

## NARROW-LINE SEYFERT 1 GALAXIES AND THE $M_{\text{BH}}\text{-}\sigma$ RELATION

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Received 2007 June 18; accepted 2007 July 31; published 2007 September 4

### ABSTRACT

We have studied the location of narrow-line Seyfert 1 (NLS1) galaxies and broad-line Seyfert 1 (BLS1) galaxies on the  $M_{\text{BH}}\text{-}\sigma$  relation of nonactive galaxies. We find that NLS1 galaxies as a class—as well as the BLS1 galaxies of our comparison sample—do follow the  $M_{\text{BH}}\text{-}\sigma$  relation of nonactive galaxies if we use the width of the [S II]  $\lambda\lambda 6716, 6731$  emission lines as a surrogate for stellar velocity dispersion,  $\sigma_*$ . We also find that the width of [O III]  $\lambda 5007$  is a good surrogate for  $\sigma_*$ , but only after (1) removal of asymmetric blue wings and, more importantly, after (2) excluding core [O III] lines with strong blueshifts (i.e., excluding galaxies which have their [O III] velocity fields dominated by radial motions, presumably outflows). The same galaxies which are extreme outliers in [O III] still follow the  $M_{\text{BH}}\text{-}\sigma$  relation in [S II]. We systematically investigate the influence of several parameters on the NLS1 galaxies' location on the  $M_{\text{BH}}\text{-}\sigma$  plane: [O III]<sub>core</sub> blueshift,  $L/L_{\text{Edd}}$ , intensity ratio Fe II/H $\beta$ , NLR density, and absolute magnitude. Implications for NLS1 models and for their evolution along the  $M_{\text{BH}}\text{-}\sigma$  relation are discussed.

*Subject headings:* galaxies: active — galaxies: bulges — galaxies: evolution — quasars: emission lines

### 1. INTRODUCTION

Correlations between the properties of galaxies and the masses of their central black holes are of fundamental importance for our understanding of galaxy formation and evolution. The relations between black hole mass and bulge stellar velocity dispersion,  $M_{\text{BH}}\text{-}\sigma_*$  (Ferrarese & Merritt 2000; Gebhardt et al. 2000; Merritt & Ferrarese 2001), and between black hole mass and bulge mass (Marconi & Hunt 2003; Häring & Rix 2004) imply a close link between black hole and bulge formation and growth (e.g., Haehnelt & Kauffmann 2000).

Mathur et al. (2001) emphasized the importance of studying the locus of NLS1 galaxies on the  $M_{\text{BH}}\text{-}\sigma$  plane. NLS1s are a subclass of active galactic nuclei (AGNs) characterized by small widths of their broad Balmer lines (e.g., Veron-Cetty et al. 2001). They are believed to have low-mass black holes (BHs) accreting close to the Eddington limit (e.g., Boroson 2002). As such, they are an “extreme” class of AGNs in the local universe, potentially holding important clues as to the origin of the  $M_{\text{BH}}\text{-}\sigma$  relation (see § 1 of Li et al. 2007 for a review on models), and whether it holds at all times and for all types of galaxies, and at low BH masses.

However, previous studies of NLS1 galaxies, employing different samples and methods, led to partially conflicting results regarding the galaxies' location on the  $M_{\text{BH}}\text{-}\sigma$  relation. When using the width of the narrow [O III]  $\lambda 5007$  emission line,  $\text{FWHM}_{[\text{O III}]}$ , as a replacement for stellar velocity dispersion  $\sigma_*$ , most authors found that, on average, NLS1 galaxies are off the  $M_{\text{BH}}\text{-}\sigma_{[\text{O III}]}$  relation (Mathur et al. 2001; Grupe & Mathur 2004; Mathur & Grupe 2005a, 2005b; Bian et al. 2006; Watson et al. 2007), while in the study of Wang & Lu (2001) most NLS1s are, on average, on the relation (with a significant scatter in all cases). Furthermore, NLS1 galaxies were found to be off (Wandel 2002; Ryan et al. 2007) or on (Botte et al. 2004) the black hole mass–bulge luminosity,  $M_{\text{BH}}\text{-}L_{\text{bulge}}$ , relation; and on (Botte et al. 2005; Barth et al. 2005) or off (Zhou et al. 2006) the  $M_{\text{BH}}\text{-}\sigma_*$  relation. Most larger samples are actually based on  $\text{FWHM}_{[\text{O III}]} / 2.35$  as surrogate for  $\sigma_*$  (Nelson 2000), because the

bulge velocity dispersion  $\sigma_*$  is very difficult to measure in NLS1 galaxies due to superposed emission-line complexes.

