OPTICAL EMISSION-LINE PROPERTIES OF A SAMPLE OF THE BROAD-LINE ACTIVE GALACTIC NUCLEI: THE BALDWIN EFFECT AND EIGENVECTOR 1

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ABSTRACT

We divide a sample of 302 type-1 active galactic nuclei into two subsamples based on the narrow-line [O iii]/Hβ_{NLR} ratio, expecting that there will be a stronger starburst (H I region) contribution to the narrow-line emission for R = log([O iii]/Hβ_{NLR}) < 0.5. For both samples, we find significant differences in correlations between spectral properties of objects with R < 0.5 and R > 0.5. We find similar differences when we divide the sample based on the FWHM ratios of [O iii] and broad Hβ lines (R1 = log (FWHM [O iii]/FWHM Hβ_{broad}) < 0.8), i.e., similar correlations between R > 0.5 and R1 < −0.8 subsamples from one side and R < 0.5 and R1 > −0.8 subsamples from the other side. The most interesting difference is in the correlation between the broad Hβ FWHM and luminosity in the R < 0.5 (R1 > −0.8) sample, which indicates a connection between the broad-line region kinematics and the photoionization source. We discuss possible effects that can cause these differences in spectral properties of two subsamples.

Key words: galaxies: nuclei – line: profiles – quasars: emission lines

1. INTRODUCTION

Spectral properties of active galactic nuclei (AGNs) depend on the physical conditions and geometry of emission regions, which quite likely change during AGN evolution (see, e.g., Lipari & Terlevich 2006; Wang & Zhang 2007). To understand the complex nature of AGNs, many authors have investigated the correlations between different spectral properties, trying to find and explain their physical backgrounds (see, e.g., Boroson & Green 1992; Wills et al. 1999; Croom et al. 2002; Shang et al. 2003; Yip et al. 2004; Grupe 2004; Wang et al. 2006, 2009; Ludwig et al. 2009, and references therein). Boroson & Green (1992, hereafter BG92) found in a sample of AGNs a number of AGN spectral properties, e.g., that as the optical to X-ray slope and equivalent width (EW) of Fe ii increase, the EW of [O iii] decreases, as does the FWHM3 of Hβ. These correlations are part of the eigenvector 1 (EV1) in the principal component (PC) analysis of BG92. The underlying physics driving EV1 is not yet completely understood.

The Baldwin effect (Baldwin 1977; Baldwin et al. 1978) is present in a number of lines, i.e., their line EW decreases with increasing continuum luminosity. A majority of the UV and optical lines show the Baldwin effect (Dietrich et al. 2002), but for some lines there is no trend with the continuum luminosity, or even an inverse Baldwin effect. The inverse Baldwin effect is found for the Fe ii optical lines (Netzer & Trakhtenbrot 2007; Kovačević et al. 2010) and Hβ (Croen et al. 2002; Netzer & Trakhtenbrot 2007). Kovačević et al. (2010) found an inverse Baldwin effect for the broad Hβ component (in a FWHM Hβ_{broad} < 3000 km s^{-1} subsample), but the narrow Hβ component shows a normal Baldwin effect, as do the [O iii] lines. The origin of the Baldwin effect is an open question still under debate (for a review, see Green et al. 2001, and references therein). Some indications of the connection between the BG92 EV1 correlation and the Baldwin effect are discussed in the literature (see, e.g., Baskin & Laor 2004; Kovačević et al. 2010; Zhang et al. 2011).

Note that EV1 may be connected with AGN evolution (see Marziani et al. 2003; Grupe 2004; Wang et al. 2006), while the evolution of AGNs is probably related to starburst regions (Lipari & Terlevich 2006; Mao et al. 2009; Sani et al. 2010). For example, it is possible that AGNs in an earlier phase of their evolution are composed of starburst (star-forming) regions and the central engine (AGN), and, during evolution, the starburst contribution becomes weaker and/or negligible (Wang & Wei 2006, 2008; Mao et al. 2009).

Recently, some authors (see, e.g., Yip et al. 2004; Grupe 2004; Ludwig et al. 2009) used a large sample of Sloan Digital Sky Survey (SDSS) objects and applied PC analysis to some spectral parameters. They noted that PC projections depend on the sample properties; i.e., different divisions of the sample by luminosity, [O iii] strength, FWHM Hβ, etc., lead to different correlations between spectral parameters, sometimes even opposite correlations for different subsamples. Other authors found that the significance of the Baldwin effect depends on the FWHM Hβ range of the sample (see, e.g., Sulentic et al. 2009; Zamfir et al. 2010; Kovačević et al. 2010).

In this paper, we investigate a sample of the broad-line AGNs. Using the ratio of the [O iii] and narrow Hβ lines, we divide the sample into two groups and separately consider the connection between the BG92 EV1 and the Baldwin effect of these groups.

This paper is organized as follows: in Section 2, we briefly describe the sample (subsamples) and methods of analysis. In Section 3, we present the correlations obtained and discuss the results. Finally, we outline our conclusions in Section 4.

