Partly obscured accretion disc model to explain shifted broad Balmer emission lines of active galactic nuclei

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ABSTRACT

We present a new model to explain the appearance of red/blueshifted broad low-ionization emission lines, especially emission lines in the optical band, which is commonly considered as an indicator of radial motion of the line emitting gas in broad emission line regions (BLRs) of active galactic nuclei (AGN). We show that partly obscured disc-like BLRs of dbp emitters (AGN with double-peaked broad low-ionization emission lines) can also successfully produce shifted standard Gaussian broad Balmer emission lines. Then, we select eight high-quality objects (signal-to-noise ratio >40 at r-band) with shifted standard Gaussian broad Hα (shifted velocity larger than 180 km s⁻¹) from the Sloan Digital Sky Survey Data Release 4. All eight selected objects have visible stellar absorption features in their spectra, except SDSS J1007+1246, which allows us to estimate black hole (BH) masses through the M–σ relation which has proven to be the most reliable method. We also calculate virial BH masses from the continuum luminosity and linewidth of broad Hα, assuming broad emission lines from ‘normal’ BLRs dominated by virialized motions. We find that the BH masses calculated from the M–σ relation are systematically larger than virial BH masses for the selected objects, even after the correction of internal reddening effects in BLRs. The smaller virial BH masses than BH masses from the M–σ relation for objects with shifted broad emission lines are coincident with what we expect from the partly obscured accretion disc model. Thus, we provide an optional better model to explain the appearance of shifted broad emission lines, especially for those objects with underestimated virial BH masses. Finally, we make predictions about the variation of shifted broad Hα with time for the two models: broad Hα from ‘normal’ radially moving clouds or broad Hα from dbp BLRs in a partly obscured accretion disc.

Key words: galaxies: active – galaxies: nuclei – quasars: emission lines.

1 INTRODUCTION

There is no way to spatially resolve broad emission line regions (BLRs) of active galactic nuclei (AGN) by direct observation, and no hope of doing so in the foreseeable future. Information about geometry and kinematics/dynamics of BLRs closer to the central black hole (BH) can be obtained from the study of properties of broad emission lines in observed spectra of AGN. In order to carry out this type of analysis, high signal-to-noise ratio (S/N > 30) spectra are required. Pioneer work on broad line profiles based on high S/N quasar spectra prior to the Sloan Digital Sky Survey (SDSS) data base (Adelman-McCarthy et al. 2006) is summarized in Sulentic, Marziani & Dultzin-Hacyan (2000). An atlas of more than 200 broad Hα (some with higher S/N than data from SDSS) can be found in Marziani et al. (2003). Broad emission lines can be roughly classified into two kinds according to line profiles. Most of them have approximately logarithmic forms, sometimes with slight asymmetry. A small part of them have very complex profiles, such as double-peaked line profiles. Besides line profiles, variations of broad emission lines, especially variations of strength, have been studied for several decades. From the variations of the broad lines as a response to variations in ionizing continuum emission, the size of BLRs (here ‘size’ means the distance between the central region and BLRs) can be estimated by the reverberation mapping technique (Peterson 1993, 2001) based on the pioneer theoretical work by Blandford & McKee (1982). In practice, there are some problems with the application of this technique, for example Maoz (1997) has shown that there is no unique one-dimensional transfer function (which can provide some information about the geometry of BLRs) for NGC 5548. Not to mention the observational effort to monitor the variability of both lines and continuum simultaneously,
this has been accomplished for no more than 50 low-redshift objects (Collin 2007).

Both from the reverberation mapping technique and from the analysis of high S/N line profiles, we have been able to gather some information on velocity fields of BLRs of AGN. It is widely accepted that the profiles clearly have a Doppler origin, and commonly assumed that BLR clouds are mainly gravitationally dominated by the central mass of the host galaxy (Gaskell 1988, 1996; Peterson & Wandel 1999; Wandel, Peterson & Malkan 1999b). However, the basic assumptions cannot explain asymmetry in part of broad emission lines. Although there are several possible explanations for the asymmetry, the first and most obvious one is that there is radial motion of BLR clouds, which has been proved by a cross-correlation test (Netzer 1990). Thus, asymmetry in broad emission lines indicates that part of the emission line clouds in BLRs can be moving away, or perhaps into the central region of the AGN. Obviously, if radial flow in BLRs is the dominant component, one shifted logarithmic profile should be expected. Recently, Bonning, Shields & Salviander (2007) proposed to find recoiling BH systems in the SDSS through shifted broad emission lines due to radial motion in BLRs, although no convincing evidence to prove recoiling BHs in AGN.