Given the potentially far-reaching consequences of a deviation of low BH mass, highly accreting AGNs from the  $M_{\text{BH}}\text{-}\sigma$  relation, independent studies of large(r) samples of NLS1 galaxies are important. No matter whether they turn out to be on or off the  $M_{\text{BH}}\text{-}\sigma$  relation of nonactive galaxies and BLS1 galaxies, any result has important consequences: if NLS1s lie off the relation, for the formation of the  $M_{\text{BH}}\text{-}\sigma$  relation (how do objects move onto the relation?) and/or the gaseous kinematics of their NLRs. If they lie on the relation, the question is raised as to how to preserve  $M_{\text{BH}}\text{-}\sigma$  along the relation in objects which are rapidly growing their BHs but are typically in nonmerging galaxies (Krongold et al. 2001).

We have used an independent, large, homogeneously analyzed sample of NLS1 galaxies (55 objects) plus a comparison sample of BLS1 galaxies (39 objects), in order to study their locus on the  $M_{\text{BH}}\text{-}\sigma$  plane. We conclude that the width of the [S II] emission line, and of the narrow core of the [O III] line (but only after removal of [O III] lines with high blueshifts), are the best available surrogates for stellar velocity dispersion  $\sigma_*$ . Using these lines puts NLS1 galaxies (and BLS1 galaxies), as a class, on the  $M_{\text{BH}}\text{-}\sigma$  relation of nonactive galaxies. 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 SELECTION AND DATA ANALYSIS

We use the sample of NLS1 and BLS1 galaxies of Xu et al. (2007). Sample selection, data preparation, and data analysis methods are described in detail in that work. In brief: the sample consists of NLS1 galaxies from the catalog of Veron-Cetty & Veron (2003), plus a comparison sample of BLS1 galaxies from Boroson (2003) at  $z < 0.3$ , which have detectable ( $S/N > 5$ ) [S II] emission in their Sloan Digital Sky Survey (SDSS) DR3 (Abazajian et al. 2005) spectra. Xu et al. (2007) corrected the SDSS spectra for Galactic extinction, decomposed the continuum into stellar and AGN components, and then subtracted the stellar continuum contribution and the