2. THE SAMPLE AND ANALYSIS

The sample of 302 AGNs used in this paper is the same as that presented by Kovačević et al. (2010). The sample has been chosen from the SDSS Release 7. It contains the broad-line AGNs within approximately uniform redshift range z = 0–0.7, mainly within the luminosity range of 44 < log (L_{5100}) < 46. Other details of the sample selection can be found in Kovačević et al. (2010).
As is described by Kovačević et al. (2010), we fit the Fe II lines with a new template that enables precise estimation of the Fe II emission within the 4400–5500 Å wavelength range (see Figure 1). The Balmer lines are fitted with three components: a narrow, an intermediate, and a very broad component (Hβ NLR, ILR, and VBLR, respectively). The Hβ broad component is taken as the sum of the Hβ ILR and Hβ VBLR components (see Figure 2). The FWHM and FWMI 10% (full width at 10% of maximum) of the broad Hβ line are measured, as shown in Figure 2.

Both components of the [O III] λλ4959, 5007 doublet originate from the same lower energy level, and both have negligible optical depth since the transitions are strongly forbidden. We thus assume that the [O III] λ4959 and [O III] λ5007 lines have the same emission-line profile; i.e., we fit each line of the doublet by one Gaussian (or by two, in the case of a significant asymmetry), assuming that the [O III] λ4959 and [O III] λ5007 lines have the same widths and shifts. We also fix their intensity ratio at 2.99 (Dimitrijević et al. 2007).

To estimate the NLR contribution to the total Hβ flux (i.e., emission from the same region emitting the [O III] lines), we introduce the following assumptions: (1) only one narrow Hβ component is present in the total Hβ emission, and (2) this component has the same kinematical parameters as the [O III] lines, i.e., the same width and shift as the [O III] lines. Very often, a blue asymmetry in the [O III] lines was present, and in such a case each of the [O III] lines is fitted with two Gaussian components, but as a rule only one (central, non-shifted) has the same kinematics as the narrow Hβ line.

To plot the “BPT diagram” (Baldwin et al. 1981) shown in Figure 3, we also estimate the narrow Hα component, connecting the width and shift of the narrow component with those of the [N II] lines. As can be seen from Figure 3, a number of AGNs from the sample show a significant starburst contribution. Note that these AGNs are mostly with FWHM Hβ broad < 3000 km s⁻¹ (open circles), while in the AGN part of the BPT diagram, both fractions (with FWHM Hβ broad < 3000 km s⁻¹ and FWHM Hβ broad > 3000 km s⁻¹; full circles) are present. Note here that Sani et al. (2010) also found more intense circumnuclear star-forming activity in narrow-line Seyfert 1s (NLS1) than in the broad-line AGNs.

Since we have complete measurements of line parameters for only the narrow Hβ and [O III] lines in the entire sample (302 AGNs), we accept the criterion $R = \log([O\text{ III}]/H\beta_{\text{NLR}}) = 0.5$ (horizontal dashed line in Figure 3) as an indicator of the predominant starburst emission contribution to the narrow emission lines. We divide our sample into two subsamples: $R < 0.5$ (91 AGNs, hereafter “SB” or starburst dominant) and

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4 One spectrum (SDSS J130357.42+103313.50) is excluded from the sample because the [O III] emission is comparable to the level of noise.
$R > 0.5$ (210 AGNs, hereafter “AGN” or AGN dominant). Note that such a high number of SBs is probably caused by the selection effect, since one of the criteria is that equivalent widths of typical absorption lines are small (for more details, see Kovačević et al. 2010).

One could expect that where there is a significant starburst contribution, the widths of the [O\textsc{iii}] lines would depend on the luminosity (Brungardt 1998). We therefore plot log($L_{5100}$) against log(FWHM [O\textsc{iii}]) (see Figure 4) and find a good correlation between the continuum luminosity and FWHM of the [O\textsc{iii}] lines in the SB sample $R < 0.5$ ($r = 0.70$, $P = 7.3E-15$), while in the AGN sample there is no correlation. This indicates that even for the roughly estimated fluxes of the narrow H$\beta$ component, there is some difference between these two subsamples. In Figure 5 we plot the FWHM of the broad H$\beta$ against the FWHM of the [O\textsc{iii}] for all data, where the SB subsample is denoted by full circles. There is a good correlation between the widths for the SB subsample ($r = 0.74$, $P < 1E-16$).

It is difficult to separate AGNs, H\textsc{ii} regions, and LINERs, even if one deals with only narrow emission-line objects (see, e.g., Rola et al. 1997; Dessauges-Zavadsky et al. 2000). Therefore, the construction of BPT diagrams of broad-line objects, where the permitted lines are composed of two or more components, is very difficult. Nagao et al. (2001) constructed such diagrams for a group of broad- and narrow-line Seyfert galaxies and found that some Sy1 may be located in H\textsc{ii} regions (see their Figure 4), but there are no significant trends in the forbidden line ratios between NLSy1, Sy1, and Sy2 AGNs. Forbidden lines can be more precisely fitted than permitted lines, but even though forbidden line ratios depend on physical properties (electron density and temperature) it is hard to separate the objects using only forbidden narrow lines.

Estimation of the narrow H$\beta$ and H$\alpha$ components (in the case of a broad-line AGN) is a very complex task. One of the several problems is that, in principle, the line profiles (especially of the broad lines) are not pure Gaussians, i.e., due to complex kinematics in the NLR (e.g., blue asymmetry produced by outflows, see Smirnova et al. 2007) a single Gaussian very often cannot represent the shape of the narrow H$\beta$ and [O\textsc{iii}] components. Consequently, the approximation of two Gaussian functions could be used, which gives some indication about velocities of the subregions. Another problem in the estimation of the narrow H$\beta$ contribution is that the solution is non-unique, i.e., a combination of different Gaussians can give different contributions of the narrow H$\beta$ component. Therefore, when fitting with multi-Gaussian components, we are only able to estimate very roughly the contribution of the H$\beta$ NLR component from the [O\textsc{iii}] line-emitting region. We estimate errors using a $\chi^2$ test (see Appendix A) and find that, for the SB subsample, around 25% of the AGNs (those between estimated error bars, $R + \Delta R > 0.5$) could belong to the AGN subgroup, but when we exclude these 22 objects, the correlations obtained do not change significantly.

