For radio-quiet quasars, the correlation coefficient $r^2$ is high, indicating that the optical, near-infrared, and X-ray radiation is similar. The significant difference between the radio and infrared emission of radio-quiet quasars suggests that the radio emission is a late stage of the most energetic phase. 

**ABSTRACT**

The Ohio State University, Columbus, OH 43210

M. Verheijen

PA 16802

Department of Astronomy and Astrophysics, The Pennsylvania State University, University Park, PA 16802

M. N. Brandt

Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138

I. W. Kerr

We present new evidence for the correlation in radio-quiet quasars.
Subject headings: galaxies: active — quasars: emission lines

1. Introduction

Studies of optical emission lines in quasars have revealed some striking correlations that may well be related to the fundamental properties of the accreting black hole system. Boroson & Green (1992, hereafter BG92) performed a principal component analysis (PCA) on the BQS quasar sample (Schmidt & Green 1983) and showed that the primary eigenvector (hereafter eigenvector 1 or EV1), which was responsible for \( \sim 30\% \) of the variance in the data, was anticorrelated with various measures of FeII \( \lambda 4570 \) strength (equivalent width and FeII/H\( \beta \) ratio), correlated with [OIII] \( \lambda 5007 \) strength (luminosity and peak) and H\( \beta \) FWHM, and anticorrelated with the blue asymmetry of the H\( \beta \) line. It was later found that these optical line properties correlate with UV properties: CIII] width, SiIII]/CIII] ratio, CIV and NV strength (Wills et al. 1999; Kurazsziukiewicz et al. 2000) and with soft X-ray properties: luminosity and spectral index (Boroson & Green 1992; Corbin 1993; Laor et al. 1994, 1997). Recently Brandt & Boller (1998) showed that the correlations between EV1 and the X-ray properties are stronger than those with the individual line parameters, suggesting that the EV1 has a more fundamental physical meaning. A number of physical parameters have been suggested to drive EV1 including accretion rate, orientation, and black hole spin.

BG92 and Boroson (1992) argued that EV1 is not driven by an orientation effect (i.e. some anisotropic property), despite the strong dependence on H\( \beta \) line width, as it is strongly correlated with the [OIII] \( \lambda 5007 \) (hereafter [OIII]) luminosity, which was assumed to be isotropic. However, the isotropy of the [OIII] emission in other AGN has since been called into question. Jackson & Browne (1990) studied a sample of powerful narrow-line radio galaxies and radio-loud quasars, which, in the context of Unified Models (e.g. Antonucci 1993), are considered to be the same type of object viewed from different angles to the radio axis. The [OIII] line luminosity of the narrow-line radio galaxies (viewed edge-on) is lower by 5-10 times than that of the quasars, matched in redshift and extended radio luminosity. This result was surprising. It was expected that the [OIII] emission would be the same in both samples, as it was thought to originate from distances large enough to be unaffected by obscuring material from the dusty torus. Hes, Barthel & Fosbury (1996) found that radio-loud quasars and powerful narrow-line radio galaxies show no difference in [OII] \( \lambda 3727 \) (hereafter [OII]) emission, suggesting that [OII] emission, and not [OIII] emission, is isotropic. As [OIII] has a higher critical density and higher ionization potential, and hence lies nearer to the central engine, this difference can be explained if the [OIII] emission region extends to sufficiently small radii to be obscured by the dusty torus when the active nucleus is viewed “edge-on”. Support for this scenario was provided by the detection of [OIII] emission in polarized light in 4 out of 7 radio galaxies (one also showing [OII] polarization) while a sample of radio-loud quasars showed none (Di Serego Alighieri et al. 1997). Polarized [OIII] emission has also been observed in NGC 4258 (Wilkes et al. 1995; Barth et al. 1999) a Seyfert galaxy with an edge-on molecular disk surrounding the nucleus. Baker (1997), studying a complete sample of low frequency radio selected quasars from the
Molonglo Quasar Sample, found that the [OI] to [OIII] ratio is anticorrelated with the radio-core to lobe flux density ratio $R$, which is generally used as an orientation indicator. This again implies that [OIII] is affected by dust absorption as the orientation becomes more edge-on. Similarly, the [OIII] luminosity versus radio luminosity correlation shows a larger scatter than the similar [OI] versus radio correlation (Tadhunter et al. 1998) in the 2 Jy extended radio-selected sample (Wall & Peacock 1985). This additional scatter could again be explained by dust obscuration of the [OIII] emission although the authors prefer an interpretation in terms of the higher sensitivity of [OIII] to the ionization parameter (Tadhunter et al. 1998).

If the central regions of radio-loud quasars and powerful radio galaxies are basically similar to the central regions of radio-quiet quasars (with the exception of the existence of the radio jets) then by analogy we would expect the behavior of the [OI] and [OIII] lines to be similar in both classes. Indeed, Seyfert 1 galaxies, which in the Unified Model scenario correspond to the face-on Seyfert 2 galaxies, have higher [OIII] luminosities than Seyfert 2s with comparable radio luminosity (Lawrence 1987; but see Keel et al. 1994 who find no difference in a sample of IRAS selected Seyfert galaxies). This suggests that $L([OIII])/L([OI])$ could be an orientation indicator not only in radio-loud but also in radio-quiet quasars. Similarly FeII emission strength and the broad line widths are strongly dependent on orientation in radio-loud QSOs (e.g. Miley & Miller 1979; Wills & Browne 1986; Vestergaard, Wilkes & Barthel 2000) with stronger FeII and narrower lines in face-on sources. Again, by analogy, this suggests that the extreme EV1 objects, Narrow-Line Seyfert 1s (NLS1), which have stronger FeII emission and narrow lines, could also be face-on.

