The sizes of BLRs and BH masses of double-peaked broad low-ionization emission line objects

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ABSTRACT

In this paper, the sizes of the BLRs and BH masses of Double-Peaked broad low-ionization emission line emitters (dbp emitters) are compared using different methods: virial BH masses vs BH masses from stellar velocity dispersions, the size of BLRs from the continuum luminosity vs the size of BLRs from the accretion disk model. First, the virial BH masses of dbp emitters estimated by the continuum luminosity and line width of broad H$\beta$ are about six times (a much larger value, if including another dbp emitters, of which the stellar velocity dispersions are traced by the line widths of narrow emission lines) larger than the BH masses estimated from the relation $M_{BH} - \sigma$ which is a more accurate relation to estimate BH masses. Second, the sizes of the BLRs of dbp emitters estimated by the empirical relation of $R_{BLR} - L_{5100}$ are about three times (a much larger value, if including another dbp emitters, of which the stellar velocity dispersions are traced by the line widths of narrow emission lines) larger than the mean flux-weighted sizes of BLRs of dbp emitters estimated by the accretion disk model. The higher electron density of BLRs of dbp emitters would be the main reason which leads to smaller size of BLRs than the predicted value from the continuum luminosity.

Key words: Galaxies:Active – galaxies:nuclei – accretion disk

1 INTRODUCTION

How to measure the black hole (BH) masses of Active Galactic Nuclei (AGN) is an intriguing research subject. The masses of the central black hole in nearby galaxies can be estimated by kinematic studies of nuclear gas disks (Harms et al. 1994, Tsvetanov et al. 1998, Ford et al. 1994, Gebhardt et al. 2000b) or dynamical studies of stars in galactic centers (Gebhardt & Richstone 2000, Bower et al. 2000), using high spatial resolution data (Gebhardt et al. 2003). However, because of higher luminosity and larger distance, these two methods are non-effective for AGN. Thus, there are many efforts to find effective ways to estimate the masses of central black hole of AGN. The most successful and convenient way is under the assumption of virialization, $M_{BH} \sim v^2 R_{BLR}$. The size of Broad Emission Line Regions (BLRs, $R_{BLR}$) can be estimated through the empirical relation between continuum luminosity and the size of BLRs (Kaspi et al. 2000, 2005, Peterson et al. 2004, Wandel et al. 1999), according to the results of reverberation mapping technique (Blandford & Mckee 1982; Peterson 1993; Netzer & Peterson 1997). Throughout this paper we shall use the term 'size of BLRs' as equivalent of distance of the BLRs to the central source. The velocity $v$ can be estimated by the line width of broad low-ionization emission lines coming from BLRs, assuming motions of the BLRs clouds are gravitationally dominated by the central mass of the host galaxy (Gaskell 1988, Wandel et al. 1999, Peterson & Wandel 1999, Gaskell 1996). Using these methods, BH masses have been determined for a large number of AGN. From BH masses, other fundamental parameters of AGN, such as the dimensionless accretion rate $\dot{m}$, can be estimated. Thus, the nature of AGN can be understood better.

The empirical relation between $R_{BLR}$ and continuum luminosity $L_{5100}$ has been studied for several years, since it was found by Kaspi et al. (2000) and Wandel et al. (1999). More and more evidence indicates that the assumption of virialization combined with the empirical relation of $R_{BLR} - L_{5100}$ is a better method to estimate the BH masses of AGN (Ovcharov et al. 2005, Wu et al. 2004, McLure & Jarvis 2004, 2002, Marziani et al. 2003), although there are few inconsistencies of the reverberation Mapping technique (Maoz 1996). Recently, the method was used to estimate the BH masses for high redshift AGN (Dietrich & Hamann 2004;
Brotherton & Scoggins 2004; McLure & Jarvis 2002). However, there is an answered question: can the empirical relation between $R_{BLR}$ and continuum luminosity $L_{5100\AA}$ be applied to any type of AGN. Wang & Zhang (2003) have found that the size of BLRs of dwarf Active Galaxies (luminosity of Hα less than $10^{41}$ erg s$^{-1}$, Ho et al. 1997a, 1997b, Maoz 1999) is not consistent with the value from the empirical relation $R_{BLR} \sim L_{5100\AA}^{0.4}$ (new results about dwarf AGN can be found in Zhang, Dultzin-Hacyan & Wang 2007a). Perhaps, we need more tests to verify whether the empirical relation can be applied to some special types of AGN, for which the sizes of BLRs can be estimated by other methods.