Besides normal AGN with broad emission lines having logarithmic form, there is one special kind of AGN, AGN with Double-Peaked low-ionization broad emission lines (hereafter dbp emitters), which have undoubtedly distinct properties of broad emission lines. There are three famous dbp emitters: NGC 1097 (Storchi-Bergmann, Baldwin & Wilson 1993; Storchi-Bergmann et al. 1997; Storchi-Bergmann et al. 1995; Storchi-Bergmann et al. 2003), Arp 102B (Chen & Halpern 1989; Chen, Halpern & Filippenko 1989; Chen, Halpern & Filippenko 1989; Chen, Halpern & Titarchuk 1997; Sulentic et al. 1990; Antonucci, Hurt & Agol 1996; Halpern et al. 1996) and 3C 390.3 (Gilbert et al. 1999; Shapovalova et al. 2001). There are at least two different models proposed to explain observed features of double-peaked broad emission lines. One is the binary BH model (Begelman, Blandford & Rees 1980; Gaskell 1983). However, this model has failed to account for properties of long-term variability and leads to much larger central BH masses than $10^6 M_{\odot}$ (Eracleous et al. 1997). Thus, we prefer the other model, the accretion disc model. This model was first proposed by Chen et al. (1989a, 1989b), and then improved from a circular accretion disc model to an elliptical accretion disc model by Eracleous et al. (1995). The accretion disc model can be successfully applied to reproduce the complex double-peaked broad emission lines and to reproduce the long-term variations of double-peaked emission lines, under the assumption that double-peaked broad emission lines come from disc-like BLRs located on to the central accretion disc.

For dbp emitters, because disc-like BLRs are located on accretion discs, one interesting result is that the disc-like BLRs can be partly obscured by a dust torus in the unified model (Antonucci 1993; Urry & Padovani 1995) and/or by some dust clouds. So, the interesting question is proposed whether broad emission lines of dbp emitters with partly obscured BLRs have similar properties to those of ‘normal’ broad emission lines. In the following section, we develop our model and give some simple but interesting examples of broad emission lines with standard profiles from partly obscured disc-like BLRs of dbp emitters. In Section 3, we try to find some candidates which have shifted standard broad emission lines, but actually are partly obscured dbp emitters. Section 4 gives the discussion and conclusion. The cosmological parameters $H_0 = 70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$, $\Omega_{\Lambda} = 0.7$ and $\Omega_m = 0.3$ have been adopted here.

2 THEORETICAL RESULTS FROM PARTLY OBSCURED BLRs OF DBP EMITTERS

The accretion disc model has been proposed and studied by many authors: the circular disc model (Chen & Halpern 1989; Chen, Halpern & Filippenko 1989); the warped disc model (Eracleous et al. 1995); the warped disc model (Bachev 1999; Hartnoll & Blackman 2000); the circular disc with spiral arm model (Karas, Martocchia & Subr 2001; Hartnoll & Blackman 2002). Here, we select the elliptical accretion disc model (Eracleous et al. 1995) rather than the other models, because the fewer parameters of the model can better explain most of the aspects of double-peaked broad emission lines. The elliptical accretion disc model of Eracleous et al. (1995) has eight free parameters. Five of them are applied to determine the geometrical structure of the disc-like BLRs: the inner radius of disc-like BLRs $R_{in}$, the outer radius $R_{out}$, the eccentricity $e$, the inclination angle $i$ and the original orientation angle of the BLRs in the accretion disc $\phi_0$ (the angle between the major axis of elliptical disc-like BLRs and the direction of the projected line of sight into the accretion disc). Another parameter $q$ is used to determine line emissivity as $f_\nu \propto r^{-1+q}$. Then, two other parameters, the local broadening velocity dispersion $\sigma_l$ and the amplitude factor $k$, are used to broaden and strengthen the outer broad emission lines. Here, we do not use the parameter $k$. The normalized flux densities of broad Hα from the accretion disc model have a maximum value of 1.

In order to discuss the effects of the dust torus on observed broad emission lines from the accretion disc model, some parameters of the dust torus should be first determined. The size of the torus has been determined by the reverberation mapping technique applied to the flux variations in the near-infrared and optical bands for some nearby Seyfert 1 galaxies by Suganuma et al. (2006). The mean size of the inner side of the torus for these nearby objects is about $c_\alpha [\nu L_\nu(V)]^{0.5}$, which is about three times larger than the size of BLRs of ‘normal’ AGN as obtained by Kaspi et al. (2005). However, the opening angle of the torus cannot be determined by means of this unique parameter. If we accept that the size of BLRs of normal AGN should be less than the height of the inner side of the dust torus, we can roughly determine the opening angle of the torus as about 40°–50°. Furthermore, the opening angle of the torus can be estimated from the number ratio of type 1 to type 2 AGN (Zakamska et al. 2003). We can accept that an opening angle of the dust torus around 60° is a reasonable value. Thus, if we adopt 60° as the origin value of the inclination angle in the accretion disc model, $i = \pi/3$, which leads to the result that some part of disc-like BLRs should be seriously obscured by the dust torus.