Given the strong evidence for anisotropic [OIII] emission in radio-loud quasars, we present an investigation of the behavior of [OIII] emission in a radio-quiet subset of the optically-selected Palomar BQS sample to study the [OI] relation to EV1 in comparison with that of [OIII]. This allows us to revisit the question of orientation as a driver of EV1 and will lead to a better understanding of the underlying physics driving the strongest set of emission line correlations found to date for quasars, and so provide information on their central regions. We also compare the [OI] and [OIII] emission in our radio-quiet, optically selected sample with radio-loud samples to investigate whether the behavior of [OI] and [OIII] emission is similar in the two classes. Finally, we address the question of whether the [OI]$/[OIII]$ ratio is an orientation indicator in radio-quiet quasars.

2. Observations and Data Reduction

In order to carry out this investigation the sample needs to cover a wide range of EV1 values. Since the [OIII] luminosity ($M_{[OIII]}$) is directly measurable and strongly correlates with EV1, our objects were selected to have either high or low [OIII] luminosity i.e. $M_{[OIII]} < -28$ or $M_{[OIII]} > -25.5$ in the BG92 sample (see Figure 1; however a few radio-quiet quasars satisfying these selection criteria were not included in our sample due to lack of observing time). Our sample consists of 11 objects with low [OIII] luminosity and 9 objects with high [OIII] luminosity. We have obtained high signal-to-noise spectra of these quasars which include both the [OIII] $\lambda 5007\text{Å}$ and [OII] $\lambda 3727\text{Å}$
Fig. 1.— The [OIII] absolute magnitude ($M_{[OIII]}$) from BG92 versus BG92 eigenvector 1. Filled circles indicate the radio-quiet quasars in the current sample, open circles: radio-quiet QSOs in BG92, stars: steep spectrum radio-loud QSOs, and open triangles: flat spectrum radio-loud QSOs.

The observations were made between 1997 June and December with the FAST spectrograph on the 1.5 m Tillinghast telescope on Mt. Hopkins in Arizona. A 300 gpm grating set to cover the wavelength range 3500–7500Å was used with a 2′′ aperture, yielding a resolution of ~ 6Å. Spectrophotometry was carried out, in photometric conditions, by observing each quasar twice, first through a large 5′′ aperture and second through the small, 2′′, aperture with a longer exposure time to obtain high spectral resolution and signal-to-noise. A standard star was observed through the wide aperture, at similar air mass, immediately before or after the quasar observation, to provide flux calibration. The data were reduced in the standard manner using IRAF$^3$ (see Tokarz & Roll 1997 for details). The continuum of the small aperture data was then normalized to match the shape and absolute flux level of the large aperture observation yielding a final spectrum with a (judged from our experience) photometric accuracy of ~ 5%. The observational details are given in Table 1 and the calibrated spectra are presented in Figure 2.

$^3$IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.
Fig. 2.— The observed and FeII-subtracted spectra in the rest frame, in order of increasing right ascension. Only the wavelength range around the [OII] and [OIII] lines is presented on a scale $F_{\lambda}$ (in units of $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$) as a function of $\lambda$ (Å). The top spectrum is the observed spectrum, middle is the FeII subtracted spectrum and the bottom spectrum is the fitted FeII model. The FeII subtracted spectrum and the FeII model have been shifted downwards by an arbitrary value for clarity.
Fig. 2. — continued
Fig. 2.—continued
2.1. FeII subtraction

It has been shown (e.g., BG92) that FeII emission is present in the form of broad humps of blended lines at \( \lambda \lambda 4450-4700 \) and \( \lambda \lambda 5150-5350 \). This emission severely complicates measurements of emission line strengths and widths. Around the [OIII] \( \lambda \lambda 4949,5007 \) lines, a strong FeII optical multiplet (42) consisting of 3 lines at \( \lambda \lambda 4924,5018,5169 \) contaminates the [OIII] emission. This contamination is particularly strong in the weak [OIII] sources since, following EV1, these objects usually have strong FeII emission (see BG92). At the [OII] \( \lambda 3727 \) wavelength a “small bump” (spanning 2000–4000Å, which is a blend of FeII lines with the Balmer continuum emission) resides, which has to be taken into account when making measurements of the [OII] line.

In our spectra we have fitted the underlying continuum with a power-law using only those regions of the spectrum uncontaminated by the FeII emission (\( \lambda \lambda 4150-4270 \) and \( \lambda \lambda 6160-6280 \)). The underlying power-law continuum was then subtracted from each spectrum and the FeII emission was modeled using an optical (\( \lambda \lambda 4247-7000 \)) FeII template, kindly provided by T. Boroson (BG92). The template FeII spectrum was broadened by convolving with Gaussian functions to multiple widths starting at 1000 km s\(^{-1}\) and separated by steps of 250 km s\(^{-1}\). A two-dimensional iron emission model was constructed with line width as one dimension and rest wavelength as the other (see Vestergaard & Wilkes 2000). The iron emission in the object’s spectrum was fitted by scaling this 2-D iron model to the iron emission on either side of the H\( \beta \) and [OIII] lines. As a check-up and confirmation of this primary normalization, five additional scalings from 0.6 to 1.4 in steps of 0.2
were applied to each normalized iron model and these were also compared to the object’s spectrum. These additionally scaled models were never needed, confirming that the primary normalization was satisfactory and appropriate in each case. $\chi^2$ statistics and residual flux measurements were used to determine the best fit iron model, but manual inspection of how each model fits the spectrum and of the residual spectra was also necessary and was of high importance due to the complexity of QSO spectra. Once the best-fitting FeII model was identified it was subtracted from the original QSO spectrum allowing for an improved underlying continuum to be determined. The iteration over the FeII model and continuum setting (Vestergaard & Wilkes 2000) was continued until little change was seen from one step to next. Usually no more than 2 iterations were needed.