There is a special kind of AGN with Double-Peaked broad low-ionization emission lines (hereafter, dbp emitters) originated from the accretion disk near the central black hole. The most famous dbp emitters are those selected from radio galaxies (Eracleous & Halpern 1994, 2003, Karas et al. 2001). There are now two samples of dbp emitters, one includes 23 objects which are nearly all LINERs selected from SDSS DR2 (York et al. 2000). The other four dbp emitters with stellar velocity dispersions measured are SDSS J142314.19+505537.4, SDSS J083225.34+370736.2 and SDSS J144302.76+520137.2. Thus, the line width of narrow emission lines can be measured accurately from SDSS spectra. In Table 1, the first column gives the name of the object, the second column gives the stellar velocity dispersion in units of km s$^{-1}$, the third column lists the logarithmic BH masses in units of $M_\odot$ from the empirical relation $M_{BH} \sim \sigma^{4.02}$, the forth column gives the size of BLRs in units of light-days from accretion disk model, the fifth column gives the continuum luminosity at 5100Å in units of erg s$^{-1}$, the sixth column gives the line width of broad emission lines in units of km s$^{-1}$, the seventh column gives the size of BLRs in units of light-days from the empirical relation $R_{BLR} \sim L_{5100\AA}^{0.4}$, the eighth column is the logarithmic virial BH masses in units of $M_\odot$ estimated under the assumption of virialization, the ninth column presents the power law index of the line emissivity for each object according to accretion disk model, the last column lists the references.

### 3 RESULTS

#### 3.1 Black Hole Masses

The most accurate way to estimate central BH masses is by kinematic or dynamics analysis. Using the results of some tens of nearby galaxies, a strongly tight relation between stellar velocity dispersion $\sigma$ and BH masses $M_{BH}(\sigma)$ has been found (Tremaine et al. 2002, Ferrarese & Merritt 2001, Gebhardt et al. 2000a):

$$M_{BH}(\sigma) = 10^{8.13 \pm 0.06} \times \left(\frac{\sigma}{200 \text{ km s}^{-1}}\right)^{4.02 \pm 0.32} M_\odot$$

which indicates a tight relation between the evolution of bulge and that of the central black hole in galaxies, which is further confirmed by the tight relation between central BH masses and the masses of bulge of the host galaxy (Haring & Rix 2004, Marconi & Hunt 2003, McLure & Dunlop 2002, Laor 2001, Kormendy 1999, Wandel 1999). Whether the relation $M_{BH} \sim \sigma^{4.02}$ can be applied for higher redshift, higher luminosity AGN or other types of AGN has been studied by Treu et al. (2004), Nelson et al. (2004), Treves et al. (2003), Falomo et al. (2002), Wang & Lu (2001) among others. These studies reach a similar conclusion that the empirical relation $M_{BH} \sim \sigma^{4.02}$ holds for all AGN. Thus, we first estimate the central BH masses using this relation. There are eight dbp emitters with stellar velocity dispersions measured from absorption properties. The other four dbp emitters are classified as QSOs in SDSS. It is difficult to measure the stellar velocity dispersion for QSOs. There are some other ways to estimate the central BH masses by physical parameters of bulge of the host galaxy, such as using the magnitude of the bulge (Mclure & Dunlop 2001, 2002), using the line width of narrow emission lines (Borson 2003, Greene & Ho 2005a). Here, we measure the line width of the core of [OII] doublet to trace the stellar velocity dispersion of the bulge.
There can be also a broad gaussian function for the extended asymmetric components of the [OIII] emission lines as described in Greene & Ho (2005a). The correlation between stellar velocity dispersion and line width of narrow emission lines has been studied by Greene & Ho (2005a) for a large sample of AGN selected from SDSS. For radio loud AGN, the line width of [OIII]λ5007Å is broader than that of other narrow emission lines, however the line width of the core of [OIII]λ5007Å can trace stellar velocity dispersion. Further, the line width of the core of [OIII]λ5007Å of the four objects in our sample is the same as that of the other narrow emission lines within the errors. Here we assume the uncertainty of the line width to trace the stellar velocity dispersion is about 40 percent (the value for high radio AGN in Greene & Ho 2005a). Once we obtain the central BH masses, the sizes of BLRs, $R_{BLR}(M)$, from accretion disk model can be translated from units of $R_{G}$ to units of light-days in order to compare with the values, $R_{BLR}(E)$, from the empirical relation $R_{BLR}(E) = L^\alpha_{5100\AA}$.

