THE BLUESHIFTING AND BALDWIN EFFECTS FOR THE [O iii] $\lambda$5007 EMISSION LINE IN TYPE 1 ACTIVE GALACTIC NUCLEI

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ABSTRACT

We use homogeneous samples of radio-quiet Seyfert 1 galaxies and QSOs selected from the Sloan Digital Sky Survey to investigate the connection between the velocity shift and the equivalent width (EW) of the [O iii] $\lambda$5007 emission line, and their correlations with physical parameters of active galactic nuclei (AGNs). We find a significant and negative correlation between the EW of the core component, EW(core), and the blueshift of either the core (the peak), the wing, or the total profile of [O iii] emission; it is fairly strong for the blueshift of the total profile in particular. However, both quantities (EW and velocity shift) generally have only weak, if any, correlations with fundamental AGN parameters such as the nuclear continuum luminosity at 5100 Å ($L_{5100}$), black hole mass ($M_{BH}$), and the Eddington ratio ($L/L_{Edd}$); these correlations include the classical Baldwin effect of EW(core), an inverse Baldwin effect of EW(wing), and the relationship between velocity shifts and $L/L_{Edd}$. Our findings suggest that both the large object-to-object variation in the strength of [O iii] emission and the blueshift–EW(core) connection are not governed primarily by fundamental AGN parameters such as $L_{5100}$, $M_{BH}$, and $L/L_{Edd}$. We propose that the interstellar medium conditions of the host galaxies play a major role instead in the diversity of the [O iii] properties in active galaxies. This suggests that the use of [O iii] $\lambda$5007 luminosity as a proxy of AGN luminosity does not depend strongly on the above-mentioned fundamental AGN parameters.

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

Online-only material: color figures, machine-readable tables

1. INTRODUCTION

In terms of size, the narrow-line region (NLR) of active galactic nuclei (AGNs; including Seyfert galaxies and quasars) represents the link between the inner structure of the AGN—the dusty torus and the broad-line region (BLR)—and the interstellar medium (ISM) in the host galaxy. The NLR bridges the region dominated by the gravitational field of the central massive black hole and the region dominated by the gravitational potential of the bulge stars of the host galaxy. To gain a complete understanding of the AGN phenomenon, the role of the NLR therefore needs to be understood. Unlike the BLR, the NLR (or at least the outer parts of the NLR) can be spatially resolved in nearby AGNs. Despite this, however, the NLR remains remarkably poorly understood and there are many unanswered questions about the structure and kinematics of the NLR and its relationship to the BLR/torus.

[O iii] $\lambda$5007 is one of the most important NLR lines. Its equivalent width (EW) in the AGN ensemble varies dramatically by a factor of $>300$ (from $<0.5$ to $157$ Å; Baskin & Laor 2005b), and is one of the things showing the most object-to-object variation in AGNs. It is a dominant variable in the set of correlations making up the first principal component (commonly called “eigenvector 1”; EV1) in the principal component analysis of QSO properties of Boroson & Green (1992); EV1 is believed to be linked to certain fundamental parameters of the accretion process. [O iii] luminosity is commonly used as a surrogate for the bolometric luminosity (e.g., Heckman et al. 2004) and its Doppler width as a surrogate for the stellar velocity dispersion ($\sigma_*$) of the host galaxy (e.g., Nelson & Whittle 1996; Wang & Lu 2001; Komossa & Xu 2007; Gaskell 2009a).

Although the spatial distribution of [O iii]-emitting gas in the NLR of AGNs is rather inhomogeneous (see, e.g., Das et al. 2006; Crenshaw et al. 2010), there are some global regularities in its strength and kinematics. Its EW was found to correlate negatively, albeit with a large scatter, with the continuum luminosity (Grindlay et al. 1980; Steiner 1981; Dietrich et al. 2002; Kovačević et al. 2010; cf. Table 3 of Dong et al. 2011). This is similar to the famous “Baldwin effect” (Baldwin 1977; Baldwin et al. 1978) first discovered for the broad C iv $\lambda$1549 line. The [O iii] line profile can be regarded as consisting of two components: a narrow component (hereinafter the “core”) with a velocity close to the systemic redshift of the host galaxy and a low, broad base that is usually blueshifted (hereinafter the “wing”). There is mounting evidence that the core component is a good tracer of the gravitational potential of the host galaxy bulge (see, e.g., Gaskell 2009a and references therein) while the wing component arises from AGN outflows (see, e.g., Crenshaw et al. 2010; Komossa & Xu 2007 and references therein). Scattering could also be a contributor to broadening of the wings (Gaskell & Goosmann 2008).

Besides these general global trends in the AGN ensemble, there are some interesting peculiar [O iii] phenomena that have been discovered in some particular AGN subclasses. For instance, in narrow-line Seyfert 1s (NLS1s) that have broad-H$\beta$ lines with FWHM < 2000 km s$^{-1}$ (the “population A” of the EV1 domain; Zamanov et al. 2002; see Xu & Komossa 2010 for a recent review), [O iii] $\lambda$5007 is generally very weak. Moreover, in a small fraction of NLS1s, the whole [O iii] $\lambda$5007 profile has a bulk velocity shift of $\gtrsim 250$ km s$^{-1}$ blueward (the so-called blue outliers; Zamanov et al. 2002; Boroson 2005; Zhou et al. 2006; Komossa et al. 2008) and there seems to be...
no non-blueshifted component from a canonical NLR as seen in low-ionization lines (Komossa et al. 2008). Komossa & Xu (2007) found that although the width of the core component of [O III] λ5007 is generally a good surrogate for σ*, this however does not hold in “blue outliers.”