The best-fitting FeII emission model was then subtracted from the QSO spectrum. The previously subtracted power-law continuum was then added back into the spectrum giving an FeII-subtracted spectrum. We present these spectra in Figure 2 along with the fitted FeII models to each spectrum and the original, uncorrected QSO spectra.

### 2.2. Line Measurements

The fluxes and equivalent widths (EW) of the [OIII] $\lambda5007$, [OII] $\lambda3727$, H$\beta$ $\lambda4861$ and FeII $\lambda4570$ lines (for comparison with the BG92 data) in the FeII subtracted spectra were measured using the *splot* task in IRAF. For [OIII] and H$\beta$ we took the previously fitted, underlying, power-law continuum and integrated the spectrum above this continuum and across the observed emission line (we used keystroke ‘e’ in the IRAF *splot* task). The flux and equivalent width of the FeII $\lambda4570$ optical multiplet were measured in the $\lambda\lambda4434$–$4684$ range across the fitted FeII emission models. The equivalent widths and line luminosities of the emission lines are presented in Table 2. Our measurements of equivalent widths of H$\beta$, [OIII], FeII lines and FeII/H$\beta$ agree with BG92 to within 30%, except where noted in the table.

The flux of the [OIII] $\lambda3727$ line was measured by integrating the spectrum above a “local” continuum i.e. the “small bump” (dashed line in Figure 3; we did not subtract the “small bump” as it is not included in the template). The equivalent width was then defined as the ratio of the flux of the [OII] line estimated above the “small bump” to the flux over the same wavelength range in the power-law continuum (solid line in Figure 3; this took care of the contamination from the “small bump”). If instead the [OII] flux was divided by the local underlying continuum, as is more usual, then the equivalent width would be underestimated (by factors up to ~ 5). A comparison of the equivalent widths obtained by the two methods (Figure 4) illustrates a significant systematic shift in equivalent widths whose magnitude varies from source to source, emphasizing the need to take into account the small bump when measuring the [OII] line.

Our sample consists of luminous quasars ($M_B < -23$), which are generally not highly variable at optical wavelengths (e.g. Givernon et al. 1999). However, if any of the quasars had undergone a change of continuum from the time of BG92 observations, it would be seen in the differing
Fig. 3.— The spectrum of PG 0923+129 around the [OII] line. The local continuum representing the continuum from the “small bump” is indicated by a dashed line, while the power-law continuum fitted to the whole spectrum and lying well below the “small bump” is shown by a solid line.

EW([OIII]) measurements (as the [OIII] emitting region lies far enough from the central engine to be unaffected by the changing continuum on time scales of a few years). This may be the case for the following objects: PG 0026+129, PG 1427+480, where our EW([OIII]) measurements are lower than those of BG92 and in PG 1354+213, where our EW([OIII]) is higher (see Table 2). These objects also show lower (or higher respectively) EW(Hβ) and slightly lower/higher EW(FeII) measurements (although the change is less than 30% and hence not noted by † in Table 2). The FeII/Hβ ratio did not differ significantly from BG92 in these objects. For PG 1543+489 BG92 quote EW([OIII])=0, while we were able to measure this line in our spectra and obtained a value of 4.8Å. A comparison of our line equivalent width measurements in PG 1612+261 and PG 2304+042 indicates that we have set the underlying continuum higher for PG 1612+261 and lower for PG 2304+042, and with a flatter slope, probably due to the wider wavelength range covered by our spectra, allowing a better continuum determination.

The line equivalent width measurements are influenced by the choice of aperture. BG92 used 1.5″ aperture, while we use spectra obtained with a 2″ aperture and flux calibrated using quasar spectra through a 5″ aperture (which in turn reference a star through a 5″ aperture). The amount of starlight for many PG quasars has been measured by McLeod & Rieke (1994a,b). We found that for most of the objects in our sample the starlight contribution is of the order of 20% of the total flux in the H (1.65μm) band i.e. 13% at 4000Å, assuming a starlight template from Elvis
Fig. 4.— The [OII] equivalent width (EW) versus the Boroson & Green (1992) eigenvector 1. Circles denote our equivalent width measurements with respect to our fitted underlying continuum, crosses denote equivalent width measurements relative to the local continuum i.e. with the small bump not taken into account.

et al. (1994). However, PG 0157+001 has a 43% starlight contribution at band H (i.e. 29% at 4000Å) and is also spatially extended (12” × 12”). Assuming a uniform distribution of starlight, and a constant AGN energy output, we can roughly estimate the starlight contribution in this (worst case scenario) object, which is 7% (0.43 × 5^2/12^2) at H band and 5% (0.29 × 5^2/12^2) at 4000Å in our spectra, and 0.7% and 0.5% respectively in BG92 spectra. Hence the level of starlight contamination in ours and the BG92’s equivalent widths is well below the typical 30% errors due to other factors such as continuum placement and line measurement.

2.3. Eigenvector 1

The EV1 values for our sample QSOs (kindly provided by T. Boroson) were calculated by applying the PCA analysis to the BQS QSOs sample. We quote these values (after BG92) in the last column of Table 2. EV1 was shown by BG92 to depend strongly on the peak and absolute magnitude of the [OIII] line (M_[OIII]) and the FeII/Hβ ratio. In general, our line measurements agree well (to within 30%) with those of BG92, implying that it is valid to use the EV1 values from BG92. In Figure 5 we present a comparison of the [OIII] luminosity measured by us and the absolute magnitude M_[OIII] from BG92, defined as $M_V - 2.5 \log EW([OIII])$. The general agreement is good
with only one highly discrepant object: PG 1543+489 (indicated in Figure 5 by a filled circle; see Section 2.2 for further explanation of the differences between our and BG92 measurements). In four other objects (PG 0157+001, PG 0953+414, PG 1612+261 and PG 2304+042) we measured the FeII/Hβ ratio to be significantly larger (> 30%) than in BG92 (see Table 2 and Figure 6). A comparison of our line equivalent width measurements in these objects indicate that we have set the underlying continuum lower and with a flatter slope in our objects, probably due to the fact that our spectra cover a larger wavelength range and that we iterated over the continuum setting and FeII models in the FeII subtraction process. In PG 0052+251 the FeII/Hβ measured by us is smaller than in BG92. However in our FeII subtracted spectrum we still have some residual FeII λ4570 emission left (as our primary goal was to optimize the FeII fit around the [OIII] line and not FeII λ4570), so the BG92 FeII measurement, and hence the EV1, are probably more correct.

