurement interval:

\[
f = \int_{C_{\text{IV}}} F_\lambda \, d\lambda,
\]

where \(C_{\text{IV}}\) indicates the interval [1496 Å, 1596 Å], as described above. In §§ 3.3 and 3.4, we calculate the first three moments of the \(C_{\text{IV}}\) line, using this continuum-free region.

### 3.3. First Moment: Line Center

In a perfectly symmetric line, the meaning of the line “center” is easily understood; the mean, median, and mode of the line’s flux distribution all fall at the same wavelength. It is thought, however, that the \(C_{\text{IV}}\) line is typically asymmetric (Wills et al. 1993). Therefore, one must choose which statistic to use. In the spectra used here, some of which have low S/N, the median is a far more reliable measurement than the mean, which is easily affected by noisy pixels in the line wings. Thus, for robustness and simplicity, we calculate the line center using the median. The median is simply the midpoint of the line flux, the wavelength that evenly divides the continuum-subtracted flux in the [1496 Å, 1596 Å] interval.

We also use this measurement of the line center to calculate the local continuum. The continuum flux density is determined by evaluating the straight-line continuum fit (see § 3.2) at the median-determined line center.

### 3.4. Second and Third Moments: Line Width and Skewness

We use the second moment about the median wavelength as a measurement of line width:

\[
\sigma^2 = \frac{\int_{C_{\text{IV}}} (\lambda - \bar{\lambda}_{\text{median}})^2 F_\lambda \, d\lambda}{\int_{C_{\text{IV}}} F_\lambda \, d\lambda},
\]

Visual inspection reveals that the Pearson skewness,

\[
P_{\text{skew}} = \frac{3(\text{mean} - \text{median})}{\sigma},
\]

is a more stable statistic between epochs than the third moment of the flux. Thus, as did Vanden Berk et al. (2001), we use the Pearson skewness to measure line asymmetry. To keep the mean from being unduly affected by the noisy tails of the \(C_{\text{IV}}\) line, we measure the mean of the line over the interval [1516 Å, 1576 Å], using \(\bar{\lambda}_{\text{mean}} = (\int \lambda F_\lambda \, d\lambda)/(\int F_\lambda \, d\lambda)\). This is tantamount to Vanden Berk et al. (2001) using only the “top 50%” of the line. The single-object spectra used here are too noisy to allow for a reliable determination of the “top 50%,” so this 60 Å interval, chosen because it closely approximates the “top 50%,” is used instead.

Figure 1 is a histogram of the high-S/N epoch Pearson skewness values for the objects in our sample. The median value of \(-0.012 \pm 0.013\) is consistent with no skewness of the \(C_{\text{IV}}\) line. Vanden Berk et al. (2001) measured a \(C_{\text{IV}}\) Pearson skewness of \(-0.04\) for the SDSS composite quasar spectrum. The lower value measured here is likely due to the difference in fitting the continuum. Using the region around 1690 Å to fit the red side of the continuum leads to a bluer continuum and therefore the inclusion of more flux from the red side of the \(C_{\text{IV}}\) line than in either Vanden Berk et al. (2001) or Wills et al. (1993).

### 3.5. Line Flux Requirement

Accurate measurement of line width, skewness, and \(C_{\text{IV}}–Mg\,\text{II}\) line shift requires accurate and precise determination of the line center. When searching for changes in these quantities with time, it is essential to have reliable measurements at both epochs. Visual inspection indicates that the fitting procedure returns the correct peak position.
reasonable parameter values for those objects with flux $f_{\text{line, HSN}} > 200 \times 10^{-17} \text{ ergs s}^{-1} \text{ cm}^{-2}$. We thus remove those 10 objects below this limit from future study. For reference, we do include the results of the fitting code for these objects in Tables 2 and 3.

### 3.6. Errors in Fitted Quantities

We use a Monte Carlo method for determination of errors. We add random, Gaussian noise to each pixel in the region of interest by assigning a random number drawn from a Gaussian distribution with mean equal to the measured flux in that pixel and standard deviation equal to the measured error in that pixel. The moment analysis code is run on this altered spectrum, and values for continuum flux, line flux, center, width, and skewness are calculated. This is repeated 1000 times; the error assigned to each quantity is equal to the standard deviation of the distribution of resulting values.