We also search for another method to separate these two groups. We investigate the line width ratios of [O\textsc{iii}]/H$\beta$$_\text{broad}$ as
a function of the continuum luminosity and find that there is no correlation (see Figure 6), but points with $R < 0.5$ (solid circles) mostly have $R_1 = \log(\text{FWHM} \, \text{[O III]}/\text{FWHM H}_\beta \text{broad}) > -0.8$. Consequently, we also divide the sample into two subsamples with $R_1 < -0.8$ (hereafter the “AGN1” subsample) and $R_1 > -0.8$ (hereafter the “SB1” subsample).

3. RESULTS AND DISCUSSION

We calculate Spearman correlations between the spectral properties for the total sample of 302 AGN spectra, and for the “SB” and “AGN” subsamples with $R < 0.5$ and $R > 0.5$, respectively (which correspond closely to $R_1 < -0.8$ and $R_1 > -0.8$). The results are given in Tables 1–4 and Figures 7–9.

One of the most interesting correlations is between the FWHM (FWMI 10%) of the broad H$\beta$ versus continuum luminosity ($\lambda L_{5100}$) (a similar correlation was found by Steiner 1981 for the FWZI (full width at zero intensity) of H$\alpha$) and the FWHM (FWMI 10%) H$\beta$ versus EW Fe$\Pi$. These correlations are quite different for the SB and AGN subsamples.

The velocity–luminosity relation in AGNs has been discussed previously. Shuder (1984) found that the FWHM of the Balmer lines increases with luminosity for a sample of 25 AGNs. Also, Wandel & Yahil (1985) reported a correlation ($r = 0.5$) between the FWZI of H$\beta$ and the 4000 Å continuum luminosity for a literature compilation of 94 AGNs. Strupe & Robinson (1999) found a weak correlation between the width of H$\beta$ and luminosity in the case of 126 AGNs. The same trend, i.e., a weak correlation, was found by Joly et al. (1985), but Boroson & Green (1992) found an anticorrelation ($r = -0.275$) between the H$\beta$ FWHM and absolute $V$ magnitude, significant at the 99% confidence level, in a sample of 87 PG quasars. They also noted that the FWZI of H$\beta$ is quite sensitive to noise and depends strongly on the quality of the Fe$\Pi$ subtraction. We therefore measure FWMI 10%.

In Figure 7 we plot $\log(\Delta L_{4100})$ versus $\log($FWHM H$\beta$) and $\log($FWMI 10% H$\beta$) of the broad H$\beta$ component. We find a strong correlation between the continuum luminosity and FWHM H$\beta$ for the SB and SB1 subsamples, while in the AGN and AGN1 subsamples (see Tables 1 and 2).

The relationship between the EW Fe$\Pi$ and FWHM (FWMI 10%) H$\beta$ is also different for the SB and AGN subsamples (see Figure 8 and Table 1). For example, the well-known anticorrelation of EW Fe$\Pi$ and FWHM H$\beta$, which is part of the BG92 EV1 correlations, is noticeable only for the AGN and AGN1 subsamples, while the SB and SB1 subsamples show an opposite but statistically insignificant trend. Grupe (2004) also found a positive correlation between the EW Fe$\Pi$ and FWHM H$\beta$ for NLS1 objects, and a negative correlation for broad-line Sy1s.

Figure 6. Continuum luminosity vs. the ratio of FWHM [O III] and broad H$\beta$.