For the five, discrepant objects, discussed above, we indicate the direction in which EV1 should move in our figures based on the EV1 range of objects with similar values of FeII/Hβ, $M_{\text{OIII}}$ and [OIII] peak measurements in BG92. The only way to improve on this would be to re-run the PCA analysis for the full BG92 sample using our new values of line measurements, which is beyond the scope of this paper.
Fig. 6.— A histogram of the ratio of FeII/Hβ measured by Boroson & Green (1992) to the FeII/Hβ ratio measured by us. Shaded areas denote quasars which FeII/Hβ measurements differed from Boroson & Green (1992) by at least 30%.

3. Discussion

As outlined in the introduction the differences in [OIII] emission between the narrow-line radio galaxies and radio-loud quasars reported by Jackson & Browne (1990) and lack thereof in [OII] (Hes, Barthel & Fosbury 1996) suggest that [OIII] is orientation dependent, while [OII] is more isotropic in the radio-loud AGN. The correlation between the [OII]/[OIII] ratio and the orientation indicator $R$ reported by Baker (1997), furthermore suggests orientation-dependent dust obscuration of [OIII] emission and more isotropic [OII] emission. These results question the BG92 conclusion that EV1 is independent of orientation based on the assumption of [OIII] isotropy and allow us to readdress the question of orientation as the driver of EV1 by studying the dependence of BG92 EV1 on isotropic [OII] emission. To ensure a wide range in EV1 values we selected radio-quiet quasars with either high or low [OIII] luminosities (see Section 2). Under the assumption that our radio-quiet quasars, which are a subset of the BQS sample, have similar narrow line emitting regions to the radio-loud quasars and powerful radio-loud galaxies we presume that [OII] emission is independent of orientation in radio-quiet quasars. As a result finding a strong relation between EV1 and [OII] luminosity would imply that EV1 is independent of orientation (furthermore suggesting isotropic [OIII] emission in radio-quiet quasars, as [OIII] correlates with EV1) while the lack of such a relation would suggest that orientation is a factor.
Fig. 7.— The [OIII] and [OII] luminosity versus Boroson & Green (1992) eigenvector 1 correlations. PG 1543+489 is shown as a filled circle. Arrows indicate a range of EV1 values for PG 0157+001, PG 0953+414, PG 1543+489, PG 1612+261 and PG 2304+042 based upon our differing line measurements in comparison with BG92.

The relations between [OIII] and [OII] luminosities (L([OIII]), L([OII])) and the Boroson & Green EV1 are presented in Figure 7. We find a significant correlation between L([OIII]) and EV1 consistent with the $M_{\text{OIII}}$ versus EV1 correlation found by BG92. The Spearman rank test shows a 0.09% probability of this correlation occurring by chance (hereafter we will use $P_{S}$ to indicate the chance probability in the Spearman rank test$^4$). We also find a significant correlation between L([OII]) and EV1 with $P_{S} = 0.23\%$, which becomes stronger with $P_{S} = 0.08\%$ if the values of EV1 were updated to allow for the differences between our measurements and those of BG92 (i.e., values in the range shown by the arrows in Figure 7). These results imply that EV1 is independent of orientation and suggest that an intrinsic property, such as the accretion rate onto a black hole (as suggested by BG92; Pounds, Done & Osborne 1995; Boller, Brandt & Fink 1996; Laor et al. 1997) or the black hole spin (BG92) may be driving EV1. In Figure 8 we present the spectra around the [OII] wavelength for the most positive and the most negative EV1 objects to show in detail the

$^4$We use the ASURV statistical package (Isobe, Feigelson & Nelson 1986), which includes allowance for the presence of upper limits in [OII] measurements.
Fig. 8.— The observed spectra in the rest frame showing in detail the wavelength range around the [OII] line for the most extreme EV1 objects on a scale $F_\lambda$ (in units of $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$) as a function of $\lambda$ (Å). Spectra have been shifted downwards by an arbitrary value for clarity. The left panel shows objects with EV1 $< -5$ (from top: PG 1402+261, PG 1404+226, PG 1415+451, PG 1552+085) and the right panel objects with EV1 $> 2$ (from top: PG 0026+129, PG 0052+251, PG 1049–005, PG 1612+261).

dependence of [OII] on EV1.

3.1. Radio-quiet versus Radio-loud Quasars

The presence of the correlations between $L([\text{OII}])$, $L([\text{OIII}])$ and EV1 found above suggest that in our radio-quiet quasars from the BQS sample the [OIII] emission is independent of orientation in contrast to the case of radio-loud quasars. In order to understand this apparent dichotomy we study in detail the $L([\text{OII}])$ versus $L([\text{OIII}])$ and $EW([\text{OIII}])$ versus $EW([\text{OII}])$ relations in our radio-quiet sample and compare it with the radio-loud samples of Baker (1997; hereafter JB97), and Tadhunter et al. (1998) where orientation combined with dust or ionization effects (respectively) were found to be present.
Fig. 9.— The [OII] luminosity versus [OIII] luminosity correlation.