At the high-S/N epoch, the median errors in the line flux and the continuum flux density are $33 \times 10^{-17} \text{ ergs cm}^{-2}$ and $0.093 \times 10^{-17} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ cm}^{-2}$, respectively. The median error in the line center (as determined by the median) is 1.2 Å. This is less than half the value for any of the other methods used to measure the line center. The medians in the line width and skewness error distributions are 2.8 Å and 0.05, respectively.

### 3.7. Mg II Line Fitting

For use in studying the effect of variability on the C iv–Mg ii line shift, we also fit the Mg ii line for those objects where the line also falls in the SDSS spectroscopic wavelength range. For Mg ii, the region of interest for each line was defined to be those pixels that correspond to rest-frame wavelengths between 2684 and 2913 Å, the same range used in Vanden Berk et al. (2001). Requiring SDSS coverage of the entire region of interest means that the Mg ii line is fitted to those 77 objects in the C iv sample with $z < 2.12$. The Mg ii line is fitted at both the high- and low-S/N epochs, using the same algorithm as the C iv lines. It should be noted that there is significant Fe ii emission on either side of the Mg ii line (e.g., Vestergaard & Wilkes 2001; Sigut & Pradhan 2003; Baldwin et al. 2004). No attempt has been made in this work to remove this Fe ii flux, as only the robust Mg ii line median measurement is used. In any detailed study of the Mg ii line profile, however, this Fe ii emission should be removed. See §4.3 for a discussion of variability of the blueshift of the C iv line relative to Mg ii.

### 4. VARIABILITY OF THE C IV LINE

#### 4.1. Profile

There appears to be a strong correlation between the change in the line flux and the change in the line width. Figure 2 shows the epoch-to-epoch flux ratio ($f_{\text{HSN}}/f_{\text{LSN}}$) versus the ratio of line widths ($\sigma_{\text{HSN}}/\sigma_{\text{LSN}}$). A Spearman rank correlation test yields a correlation coefficient of 0.42, with a significance of $2.3 \times 10^{-5}$. The Kendall correlation coefficient is 0.29, with a significance of $2.5 \times 10^{-5}$. These tests indicate that there is a very low probability that no correlation exists. This strongly suggests that, for an individual object, the C iv line width increases with the line flux. This is opposite to the sense of the single epoch anticorrelation between C iv equivalent width and FWHM seen by Wills et al. (1992). It appears that there are two separate relations between line strength and line width: a global relation, such as those seen by Wills et al. (1992) and Francis et al. (1992), which suggests that from object to object, line strength is anticorrelated with line width, and an intrinsic relation such as that seen in

![Figure 2](image)

**Figure 2.**—Change in C iv line width vs. line flux change. The Spearman rank correlation coefficient for this distribution is 0.42, with a significance of $2.3 \times 10^{-5}$.

Figure 2, which suggests that line width and line strength are correlated for an individual object.

There is no obvious correlation between the C iv line flux and either line center or skewness. Figure 3 shows the epoch-to-epoch flux ratio ($f_{\text{HSN}}/f_{\text{LSN}}$) versus the change in the median-determined redshift ($\Delta z = z_{\text{HSN}} - z_{\text{LSN}}$), and Figure 4 shows the flux ratio versus the change in the Pearson skewness ($\Delta \text{Pskew} = \text{Pskew}_{\text{HSN}} - \text{Pskew}_{\text{LSN}}$). No trend is apparent in either plot. This is reinforced by the Spearman rank correlation tests. The Spearman significances are 0.86 and 0.734 for the flux-redshift and flux-skewness distributions, respectively, indicating that there is no significant correlation with flux change for either redshift change or skewness change.

#### 4.2. Flux

##### 4.2.1. Luminosity and Time Dependences

The top panels of Figures 5 and 6 show the well-known dependence of continuum variability amplitude on rest-frame time lag and absolute magnitude, respectively. To make comparisons with past photometric studies easier, we measure the change in flux between epochs by computing the logarithm of the ratio of the fitted continuum fluxes at the two epochs for each object:

![Figure 3](image)

**Figure 3.**—Change in C iv line center vs. line flux change. The Spearman rank correlation significance for this distribution is 0.86.
\[ \Delta f = -2.5 \log \left( \frac{f_{\text{cont}, \text{HSN}}}{f_{\text{cont}, \text{LSN}}} \right) \]

The error in \( \Delta f \), \( \sigma_{\Delta f} \), is calculated for each object through standard error propagation:

\[ \sigma_{\Delta f} = (2.5/\ln 10) \left( (\sigma_{f_{\text{cont}, \text{HSN}}} / f_{\text{cont}, \text{HSN}})^2 + (\sigma_{f_{\text{cont}, \text{LSN}}} / f_{\text{cont}, \text{LSN}})^2 \right)^{1/2}. \]