Figure 7. Correlations between continuum luminosity and FWHM H$\beta$ (top panels) or FWMI 10% H$\beta$ (lower panels) for AGNs with $R < 0.5$ (left panels) and $R > 0.5$ (right panels). Notation (see Appendix A): full squares, $R + \Delta R < 0.5$; open squares, $R + \Delta R > 0.5$; crosses, flat minimum; full circles, $R - \Delta R > 0.5$; open circles, $R - \Delta R < 0.5$. 
| Spectral Parameter | log($\lambda_{5100}$) | log(FWHM H$\beta$) | log(EW [O iii]) | log(EW Fe ii) | log(EW H$\beta$ NLR) | log(EW H$\beta$ broad) | log(FWMI 10% H$\beta$) |
|-------------------|------------------------|---------------------|-----------------|-------------|-----------------------|------------------------|-----------------------|
| log($\lambda_{5100}$) |                        |                     |                 |             |                       |                        |                       |
| Total sample      | 0.42                   | 2.3E-14             | −0.45           | 2.2E-16     | 0.27                  | 1.6E-6                 | −0.41                 | 9.4E-14               | 0.14                  | 0.02                  | 0.43                  | 5.1E-15               |
| (1)               | 0.26                   | 1.1E-4              | −0.51           | 3.6E-15     | 0.29                  | 2.4E-5                 | −0.56                 | 0                    | −0.03                 | 0.67                  | 0.29                  | 2.3E-5               |
| (2)               | 0.81                   | 0                   | −0.46           | 4.2E-6      | 0.26                  | 0.01                   | −0.27                 | 0.01                 | 0.56                  | 9E-9                  | 0.81                  | 0                   |
| log(FWHM H$\beta$) |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | 0.42                   | 2.3E-14             | −0.07           | 0.24        | −0.24                 | 2.3E-5                 | −0.34                 | 1.5E-9               | 0.48                  | 0                    | 0.90                  | 0                   |
| (1)               | 0.26                   | 1.1E-4              | −0.08           | 0.24        | −0.37                 | 3.2E-8                 | −0.25                 | 1.9E-4               | 0.38                  | 0.88                  | 0.88                  | 0                   |
| (2)               | 0.81                   | 0                   | −0.42           | 4.1E-5      | 0.26                  | 0.01                   | −0.15                 | 0.16                 | 0.53                  | 4.8E-8                | 0.89                  | 0                   |
| log(EW [O iii])   |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | −0.45                  | 2.2E-16             | −0.07           | 0.24        | −0.41                 | 6.8E-14                | 0.32                  | 2.1E-8               | 0.24                  | 2.4E-5                | −0.05                 | 0.38                 |
| (1)               | −0.51                  | 3.6E-15             | −0.08           | 0.24        | −0.38                 | 7.9E-9                 | 0.73                  | 0                    | 0.26                  | 1.1E-4                | −0.05                 | 0.51                 |
| (2)               | −0.46                  | 4.2E-6              | −0.42           | 4.1E-5      | −0.27                 | 0.01                   | 0.53                  | 5.9E-8               | −0.11                 | 0.29                  | −0.48                 | 1.5E-6               |
| log(EW Fe ii)     |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | 0.27                   | 1.6E-6              | −0.24           | 2.3E-5      | −0.41                 | 6.8E-14                | 0.32                  | 2.1E-8               | 0.07                  | 0.23                  | −0.26                 | 6.3E-6               |
| (1)               | 0.29                   | 2.4E-5              | −0.37           | 3.2E-8      | −0.38                 | 7.9E-9                 | 0.73                  | 0                    | 0.26                  | 1.1E-4                | −0.05                 | 0.51                 |
| (2)               | 0.26                   | 0.01                | −0.27           | 0.01        | −0.27                 | 0.01                   | 0.53                  | 5.9E-8               | −0.11                 | 0.29                  | −0.48                 | 1.5E-6               |
| log(EW H$\beta$ NLR) |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | −0.41                  | 9.4E-14             | −0.34           | 1.5E-9      | 0.32                  | 2.1E-8                 | −0.01                 | 0.80                 | 0.07                  | 0.23                  | −0.26                 | 6.3E-6               |
| (1)               | −0.56                  | 0                   | −0.25           | 1.9E-4      | 0.73                  | 0                     | −0.28                 | 3.9E-5               | 0.04                  | 0.57                  | −0.38                 | 1.4E-8               |
| (2)               | −0.27                  | 0.01                | −0.15           | 0.16        | 0.53                  | 5.9E-8                 | −0.04                 | 0.67                 | 0.49                  | 9.4E-7                | 0.27                  | 0.01                 |
| log(EW H$\beta$ broad) |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | 0.14                   | 0.02                | 0.48            | 0           | 0.24                  | 2.4E-5                 | 0.07                  | 0.23                 | −0.16                 | 0.005                 | Total sample          | 0.50                  | 0                   |
| (1)               | −0.03                  | 0.67                | 0.38            | 1.2E-8      | 0.26                  | 1.1E-4                 | 0.04                  | 0.57                 | 0.08                  | 0.23                  | 0.42                  | 1.5E-10              |
| (2)               | 0.56                   | 9E-9                | 0.53            | 4.8E-8      | −0.11                 | 0.29                   | 0.49                  | 9.4E-7               | −0.21                 | 0.05                  | 0.49                  | 6.4E-7               |
| log(FWMI 10% H$\beta$) |                        |                     |                 |             |                       |                        |                       |                       |                       |                       |                       |                       |
| Total sample      | 0.43                   | 5.1E-15             | 0.90            | 0           | −0.05                 | 0.38                   | −0.26                 | 6.3E-6               | −0.36                 | 1.6E-10               | 0.50                  | 0                   |
| (1)               | 0.29                   | 2.3E-5              | 0.88            | 0           | −0.05                 | 0.51                   | −0.38                 | 1.4E-8               | −0.25                 | 2.4E-4                | 0.42                  | 1.5E-10              |
| (2)               | 0.81                   | 0.89                | −0.48           | 1.5E-6      | 0.27                  | 0.01                   | −0.21                 | 0.05                 | 0.49                  | 6.4E-7                | (2)                  |                     |
Table 2
Spearman Rank–Order Correlations for the Total Sample and for Subsamples (1) log(FWHM [O III]narrow/FWHM Hβ) < −0.8 and (2) log(FWHM [O III]/FWHM Hβ) > −0.8