The [OII] and [OIII] luminosities and equivalent widths in our radio-quiet sample correlate significantly with one another ($P_S = 0.04\%$ for $L([\text{OIII}])$ versus $L([\text{OII}])$ correlation and $P_S = 0.31\%$ for $\text{EW}([\text{OIII}])$ versus $\text{EW}([\text{OII}])$ correlation). Additionally the range in $L([\text{OII}])$ and $L([\text{OIII}])$ is similar ($\sim 2\ \text{dex}$) and the best-fitted linear regression slope is consistent with 1 within the errors ($0.84\pm0.11$ for $L([\text{OII}])$ versus $L([\text{OIII}])$ and $1.27\pm0.37$ for $L([\text{OIII}])$ versus $L([\text{OII}])$, see Figure 9). The range in equivalent widths is also similar ($1.6\ \text{dex}$ for $\text{EW}([\text{OIII}])$ and $1.7\ \text{dex}$ for $\text{EW}([\text{OII}])$).

If our sample was affected by orientation dependent dust obscuration (where, as in JB97, substantial numbers of dust clouds lie within the torus opening angle, and their number increases towards the plane of the torus) a larger range in $L([\text{OIII}])$ than in $L([\text{OII}])$ would be observed, due to the obscuration of $[\text{OIII}]$ emission at large inclination angles. Additionally a smaller range in $\text{EW}([\text{OIII}])$ than $\text{EW}([\text{OII}])$ would be expected as the result of the orientation dependent dust reddening of the continuum and the $[\text{OIII}]$ emission. If, on the other hand, only ionization effects were present in our sample, we would observe a larger range in $L([\text{OIII}])$ than in $L([\text{OII}])$, and a larger range in $\text{EW}([\text{OIII}])$ than $\text{EW}([\text{OII}])$, as the $[\text{OIII}]$ line is much more dependent on the ionization parameter $U$ than $[\text{OII}]$ (see for example Simpson 1998 Figure 5). Neither effect is present in our sample, suggesting that the BQS quasars (at least our radio-quiet sample) is remarkably free of orientation dependent dust effects or ionization effects in the narrow-line region (NLR). As both the $[\text{OII}]$ and $[\text{OIII}]$ emission are independent of orientation effects, the $[\text{OII}]/[\text{OIII}]$ ratio in these optically selected radio-quiet quasars is not an orientation indicator, contrary to results for radio-loud AGN.
Fig. 10.— a) The comparison of the [OIII] and [OII] equivalent widths of our sample (filled circles) with Baker (1997; stars). Our sample extends to smaller $EW([OIII])$ than JB97 probably due to our FeII subtraction. The $EW([OIII])$ can be overestimated by up to a factor of 10 in strong FeII/weak [OIII] sources (see text) if FeII is not subtracted. b) The comparison of the [OIII] and [OII] equivalent widths of our sample (filled circles) with Tadhunter et al. (1998) (crosses: quasars, open squares: broad-line radio galaxies, filled squares: narrow-line radio galaxies).

We compare the equivalent widths and luminosities of [OIII] and [OII] lines of objects in our optically selected radio-quiet sample with the JB97 low frequency radio selected quasar sample (Figure 10a, 11a) and the complete sample of southern 2 Jy radio sources presented by Tadhunter et al. (1998; Figure 10b, 11b). A number of JB97 quasars and almost all broad- and narrow-line radio galaxies of Tadhunter et al. are found to occupy a region of higher $EW([OII])$ and $EW([OIII])$ (see Figure 10a, 10b) than our radio-quiet quasars. We found that these comparison objects cover the whole range of [OIII] and [OII] luminosities, indicating that the high equivalent widths of the radio-loud objects are due either to higher [OIII] and [OII] luminosities or to lower observed continuum. In the latter case the continuum could be obscured by dust in the radio-selected AGN. This would confirm previous suggestions (based on the comparison of the BQS quasars optical slopes [Francis et al. 1991] with the X-ray selected RIXOS sample of Puchnarewicz et al. 1996 and a heterogeneous sample of Elvis et al. 1994) that the blue color selection of the BQS QSOs biases against dust obscured objects while radio-selection is unaffected.

Figures 10a, 11a also show that our sample extends to lower $EW([OIII])$ and $L([OIII])$ than JB97 while having similar cut-off minimum values of $EW([OII])$ and $L([OII])$. The [OII] was mea-
Fig. 11.—a) The comparison of the [OIII] and [OII] luminosities of our sample (filled circles) with Baker (1997; stars). b) The comparison of [OIII] and [OII] luminosities of our sample (filled circles) with Tadhunter et al. (1998; crosses: quasars, open squares: broad-line radio galaxies, filled squares: narrow-line radio galaxies).

...sured with respect to the underlying continuum in both samples and the lowest values are at the detection limit. It is possible that the [OIII] emission may be overestimated in the lowest equivalent width/luminosity JB97 objects due to the lack of FeII subtraction. For the extremely strong FeII objects in our radio-quiet sample, the equivalent width and luminosity of [OIII] would be overestimated by a factor of up to 10 if the FeII emission were not subtracted (e.g. for PG 1402+261 \( \text{EW}([\text{OIII}]) = 36 \) with FeII included and \( \text{EW}([\text{OIII}]) = 3 \) after FeII subtraction). Correction for FeII contamination in JB97 sample could potentially result in an intrinsic range of \( \text{EW}([\text{OIII}]) \) and \( \text{L}([\text{OIII}]) \) larger (by a factor of 10) than shown in Figures 10a, 11a and comparable to the range of \( \text{EW}([\text{OIII}]) \) and \( \text{L}([\text{OIII}]) \) respectively. This would suggest (contrary to the conclusion reached by the author), that in the JB97 sample there is no dust obscuring the inner region of [OIII] emission. Confirmation of this suggestion would require a re-analysis of the JB97 sample. However to account for the broad line and continuum reddening observed by JB97, dust between the broad-line and narrow-line region is still needed.
Fig. 12.—a) A histogram of the [OII] to [OIII] luminosity ratio. Area shaded with solid lines indicates L[OII]/L[OIII] ratios for our sample, unshaded, dashed contours are radio-loud quasars from Baker (1997). b) A histogram of the [OII] to [OIII] luminosity ratio. Area shaded with solid lines indicates L[OII]/L[OIII] ratios for our sample, dashed line contours are powerful radio galaxies from Tadhunter et al. (1998). The area shaded with dotted lines indicates the narrow-line radio galaxies within the Tadhunter et al. sample.