It is an interesting question whether or not these various regularities and phenomena can be unified and this has been looked at by previous authors. For instance, Zamanov et al. (2002) suggested that “blue outliers” with extreme blue wing components originate in strong AGN outflows, and moreover are associated with the same outflows as the blueshifted component of the broad C IV λ1549 emission line. The origin of the blueshifting of high-ionization broad emission lines such as C IV λ1549 remains a subject of debate. There is general agreement that there has to be a radial component of motion and some opacity source. Gaskell (1982) proposed that the blueshifting was due to an outflow of the high-ionization gas and obscuration by the accretion disk. While this has remained the most popular model, it contains the major problem that outflows of the dominant line-emitting gas seem to be strongly ruled out by velocity-resolved reverberation mapping (Gaskell 1988; Koratkar & Gaskell 1989; see Gaskell 2009b for a review). Gaskell & Goosmann (2008) therefore argue that the blueshifting is due instead to the scattering of photons by material with a net inward motion as suggested by Corbin (1990).

Observationally, the C IV λ1549 Baldwin effect and blueshifting are related in the sense that higher-luminosity AGNs have both lower C IV EWs and larger blueshifts (Corbin 1991, 1992). This is further supported by the study of Richards et al. (2002). If this is also true for [O III] λ5007, we will gain important insights into the origin and kinematics of the NLR. It might point to similar underlying causes for the two effects in both the BLR and NLR. Meanwhile, understanding these effects should enable us to calibrate better the Doppler widths and luminosities of [O III] λ5007 to serve as proxies for the bulge gravitational potential and AGN bolometric luminosity.

Motivated by these considerations, we present here the results of a systematic study of the velocity shift of [O III] λ5007 emission line, its connection to the Baldwin effect, and its connection to possible physical drivers. This study takes advantage of the unprecedented spectroscopic data from the Sloan Digital Sky Survey (SDSS; York et al. 2000). Throughout this paper, we use a cosmology with \( H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}, \Omega_m = 0.3, \) and \( \Omega_\Lambda = 0.7. \)

2. SAMPLE AND MEASUREMENTS

2.1. Samples

Type 1 AGNs are chosen from the sample of Seyfert 1 galaxies and quasars of Dong et al. (2011) taken from the Fourth Data Release (Adelman-McCarthy et al. 2006) of SDSS. We select type 1 AGNs having the [O III] λ5007 emission line in the SDSS bandpass and with continuum and emission lines suffering only minimally from contamination by host galaxy starlight. To ensure reliable analysis of the [O III] λ5007 profile, we also require high spectral quality in the [O III] λ5007 region. Our primary goal is to study the connection between velocity shifts and EWs. To ensure the reliable analysis of the velocity shift of [O III], we first construct a basic sample by taking the [S II] λλ6716, 6731 doublet lines as the fiducial reference for the systematic redshift. [S II] is free from broad-line contamination so using it is more accurate than using narrow Hβ (see Section 2.2).

The final criteria used for the basic sample are therefore (1) \( z \leq 0.3 \) to ensure that [S II] emission lines, as well as [O III] λ5007 and broad Hβ, are in the bandpass; (2) a median signal-to-noise ratio (S/N) \( \geq 10 \) pixel\(^{-1} \) for the optical spectra, and particularly \( \geq 15 \) in the [O III] region (4995–5020 Å); (3) the S/N of either [S II] λ6716 or λ6731 line \( \geq 3 \) to ensure [S II] to be a reliable reference for velocity shift; and (4) weak stellar absorption features, such that the rest-frame EWs of Ca K (3934 Å), Ca H + He (3970 Å), and Hδ (4102 Å) absorption features are undetected at \( < 2 \sigma \) significance. The last criterion ensures that the measurement of the AGN luminosity and the emission-line EWs suffer little from the contamination of the host galaxy starlight (see the Appendix of Dong et al. 2011).

After removing duplications and sources with too many bad pixels in the Hβ + [O III] region, we obtain 565 type 1 AGNs. Radio jets may enhance [O III] emission (Labiano 2008) and thus possibly affect the results. We therefore use the method of Lu et al. (2007) to exclude sources detected by the Faint Images of the Radio Sky at Twenty centimeters (FIRST) survey by matching with the FIRST catalog (Becker et al. 1995). After this, our basic sample consists of 383 sources.

Because of the redshift cutoff of \( z \leq 0.3 \) to ensure the presence of [S II] as the redshift reference, the dynamic ranges of AGN parameters are somewhat restricted (see Section 3.2). So in the investigation concerning [O III] EWs only we further define an extended sample by relaxing both the redshift cutoff and the S/N requirement for [S II]. The extended sample comprises 1951 radio-quiet type 1 AGNs at \( z < 0.8 \) culled from the Dong et al. (2011) sample, with a median S/N \( \geq 15 \) pixel\(^{-1} \) in the [O III] region.