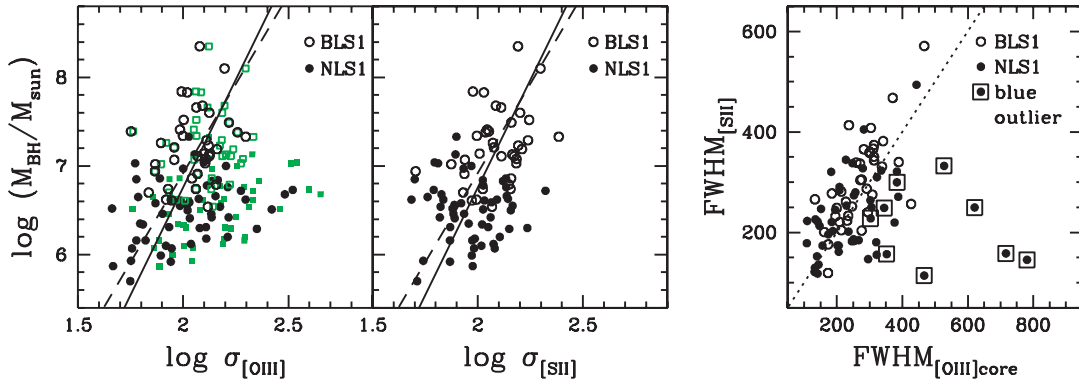


FIG. 1.—*Left panels:* Location of NLS1 galaxies (*filled symbols*) and BLS1 galaxies (*open symbols*) on the  $M_{\text{BH}}-\sigma_{[\text{O III}]}$  and  $M_{\text{BH}}-\sigma_{[\text{S II}]}$  plane, respectively. For [O III], black circles refer to measurements of the core of the line after correction for asymmetric blue wings, while green squares correspond to measurements of the full profile (as described in the text). The dashed and solid lines correspond to the  $M_{\text{BH}}-\sigma_*$  relation of nonactive galaxies of Tremaine et al. (2002) and of Ferrarese & Ford (2005), respectively. The quantities  $\sigma$  and FWHM are measured in  $\text{km s}^{-1}$ . *Right:* Correlation between the FWHM of [S II] and [O III]<sub>core</sub> (*dotted line*: one-to-one line for equal FWHMs; note the different scales of the  $x$ - and  $y$ -axes). Blue outliers in [O III]<sub>core</sub> ( $v_{[\text{O III}]}$  > 150  $\text{km s}^{-1}$ ) are marked with an extra open square.

Fe II complexes from the spectra. Emission lines were fit with Gaussian profiles.

Special attention was paid to [O III] profile shapes. The deviation of [O III] profiles from single Gaussians is well known, and NLS1 galaxies show strong blue wings particularly often (Boroson 2005 and references therein). We followed two approaches in measuring  $\text{FWHM}_{[\text{O III}]}$ : (1) determination of the total FWHM of the summed two-component Gaussian from a careful decomposition into a core and a blue wing component whenever present,  $\text{FWHM}_{[\text{O III}]_{\text{full}}}$ ; and (2) the FWHM of the core component of [O III],  $\text{FWHM}_{[\text{O III}]_{\text{core}}}$ . Emission lines other than [O III] are well represented by a single Gaussian. The lines [S II]  $\lambda\lambda 6716, 6731$  (hereafter referred to as [S II]) were both fit with the same width. We follow the standard procedure of using the radius ( $R_{\text{BLR}}$ )–luminosity ( $L$ ) relation of BLS1 galaxies (which appears to hold for NLS1 galaxies; Peterson et al. 2000) to compute BH masses, following Kaspi et al. (2005). We then compare our results with the  $M_{\text{BH}}-\sigma_*$  relation of Tremaine et al. (2002, their eqs. [1] and [19]) and of Ferrarese & Ford (2005, hereafter FF05; their eq. [20]). An error in black hole mass of 0.5 dex (as in Grupe & Mathur 2004) was conservatively assumed. Formal measurement errors in FWHM are typically 5%–20%.

We note that all SDSS observations of our sample include emission from the entire NLR (so we are not systematically excluding the outer parts of the NLR in the nearest objects). At the lowest redshift in our sample,  $z = 0.034$ , an SDSS fiber diameter of  $3''$  corresponds to 2 kpc, larger than typical NLRs.

### 3. RESULTS

We investigated how the following factors affect the galaxies’ location on the  $M_{\text{BH}}-\sigma$  plane: (1) different methods of fitting the [O III] profile; (2) the use of other emission lines as surrogates for  $\sigma_*$ ; and (3) the influence of other parameters, such as [O III] blueshift and  $L/L_{\text{Edd}}$ .

#### 3.1. NLS1 Galaxies on the $M_{\text{BH}}-\sigma_{[\text{O III}]}$ Plane

First, we confirm that NLS1 galaxies as a class deviate from the  $M_{\text{BH}}-\sigma$  relation of nonactive galaxies if we use the full profile of [O III] to measure  $\sigma$  (Fig. 1). We computed the deviation  $\Delta\sigma \equiv \log \sigma_{\text{obs}} - \log \sigma_{\text{pred}}$  of the NLS1 and BLS1 galaxies from

the FF05 relation. Applying a Kolmogorov-Smirnov (K-S) test shows that the two samples are drawn from different parent distributions (K-S probability of being drawn from the same population: 0.002). NLS1 galaxies follow the  $M_{\text{BH}}-\sigma$  relation much better if only the narrow core of [O III] is used to measure  $\sigma$  (Fig. 1). However, there are still a number of NLS1 galaxies with very broad [O III] profiles and these lie systematically below the  $M_{\text{BH}}-\sigma$  relation. In § 3.3 we identify the cause of this. We show that the majority of these “[O III] outliers” are characterized by high NLR outflow velocities, and therefore, their velocity fields are not dominated by the bulge potential and their line widths cannot be used as surrogates for  $\sigma_*$ .