We then create four equally populated bins in rest-frame time lag and in absolute magnitude. In each bin, we calculate the average continuum variability by removing the average flux change error \( \sigma_{\Delta f} \) from the average flux change \( \Delta f \):

\[ V = \frac{\sqrt{\frac{\pi}{2}} \langle \Delta f \rangle^2 - \langle \sigma_{\Delta f} \rangle^2}{}, \]

as was done in VB04. Because of the small number of objects in each bin (\( \sim 25 \)), we use the median for the average (instead of the mean, as in VB04). The rest-frame time lag dependence of variability is commonly referred to as the structure function. The top panel of Figure 5 shows the continuum variability \( |\Delta f| \) versus rest-frame time lag for all individual objects, with the binned ensemble structure function overlaid. Similarly, the top panel of Figure 6 shows the binned ensemble luminosity dependence overlaid on the individual objects’ continuum variability versus luminosity.

Qualitatively, the structure function in the top panel of Figure 5 is similar to that seen in previous studies of continuum variability (see VB04; Hook et al. 1994). The structure function increases with time, indicating that quasar continua are more likely to appear to have varied when the time interval between observations is long, as seen in Rengstorf et al. (2006). The well-known (e.g., VB04; Giveon et al. 1999) anticorrelation between variability amplitude and quasar luminosity is seen in the top panel of Figure 6; more luminous quasars tend to exhibit less continuum variability. The bin containing the intrinsically faintest objects does not follow this trend; it is unlikely that this dip in the variability amplitude is statistically significant. With such a small number of objects per bin, this measure of the variability is easily affected by large or overestimated errors in the variability of individual objects. To avoid this problem, VB04 required that each bin contain a minimum of 75 objects; with only 94 total objects, we do not have this luxury here. Quantitatively, the amplitude of the variability in the top panels of Figures 5 and 6 is larger than that of previous studies. This can be at least partially understood as an artifact of the creation of the sample; only those quasars that had demonstrated significant variability were chosen for study in Paper I.

The well-known relationships between continuum variability amplitude and time lag and luminosity do not appear to hold for the C iv line flux. Replacing continuum flux with line flux, we again calculate the relative flux change between epochs \( [\Delta f = -2.5 \log \left( \frac{f_{\text{line}, \text{HSN}}}{f_{\text{line}, \text{LSN}}} \right)] \), as well as the error in the relative flux change \( \sigma_{\Delta f} = (2.5/\ln 10) \left( (\sigma_{f_{\text{line}, \text{HSN}}} / f_{\text{line}, \text{HSN}})^2 + (\sigma_{f_{\text{line}, \text{LSN}}} / f_{\text{line}, \text{LSN}})^2 \right)^{1/2} \). We then calculate the line flux variability, \( V \), in each of the four bins in \( \Delta \tau \) and \( M_r \), using equation (7). These are plotted in the bottom panels of Figures 5 and 6. The bottom panel of Figure 5 appears to show a decrease in line variability amplitude with rest-frame time lag. The error bars (representing the standard deviation of the \( \Delta f \) distribution in each bin) are quite large, however, indicating that this decrease is not statistically significant. Regardless, the variability amplitude does not obviously demonstrate the same time lag dependence as the continuum variability amplitude. One is cautioned not to read too much into this lack of dependence, however. We have no knowledge of the quasars’ individual light-travel times from the central source to the C iv – emitting portion of the BLR. A true C iv structure function would likely require some correction for the light-travel time to the BLR, something that is impossible to obtain from data of only two epochs. Thus, without this...
correction, it is perhaps unsurprising that no dependence is evident. As seen in the bottom panel of Figure 6, the line variability luminosity dependence also fails to duplicate the relation seen in the continuum variability.

4.2.2. The Baldwin Effect and the Intrinsic Baldwin Effect

Using the fit values for the continuum flux at the C iv line center and the flux of the line itself determined in § 3, we are able to recreate the Baldwin effect. The top panel of Figure 7 shows continuum luminosity versus line luminosity for all 105 objects at the high-S/N epoch. Using the IDL routine POLYFITW, the power-law slope of this relation is measured to be $b = 0.78 \pm 0.03$ for the high-S/N epoch (and $b = 0.82 \pm 0.03$ for the low-S/N epoch), corresponding to $\beta = -0.22$ (and $\beta = -0.18$) for the equivalent width formulation of equation (1). These values are in rough agreement with the $\beta = -0.17 \pm 0.04$ value measured by Kinney et al. (1990).