3.2. The [OII]/[OIII] ratio as an orientation indicator

In the previous section we concluded that [OII]/[OIII] ratio is not an orientation indicator in our radio-quiet BQS sample. In this section we address the issue of the [OII]/[OIII] ratio as an orientation measure in radio-loud quasars.

The comparison of [OII]/[OIII] ratios with JB97 (Figure 12a) shows a lack of objects in our sample with the lowest values of [OII]/[OIII] ratio i.e. surprisingly the most core-dominated objects in JB97. One possibility is an overestimation of the [OIII] emission in JB97 data resulting from FeII contamination, as discussed above, which may be the case for four quasars with the smallest EW([OIII]) (see also Baker et al. 1999 for spectra). Core-dominated radio-loud quasars have stronger FeII emission than lobe-dominated quasars (e.g. Miley & Miller 1979) so the FeII contamination would be larger in core-dominated objects leading to higher apparent [OIII] luminosity (as observed by Jackson & Browne 1990) and lower [OII]/[OIII] ratios in JB97. In this case, the [OII]/[OIII] versus R relation of JB97 could be caused by the orientation dependence of FeII rather than of [OIII].
Another possible cause of low [OII]/[OIII] ratios in the JB97 sample (which could be the case for two quasars with extremely large EW([OIII])) is a higher ionization parameter in radio-loud quasars. A comparison of our subset of the BQS sample and the JB97 low frequency radio selected quasar sample, with the complete sample of 2 Jy radio sources presented by Tadhunter et al. (1998) shows that both ours and JB97 samples lack objects with the highest [OII]/[OIII] ratios (log L([OII])/L([OIII]) > 0 see Figure 12b). These high [OII]/[OIII] objects in Tadhunter et al. (1998) are mostly narrow-line radio galaxies (see Figure 12b) believed to be edge-on AGN. These objects are expected to have a large fraction of the [OIII] nuclear emission obscured by the dusty torus resulting in a higher [OII]/[OIII] ratio. However, there are also narrow-line radio galaxies (in Figure 12b) which show values of L([OII])/L([OIII]) < 0, within the range of ours and the JB97 quasars as well as the broad-line radio galaxies from Tadhunter et al. This seems to be inconsistent with the orientation dependent [OII] scenario in powerful radio-loud galaxies, and suggests that the [OII]/[OIII] ratio instead depends on the ionization parameter U, as suggested by Tadhunter et al. (1998).

Based on our comparisons, we conclude that the [OII]/[OIII] ratio is not a reliable orientation indicator either in the radio-quiet sample of the BQS quasars or in the radio-loud quasars.

4. Conclusions

Until recently it was generally accepted that eigenvector 1 does not depend on orientation as it is strongly correlated with [OIII] emission, originally thought to be an isotropic property in quasars. As recent studies of radio selected AGN samples have questioned the isotropy of [OIII] emission, we have investigated the relation between [OII] emission, which appears to be more isotropic, and eigenvector 1 and once again addressed the question of orientation as a driver of eigenvector 1.

We chose radio-quiet quasars from the optically selected Bright Quasar Survey which showed either high or low [OIII] luminosity, spanning a wide range of EV1 values in BG92. We subtracted FeII emission, which contaminates the [OIII] emission, from our spectra (using the BG92 iron template). We also demonstrated the significant effect of the presence of the small blue bump (Balmer continuum and FeII emission) on accurate measurements of the [OII] emission line, emphasizing the need for spectra covering a wide ($\geq 1000\AA$) wavelength range in order to determine the underlying continuum.

We found:

1. strong correlations between L([OII]), L([OIII]) and EV1 implying that EV1 does not depend on orientation, confirming earlier conclusions of BG92 and Boroson (1992), based on [OIII] alone. EV1 is likely driven by an intrinsic property (e.g., accretion rate or black hole spin).

2. significant EW([OIII])-- EW([OII]) and L([OIII])-- L([OII]) correlations
3. similar ranges in $EW([OIII])$ and $EW([OII])$ and in $L([OIII])$ and $L([OII])$ respectively.

These results lead us to conclude that the optically selected BQS sample (at least our radio-quiet sample) is free from orientation dependent dust effects and ionization dependent effects in the narrow-line region. Assuming our sample is representative of bright, optically selected radio-quiet quasars, this implies that their [OIII] emission is isotropic and the [OII]/[OIII] ratio is not an orientation indicator. This is in contrast with earlier results for the radio selected AGN (Baker 1997; Jackson & Browne 1990). We suggest that this discrepancy may be due to, contamination of the [OIII] emission by orientation dependent FeII emission in the latter samples.