#### 3.2. Widths of Other NLR Lines as Surrogate for $\sigma_*$

The strongest (high ionization) emission line in AGN spectra is [O III]  $\lambda 5007$ , which is commonly used for  $\sigma$  estimates. Because of its strength, we are able to decompose the line into a core and blue wing. Low-ionization emission lines generally do not show this spectral complexity, and we therefore also consider using their widths as surrogates for  $\sigma_*$ . The strongest lines in the commonly available wavelength range between  $\sim 4000$  and  $7000 \text{ \AA}$  are [N II]  $\lambda\lambda 6584, 6548$ ; [S II]; and [O I]  $\lambda 6300$ . [N II] is, however, blended with  $\text{H}\alpha$  except in high-resolution spectra (see Zhou et al. 2006 for the use of  $\sigma_{[\text{N II}]}$  as a surrogate for  $\sigma_*$ ). We focus on [S II] here, which is detected in all galaxies of our sample. As shown by Greene & Ho (2005),  $\sigma_{[\text{S II}]}$  is indeed a good substitute for  $\sigma_*$  in Seyfert 2 galaxies.

Using the width of [S II] as a surrogate for  $\sigma_*$ , NLS1 galaxies as a class are now on the  $M_{\text{BH}}-\sigma$  relation (Fig. 1). Repeating the K-S test on the  $\Delta\sigma$  distribution of NLS1 and BLS1 galaxies (Fig. 3) shows that the two samples are consistent with being drawn from the same parent distribution (K-S probability of 0.4). We note that the FWHMs of [S II] and [O III]<sub>core</sub> correlate well with each other (after removal of “blue outliers”; § 3.3), demonstrating that both emission lines trace similar NLR velocity fields (Fig. 1). Only 40% of the NLS1 galaxies of our sample have [O I] detected. The scatter in  $\sigma_{[\text{O I}]}$  is relatively small and most galaxies are close to the FF05 relation, except two outliers with large  $\sigma_{[\text{O I}]}$ .