2.2. Analysis of Spectra

Data analysis methods are as described in detail in Dong et al. (2011). We only provide a brief description here. Following Dong et al. (2008), we fit simultaneously the AGN featureless continuum, the Fe II multiplets, and other emission lines using a code based on the MPFIT package (Markwardt 2009), and if necessary we refine the emission-line fitting with the continuum subtracted spectra using a code described in detail in Dong et al. (2005). The AGN continua are modeled by local power laws for 4200–5600 Å and the Hα regions. The Fe II emission is modeled with two separate sets of templates in analytical forms, one for the broad-line system and the other for the narrow-line system, using the identification and measurement of Fe II lines in I Zw 1 from Véron-Cetty et al. (2004), as listed in their Tables A1 and A2. Within each system, we assume that the respective sets of Fe II lines have no relative velocity shifts and have the same relative strengths as those in I Zw 1. Broad Fe II lines are assumed to have the same profile as broad Hβ, while each narrow Fe II line is modeled with a Gaussian. During the fitting, the normalization and redshift of every system are set to be free parameters. Broad hydrogen Balmer lines are fitted with many Gaussians as is statistically justified.

All narrow emission lines are fitted with a single Gaussian, except for the [O III] λλ4959, 5007 doublet lines. Each line of the doublet is modeled with two Gaussians, one accounting for the line core and the other for a possible blue wing, as seen in many objects. The Gaussian that has a smaller velocity shift relative to [S II], whether blueward or redward, is taken to be the core component. It also turns out to be narrower than the other Gaussian component (if the other one was present). The velocity shifts of the core component with respect to [S II] in the basic sample have a mean of \( -47 \text{ km s}^{-1} \) (negative values...
Table 1

Parameters of the Core and Wing Components of [O iii] λ5007 Emission Line: Basic Sample

| SDSS Name       | log F(core) | EW(core) | log F(wing) | EW(wing) | Δv(core) | Δv(wing) | Δv(centroid) |
|-----------------|-------------|----------|-------------|----------|----------|----------|--------------|
| J000410.80−104527.2 | −15.02     | 4.39     | −15.00      | 4.64     | −77.52  | −608.9    | −351.3      |
| J000904.54−103428.6 | −14.24     | 33.43    | −14.59      | 14.93    | −1.43   | −88.4     | −28.3       |
| J001247.93−084700.4 | −14.75     | 6.55     | −14.46      | 12.91    | −23.71  | −186.9    | −132.7      |
| J001340.73−111100.6 | −15.56     | 15.29    | −15.13      | 4.10     | −319.6  | −113.4    | −492.9      |
| J001416.92+145038.4 | −14.94     | 9.24     | −14.85      | 11.26    | −130.5  | −483.8    | −324.9      |
| J003723.49+000812.5 | −14.82     | 13.12    | −14.97      | 9.35     | −35.72  | −422.4    | −197.9      |
| J004930.90+153216.3 | −14.08     | 32.48    | −14.62      | 9.24     | 16.22   | −480.5    | −94.2       |
| J005118.27+135448.0 | −14.07     | 26.38    | −15.26      | 1.72     | 2.772   | 265.9     | 18.8        |
| J005328.80−085755.0 | −14.69     | 10.91    | −14.98      | 5.51     | −32.51  | −250.1    | −105.7      |
| J005709.93+144610.2 | −14.02     | 6.72     | −14.19      | 4.57     | 106.7   | −487.3    | −134.7      |

Notes. Parameters for the 383 objects in the basic sample. Column 1: official SDSS name; Column 2: flux of the core component; Column 3: equivalent width of the core component; Column 4: flux of the wing component; Column 5: equivalent width of the wing component; Column 6: velocity shift of the core component with respect to [S ii] λ6716, 6731 doublet lines; Column 7: velocity shift of the wing component with respect to [S ii]; Column 8: velocity shift of the centroid with respect to [S ii].

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Table 2

EW and Flux of the Core and Wing Components of [O iii] λ5007 Emission Line: Extended Sample

| SDSS Name       | log F(core) | EW(core) | log F(wing) | EW(wing) | Δv(core) | Δv(wing) | Δv(centroid) |
|-----------------|-------------|----------|-------------|----------|----------|----------|--------------|
| J000043.95−091134.9 | −15.27     | 4.38     | −15.42      | 3.11     |          |          |              |
| J000102.19−102326.8 | −14.39     | 35.43    | −14.66      | 18.9     |          |          |              |
| J000110.96−105247.4 | −14.99     | 5.52     | −14.70      | 10.8     |          |          |              |
| J000545.61+153833.8 | −14.88     | 7.73     | −14.59      | 15.0     |          |          |              |
| J000945.46+001337.1 | −15.73     | 2.77     | −15.03      | 13.7     |          |          |              |
| J001030.58+001006.0 | −13.84     | 82.26    | −14.43      | 21.4     |          |          |              |
| J001327.31+005232.0 | −14.33     | 24.42    | −14.34      | 23.6     |          |          |              |
| J001630.43−093853.4 | −14.98     | 7.48     | −15.00      | 7.18     |          |          |              |
| J001725.35+141325.2 | −14.74     | 5.28     | −14.52      | 8.82     |          |          |              |
| J001855.22−091351.1 | −15.08     | 3.85     | −14.70      | 9.39     |          |          |              |