Acknowledgements - We are grateful to Perry Berlind for observing the spectra of our sample quasars, Martin Elvis and Joanne Baker for helpful discussions, and Todd Boroson for providing the FeII optical template and the eigenvector 1 values. We gratefully acknowledges the support: of the Smithsonian pre-doctoral fellowship at the Harvard-Smithsonian Center for Astrophysics and grant no. 2P03D00410 of the Polish State Committee for Scientific Research (JK), NASA contract NAS8-39673(CXC) (BJW), NASA LTSA grant NAG5-8107 and the Alfred P. Sloan Foundation (WNB), and a Research Assistantship at SAO made possible through NASA grants: NAGW-4266, NAGW-3134, NAG5-4089 to BJW and the Columbus Fellowship at The Ohio State University (MV).

REFERENCES

Brandt, N., & Boller, Th. 1998, AN, 319, 163
Jackson, N., & Browne, I. W. A. 1990, Nature, 343, 43

This preprint was prepared with the AAS LaTeX macros v5.0.
<table>
<thead>
<tr>
<th>Name</th>
<th>Other Name</th>
<th>( \alpha (2000) )</th>
<th>( \delta (2000) )</th>
<th>( z )</th>
<th>UT Date</th>
<th>Exp. time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 0009+199</td>
<td>Mkn 335</td>
<td>00 06 19.60</td>
<td>+20 12 10.6</td>
<td>0.025</td>
<td>06/07/97</td>
<td>180</td>
</tr>
<tr>
<td>PG 0030+129</td>
<td></td>
<td>00 29 13.81</td>
<td>+13 16 04.5</td>
<td>0.145</td>
<td>06/10/97</td>
<td>240</td>
</tr>
<tr>
<td>PG 0052+251</td>
<td></td>
<td>00 54 52.24</td>
<td>+25 25 39.0</td>
<td>0.154</td>
<td>06/10/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 0157+001</td>
<td>Mkn1014</td>
<td>01 59 50.28</td>
<td>+00 23 40.8</td>
<td>0.163</td>
<td>06/10/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 0923+129</td>
<td>Mkn705</td>
<td>09 26 03.35</td>
<td>+12 44 03.5</td>
<td>0.029</td>
<td>29/11/97</td>
<td>1200</td>
</tr>
<tr>
<td>PG 0953+414</td>
<td></td>
<td>09 56 52.46</td>
<td>+41 15 22.0</td>
<td>0.234</td>
<td>29/11/97</td>
<td>1020</td>
</tr>
<tr>
<td>PG 1049-005</td>
<td></td>
<td>10 51 51.56</td>
<td>-00 51 16.8</td>
<td>0.360</td>
<td>31/12/97</td>
<td>390</td>
</tr>
<tr>
<td>PG 1116+215</td>
<td>Ton 1388</td>
<td>11 19 08.77</td>
<td>+21 19 17.9</td>
<td>0.177</td>
<td>05/06/97</td>
<td>240</td>
</tr>
<tr>
<td>PG 1351+236</td>
<td>Mkn 662</td>
<td>13 54 06.51</td>
<td>+23 25 49.0</td>
<td>0.055</td>
<td>05/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1354+213</td>
<td></td>
<td>13 56 32.94</td>
<td>+21 03 51.1</td>
<td>0.301</td>
<td>05/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1402+261</td>
<td>Ton 182</td>
<td>14 05 16.20</td>
<td>+25 55 33.0</td>
<td>0.164</td>
<td>10/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1404+226</td>
<td></td>
<td>14 06 21.98</td>
<td>+22 23 46.7</td>
<td>0.098</td>
<td>10/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1415+451</td>
<td></td>
<td>14 17 00.70</td>
<td>+44 56 06.4</td>
<td>0.114</td>
<td>05/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1427+480</td>
<td></td>
<td>14 29 43.14</td>
<td>+47 47 26.9</td>
<td>0.221</td>
<td>11/06/97</td>
<td>420</td>
</tr>
<tr>
<td>PG 1519+226</td>
<td></td>
<td>15 21 14.29</td>
<td>+22 27 43.2</td>
<td>0.136</td>
<td>11/06/97</td>
<td>420</td>
</tr>
<tr>
<td>PG 1535+547</td>
<td>I Zw120</td>
<td>15 36 38.36</td>
<td>+54 33 33.2</td>
<td>0.039</td>
<td>10/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1543+489</td>
<td></td>
<td>15 45 30.31</td>
<td>+48 46 09.0</td>
<td>0.400</td>
<td>10/06/97</td>
<td>300</td>
</tr>
<tr>
<td>PG 1552+085</td>
<td></td>
<td>15 54 44.62</td>
<td>+08 22 20.5</td>
<td>0.119</td>
<td>11/06/97</td>
<td>420</td>
</tr>
<tr>
<td>PG 1612+261</td>
<td>Ton 256</td>
<td>16 14 13.29</td>
<td>+26 04 16.4</td>
<td>0.131</td>
<td>10/06/97</td>
<td>1200</td>
</tr>
<tr>
<td>PG 2304+042</td>
<td>PB 5250</td>
<td>23 07 02.70</td>
<td>+04 32 55.0</td>
<td>0.043</td>
<td>06/07/97</td>
<td>300</td>
</tr>
</tbody>
</table>
TABLE 2
LINE MEASUREMENTS$^{a,b}$