Combining the data from both epochs, we calculate an intrinsic Baldwin effect slope for every object in the sample:

$$b_{\text{int}} = \log \left( \frac{L_{\text{line}, \text{HSN}}}{L_{\text{line}, \text{LSN}}} \right) - \log \left( \frac{L_{\text{cont}, \text{HSN}}}{L_{\text{cont}, \text{LSN}}} \right).$$ (8)

The calculated IBE slope for any one object should not be taken as a definitive measurement of the IBE slope for that object, since it is determined with data from only two epochs, but the distribution of IBE slopes should be meaningful. This distribution is quite wide, as is seen in the bottom panel of Figure 7. The median IBE slope of the entire sample is $b_{\text{int}} = 0.15 \pm 0.49$. The error in the mean is large because of the few objects with large values for the IBE slope. These large slopes are not likely to be trustworthy (a very small change in continuum luminosity between epochs can lead to a very large, but essentially meaningless, value for the IBE slope). If we exclude those 12 objects with an absolute value for the IBE slope greater than 2, we find $b_{\text{int}} = 0.15 \pm 0.06$. This is shallower than the $b_{\text{int}} \approx 0.35$ value found by Kinney et al. (1990). The small number of objects (six) in the Kinney et al. (1990) sample precludes us from drawing strong conclusions about this difference. However, if this difference is real, it is an indication that the C iv lines of high-luminosity quasars are less responsive to continuum variations than those of low-luminosity quasars, in agreement with the results of Kaspi et al. (2003).

![Figure 7](image7.png)

Fig. 7.—C iv line flux vs. continuum flux (top) for objects at high-S/N epoch displaying the familiar Baldwin effect. Bottom: Histogram of C iv IBE slopes. The median slope (after untrustworthy outliers are removed) is $b_{\text{int}} = 0.15 \pm 0.06$.

4.3. Line Shifts

We are able to reproduce the single-epoch C iv line shift with respect to Mg ii, seen recently by Richards et al. (2002a). The top panel of Figure 8 shows a histogram of these line shifts at the high-S/N epoch. In this representation, a positive velocity ($v_{\text{HSN}} > 0$ km s$^{-1}$) indicates a blueshift of C iv with respect to Mg ii. The median line shift for our 77 objects is 722 km s$^{-1}$, with a standard deviation of 1750 km s$^{-1}$. With over 700 objects, Richards et al. (2002a) found a median blueshift of 824 km s$^{-1}$ and a dispersion of 511 km s$^{-1}$.

The bottom panel of Figure 8 shows the differences in line shift between the two epochs ($\Delta v = v_{\text{HSN}} - v_{\text{LSN}}$). The median line shift difference is near 0, $\langle \Delta v \rangle = 36$ km s$^{-1}$, but the width of the $\Delta v$ distribution (1680 km s$^{-1}$) is almost as wide as the distribution of single-epoch line shifts.

Figure 9 is similar to Figure 8, but only includes those objects with the highest C iv line fluxes ($f_{\text{line, HSN}} > 800 \times 10^{-17}$ ergs s$^{-1}$ cm$^{-2}$). This high line flux sample shows a similar median line shift (719 km s$^{-1}$) and a smaller standard deviation (710 km s$^{-1}$) than the sample as a whole.

The bottom panel of Figure 9 shows the distribution of differences in line shift between epochs for the high line flux sample. This distribution has a median of 120 km s$^{-1}$ and a dispersion of...
280 km s$^{-1}$, much narrower than its counterpart for the entire sample. As the distribution of line shift differences for these objects is essentially centered at 0 km s$^{-1}$ and has a much narrower width than the single-epoch distribution of line shifts (300 km s$^{-1}$ vs. 940 km s$^{-1}$), it is consistent with no difference in C$\text{iv}$–Mg$\text{ii}$ line shift between epochs. As will be discussed in §6, this is a further indication that C$\text{iv}$ line shifts with respect to Mg$\text{ii}$ might be useful as an orientation measure for radio-quiet quasars if a high enough line flux could be obtained.