| Spectral Parameter | log(λL5100) | log(FWHM Hβ) | log(EW [O III]) | log(EW Fe II) | log(EW Hβ NLR) | log(EW Hβ broad) | log(FWMI 10% Hβ) |
|--------------------|-------------|---------------|-----------------|---------------|----------------|------------------|-----------------|
|                    | r           | P             | r               | P             | r              | P                | r               | P               |
| **log(λL5100)**    |             |               |                 |               |                |                  |                 |                 |
| (1) Total sample   | 0.42        | 2.3E-14       | −0.45           | 2.2E-16       | 0.27           | 1.6E-6           | −0.41           | 9.4E-14         |
|                    | 0.21        | 0.01          | −0.45           | 2.1E-8        | 0.25           | 0.003            | −0.56           | 1.2E-12         |
| (2)                | 0.74        | 0             | −0.44           | 2.5E-8        | 0.32           | 8.0E-5           | −0.37           | 5.9E-6          |
|                    | 0.42        | 2.3E-14       | −0.07           | 0.24          | −0.24          | 2.3E-5           | −0.34           | 1.5E-9          |
| log(FWHM Hβ)       | 0.21        | 0.09          | 0.09            | 0.29          | −0.41          | 5.9E-7           | −0.12           | 0.14            |
| (1)                | 0.09        | 0.29          | −0.41           | 2.3E-5        | −0.07           | 0.24             | −0.24           | 2.3E-5          |
| (2)                | 0.74        | 1.0E-4        | −0.32           | 1.0E-4        | 0.24           | 0.003            | −0.21           | 0.009           |
|                    | 0.74        | 1.0E-4        | −0.32           | 1.0E-4        | 0.24           | 0.003            | −0.21           | 0.009           |
| log(EW [O III])    | −0.45       | 2.2E-16       | −0.07           | 0.24          | −0.41          | 6.9E-14          | 0.32            | 2.1E-8          |
| (1)                | 0.09        | 0.29          | −0.42           | 3.0E-7        | −0.07           | 0.24             | −0.24           | 2.3E-5          |
| (2)                | −0.32       | 1.0E-4        | −0.43           | 7.2E-8        | 0.18           | 0.03             | 0.07            | 0.24            |
| log(EW Fe II)      | 0.27        | 1.6E-6        | −0.24           | 2.3E-5        | −0.41          | 6.9E-14          | 0.32            | 2.1E-8          |
|                    | −0.41       | 9.4E-14       | −0.34           | 1.5E-9        | 0.21           | 2.1E-8           | −0.07           | 0.80            |
| (1)                | 0.09        | 0.29          | −0.42           | 3.0E-7        | −0.07           | 0.24             | −0.24           | 2.3E-5          |
| (2)                | 0.32        | 8.0E-5        | −0.43           | 7.2E-8        | 0.18           | 0.03             | 0.07            | 0.24            |
| log(EW Hβ NLR)     | −0.56       | 1.2E-12       | −0.12           | 0.14          | 0.71           | 0                | −0.36           | 1.1E-5          |
|                    | −0.37       | 5.9E-6        | 0.21            | 0.009         | 0.18           | 0.03             | −0.04           | 0.65            |
| (1)                | −0.12       | 1.4E-4        | 0.71            | 0             | −0.36           | 1.1E-5           | 0.05            | 0.55            |
| (2)                | −0.37       | 5.9E-6        | 0.21            | 0.009         | 0.18           | 0.03             | −0.04           | 0.65            |
| log(EW Hβ broad)   | 0.14        | 0.02          | 0.48            | 0             | 0.24           | 2.4E-5           | 0.07            | 0.23            |
| (1)                | −0.08       | 0.35          | 0.32            | 1.1E-4        | 0.46           | 1.7E-8           | 0.05            | 0.55            |
| (2)                | 0.34        | 3.1E-5        | 0.50            | 1.6E-10       | 0.02           | 0.81             | 0.36            | 6.7E-6          |
| log(FWMI 10% Hβ)   | 0.43        | 5.1E-15       | 0.90            | 0             | −0.05          | 0.38             | −0.26           | 6.3E-6          |
| (1)                | 0.23        | 0.005         | 0.87            | 0             | 0.13           | 0.13             | −0.42           | 2.0E-7          |
| (2)                | 0.74        | 0.87          | 0.87            | 0             | −0.33          | 6.4E-5           | 0.18            | 0.03            |
Table 3
Principal Component Analysis of Subsamples Dependent on [O\textsc{iii}]/Hβ\textsubscript{NLR} and Total Sample

|                      | Component 1 | Component 2 | Component 3 |
|----------------------|-------------|-------------|-------------|
| log([O\textsc{iii}]/Hβ\textsubscript{NLR} > 0.5 subsample) | 1.519       | 1.237       | 1.046       |
| Standard deviation   |             |             |             |
| Proportion of variance| 0.385     | 0.255       | 0.182       |
| Cumulative proportion| 0.385     | 0.640       | 0.822       |
| \(\lambda_{L5100}\) | −0.523      | 0.088       | 0.009       |
| FWHM H\γ         | −0.154      | 0.737       | −0.135      |
| EW [O\textsc{iii}] | 0.571       | 0.138       | 0.119       |
| EW Fe\textsc{ii}  | −0.307      | −0.382      | 0.676       |
| EW H\γ\textsubscript{NLR} | 0.529   | −0.124      | 0.158       |
| EW H\γ\textsubscript{broad} | 0.057   | 0.518       | 0.696       |
| log([O\textsc{iii}]/Hβ\textsubscript{NLR} < 0.5 subsample) | 1.706       | 1.157       | 0.903       |
| Standard deviation   |             |             |             |
| Proportion of variance| 0.485    | 0.223       | 0.136       |
| Cumulative proportion| 0.485    | 0.708       | 0.844       |
| \(\lambda_{L5100}\) | −0.512      | −0.044      | −0.377      |
| FWHM H\γ         | −0.490      | −0.111      | −0.446      |
| EW [O\textsc{iii}] | 0.384       | −0.532      | −0.160      |
| EW Fe\textsc{ii}  | −0.331      | −0.326      | 0.758       |
| EW H\γ\textsubscript{NLR} | 0.277   | −0.613      | −0.225      |
| EW H\γ\textsubscript{broad} | −0.404  | −0.469      | 0.091       |