Notes. Parameters for the 1568 objects that are not in the basic sample but in the extended sample. Column 1: official SDSS name; Column 2: flux of the core component; Column 3: equivalent width of the core component; Column 4: flux of the wing component; Column 5: equivalent width of the wing component. (This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Figure 1. Results of the emission-line profile fitting applied to the Hβ-[O iii] region of SDSS J080131.58+354436.4. We plot the continuum and Fe ii subtracted spectrum (black), the sum of all the best-fitting components (red), the fitted narrow (green) and broad Hβ (cyan), and particularly the decomposed core (pink) and wing (blue) components of [O iii] λ5007 line. The green dashed vertical line denotes the wavelength for [O iii] λ5007 as inferred from the [S ii] line. (A color version of this figure is available in the online journal.)

denoting blueshifts) and a standard deviation of 72 km s$^{-1}$, while the mean shift of the wing component is $−225$ km s$^{-1}$ with a standard deviation of 240 km s$^{-1}$. On average the core components comprise 54% of the total emission, with a standard deviation of 0.16 dex. We list in Table 1 the fluxes, EWs, and velocity shifts of the core and wing components and the whole profile of [O iii] λ5007 for all the objects in the basic sample. The velocity shifts are calculated by assuming that the [S ii] doublet lines are located at the systematic redshift. In Table 2, we list the fluxes and EWs of the core and wing components of [O iii] λ5007 for all the objects at higher redshifts that are thus not in the basic sample but in the extended sample. The other spectral parameters of this sample are given in Dong et al. (2011). An example is illustrated in Figure 1 of fitting the [O iii] λ5007 line profile of the SDSS spectrum of J080131.58+354436.4 (i.e., the decomposition of the core and wing components).

In the basic sample, the velocity shifts of narrow Hβ with respect to [S ii] have a mean of $−21$ km s$^{-1}$ and a standard deviation of $82$ km s$^{-1}$. Such a scatter is a bit larger than that of the core component of [O iii]. So if we use narrow Hβ as the fiducial reference for the systematic redshift to study the velocity shift of [O iii], it would smear the correlations of interest in this study. This should be especially true for the sources at relatively higher redshifts in the extended sample. Those sources have lower spectral S/N and a weaker narrow Hβ component than the sources in the basic sample, thus the deblending of narrow Hβ from the broad component has a larger uncertainty. The use of narrow Hβ is checked in Section 3.

We note that there is usually a prominent Fe ii emission feature immediately redward of [O iii] λ5007, which is dominated by Fe ii λ5018 and [Fe ii] 20F λ5020. To ensure that the [O iii] measurements suffer little from poor subtraction of this Fe ii feature, we visually inspect the fits for the entire extended sample and fine tune the fits for some objects by carefully...
matching the model to this local feature. In such objects, the relative strengths of Fe\textsc{ii} lines are significantly different from those of I Zw 1 on which the Fe\textsc{ii} lines are based.

### 3. RESULTS

#### 3.1. The Connection between the Blueshifting and Baldwin Effects for [O\textsc{iii}] λ5007

We explore the connection between the velocity shift and strength of [O\textsc{iii}] λ5007 in the basic sample. We calculate the velocity shifts of the core and wing components and the centroid (i.e., intensity-weighted average) of the whole profile (Δv(core), Δv(wing), and Δv(centroid), respectively) with respect to [S\textsc{ii}] λ6716 and λ6731. The line strength is characterized by the rest-frame EW, as measured by dividing the emission-line flux by the underlying AGN continuum flux density at the central wavelength, for the core and wing components and the whole [O\textsc{iii}] emission, respectively. We perform bivariate Spearman rank correlations to test the relationship between these kinds of velocity shifts and EWs. This method tests not only a linear relation but also a monotonic one. The results are summarized in Table 3, where we report the Spearman coefficient (r_s) and the probability (P_{null}) that a correlation is not present.

Table 3

|          | EW(core) | EW(wing) | EW(total) |
|----------|----------|----------|-----------|
| Δv(core) | 0.23 (4e-06) | 0.10 (4e-02) | 0.20 (7e-05) |
| Δv(wing) | 0.41 (6e-17) | 0.19 (2e-04) | 0.38 (1e-14) |
| Δv(centroid) | 0.51 (2e-26) | 0.11 (3e-02) | 0.41 (8e-17) |

Note. For each entry, we list the Spearman rank correlation coefficient (r_s) and the probability of the null hypothesis that the correlation is not present (P_{null}) in parentheses for the 383 objects in the basic sample.

We first subtract broad H\textbeta\ and Fe\textsc{ii} emission from the SDSS spectra, normalize every spectrum by the average flux density in the continuum window around 4200 Å, and then construct the composite in the same manner as Richards et al. (2002, see their Figure 4). The composite spectra are demonstrated in Figure 3 (panel (a)).

The variations in EWs and velocity shifts among the composite spectra can be seen readily to be consistent with our correlation analysis in the sense that the more the peak of the line is blueshifted, the more the EWs of the total emission and, particularly, the core component decrease dramatically, while the blue wing changes much less. This is similar to the case of C\textsc{iv} as Richards et al. (2002) found (see also Richards et al. 2010; Wang et al. 2011). In addition, there seems to be a trend of a positive connection between the blueshift of the peak and the strength of the wing component, which is not very significant according to the above correlation result between Δv(core) and EW(wing), yet (P_{null} = 4%).