5. INDIVIDUAL OBJECTS

5.1. High Line Flux Objects

We have selected some of the highest C$\text{iv}$ line flux objects in our sample to illustrate the relationship between line flux change and line width change. SDSS J115154.83$-$005904.6 was selected on the basis of an odd change in C$\text{iv}$ line profile (see §5.2). In all figures, the black curve represents the spectrum from the high-S/N epoch, and the gray curve represents the low-S/N epoch.

1. SDSS J081931.48+055523.6 (Fig. 10) has line flux ratio $f_{\text{HSN}}/f_{\text{LSN}} = 1.39$ and width ratio $\sigma_{\text{HSN}}/\sigma_{\text{LSN}} = 1.12$.
2. SDSS J100013.37+011203.2 (Fig. 11) has line flux ratio $f_{\text{HSN}}/f_{\text{LSN}} = 1.09$ and width ratio $\sigma_{\text{HSN}}/\sigma_{\text{LSN}} = 1.03$.
3. SDSS J231147.90+002941.9 (Fig. 12) has line flux ratio $f_{\text{HSN}}/f_{\text{LSN}} = 1.03$ and width ratio $\sigma_{\text{HSN}}/\sigma_{\text{LSN}} = 1.03$.
4. SDSS J160126.31+511038.1 (Fig. 13) has line flux ratio $f_{\text{HSN}}/f_{\text{LSN}} = 0.92$ and width ratio $\sigma_{\text{HSN}}/\sigma_{\text{LSN}} = 0.97$.

5.2. SDSS J115154.83$-$005904.6

Figure 14 shows the C$\text{iv}$ line of SDSS J115154.83$-$005904.6, a quasar at redshift $z = 1.93$. This C$\text{iv}$ line was noted as a part of the manual inspection for night-sky and absorption lines done before line fitting. The low-S/N epoch line (gray curve) appears to be bifurcated, while the high-S/N epoch line (black curve) does not; it is thus unlikely to be the result of an intervening absorption system. These spectra were taken 281 days apart, corresponding to a separation of roughly 96 days in the quasar rest frame. The depression near the peak of the line at the low-S/N epoch lies at 4500 Å in the observed frame, where there is not expected to be a large contamination from night-sky lines. This dip in flux near 4500 Å is not seen in other objects observed simultaneously with the same plate. If this bifurcation is a real effect, this could potentially be an intriguing object for follow-up study. The line profile looks similar to the C$\text{iv}$ line of NGC 3516, a well-studied intrinsic absorption system that varied by roughly 50% in absorption equivalent width (Voit et al. 1987). However, in the case of NGC 3516, the absorption was visible in all 11 epochs. It should also be noted that NGC 3783, a nearby
The intrinsic relation between C iv flux and width—as an individual line gets stronger, it also becomes wider—may be explained through similar geometric arguments. In fact, one should expect individual lines to broaden with increasing flux if one believes that (1) the broad portion of the line is produced near to the central engine and (2) the portion of the line produced near to the central engine is more variable.

That the line base is produced nearer to the central source is widely believed. It is assumed that the increased width comes with the higher rotational velocities of the BLR gas that is nearer to the central black hole and thus in a deeper potential well.

That the flux from the inner region of the BLR should be more variable is an essentially geometric argument. The relatively small size allows for more coherent variability (Korista & Goad 2004). The larger the region, the more “washed out” the fluctuations in the continuum flux will be, due to a larger range in light-travel times from the various portions of the BLR to the observer. This effect has been seen in reverberation mapping studies; recent attempts at reverberation mapping in high-luminosity objects have not yet produced conclusive results, due to the relative lack of variability in the emission lines (Kaspi et al. 2003). The large ionizing flux in these high-luminosity systems pushes the BLR to great distances from the central engine, resulting in larger ranges in light-travel times throughout the BLR and decreased coherent variability.

Most current models make both of the assumptions necessary to explain the observed intrinsic flux-width relation. Both assumptions are a part of the ILR and disk wind models. While this relation does not currently have the power to differentiate between discrete and continuous models of the BLR, it does strongly rule out any models that cannot predict such a relation.

It is also worth noting that in the Wills et al. (1993) ILR model, the C iv line base is blueshifted with respect to the line core. This suggests that the line skewness and median should also change with flux; as the more variable, blueshifted broad line base increases in relative importance, the median should be “dragged” to the blue, and the line should be skewed blueward as well. That this is not seen at all in Figures 3 and 4 is intriguing and merits further study.