Total sample

|                      | Component 1 | Component 2 | Component 3 |
|----------------------|-------------|-------------|-------------|
| Standard deviation   | 1.458       | 1.272       | 1.023       |
| Proportion of variance| 0.354    | 0.270       | 0.174       |
| Cumulative proportion| 0.354    | 0.624       | 0.798       |
| \(\lambda_{L5100}\) | −0.570      | −0.067      | 0.004       |
| FWHM H\γ         | −0.394      | 0.544       | −0.117      |
| EW [O\textsc{iii}] | 0.454       | 0.458       | 0.178       |
| EW Fe\textsc{ii}  | −0.246      | −0.471      | 0.651       |
| EW H\γ\textsubscript{NLR} | 0.459   | −0.090      | 0.363       |
| EW H\γ\textsubscript{broad} | −0.208  | 0.510       | 0.631       |

Table 4
Principal Component Analysis of Subsamples Dependent on log(FWHM [O\textsc{iii}]/FWHM H\γ) Ratio

|                      | Component 1 | Component 2 | Component 3 |
|----------------------|-------------|-------------|-------------|
| log(FWHM [O\textsc{iii}]/FWHM H\γ) < −0.8 subsample) | 1.531       | 1.203       | 1.070       |
| Standard deviation   |             |             |             |
| Proportion of variance| 0.391    | 0.241       | 0.191       |
| Cumulative proportion| 0.391    | 0.632       | 0.823       |
| \(\lambda_{L5100}\) | −0.481      | −0.248      | 0.030       |
| FWHM H\γ         | 0.058       | −0.763      | −0.194      |
| EW [O\textsc{iii}] | 0.585       | −0.067      | 0.138       |
| EW Fe\textsc{ii}  | −0.362      | 0.225       | 0.686       |
| EW H\γ\textsubscript{NLR} | 0.501   | 0.281       | 0.116       |
| EW H\γ\textsubscript{broad} | 0.200   | −0.471      | 0.677       |
| log(FWHM [O\textsc{iii}]/FWHM H\γ) > −0.8 subsample) | 1.577       | 1.047       | 1.004       |
| Standard deviation   |             |             |             |
| Proportion of variance| 0.414    | 0.183       | 0.168       |
| Cumulative proportion| 0.414    | 0.597       | 0.765       |
| \(\lambda_{L5100}\) | −0.530      | −0.014      | 0.245       |
| FWHM H\γ         | −0.530      | 0.137       | 0.065       |
| EW [O\textsc{iii}] | 0.302       | 0.763       | −0.083      |
| EW Fe\textsc{ii}  | −0.365      | −0.265      | −0.514      |
| EW H\γ\textsubscript{NLR} | 0.266   | −0.250      | −0.664      |
| EW H\γ\textsubscript{broad} | −0.378  | 0.516       | −0.472      |

Some other correlations shown in Table 1 are also sample-dependent, i.e., there is a significant difference in the correlation coefficients for the AGN and AGN1 compared to the SB and SB1 subsamples. The Baldwin effect for [O\textsc{iii}] and H\γ\textsubscript{NLR} tends to be stronger in the AGN and AGN1 subsamples than in the SB and SB1 subsamples.

3.0.1. Principal Component Analysis

We apply PC analysis to the total sample and subsamples. The results of the PC analysis for the two subsamples and the total sample are shown in Tables 3 and 4. The AGN-dominant subsamples (AGN and AGN1) may be described with the first
three eigenvectors, which represent ~82% of the variance (see Tables 3 and 4). The first eigenvector, which describes ~39% of the variance, represents dependence on line EWs versus continuum luminosity (i.e., the Baldwin effect). The EW Fe II versus EW [O III] anticorrelation is clearly present, implying that it is related to the Baldwin effect. Note that in this eigenvector, there is no influence of the FWHM Hβ. The second eigenvector represents a relationship between line EWs and FWHM Hβ, which should be similar to the BG92 EV1, but in our case the EW Fe II versus EW [O III] anticorrelation is not detected. In this eigenvector, we find the anticorrelation of FWHM Hβ versus EW Fe II and the expected correlation between FWHM Hβ and EW Hβ broad. Our third eigenvector is dominated by the broad Hβ component and EW Fe II, indicating a connection between the BLR and Fe II emitting region (see Kovačević et al. 2010).

Results of the PC analysis for the SB and SB1 subsamples are significantly different (Tables 3 and 4). The variance may also be described with the first three eigenvectors, which represent 84%
(SB) and 76.5% (SB1) of the variance. The first eigenvector accounts for 48.5% and 41.4%, respectively, of the variance of the subsamples, which implies that it dominates in both SB subsamples. It represents not only a relationship between the line EWs and continuum luminosity (the Baldwin effect), but also correlations/anticorrelations between the EWs with the broad $H\beta$ FWHM, since a strong correlation between FWHM $H\beta$ and $\lambda L_{5100}$ is present. The EW [O iii] versus EW Fe ii anticorrelation is also present as the Baldwin effect of the lines. This eigenvector does not represent the BG92 EV1 since the FWHM $H\beta$ and EW Fe ii have a positive correlation.