#### 3.2. Correlations with Physical AGN Parameters

It is interesting to explore whether the blueshifting/Baldwin effect of [O\textsc{iii}] λ5007 is driven by some fundamental physical parameter. We have therefore investigated the correlations of the
velocity shifts and EWs of the core and wing components and of the total [O III] emission with broad Hβ FWHM, continuum luminosity $L_{5100} \equiv \lambda L_{\lambda}(5100 \text{ Å})$, $M_{\text{BH}}$, and $L/L_{\text{Edd}}$ for the sources in the basic sample. We calculate the black hole masses based on the FWHM of broad Hβ using the formalism presented by Wang et al. (2009, their Equation (11)). This formalism was calibrated with recently updated reverberation mapping-based masses and assuming a BLR radius of $R \propto L^{0.5}$ (Bentz et al. 2009). The Eddington ratios are calculated assuming a bolometric luminosity correction $L_{\text{bol}} \approx 9 \lambda L_{\lambda}(5100 \text{ Å})$ (Elvis et al. 1994; Kaspi et al. 2000). The correlation results are summarized in Table 4.

We find that there are some significant correlations ($P_{\text{null}} < 10^{-5}$). The EW of the core component has a negative correlation with the continuum luminosity (i.e., the classical Baldwin effect) and with the Eddington ratio (see also Dong et al. 2011). There is also a positive correlation of the blueshifting with the Eddington ratio, but none of these correlations are strong ($r_s < 0.4$). In particular, no correlation of any EW or velocity shift with these physical AGN parameters is more significant (stronger) than the $\Delta v (\text{centroid})$--EW(core) relationship for the same sample.

We also divide the 383 sources into three subsamples by $L_{5100}$ and three subsamples by $L/L_{\text{Edd}}$. We construct composite spectra for each subsample as described in Section 3.1. The three $L_{5100}$ subsamples have $L_{5100} \geq 10^{43.3}$, $10^{44.3} > L_{5100} \geq 10^{43.8}$, and $L_{5100} < 10^{43.8}$ erg s$^{-1}$, and the three $L/L_{\text{Edd}}$ subsamples have $L/L_{\text{Edd}} \geq 10^{-0.8}$, $10^{-0.4} > L/L_{\text{Edd}} \geq 10^{-0.3}$, and $L/L_{\text{Edd}} < 10^{-0.8}$. The composite spectra are shown in panels (b) and (c) of Figure 3. All of the already mentioned correlations can be seen. We also plot the relatively strong correlations of the velocity shifts of the peak (i.e., the core) and centroid of [O III] $\lambda 5007$ with Eddington ratio (Figure 4).

In summary, the results worthy of note in the correlation matrix are as follows.

1. The most significant correlation in the EW-related correlation matrix is the positive one between the intensity ratio of the wing to the core component and the continuum luminosity ($P_{\text{null}} = 8 \times 10^{-10}$ for the 383 sources), which hints at a positive correlation—albeit a weak one to be sure—between the EW of the wing component and the continuum luminosity. This is confirmed by our analysis using the extended sample free from the redshift cutoff required by the presence of [S II] (see below), which gives a significant correlation between EW(wing) and $L_{5100}$ with $P_{\text{null}} = 6 \times 10^{-18}$. The significance is high because of the large number of sources (1951) but is still not strong ($r_s \approx 0.2$). The correlation of the EW of the core component with luminosity is slightly weaker than that with Eddington ratio in the basic sample (and much weaker in the extended sample—see below). Both are much more significant than those with broad-line FWHM or black hole mass.

2. The most significant correlations of all the velocity shifts of the core and wing components and of the total profile are with $L/L_{\text{Edd}}$ ($P_{\text{null}} < 10^{-5}$), rather than with broad-line FWHM, $L_{5100}$, or $M_{\text{BH}}$. These correlations are in the sense that the higher the $L/L_{\text{Edd}}$ the more the line is blueshifted. Moreover, all three kinds of velocity shifts have no significant correlation with $M_{\text{BH}}$ at all ($P_{\text{null}} > 10\%$). Furthermore, all the objects with large blueshifts have a high Eddington ratio, but the reverse is not true (see Figure 4; also Komossa et al. 2008).

The dynamic ranges of $L_{5100}$, $M_{\text{BH}}$, and $L/L_{\text{Edd}}$ in the basic sample are 2, 1.5, and 1.5 dex, respectively, which are not very large. It is thus possible that some weak but real correlations are obscured by the significant measurement errors (see Section 4.1 below; also Wang et al. 2009; Dong et al. 2011). To check the correlations concerning EWs that do not require [S II] as the reference for systematic redshift, we use the extended sample as defined in Section 2.1. This sample enlarges the dynamic ranges...
Table 4: Correlation Results between [O III] Quantities and Physical Parameters

|      | $\Delta v$(core) | $\Delta v$(wing) | $\Delta v$(centroid) | EW(core) | EW(wing) | EW(total) | EW(core) | EW(wing) | EW(total) |
|------|------------------|------------------|----------------------|----------|----------|----------|----------|----------|----------|
|      | 383              | 383              | 383                  | 383      | 1951     | 1951     | 383      | 1951     | 1951     |
|      | 0.28 (3e-08)     | 0.17 (7e-04)     | 0.22 (2e-05)         | 0.14 (5e-03) | 0.10 (6e-02) | 0.14 (5e-03) | 0.11 (1e-06) | 0.08 (5e-04) | 0.12 (7e-08) |
|      | $-0.12$ (1e-02)  | $-0.25$ (1e-06)  | $-0.27$ (6e-08)      | $-0.26$ (2e-07) | $0.02$ (7e-01) | $-0.18$ (3e-04) | $-0.16$ (3e-12) | $0.19$ (6e-18) | $0.01$ (6e-01) |
|      | 0.17 (7e-04)     | 0.03 (5e-01)     | 0.06 (2e-01)         | $-0.01$ (9e-01) | $0.08$ (1e-01) | $0.03$ (6e-01) | $-0.02$ (4e-01) | $0.16$ (9e-13) | $0.08$ (3e-04) |
|      | $-0.35$ (3e-12)  | $-0.31$ (1e-09)  | $-0.36$ (2e-13)      | $-0.28$ (4e-08) | $-0.07$ (1e-01) | $-0.23$ (5e-06) | $-0.22$ (6e-23) | $0.07$ (1e-03) | $-0.11$ (3e-06) |

Notes.