6.2. Orientation

Richards et al. (2002a) suggested that the size of the C iv—Mg ii line shift could be a function of the orientation of the quasar with respect to the observer or of the disk wind opening angle. They noted that the C iv blueshift seems to be the result of the degradation of the red side of the C iv line, rather than a systemic shift of the entire emission line.

A wide distribution of values of $\Delta v$ (as seen in the bottom panel of Fig. 8) suggests that individual blueshift measurements may not be reliable. Even if the C iv—Mg ii blueshift is due to orientation, the measurements of the shift must be nonvariable and reproducible in order to be a useful measure of viewing angle for an individual object, although the ensemble average would still be useful. Figure 8 shows a large scatter in $\Delta v$ when the entire sample is included, which casts doubt on the reliability of any single measurement of blueshift. However, for the highest flux C iv lines, we have demonstrated that the line shifts for these objects appear to be robust (see Fig. 9). While this certainly does not constitute proof that the blueshift is an orientation effect, the opposite result would have caused serious problems for its use as a measure of orientation. It is certainly possible to imagine a scenario in which the C iv—Mg ii line shift is a product of viewing angle but varies in size. However, in such a system, the line shift
would not be useful as an orientation measure, even if it is an orientation effect.

Although the distribution of line shift differences between epochs, $\Delta v$, for the whole sample is impractically large, the narrow distribution for the highest flux objects indicates that the Mg ii $\rightarrow$ C iv line shift may hold promise as an orientation measure. Observers are warned, however, that an adequate line flux is necessary to reliably measure the line shift.

6.3. Line Flux Variability

Reverberation mapping studies indicate that the distance that the BLR lies from the central source increases with continuum luminosity (e.g., Wandel et al. 1999; Kaspi et al. 2005). More luminous central sources produce a greater number of ionizing photons, “pushing” the BLR to greater distances. As was mentioned in $\S$ 6.1, one would expect the emission lines from more luminous quasars to be less variable, as their larger sizes allow less coherent variability, “smearing out” the variations in the incident continuum over a greater range in light-travel times. The median IBE slope for our sample ($b_{\text{int}} = 0.15 \pm 0.06$) is shallower than that of the value of $b_{\text{int}} \approx 0.35$ from Kinney et al. (1990). This is to be expected, given that objects in our sample are of much higher luminosity ($M_{\text{Fe}} = -25.6$) than those studied in Kinney et al. (1990). NGC 5548, for example, has an absolute magnitude of $M_{\text{B}} \approx -22.5$ (Tyson et al. 1998).

It is not clear, however, why there is no sign of a decrease in C iv line flux variability with increasing luminosity (decreasing absolute magnitude) in Figure 6. If more luminous sources are less variable and line variability is a result of continuum variations, one might expect line variability to share the anticorrelation with continuum luminosity. It could simply be a function of binning; although our sample spans 4 mag in luminosity, the difference between the median luminosities of the two most extreme bins is only 1.5 mag. However, as this was only a two-epoch study and we have no knowledge for individual objects of the time lag between continuum and C iv variability, the issue may not be that simple. A larger dynamic range, or a larger number of objects per bin, might yield a more illuminating result.

7. CONCLUSIONS

Using a sample of 105 quasars observed multiple times by the Sloan Digital Sky Survey, we have studied the variability of the C iv line. Spectra were fitted using moment analysis techniques, and four main conclusions are drawn:

1. We find a strong correlation between the change in C iv line flux and the change in line width. As an individual quasar’s C iv line flux increases, so does the C iv line width. This is consistent with any picture of the BLR in which the broad line base is produced nearer to the central engine and the portion of the BLR nearer to the central engine exhibits more coherent line flux variability.

2. We demonstrate that there is no apparent variability in the blueshift of the C iv line with respect to the Mg ii line for the highest flux C iv lines, a possibly positive sign for the use of line shifts as an orientation measure.

3. With our measurements of continuum and line fluxes, we are able to reproduce the Baldwin effect, deriving a slope of $b = 0.78$. We also calculate a median slope for the intrinsic Baldwin effect of $b_{\text{int}} = 0.15$, which is shallower than the value of $b_{\text{int}} \approx 0.35$ determined by Kinney et al. (1990) for lower luminosity AGNs.

4. Using the continuum flux at the position of the line center, we reproduce well-known dependences of continuum variability amplitude on quasar luminosity and rest-frame time lag. However, these same dependences are not evident for the amplitude of the C iv line variability. This may be due to the “smearing out” of continuum variability by the extended BLR.

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