Furthermore, in order to compare the central BH masses estimated by different methods, the virial BH masses $M_{BH}(V)$ estimated under the assumption of virialization are also shown in Table 1:

$$\frac{R_{BLR}(E)}{\text{light-days}} = 22.3 \times \left(\frac{L_{5100\AA}}{10^{44}\text{erg s}^{-1}}\right)^{0.09}$$  \hspace{1cm} (2a)$$
$$M_{BH}(V) = f_{FWHM} \times \frac{R_{BLR}(E) \times FWHM_B^2}{G}$$  \hspace{1cm} (2b)$$

where $FWHM_B$ is the line width of broad H\textbeta, $f_{FWHM}$ is a scale factor which depends on the structure of BLRs. Here, we use the up-to-date empirical relation $R_{BLR} = L^{1/3}_{5100\AA}$ selected from Kaspi et al. (2005). However, we notice that there are several dbp emitters for which the continuum luminosities are less than $10^{42}\text{erg s}^{-1}$, which is out of the range of continuum luminosity of the sample of Kaspi et al. (2005). However, we have found that for low luminous AGN, the size of BLRs is somewhat larger than the predicted value from the empirical relation equation 2a (Wang & Zhang 2003; Zhang, Dultzin-Hacyan & Wang 2007a). Thus, the BH masses estimated from the above equations for objects with lower continuum luminosity are smaller than the expected virial BH masses.

Moreover, Collin et al. (2006) demonstrate that the scale factor $f$ depends on the line width of the broad emission lines, and this factor is much different from objects in Population A and Population B (Sulentic, Marziani & Dultzin-Hacyan 2000) and the inclination effects play a role in some cases. We can not get an accurate spectra for all the dbp emitters to determine the factor of $f$. Here, we use the mean factor $f_{DBP} = 5.5$ for the second moment of broad emission lines rather than the value of FWHM (Onken et al. 2004; Peterson et al. 2004). $M_{BH} = f_{DBP} \frac{R_{BLR}\beta \lambda}{G}$. We do not have enough information to get the mean/rms line spectra to determine the relation between FWHM(H\textbeta) and the second moment $\sigma_{H\beta}$. We commonly select the mean value of 1.87, $FWHM \sim 1.87\sigma$, of the famous dbp emitter 3C390.3 (the line widths and second moment of the emission lines can be found in Peterson et al. 2004). Last, we accept $f_{FWHM} \sim 1.56$ in equation 2b. Also, the values of $R_{BLR}(E)$ from equation 2a are shown in Table 1. Moreover, the continuum luminosity is the value after the subtraction of contributions of star light according to the starlight fraction in Eracleous & Halpen (1994, 2003). For the two dbp emitters, NGC 1097 and NGC 4450, not included in the paper of Eracleous & Halpern (1994, 2003), the continuum luminosities of the nucleus are estimated according to the absolute B magnitude of the featureless continuum of the nucleus from the paper of Ho et al. (2000).