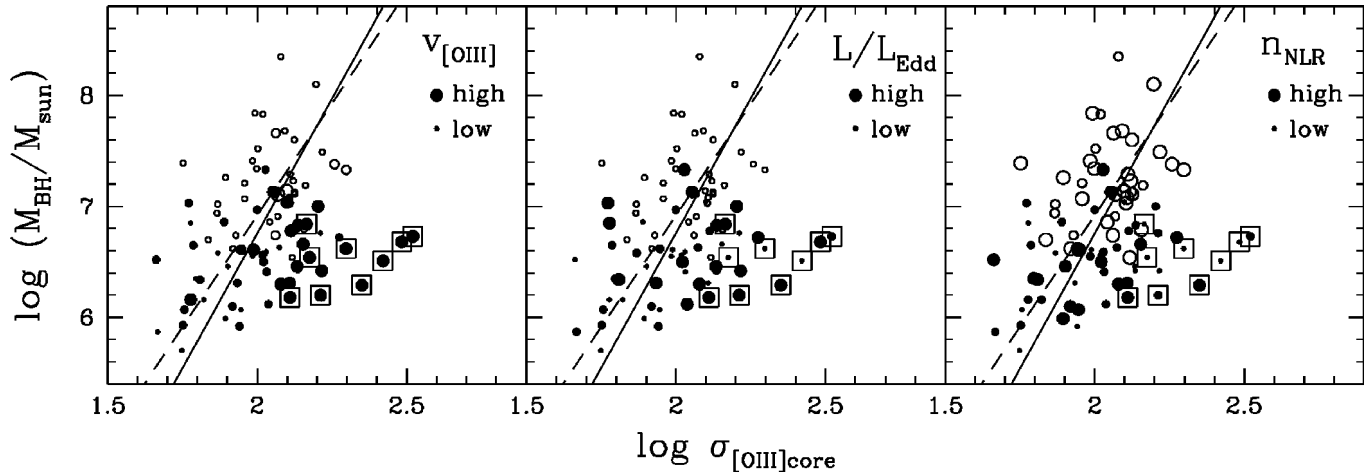


FIG. 2.—Influence of different parameters on the galaxies’ positions on the  $M_{\text{BH}}-\sigma_{[\text{O III}]_{\text{core}}}$  plane (open circles, BLS1 galaxies; filled circles, NLS1 galaxies). Each parameter is divided into three bins and coded by circle size: *small circles*, low value; *medium circles*, intermediate value; *large circles*, high value. Left to right: Coding according to  $[\text{O III}]_{\text{core}}$  blueshift ( $v_{[\text{O III}]}$  < 30 km s<sup>-1</sup>, 30–75 km s<sup>-1</sup>, >75 km s<sup>-1</sup> in lowest, intermediate, and highest velocity bin, respectively),  $L/L_{\text{Edd}}$  (<0.6, 0.6–0.9, >0.9), and NLR density (<140 cm<sup>-3</sup>, 140–240 cm<sup>-3</sup>, >240 cm<sup>-3</sup>). Blue outliers in  $[\text{O III}]_{\text{core}}$  are marked with an extra open square.

### 3.3. Influence of Several Parameters on the Galaxies’ Location on the $M_{\text{BH}}-\sigma$ Plane

We investigated the influence of several quantities— $[\text{O III}]_{\text{core}}$  blueshift,  $L/L_{\text{Edd}}$ , intensity ratio  $\text{Fe II } \lambda 4570/\text{H}\beta$ , NLR density, and absolute magnitude—on the galaxies’ location on the  $M_{\text{BH}}-\sigma$  plane. We divided each of these parameters into three bins—low values, intermediate values, and high values—such that about equal numbers of NLS1 galaxies fell in each bin. We measured the velocity shift of  $[\text{O III}]_{\text{core}}$ ,  $v_{[\text{O III}]}$ , relative to  $[\text{S II}]$  (we use positive velocity values for blueshifts).  $L_{\text{Edd}}$  was derived from the black hole mass, according to  $L_{\text{Edd}} = 1.3 \times 10^{38} M_{\text{BH}}/M_{\odot} \text{ ergs s}^{-1}$ . The bolometric luminosity  $L_{\text{bol}}$  was estimated from the luminosity at 5100 Å,  $L_{5100}$ , and a bolometric correction of  $L_{\text{bol}} = 9\lambda L_{5100}$ . The NLR density was derived from the density-sensitive  $[\text{S II}]$  intensity ratio,  $[\text{S II}] \lambda 6716/[\text{S II}] \lambda 6731$  (Xu et al. 2007), and the absolute magnitude from the SDSS  $i$ -band magnitude. Our aim is to search for trends across the  $M_{\text{BH}}-\sigma$  plane in order to see whether we can identify physical mechanisms that determine an object’s location on the plane and, in particular, that are responsible for the  $[\text{O III}]$  outliers.

First, we find that almost all outliers in  $\sigma_{[\text{O III}]}$  actually show a very high blueshift of  $[\text{O III}]_{\text{core}}$  with a velocity shift  $v_{[\text{O III}]}$  > 150 km s<sup>-1</sup> (hereafter referred to as “blue outliers” [Zamanov et al. 2002]; marked in Fig. 2). More generally, we find the trend across the  $M_{\text{BH}}-\sigma_{[\text{O III}]}$  plane that  $[\text{O III}]$  lines of higher  $\sigma$  also show higher outflow velocity, revealing the presence of an extra radial velocity field presumably due to outflows. Among the galaxies with positive  $\Delta\sigma$  (those below the FF05 relation), 49% are in the highest velocity bin, while only 26% are in the lowest bin. However, if we exclude all galaxies with  $\sigma_{[\text{O III}]}$  in the highest bin ( $v_{[\text{O III}]}$  > 75 km s<sup>-1</sup>), NLS1 and BLS1 galaxies show similar scatter and agree with the  $M_{\text{BH}}-\sigma$  relation of normal galaxies (Fig. 3; the K-S test shows that the two samples are not statistically distinguishable with K-S probability 0.5). We have checked that  $[\text{S II}]$  is *not* systematically influenced by the outflow components that appear in  $[\text{O III}]_{\text{core}}$ . NLS1 galaxies with blue outliers in  $[\text{O III}]_{\text{core}}$  are uniformly distributed across the  $M_{\text{BH}}-\sigma$  plane in  $[\text{S II}]$ .