4 For each entry, we list the Spearman rank correlation coefficient ($r_s$) and the probability of the null hypothesis that the correlation is not present ($P_{null}$) in parenthesis.

5 The number of the sources used in every bivariate correlation test.

6 $L_{5100} = \lambda L_\lambda(5100 \text{ Å})$, the BH masses are calculated using the formalism presented in Wang et al. (2009, their Equation (11)); Eddington ratios ($L/L_{\text{Edd}}$) are calculated assuming that the bolometric luminosity $L_{\text{bol}} \approx 9 L_{5100}$.

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Figure 4. Distributions of velocity shifts of the core component (top) and the centroid of the whole profile (bottom) of [O III] $\lambda$5007 vs. the Eddington ratio for the basic sample of 383 objects.
extended sample, the existing correlations get more statistically significant due to the larger sample size, yet the strengths \( r_s \) get weaker; e.g., \( r_s = 0.34 \) (\( P_{\text{null}} = 10^{-10} \)) for the correlation of \( \Delta \nu(\text{centroid}) \) with EW(core), and \( r_s = 0.29 \) (\( P_{\text{null}} = 10^{-41} \)) for its correlation with \( L/L_{\text{Edd}} \). Again, the relative strengths among the correlations remain almost unchanged.

It is, obviously, rather artificial to decompose the [O\textsc{iii}] profile into “core” and “wing” components by using simply two Gaussians. There is, for example, no theoretical justification that the wing component should have a Gaussian profile. And decomposing the line profile into different components certainly depends on the line width at the SDSS spectral resolution. For objects with small line widths and small velocity shifts, the decomposition would be more difficult. We do several investigations to check possible decomposition effects. We find that the width of the decomposed core component, which is the most sensitive one to the spectral resolution, has only weak \( r_s \) < 0.1 correlations with EW(wing), EW(total), and the velocity shifts of the core and wing components and of the total emission, and no correlation \( (P_{\text{null}} = 30\%) \) with EW(core) at all. The width of the decomposed wing component has no strong correlations with the EWs or velocity shifts of the core component and of the total emission too, and almost no correlations with either the EW or velocity shift \( (P_{\text{null}} > 1\%) \) of the wing component. These mean that the decomposition process would not bring a serious systematic effect into our results.

4. CONCLUSION AND DISCUSSIONS

4.1. [O\textsc{iii}] Properties are not Governed Preponderantly by AGN Parameters?

Despite the crude nature of the decomposition, the primary results about the velocity shifts and the EWs of [O\textsc{iii}] \( \lambda 5007 \) (and its core and wing components) appear quite robust, according to both the correlation analysis and the composite spectrum analysis. Our main result is that, while there is a fairly strong correlation between the EW of the core component and the velocity shifts, there are no similarly strong correlations of the EWs or velocity shifts of either the cores, wings, or of the whole emission with black hole mass, Eddington ratio, or AGN luminosity. Thus a tentative conclusion is that neither the large object-to-object variation of the EW of [O\textsc{iii}] \( \lambda 5007 \) nor its blueshift is readily attributable to some fundamental AGN parameters such as \( L_{\text{5100}}, M_{\text{BH}}, \) and \( L/L_{\text{Edd}} \) (see also Baskin & Laor 2005b). Likewise, neither does the velocity shift–EW relationship seem to be primarily driven by some AGN parameter. The weakness of the correlations of [O\textsc{iii}] properties with fundamental AGN parameters (including nuclear luminosity, \( M_{\text{BH}} \), and \( L/L_{\text{Edd}} \)) has also been reported in the literature by using samples with much larger dynamic ranges (e.g., Dietrich et al. 2002; Netzer et al. 2004).

This is in sharp contrast with the results for the EWs of broad Mg \textsc{ii} \( \lambda 2800 \) doublet emission lines and of narrow optical Fe \textsc{ii} emission lines, and the intensity ratios of ultraviolet and optical Fe \textsc{ii} to Mg \textsc{ii}, as recently discovered by Dong et al. (2009b, 2011). They found that those EWs and intensity ratios correlate with \( L/L_{\text{Edd}} \) strongly \( (r_s > 0.5 \text{ and } P_{\text{null}} \ll 10^{-15} \text{; see the above references}) \), using the same data set as the present study. Considering that the effects of measurement errors are similar on the correlations of both those lines and [O\textsc{iii}], we believe that the correlations of [O\textsc{iii}] properties with \( L_{\text{5100}}, M_{\text{BH}}, \) and \( L/L_{\text{Edd}} \) are intrinsically weak. For those emission lines arising from the BLR and inner NLR (narrow Fe \textsc{ii} lines; Dong et al. 2010), Dong et al. (2009a, 2009b, 2011) proposed that the essential physical mechanism is that the Eddington ratio regulates the global properties (particularly, the distribution of column density) of the clouds gravitationally bound in the line-emitting regions. It appears now that the mechanism operating in the BLR and the inner NLR does not play a major role in the canonical NLR located far out in the host galaxies and free from the gravitational influence of the central supermassive black holes. A useful positive inference is that, at least in a statistical sense, the above-mentioned use of [O\textsc{iii}] \( \lambda 5007 \) as the proxy of AGN luminosity does not depend seriously on \( L_{\text{5100}}, M_{\text{BH}}, \) and \( L/L_{\text{Edd}} \).