Which parameters of double-peaked emission lines, FWHM, the second moment of the lines or other parameters, can be used to trace more accurately the velocity dispersion of BLRs is an open question. However, the main objective of this paper is to inspect whether the virial BH masses estimated by the line parameter FWHM are reliable. Thus the parameter, FWHM, is also selected from the paper of Strateva et al. (2003) and Eracleous & Halpern (1994, 2003) measured according to the definition of FWHM: the full width at half maximum. Another problem is the inclination angle of the accretion disk. From the accretion disk model, we can accept the inclination angle of accretion disk $i$, thus, the local value of FWHM in the accretion disk can be similarly estimated by $FWHM_{local} \sim FWHM_{obs}/\sin(i)$, which is several times larger than the observed value of FWHM. However, the scale factor $f_{FWHM}$ in equation 2 is a factor to correct the effects of inclination angle to some extent. Assuming a simple disk structure of BLRs, the scale factor we used represents a mean inclination angle $i \sim 30^\circ$ (Onken et al., 2004). The inclination angles of dbp emitters in our sample are always in the range from $\sim 20^\circ$ to $\sim 45^\circ$ (Eracleous & Halpern 1994, 2003), thus the inclination angle has little effects on the results about BH masses.

Figure 1 shows the correlation between two kinds of BH masses: $M_{BH}(\sigma)$ and $M_{BH}(V)$. The Spearman rank correlation analysis gives the rank correlation coefficient ($r_s$) of -0.23 and the significance level of its deviation from zero of $P_{null} \sim 47\%$ for all 12 dbp emitters. The Kendall's correlation analysis presents the same results: correlation coefficient is -0.15 with $P_{null} \sim 49\%$. This result indicates that there is no significant correlation between the central BH masses estimated by means of the two different methods for dbp emitters. The mean value of the BH masses ratio of $M_{BH}(V)$ to $M_{BH}(\sigma)$ is no less than 30.47 $\pm$ 13.83, because the virial BH masses for two dbp emitters, NGC 1097 and NGC 4450 are smaller ones. If we consider only the six objects with measured stellar velocity dispersions of the bulge and with continuum luminosity larger than $10^{42}\text{erg s}^{-1}$, the Spearman and Kendall’s rank correlation coefficients are 0.48 with $P_{null} \sim 33\%$ and 0.33 with $P_{null} \sim 35\%$. Moreover, the Kolmogorov-Smirnov statistic analysis indicates that there are about 32% probability that the two kinds of BH masses having the same distribution. The ratio of $M_{BH}(V)$ to $M_{BH}(\sigma)$ for the six objects is 5.81 $\pm$ 2.01.

### 3.2 The size of Broad Emission Line Regions

Now, the sizes of BLRs of dbp emitters can be calculated from two different methods: from the accretion disk model, $R_{BLR}(M)$, and from the empirical relation according to the continuum luminosity, $R_{BLR}(E)$. Here, the range of the size from accretion disk model is larger, so the flux-weighted mean radius is used as the mean size of BLRs (here, we can not consider the effects of eccentricity of elliptical accretion
disk model):
\[ R_{BLR}(M) = \sum_i r_i f_i \]  \tag{3}

where \( f_i = f_0 \times r^{-9} \) is the line emissivity, the value of \( q \) for each dbp emitter is listed in Table 1 according to the accretion disk model. Here, we just calculate the flux-weighted mean size by only even ten points between the inner radius and outer radius. Because of the steep power law of line emissivity, it is a better choice to select the points in logarithmic space of the radius. The last results are listed in Table 1. For object NGC 1097, we select the mean value of \( r_q \) (inner the radius, the power-law index is \( q = −1 \) and outer the radius \( q = 1 \)) as the mean size of BLRs according to the fitted results for spectra observed during ten years (Storchi-Bergmann, Nemmen, et al. 2003; Storchi-Bergmann, Eracleous et al. 1997; Storchi-Bergmann, Eracleous & Halpern 1995; Storchi-Bergmann, Baldwin et al. 1993).