In order to see whether other parameters affect an object’s location on the  $M_{\text{BH}}-\sigma_{[\text{O III}]}$  plane (Fig. 2), we first removed all objects with the highest  $[\text{O III}]$  outflow velocities ( $v_{[\text{O III}]}$  > 75

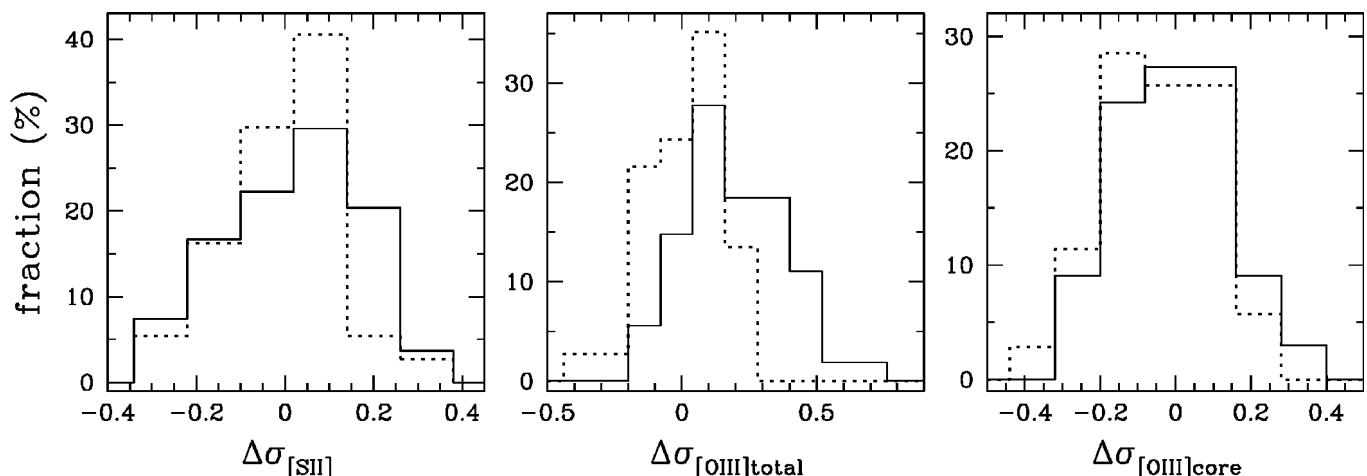


FIG. 3.—Histograms of the deviation  $\Delta\sigma \equiv \log \sigma_{\text{obs}} - \log \sigma_{\text{pred}}$  of galaxies from the  $M_{\text{BH}}-\sigma$  relation of FF05 (solid line, NLS1 galaxies; dotted line, BLS1 galaxies) for  $[\text{O III}]_{\text{core}}$  (after excluding objects in the highest velocity bin),  $[\text{O III}]_{\text{tot}}$ , and  $[\text{S II}]$  (right to left).

km s<sup>-1</sup>), and then studied the correlation of each parameter with the object's deviation from the FF05 relation, measured in terms of  $\Delta\sigma$ . We cannot identify a strong dependence of  $\Delta\sigma$  on  $L/L_{\text{Edd}}$  (Spearman rank correlation coefficient  $r_s = 0.10$ ),<sup>1</sup> Fe II  $\lambda 4570/H\beta$  ( $r_s = 0.05$ ), and density ( $r_s = -0.01$ ). However, if we keep all objects with high blueshifts,  $L/L_{\text{Edd}}$  and  $\Delta\sigma$  are correlated ( $r_s = 0.34$ ). Galaxies with higher absolute magnitudes  $M_i$  are, on average, located at higher BH masses, as expected, but there is no systematic trend horizontally across the plane.