On the other hand, although the [O\textsc{iii}] properties do not depend as strongly on \( L_{\text{5100}}, M_{\text{BH}} \), or \( L/L_{\text{Edd}} \) as the above-mentioned emission lines arising from the inner NLR and the BLR, there are still some significant (albeit not strong) correlations between [O\textsc{iii}] properties and those fundamental AGN parameters. The EW of the core component has the most significant (anti-)correlation with \( L/L_{\text{Edd}} \), a less significant correlation with continuum luminosity, a much lower correlation with the broad-line FWHM, and almost no correlation with \( M_{\text{BH}} \). For the wing component of [O\textsc{iii}] the most significant correlation is with continuum luminosity. The behavior of the total emission results from the combination of the above two factors and is mainly dominated by the core component. The magnitude of the blueshifting of the core, the wing, and the whole profile has the most significant correlation with \( L/L_{\text{Edd}} \), rather than with the other parameters. Because the SDSS spectroscopic survey is magnitude-limited and, moreover, because both \( M_{\text{BH}} \) and \( L/L_{\text{Edd}} \) are constructed from broad-H\textsc{ii} FWHM and \( L_{\text{5100}} \), there are apparent (likely not intrinsic) correlations among these four quantities. For instance, the Spearman correlation coefficients of \( L/L_{\text{Edd}} \) with broad-H\textsc{ii} FWHM, \( L_{\text{5100}} \), and \( M_{\text{BH}} \) for our basic sample of 383 sources are \( r_s = 0.82, 0.30, \) and \(-0.51 \), respectively. In light of the serious interdependence among these four quantities, the correlations of EW(wing) with broad-H\textsc{ii} FWHM, \( M_{\text{BH}}, \) or \( L/L_{\text{Edd}} \) are probably secondary effects of the stronger (thus presumably intrinsic) correlation with \( L_{\text{5100}} \), while the correlations of the velocity shifts and EW(core) with broad-H\textsc{ii} FWHM, \( L_{\text{5100}} \), or \( M_{\text{BH}} \) are secondary effects of that with \( L/L_{\text{Edd}} \). This is probably given that there are additional systematic uncertainties plaguing the estimated values of \( L/L_{\text{Edd}} \). One effect is the large uncertainties in virial black hole masses, which can be a factor of four (1\( \sigma \)) statistically, and perhaps as large as an order of magnitude for individual estimates (Vestergaard & Peterson 2006; Wang et al. 2009). Another uncertainty comes from the bolometric correction assumed for \( L_{\text{5100}} \), which is definitely an oversimplification given the diverse spectral energy distributions of AGNs (Ho 2008; Vasudevan & Fabian 2009; Grupe et al. 2010). Yet, since the above bivariate correlations of [O\textsc{iii}] properties with \( L_{\text{5100}}, M_{\text{BH}}, \) and \( L/L_{\text{Edd}} \) are not strong, being weaker than the \( \Delta \nu(\text{centroid})–\text{EW(core)} \) relationship and much weaker even than the interdependence among the AGN parameters, we refrain from an overdiscussion on this issue at present. The weakness of those correlations either reflects true scatters that are caused by multiple (and somehow independent) processes and are thus irreducible, or suggests that there are other dominant variable(s) yet to be identified (see the discussions on various possible physical variables/processes in
Baskin & Laor 2005b, Risaliti et al. 2011, and Caccianiga & Severgnini 2011).

4.2. The Velocity Shift–EW(Core) Connection

The fairly tight anti–correlation between the blueshifts and the EW of the core component appears more notable than the weak correlations with fundamental AGN properties. Interestingly, as analyzed in Section 3.1, this pattern is just like the situation for the broad C iv λ1549 emission line (Richards et al. 2002, 2010; Bachev et al. 2004), which has already been noted by some researchers (e.g., Zamanov et al. 2002). This suggests that both the blueshifting phenomenon and the classical Baldwin effect are tightly linked (Corbin 1991, 1992). Note that the classical Baldwin effect only concerns the core component. The wing component can even show an inverse Baldwin effect—the higher the AGN luminosity, the larger the EW of the wing component. This is similar to the situation of C iv λ1549 (Richards et al. 2010; Wang et al. 2011).

In light of the remarkable similarity in the velocity shift–EW connection between [O iii] and C iv, Occam’s razor would suggest that the mechanism producing the two correlations is the same. A wind has been proposed as the cause of the C iv blueshifting (Gaskell 1982) and the correlations discussed above seem to be consistent with a scenario where the core of [O iii] comes from the canonical extended NLR where the gas motions are dominated by the gravity of the bulge stars while the wing component arises from an outflow. This has been discussed by many authors (see Zamanov et al. 2002; Baskin & Laor 2005a; Richards et al. 2010; Wang et al. 2011 for details). In this model the “blue outliers” could just be extremes; presumably a higher relative accretion rate drives a stronger outflow.