The correlation between \( R_{BLR}(E) \) and \( R_{BLR}(M) \) is shown in Figure 2. The Spearman and Kendalls rank correlation coefficients are \( -0.31 \) with \( P_{null} \sim 34\% \) and \( -0.24 \) with \( P_{null} \sim 27\% \) respectively for all 12 dbp emitters. If we just consider the six dbp emitters with accurate stellar velocity dispersions and with continuum luminosities larger than \( 10^{42} \text{ erg} \cdot \text{s}^{-1} \), the Spearman and Kendalls rank correlation coefficients are \( 0.37 \) with \( P_{null} \sim 47\% \) and \( 0.21 \) with \( P_{null} \sim 57\% \) respectively. Furthermore, we notice that the size of BLRs according to the accretion disk model for 3C 390.3 is about 14.26 light-days as the same as the result \( R_{BLR} \sim 22.9 \pm 8.9 \) from Reverberation Mapping Technique within the errors (Peterson et al., 2004). The mean ratio of \( R_{BLR}(E) \) to \( R_{BLR}(M) \) is about 50.44 ± 34.91 for all 12 dbp emitters and 2.48 ± 1.22 for the six dbp emitters with stellar velocity dispersions and with continuum luminosity larger than \( 10^{42} \text{ erg} \cdot \text{s}^{-1} \). Moreover, the Kolmogorov-Smirnov statistic analysis indicates that there are about 31\% probability that the two kinds of the size of BLRs have the same distribution.

From the results about BH masses and size of BLRs, the basic results are that the virial BH masses of dbp emitters are systematically larger than the BH masses estimated from the stellar velocity dispersions and the sizes of BLRs calculated from continuum luminosity are also systematically larger than the true sizes of BLRs from the accretion disk model. However, if only considering the six objects with stellar velocity dispersions and higher continuum luminosities, the results indicate that there are some moderate correlations between the two kinds of BH masses and the two kinds of the sizes of BLRs.

### 4 DISCUSSIONS AND CONCLUSIONS

There are many references in the literature which discuss the consistency between the two kinds of BH masses according to the physical parameters of BLRs and according to the physical parameters of the bulge of the host galaxy, especially for low redshift and low luminosity AGN. It is not clear if the empirical relations (equation 2a and equation 2b) hold for AGN at \( z > 1 \) or if the BH-Bulge relation holds for AGN with higher redshift (Sultntic et al. 2006). For dbp emitters, the double-peaked low-ionization emission lines can be best fitted by accretion disk model (Eracleous et al. 1995), the local velocity in the accretion disk can be estimated by Kepler’s law, even considering the gravitational effects, especially when the radius is not nearer to the central black hole. Thus, the assumption of Virialization can be expected to hold for dbp emitters. However, we find that the mean virial BH masses are larger than BH masses from stellar velocity dispersion for dbp emitters. Although, we used the observed FWHM of broad emission lines, the scale factor \( f_{FWHM} \) has considered the effects of inclination angle. Thus, the main reason of the difference of two kinds of BH masses is due to the larger size of BLRs derived from empirical relation \( R \sim L_{\alpha}^{0.1} \).

From the results above, BH masses of dbp emitters estimated from pure stellar velocity dispersion are about six times smaller than the virial BH masses. The BH masses estimated from line width of Narrow emission lines are about several times smaller than the virial BH masses. Although, the slight correlation between BH masses \( M_{BH}(\sigma) \) and virial BH masses \( M_{BH}(V) \) can be found for dbp emitters with stellar velocity dispersions, we can not confirm the result due to the small number of our sample. Moreover, whether the line width of narrow emission lines can be used as the tracer of stellar velocity by \( \sigma \sim 1 \times \sigma_{line} \) for dbp emitters should be studied in the future using a large sample.