3.1. Possible Physical Interpretation of Results

The most interesting result is that SB subgroups show correlations between the narrow and broad line widths and luminosities, while the AGN subgroups do not. It has previously been noticed that some correlations between spectral properties depend on the FWHM $H\beta$ range of the observed sample (see, e.g., Steiner 1981; Grupe 2004; Sulentic et al. 2009; Zamfir et al. 2010; Kovačević et al. 2010). For example, Grupe (2004) found that the FWHM $H\beta$ and EW Fe ii anticorrelate for AGNs with broad lines (BLSys1s) and also anticorrelate for NLSy1s. Here we find two subsamples, one where there is a significant correlation between the FWHM $H\beta$ broad component and continuum luminosity, and another where this correlation is not present. Note that the correlation between continuum luminosity and FWMI 10% $H\beta$ is the same as that for the FWHM $H\beta$ (see the SB and SB1 subsamples in Tables 1 and 2).

The different behaviors of the two groups may be caused by, among others, (1) different contributions of starburst regions, i.e., a different nature of the ionization source, or (2) by different Eddington ratios and/or geometrical structures of the BLR.

3.1.1. A Starburst Contribution: A Difference in the Source of Ionization?

One can see from Tables 1 and 2 that there are significant differences in the spectral properties of the two subsamples, which may be due to a difference in the source of ionization.

As mentioned above, there is a possibility that an AGN spectrum in the earlier activity phase is composed of a starburst and a central engine (pure AGN) spectrum (see Croom et al. 2002; Wang & Wet 2006, 2008; Mao et al. 2009). Moreover, recently, Popović et al. (2009) found that in the case of NLSy1 galaxy Mrk 493, the narrow-line ratios correspond to starbursts rather than to an AGN origin.

In the case of a dominant contribution from a starburst region to emission in the narrow lines, one can expect that, besides the AGN emission, additional significant starburst emission may be present in the composite continuum. Then, there is probably an extensive source of continuum emission (as in the case of Mrk 493; see Popović et al. 2009) that may be produced by a number of exploding stars. Consequently, the luminosity of such objects will depend on the star-forming rate. In the starburst-dominant subsamples, there is a positive but statistically insignificant trend between the FWHM $H\beta$ and EW Fe ii, and it seems that in general the Fe ii emission is stronger in this subsample ($\log(\text{EW Fe} \text{ ii}) \sim 1.7-2.3$). The strong Fe ii emission and weak [O iii] emission can be explained with a model that contains a massive SB plus an AGN (see, e.g., Lipari & Terlevich 2006). The SB+AGN can lead to large-scale expanding supergiant shells. A good correlation between the FWHM and luminosity in one group of AGNs may indicate that the broad component is not primarily a function of geometry (e.g., by rotation due to the gravitational force), but rather of random motion of the gas caused by different effects (such as the gas being randomly accelerated in several bursts). In such a case, part of the flux of the broad Balmer emission lines may arise in the stellar envelopes of Wolf–Rayet and OB stars associated with multiple supernova events (see Izotov et al. 2007, and references therein).

Note that EW $H\beta$ broad only increases with $\lambda L_{5100}$ in the SB and SB1 subsamples, and this increase is not found in the AGN subsamples.

One can speculate that the FWHM of the broad component might not be formed as in the classical broad line region (where rotation velocity should be present), but as a sum of random motions of emitters (e.g., in extended envelopes; see Netzer 2006). In such a case, it might be that Fe ii lines are also formed in the gas located in (or around) the starburst regions, i.e., the intensity of Fe ii lines does not depend on the geometry of the BLR. The star-forming regions can affect the observed spectra of AGNs. As an example, recall here the results obtained by Croom et al. (2002), who found a strong anticorrelation with luminosity for the equivalent widths of [O iii] $\lambda 3727$ and suggested that the [O iii] line observed in the high-luminosity AGNs may be emitted, to a large extent, by intense star-forming regions, i.e., the AGN contribution to this line could be weaker than previously assumed.

On the other hand, an analysis of the AGN and AGN1 samples shows that there is no correlation between the widths (kinematics) of the broad $H\beta$ and luminosity. This would be expected if the widths were caused by the rotational component of motion (by geometry), as is assumed in the classical BLR. In addition, the EW Fe ii shows a trend of being weaker as widths increase. This can also be caused by geometry, or it could be that, as we look deeper into the BLR, the Fe ii emission becomes weaker.

In the case of a pure (or dominant) AGN emission, there is a point-like photoionization source that influences the NLR emission: as the central source gets stronger, the continuum also becomes stronger, which affects the processes in the NLR as well as the size of the region. The Fe ii emission becomes stronger, which may be caused by additional atomic processes in some parts of the BLR. In this case, the BLR is formed around the central black hole, and its geometry and gravitational motion influence line profiles (widths). Since dimensions will be affected by the central source luminosity, there will be correlations between the broad-line EWs and luminosity. However, the BLR geometry can be quite different, and one cannot expect correlations between the broad-line FWHM (FWMI 10%) and luminosity. It is clear that in this case the Baldwin effect and BG92 EV1 are caused by the luminosity of the central source and line-forming processes in the NLR and part of the BLR (probably in the ILR; see Kovačević et al. 2010).