As pointed out in Section 4.1, the large object-to-object variation in the strength of [O iii] emission and the blueshift–EW(core) connection are not governed primarily by any fundamental AGN parameters such as L5100, M BH, and L/L Edd. It is likely that it is the ISM conditions of the host galaxies that mainly determine the diversity of the [O iii] properties in active galaxies (particularly its strength; see Netzer et al. 2004). In the outflow scenario, it is natural to assume that the ISM gives rise to [O iii] emission and decelerates the outflow. Although AGN activity determines the launching speed of the outflow, the final speed of the outflow depends on the density and density profile of the ISM. Meanwhile, the density and the density profile also constrain the amount of [O iii]-emitting gas and its emissivity. At the same AGN activity level, denser ISM will produce more [O iii] emission while decelerating the outflow efficiently, leading to higher EW and lower velocity. On the other hand, the similar blueshift–EW relationship in C iv may be linked to the shape of the ionizing continuum (Richards et al. 2010). So it is possible that the above two factors work together to produce the blueshift–EW(core) connection.

Yet we should also mention that, while the outflow scenario is attractive, there seem to be problems. For instance, the outflow explanation for the blueshifting of C iv (Gaskell 1982) clashes head on with the BLR kinematics implied by velocity-resolved reverberation mapping. Velocity-resolved kinematics have long favored gravitationally dominated motions (Gaskell 1988, 2009b, 2010b; Koratkar & Gaskell 1989, 1991) and apparent cases of outflow are unlikely to be real but are instead probably the result of off-axis variability (Gaskell 2010a). Gaskell & Goosmann (2008) have proposed instead that the blueshifting is the result of scattering off material with a slight net inflo. This naturally explains the correlation of blueshifting with accretion rate. If the NLR and BLR blueshiftings have a similar cause, the blueshifting of [O iii] also might be caused by scattering, as has been proposed by Gaskell & Goosmann (2008).

Finally, we note that while all the AGNs with large blueshifts have a high Eddington ratio, the reverse is not true (see also Komossa et al. 2008). Again, this is very similar to the situation for broad C iv λ1549 (Baskin & Laor 2005a). Here we must stress once again (see Section 4.1) that the correlations between velocity shift and any fundamental AGN parameter such as nuclear luminosity, black hole mass, and the Eddington ratio are not strong (see also Boroson 2005; Komossa et al. 2008). Thus it is not clear if the velocity shift–EW(core) connection for [O iii] λ5007 can be reduced to the effect of a specific underlying physical process of the AGN activity. Anyway, whatever the cause(s) of the blueshifting of high-ionization NLR and BLR lines, the correlations discussed here provide further support for an intimate connection between the NLR and the BLR.

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REFERENCES

Adelman-McCarthy, J. K., et al. 2006, ApJS, 162, 38
Bachev, R., Marziani, P., Sulentic, J. W., Zamanov, R., Calvani, M., & Dultzin-Hacyan, D. 2004, ApJ, 617, 171
Baldwin, J. A. 1977, ApJ, 214, 679
Baldwin, J. A., Burke, W. L., Gaskell, C. M., & Wampler, E. J. 1978, Nature, 273, 431
Baskin, A., & Laor, A. 2005a, MNRAS, 356, 1029
Baskin, A., & Laor, A. 2005b, MNRAS, 358, 1043
Becker, R. H., White, R. L., & Helfand, D. J. 1995, ApJ, 450, 559
Bentz, M. C., et al. 2009, ApJ, 705, 199
Boroson, T. 2005, AJ, 130, 381
Boroson, T. A., & Green, R. F. 1992, ApJS, 80, 109
Caccianiga, A., & Severgnini, P. 2011, MNRAS, 415, 1928
Collin, S., Kawaguchi, T., Peterson, B. M., & Vestergaard, M. 2006, A&A, 456, 75
Corbin, M. R. 1990, ApJ, 357, 346
Corbin, M. R. 1991, ApJ, 371, L51
Corbin, M. R. 1992, ApJ, 391, 577
Crenshaw, D. M., Schmitt, H. R., Kraemer, S. B., Mushotzky, R. F., & Dunn, J. T. 2010, ApJ, 708, 419
Das, V., Crenshaw, D. M., Kraemer, S. B., & Deo, R. P. 2006, AJ, 132, 620
Dietrich, M., Hamann, F., Shields, J. C., Constantin, A., Vestergaard, M., Chaffee, F., Foltz, C. B., & Junkkarinen, V. T. 2002, ApJ, 581, 912
Dong, X.-B., Ho, L. C., Wang, J.-G., Wang, T.-G., Wang, H., Fan, X., & Zhou, H. 2010, ApJ, 721, L143
Dong, X.-B., Wang, J.-G., Ho, L. C., Wang, T., Fan, X., Wang, H., Zhou, H., & Yuan, W. 2011, ApJ, 736, 86
Dong, X.-B., Wang, J.-G., Wang, T.-G., Wang, H., Fan, X., Zhou, H., Yuan, W., & Long, Q. 2009a, in ASP Conf. Ser. 408, The Starburst-AGN Connection, ed. W. Wang et al. (San Francisco, CA: ASP), 83