<table>
<thead>
<tr>
<th>PG QSO</th>
<th>EW([OIII])</th>
<th>EW([OII])</th>
<th>EW(Hβ)</th>
<th>EW(FeII)</th>
<th>FeII/Hβ</th>
<th>L([OIII])</th>
<th>L([OII])</th>
<th>[OII]/[OIII]</th>
<th>EV$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0003+199</td>
<td>22.4</td>
<td>1.0</td>
<td>102.0</td>
<td>49.1</td>
<td>0.54</td>
<td>41.73</td>
<td>40.58</td>
<td>-1.15</td>
<td>-2.972</td>
</tr>
<tr>
<td>0026+129</td>
<td>*13.6</td>
<td>5.0</td>
<td>*429</td>
<td>24.6</td>
<td>0.65</td>
<td>42.56</td>
<td>41.76</td>
<td>-0.80</td>
<td>2.189</td>
</tr>
<tr>
<td>0052+251</td>
<td>33.5</td>
<td>5.0</td>
<td>91.7</td>
<td>*7.4</td>
<td>*0.09</td>
<td>42.80</td>
<td>41.78</td>
<td>-1.02</td>
<td>3.080</td>
</tr>
<tr>
<td>0157+001</td>
<td>56.0</td>
<td>2.9</td>
<td>61.6</td>
<td>71.5</td>
<td>*1.36</td>
<td>42.82</td>
<td>41.86</td>
<td>-0.96</td>
<td>1.547</td>
</tr>
<tr>
<td>0923+129</td>
<td>38.2</td>
<td>9.4</td>
<td>74.2</td>
<td>36.2</td>
<td>0.49</td>
<td>41.65</td>
<td>40.76</td>
<td>-0.89</td>
<td>-0.945</td>
</tr>
<tr>
<td>0953+414</td>
<td>19.6</td>
<td>0.3</td>
<td>*90.9</td>
<td>33.3</td>
<td>*0.43</td>
<td>42.79</td>
<td>41.22</td>
<td>-1.57</td>
<td>1.414</td>
</tr>
<tr>
<td>1049-005</td>
<td>45.0</td>
<td>4.0</td>
<td>75.9</td>
<td>39.2</td>
<td>0.60</td>
<td>43.28</td>
<td>42.34</td>
<td>-0.94</td>
<td>4.445</td>
</tr>
<tr>
<td>1116+215</td>
<td>13.5</td>
<td>0.3</td>
<td>*91.9</td>
<td>*47.0</td>
<td>0.59</td>
<td>42.67</td>
<td>41.26</td>
<td>-1.41</td>
<td>-0.036</td>
</tr>
<tr>
<td>1315+236</td>
<td>8.4</td>
<td>1.9</td>
<td>24.4</td>
<td>30.2</td>
<td>1.28</td>
<td>41.39</td>
<td>40.83</td>
<td>-0.56</td>
<td>-2.122</td>
</tr>
<tr>
<td>1354+213</td>
<td>*51.6</td>
<td>6.1</td>
<td>*107.6</td>
<td>25.8</td>
<td>0.26</td>
<td>42.61</td>
<td>41.43</td>
<td>-1.18</td>
<td>1.867</td>
</tr>
<tr>
<td>1402+361</td>
<td>3.2</td>
<td>0.3</td>
<td>85.7</td>
<td>101.4</td>
<td>1.44</td>
<td>41.67</td>
<td>41.00</td>
<td>-0.67</td>
<td>-5.389</td>
</tr>
<tr>
<td>1404+226</td>
<td>9.9</td>
<td>&lt;0.3</td>
<td>58.7</td>
<td>43.3</td>
<td>0.83</td>
<td>41.70</td>
<td>&lt;40.39</td>
<td>-1.31</td>
<td>-6.362</td>
</tr>
<tr>
<td>1415+451</td>
<td>2.9</td>
<td>&lt;0.8</td>
<td>56.6</td>
<td>81.0</td>
<td>1.60</td>
<td>41.31</td>
<td>&lt;40.96</td>
<td>-0.35</td>
<td>-6.784</td>
</tr>
<tr>
<td>1427+480</td>
<td>*56.8</td>
<td>4.8</td>
<td>*95.0</td>
<td>43.1</td>
<td>0.51</td>
<td>42.51</td>
<td>41.52</td>
<td>-0.99</td>
<td>1.756</td>
</tr>
<tr>
<td>1519+226</td>
<td>7.9</td>
<td>1.5</td>
<td>94.7</td>
<td>91.4</td>
<td>1.08</td>
<td>41.61</td>
<td>41.10</td>
<td>-0.51</td>
<td>-4.273</td>
</tr>
<tr>
<td>1535+547</td>
<td>20.3</td>
<td>1.2</td>
<td>111.1</td>
<td>48.5</td>
<td>0.46</td>
<td>41.54</td>
<td>40.43</td>
<td>-1.11</td>
<td>-3.536</td>
</tr>
<tr>
<td>1543+489</td>
<td>*4.8</td>
<td>3.2</td>
<td>64.9</td>
<td>75.1</td>
<td>1.33</td>
<td>42.11</td>
<td>41.76</td>
<td>-0.35</td>
<td>-5.808</td>
</tr>
<tr>
<td>1552+085</td>
<td>3.5</td>
<td>&lt;0.4</td>
<td>57.3</td>
<td>57.1</td>
<td>1.10</td>
<td>41.49</td>
<td>&lt;40.72</td>
<td>-0.77</td>
<td>-5.581</td>
</tr>
<tr>
<td>1612+361</td>
<td>*103.9</td>
<td>15.5</td>
<td>*83.8</td>
<td>23.7</td>
<td>*0.29</td>
<td>43.05</td>
<td>42.31</td>
<td>-0.74</td>
<td>5.989</td>
</tr>
<tr>
<td>2304+042</td>
<td>*52.0</td>
<td>6.7</td>
<td>117.7</td>
<td>*38.8</td>
<td>*0.32</td>
<td>41.71</td>
<td>40.59</td>
<td>-1.12</td>
<td>2.021</td>
</tr>
</tbody>
</table>

$^a$: [OIII] and [OII] line luminosities are in erg s$^{-1}$ and were calculated assuming $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0$. L([OIII]), L([OII]) and [OII]/[OIII] ratios are listed in logarithmic units.

$^b$: The equivalent widths (EW) are in Å and the errors are $\sim 15$-20%. The measurements of line equivalent widths and FeII/Hβ ratio agree with BG92 values to within 30$\%$ except where noted by ‘$^*$’.