3.1.2. Accretion Rate

The ratio between the bolometric and Eddington luminosities can be taken to be equal to the dimensionless accretion rate $\dot{m} \sim L/M$, and it is well known that the Boroson and Green EV1 is closely related to the Eddington ratio, $L/M$ (see, e.g., Marziani et al. 2001; Boroson 2002). The mass of a black hole ($M$) can be estimated using (Wandel & Yahil 1985; Padovani & Rafanelli 1988; Vestergaard & Peterson 2006; McGill et al. 2008)

$$M \sim L_{5100}^{0.5}(\text{FWHM})^2.$$
where FWHM is the full width at half maximum of the broad component. From this, one can extract an expected relationship between the luminosity, accretion rate, and FWHM as

\[ \log(L) = \text{const} + 2\log(L/M) + 4\log(\text{FWHM}). \]

Consequently, if two groups of AGNs (in our case SB and SB1) have similar Eddington ratios, there will be a high correlation between the luminosity and FWHM. This may be an explanation for the good correlation between luminosity and FWHM seen in the SB and SB1, but the question remains, why is there no correlation in the AGN and AGN1 subsamples? Also, why is this correlation connected with the ratio of the narrow lines? One solution might be that SB and SB1 are young objects where starburst regions also contribute to the line emission (especially to the narrow lines), and that they have similar accretion rates. In that case, we can expect a good correlation between luminosity and FWHM, and dominant starburst emission in narrow lines.

4. CONCLUSIONS

In this paper, we have investigated connections between the Baldwin effect and the BG92 EV1 and different correlations between spectral characteristics of a sample of 302 AGNs, dividing the sample with respect to the narrow [O\textsc{iii}] and H\beta ratio and also by using the ratio of widths of [O\textsc{iii}] and H\beta.

We have investigated different correlations within the subsamples, and our findings are as follows:

1. It seems that the line width of broad-line Sy1s introduced by some authors (FWHM = 3000 km s\(^{-1}\) or 4000 km s\(^{-1}\); Grupe 2004; Sulentic et al. 2009; Zamfir et al. 2010; Kovačević et al. 2010, etc.) is not relevant for the separation of AGNs with broad lines into two groups (BLS1 and NLS1, see Figure 6), since some AGNs with FWHM < 3000 km s\(^{-1}\) or < 4000 km s\(^{-1}\) have the same characteristics as AGNs with broader lines. We propose to divide the subsamples of AGNs using as a criterion the flux ratio of the narrow [O\textsc{iii}] and narrow H\beta lines, or by using the ratio of the FWHMs of [O\textsc{iii}] and broad H\beta, or H\beta narrow, and H\beta broad components.\(^5\)
2. There is a significant difference in the correlations between line properties of the two subsamples. This indicates that there is a significant difference in the physics of the emitting gas and the origin of the broad-line components. We found

\(^5\)Since the widths of the H\beta narrow and the corresponding [O\textsc{iii}] line component are essentially the same.
that BG92 EV1 and the Baldwin effect have the same physical background in both subsamples. In the SB and SB1 subsamples, eigenvector 1 shows a strong correlation between luminosity, the FWHM of broad H$\beta$, and the EWs of lines, while in the other subsamples there are high correlations only between luminosity and EWs of lines.

3. The narrow and broad line widths of the SB and SB1 subsamples are luminosity-dependent and they do not seem to be connected with only predominant rotational motion, but rather by randomly distributed high velocity gas. Conversely, in the case of the AGN and AGN1 subsamples, there is no FWHM H$\beta$ broad line dependence on luminosity, and the widths seem to be influenced by the BLR geometry. Such a high correlation between the luminosity and FWHM in the SB and SB1 subsamples may be explained as (1) a connection between starburst regions and the region where the broad H$\beta$ line is formed, and (2) the SB and SB1 subgroups having very similar accretion rates, in which case one can expect a high correlation between the luminosity and FWHM.

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APPENDIX A

ESTIMATION OF THE NARROW H$\beta$ COMPONENT

As mentioned in this paper, estimation of the narrow H$\beta$ component is difficult, especially in the case of broad-line AGNs. In principle, due to complex kinematics of the NLR, the narrow lines cannot usually be represented by a pure Gaussian profile. However, if one would like to estimate the contribution of the NLR to the whole line, a Gaussian profile approximation may be used. This also gives some indication about velocities in the subregions as well as the contribution of the NLR to the total
and found that the error bars were in the range of 5%—7% (in all cases less than 10%) in the case in which the FWHM has a value between 1000 and 2000 km s\(^{-1}\).

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APPENDIX B

ERROR BARS OF THE FWHM AND FWM 10% ESTIMATES

As mentioned in this paper, the Hβ broad component was taken to be the sum of the Hβ ILR and Hβ VBLR components (see Figure 2). Since there may be a problem in subtraction of the narrow component, we performed a test by first considering the objects with flat minima (i.e., where the narrow Hβ component cannot be properly estimated). We then fixed the narrow component, taking \( f = 0.1 \) and \( f = 1.9 \), and found the best fit of the broad component. We measured FWHM and FWM 10% from these two broad components (using the ILR and VBLR)

\[ \chi_0^2 \] is the value obtained in the primary fit.

6 Here, \( \chi_0^2 \) is the value obtained in the primary fit.