More accurate estimation of BH masses for dbp emitter is necessary to estimate the fundamental physical parameter accretion rate \( \dot{m} \). Using the BH masses from equations 2a and 2b, the dimensionless accretion rate \( \dot{m} \) is several times smaller than that based on the BH masses from \( M_{BH} \). The mean dimensionless accretion rate \( \dot{m} \) is about 0.01 from the analysed results of 135 dbp emitters by BH masses estimated under the assumption of virialization (Wu & Liu, 2004, in their paper the BH masses are estimated from equation 2a and 2b). If we accept the BH masses ratio in our sample, the mean accretion rate \( \dot{m} \) based on the BH masses from stellar velocity dispersions should be about 0.1. So, the ADAF accretion flow \( \dot{m} \leq 0.28 \times \alpha^2 \) and \( \alpha \sim 0.1–0.3 \), Mahadevan, 1997; Mahadevan & Quataert, 1997; Narayan et al., 1995) should just exist in a much smaller part of dbp emitters according to the value of accretion rate.

We have shown that the relation between the size of BLRs and continuum luminosity does not hold for dbp emitters. Also, BH masses estimated from line width of narrow emission lines have large errors. The mean flux-weighted size of BLRs is also several times smaller than the value estimated from the empirical relation \( R_{BLR} = L_{\alpha}^{0.1} \). This is perhaps due to the following reasons according to the definition of ionization parameter:

\[ \Gamma = \frac{Q}{4\pi r^2 c n_e} \]  \tag{4}

The first possible reason is due to the different value of \( Q \) between dbp emitters and normal AGN. However, as we discussed in another paper (Zhang, Dultzin-Hacyan & Wang 2007b), there is the same strong correlation between the luminosity of Hα and continuum luminosity \( L_{\alpha}^{0.1} \) for dbp emitters as that for normal AGN (Greene & Ho 2005b). Thus, there are not much different effects of ionization continuum on the size of BLRs for dbp emitters from those for normal AGN. The second possible reason is due to higher electron density of BLRs of dbp emitters than that of normal
AGN. More and more evidence indicates that double-peaked broad emission lines originate from the accretion disk near the central black hole as mentioned in the introduction. This high electron density region is also responsible for broad Fe II emission lines observed in many AGN (Ferland & Person 1989). The third possible reason is due to the different ionization parameter of BLRs of dbp emitters. We think the higher electron density of BLRs of dbp emitters is the dominant reason which leads to smaller size of BLRs. The last summary is: First: for dbp emitters, the BH masses estimated under the assumption of virialization using the continuum luminosity and line width of broad Hβ are much larger than the BH masses from $M_{BH} - \sigma$ which is a more accurate relation. Second, the sizes of the BLRs of dbp emitters can not be estimated by the empirical relation of $R_{BLR} - L_{5100}$, S. Sizes estimated from this relation are larger than the mean flux-weighted sizes of BLRs of dbp emitters. The higher electron density of BLRs of dbp emitters would be the main reason which leads to smaller size of BLRs than that of normal AGN. The dimensionless accretion rate, one of the fundamental parameters for AGN, depends sensitively on the central BH masses, thus, to find a more accurate and convenient way to estimate the BH masses for dbp emitters is an important topic for the future.