#### 4. DISCUSSION AND CONCLUSIONS

We confirm the well-known result (e.g., Grupe 2004) that NLS1 galaxies have, on average, lower BH masses than BLS1 galaxies (in our sample, masses are in the range  $\log M_{\text{BH,NLS1}} = 5.7\text{--}7.3 M_{\odot}$ , while  $\log M_{\text{BH,BLS1}} = 6.5\text{--}8.4 M_{\odot}$ ). We further confirm that NLS1s are off the  $M_{\text{BH}}\text{--}\sigma$  relation when  $[\text{O III}]_{\text{tot}}$  is used as surrogate for  $\sigma_*$ , and that—after removing blue wings— $[\text{O III}]_{\text{core}}$  gives more consistent results. However, after correction for blue wings several blue outliers still stick out with very large  $\sigma$ -values. If these were to reach the  $M_{\text{BH}}\text{--}\sigma_*$  relation moving vertically on the  $M_{\text{BH}}\text{--}\sigma$  plane by growing their black holes, they would have to increase their current BH masses by factors  $>100$ , and become more massive than the most massive BHs in the BLS1 comparison sample. Instead, the fact that all show high outflow velocities in  $[\text{O III}]_{\text{core}}$  demonstrates that the properties of the NLR (unusual outflows in the high-ionization NLR) drive the deviation of these NLS1 galaxies from the  $M_{\text{BH}}\text{--}\sigma$  relation. Those galaxies which are extreme outliers in  $[\text{O III}]$  still follow the  $M_{\text{BH}}\text{--}\sigma$  relation in  $[\text{S II}]$ .

There is good evidence that many NLS1 galaxies are accreting at a high rate relative to the Eddington rate (even if not as high as in high-redshift quasars; Warner et al. 2004), so, as emphasized by Mathur & Grupe (2005a, 2005b), their BHs

<sup>1</sup> Note that this does not imply an inconsistency with Mathur & Grupe (2005a, 2005b), since their (*soft* X-ray selected) sample includes a significant number of NLS1 galaxies with very high  $L/L_{\text{Edd}}$ , above the highest value in our sample.

must be rapidly growing. Since we find that they are on the  $M_{\text{BH}}\text{--}\sigma$  relation now, their tracks on the  $M_{\text{BH}}\text{--}\sigma$  plane must be diagonal, or else they would deviate in the future. We distinguish two possibilities: (1) NLS1 galaxies as a class *evolve* into BLS1 galaxies with respect to their BH mass distribution. Then, on average, the BHs of NLS1 galaxies have to grow by a factor  $\sim 10$ . If accreting at  $L/L_{\text{Edd}} = 1.0$  this would take them  $10^8$  years. If they did so, a corresponding change in  $\sigma_*$  of the bulge of the host galaxy is required in order to ensure that the  $M_{\text{BH}}\text{--}\sigma_*$  relation still holds. Recent host galaxy studies of NLS1s indicate that they are not preferentially merging systems (Krongold et al. 2001; Ryan et al. 2007), but have a relatively high bar fraction (Crenshaw et al. 2003; Ohta et al. 2007). In that case, some secular mechanism must be at work to adjust the bulge properties. At this stage, we can only speculate that some of the feedback mechanisms (Silk & Rees 1998) studied in the context of merger-induced BH fueling (e.g., di Matteo et al. 2005; King 2005) also hold for bar-induced fueling. Alternatively, (2) the NLS1 mass distribution does *not* evolve into the BLS1 mass distribution. In this picture, NLS1s are simply low-mass extensions of the BLS1 phenomenon (e.g., McHardy et al. 2006). In that case, the high  $L/L_{\text{Edd}}$  values could just represent a relatively *short-lived* accretion phase which would only insignificantly grow their BHs. Then, within the large scatter of  $\sigma$ , no adjustment of the host's bulge would be needed. Sources with relatively low  $L/L_{\text{Edd}}$  could be before or after an accretion event.

In summary, we conclude that the NLS1 and BLS1 galaxies of our sample, as a class, follow the  $M_{\text{BH}}\text{--}\sigma_*$  relation if we use as a surrogate for  $\sigma_*$  the widths of emission lines which are not strongly affected by outflow components ( $[\text{S II}]$ , or  $[\text{O III}]_{\text{core}}$  after removing galaxies with high outflow velocities  $v_{[\text{O III}]}$ ). Further studies of the evolution of highly accreting AGNs along the  $M_{\text{BH}}\text{--}\sigma_*$  relation will shed new light on the evolution of galaxies in general and NLS1s in particular.

We thank D. Merritt, H. Zhou, I. Strateva, S. Mathur, D. Grupe, A. Robinson, and G. Hasinger for discussions. D. X. acknowledges support under grant NSFC-10503005.

#### REFERENCES

- Abazajian, K., et al. 2005, *AJ*, 129, 1755  
 Barth, A. J., Greene, J. E., & Ho, L. C. 2005, *ApJ*, 619, L151  
 Bian, W., Yuan, Q., & Zhao, Y. 2006, *MNRAS*, 367, 860  
 Boroson, T. A. 2002, *ApJ*, 565, 78  
 ———. 2003, *ApJ*, 585, 647  
 ———. 2005, *AJ*, 130, 381  
 Botte, V., et al. 2004, *AJ*, 127, 3168  
 ———. 2005, *MNRAS*, 356, 789  
 Crenshaw, D. M., Kraemer, S. B., & Gabel, J. R. 2003, *AJ*, 126, 1690  
 di Matteo, T., Springel, V., & Hernquist, L. 2005, *Nature*, 433, 604  
 Ferrarese, L., & Ford, H. 2005, *Space Sci. Rev.*, 116, 523  
 Ferrarese, L., & Merritt, D. 2000, *ApJ*, 539, L9  
 Gebhardt, K., et al. 2000, *ApJ*, 539, L13  
 Greene, J. E., & Ho, L. C. 2005, *ApJ*, 627, 721  
 Grupe, D. 2004, *AJ*, 127, 1799  
 Grupe, D., & Mathur, S. 2004, *ApJ*, 606, L41  
 Haehnelt, M., & Kauffmann, G. 2000, *MNRAS*, 318, L35  
 Häring, N., & Rix, H.-W. 2004, *ApJ*, 604, L89  
 Kaspi, S., et al. 2005, *ApJ*, 629, 61  
 King, A. 2005, *ApJ*, 635, L121  
 Krongold, Y., et al. 2001, *AJ*, 121, 702  
 Li, Y., Haiman, Z., & Mac Low, M.-M. 2007, *ApJ*, 663, 61  
 Marconi, A., & Hunt, L. K. 2003, *ApJ*, 589, L21  
 Mathur, S., & Grupe, D. 2005a, *ApJ*, 633, 688  
 ———. 2005b, *A&A*, 432, 463  
 Mathur, S., Kuraszkiewicz, J., & Czerny, B. 2001, *NewA*, 6, 321  
 McHardy, I. M., et al. 2006, *Nature*, 444, 730  
 Merritt, D., & Ferrarese, L. 2001, *ApJ*, 547, 140  
 Nelson, C. H. 2000, *ApJ*, 544, L91  
 Ohta, Y., et al. 2007, *ApJS*, 169, 1  
 Peterson, B. M., et al. 2000, *ApJ*, 542, 161  
 Ryan, C. J., et al. 2007, *ApJ*, 654, 799  
 Silk, J., & Rees, M. 1998, *A&A*, 331, L1  
 Tremaine, S., et al. 2002, *ApJ*, 574, 740  
 Veron-Cetty, M. P., & Veron, P. 2003, *A&A*, 412, 399  
 Veron-Cetty, M. P., et al. 2001, *A&A*, 372, 730  
 Wandel, A. 2002, *ApJ*, 565, 762  
 Wang, T., & Lu, Y. 2001, *A&A*, 377, 52  
 Warner, C., Hamann, F., & Dietrich, M. 2004, *ApJ*, 608, 136  
 Watson, L., Mathur, S., & Grupe, D. 2007, *AJ*, 133, 2435  
 Xu, D., Komossa, S., Zhou, H., Wang, T., & Wei, J. 2007, *ApJ*, in press (arXiv:0706.2574)  
 Zamanov, R., et al. 2002, *ApJ*, 576, L9  
 Zhou, H.-Y., et al. 2006, *ApJS*, 166, 128