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Table 1. Data of Sample

| Name        | σ     | log($M_\star(\sigma)$) | $R_{BLR}(M)$ | $L_{5100\AA}$ | FWHM | $R_{BLR}(E)$ | log($M_\star(E)$) | q   | Ref. |
|-------------|-------|------------------------|--------------|--------------|------|-------------|-------------------|-----|------|
| NGC 1097    | 208±5° | 8.19±0.10              | 10.29        | 41.3         | 13700| 0.28L       | 7.22              | *  | 1,2,3,4 |
| 3C390.3     | 273±16° | 8.67±0.21              | 14.26        | 43.87        | 11900| 18.08       | 8.89              | 3.0 | 2,5   |
| Pictor A    | 145±20° | 7.57±0.26              | 2.15         | 43.2         | 18400| 6.14        | 8.81              | 1.5 | 2,6,7 |
| Arp 102B    | 188±8°  | 8.02±0.12              | 2.91         | 42.48        | 16000| 1.93        | 8.19              | 3.0 | 2,4,5 |
| PKS 0921-213| 144±17° | 7.56±0.22              | 3.41         | 43.06        | 8300 | 4.91        | 8.02              | 1.5 | 2,6   |
| IE 0450.3-1817 | 150±26° | 7.63±0.32              | 3.05         | 42.07        | 10900| 0.99        | 7.57              | 3.0 | 2,5   |
| IRAS 0236.6-3101 | 154±15° | 7.67±0.18              | 3.29         | 44.13        | 7800 | 27.49       | 8.72              | 3.0 | 2,5   |
| B2 0742+31  | 138.5⁠ | 7.49±0.74              | 1.38         | 45.46        | 6500 | 234.58      | 9.49              | 2.0 | 3     |
| CSO 0643    | 116.9⁠ | 7.19±0.71              | 2.01         | 44.58        | 9000 | 56.79       | 9.15              | 3.0 | 6     |
| CBS 74      | 87.3⁠ | 6.68±0.67              | 0.06         | 44.07        | 9200 | 24.96       | 8.82              | 3.0 | 6     |
| 3C 303      | 115.9⁠ | 7.18±0.71              | 1.17         | 43.39        | 6800 | 8.34        | 8.08              | 3.0 | 5     |
| NGC 4450    | 140⁠ | 7.51                    | 1.96         | 40.65        | 9500 | 0.11L       | 6.45              | 3.0 | 4,8   |

a represents that the stellar velocity dispersion is measured from the absorption spectra.
b represents that the stellar velocity dispersion is estimated from the line width of narrow emission lines and with 40 percent uncertainty.
c represents that the stellar velocity is selected from HYPERLEDA (http://www-obs.univ-lyon1.fr/hypercat/).
* represents the mean radius with 1108

The first column is the name of the object, the second column is the stellar velocity dispersion in units of km · s⁻¹, the third column is the logarithmic BH masses in units of $M_\odot$ from $M_{BH} - \sigma$ relation, the fourth column is the size of BLRs in units of light-day from accretion disk model, the fifth column is the continuum luminosity at 5100Å in units of erg · s⁻¹ after the subtraction of contribution of star light, the sixth column is the line width of broad emission lines in units of km · s⁻¹, the seventh column is the sizes of BLRs in units of light-day from the empirical relation $R_{BLR} = L_{\beta}^{5100Å}$ ($L^\beta$ means that the size of BLRs should be larger than the listed value), the eighth column is the logarithmic BH masses in units of $M_\odot$ estimated under the assumption of virialization, the ninth column presents the power law index of the line emissivity for each object according to the accretion disk model, the tenth column presents the references.

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$M_{BH}$ and $R_{BLR}$ of dbp emitters

Figure 1. The correlation between $M_{BH}(\sigma)$ and $M_{BH}(V)$. The solid circle represents the object of which $M_{BH}(\sigma)$ is estimated by the stellar velocity dispersion $\sigma$, the open circle represents the object of which $M_{BH}(\sigma)$ is estimated by the line width of narrow emission lines. The arrow represents that the value of $M_{BH}(V)$ is the lower limit one. The solid line represents the relation $M_{BH}(\sigma) = M_{BH}(V)$.

Figure 2. The correlation between $R_{BLR}(M)$ and $R_{BLR}(E)$. The solid circle represents the object of which $M_{BH}(\sigma)$ is estimated by the stellar velocity dispersion $\sigma$, the open circle represents the object of which $M_{BH}(\sigma)$ is estimated by the line width of narrow emission lines. The arrow represents that the value of $R_{BLR}(E)$ is a lower limit one. The uncertainty of $R_{BLR}(E)$ is given by assuming 5 percent uncertainty in continuum luminosity. The solid line represents the relation $R_{BLR}(M) = R_{BLR}(V)$. 