It is simple to choose the other model parameters to check output broad emission lines from the partly obscured accretion disc model. The inner radius is about several hundred gravitational radii, $R_{in} \sim 600 R_g$. The outer radius is about several thousand gravitational radii, $R_{out} \sim 4000 R_g$. The local broadening velocity is several thousands of kilometres per second, $\sigma_l \sim 3000\,\text{km}\,\text{s}^{-1}$. The slope of the line emissivity can be determined as $f_\nu \propto r^{-2}$. The eccentricity of the elliptical disc is selected as $e = 0.6$ and the original orientation angle is $\phi_0 \sim \pi/3$. The selected values for the model parameters (except local broadening velocity) above are common values for dbp emitters as shown in Eracleous & Halpern (2003). Here, we select a slightly larger local broadening velocity in order to get a clearly fine result as shown in Fig. 1. As a simple example of the partly obscured accretion disc model, we consider the
The created examples for broad Hα by the partly obscured elliptical accretion disc model. The thin line represents the created broad line by model. The solid line represents the best-fitting result by a Gaussian function. The vertical line marks the position of the centre wavelength of normal broad Hα at the rest wavelength. For each created broad Hα, a different input parameter is listed in the figure.

The case that half of the Hα emitting regions are seriously obscured, i.e. the integral range of orientation angle is not from $\phi_0$ to $\phi_0 + 2 \times \pi$, but from $\phi_0 + \pi/2$ to $\phi_0 + 3 \times \pi/2$.

Fig. 1 shows some output broad lines with some noise under the partly obscured accretion disc model. We can see that shifted standard Gaussian broad Hα emission lines by different input model parameters are produced. The random noise shown in Fig. 1 is created assuming that the maximum ratio of noise to flux density is less than 0.07, which is one standard value for SDSS spectra. We can find that different input model parameters lead to different line profiles with different shifted velocities, but can also be best fitted by a standard Gaussian function. Furthermore, the input model parameter of $\phi_0$ should determine if the observed broad Hα is blueshifted or redshifted.

Before the end of this section, it is interesting to check effects of the parameter of the original orientation angle of partly obscured disc-like BLRs ($\phi_0$) on the output broad line profile, because the original orientation angle is the only parameter in the elliptical accretion disc model which is varying with the precession of elliptical disc-like BLRs. The precession period should be proportional to $A(1-e^2)$ (A is the length of the semimajor axis), for an accretion disc around a Schwarzschild BH, which indicates that the precession for the inner part of elliptical disc-like BLRs should be about several tens of years, and leads to apparent variations of the parameter of original orientation angle, if the central BH masses are large enough and the length of the semimajor axis is small enough. Thus, it is necessary to check the effects of original orientation angle on output broad emission lines under the partly obscured.
accretion disc model. Actually, in the partly obscured accretion disc model, there are some free parameters which cannot be determined, such as the actual area of obscured disc-like BLRs. Thus, there is so far no clear way to describe the detailed effects of the original orientation angle. However, commonly we can simply show that the variation of original orientation angle should have little effect on the output model broad line profiles to some extent under the simple half partly obscured accretion disc model, although the half partly obscured accretion disc model above is oversimplified.

Fig. 2 shows some examples of the output broad emission lines with different values of original orientation angle; meanwhile the other disc-like parameters are held constant at the values listed above. There are 80 values of original orientation angle from 0 to $2\pi$ used to produce 80 output broad emission lines, and only eight of them are shown in Fig. 2. It is clear that different orientation angles could lead to standard Gaussian line profiles but with different shift velocities. Another interesting result about the partly obscured accretion disc model is that the number of redshifted model broad lines is smaller than the number of blueshifted model broad lines, 25 redshifted broad lines and 55 blueshifted model broad lines, because of the elliptical disc-like BLRs with origin point at one focus point of the ellipse. Certainly, the number ratio should depend on the location of the central BH, the near focus point to the observer or the far focus point from the observer. Detailed number ratios can

![Figure 2](https://example.com/figure2.png)

**Figure 2.** The created examples for broad Hα by the partly obscured elliptical accretion disc model. The thin line represents the created broad line by model. The solid line represents the best-fitting result by a Gaussian function. The vertical line marks the position of the centre wavelength of normal broad Hα at the rest wavelength. For each created broad Hα, a different input parameter of orientation angle is listed in the figure; meanwhile the other parameters are held constant at the values listed in the text.
be found in Section 3.2. The results shown in Fig. 2 indicate that a shifted standard Gaussian broad emission line is not the case from some specially selected original orientation angle.

The results obtained above imply that some AGN (albeit a small number) with shifted broad emission lines with logarithmic profiles may well be dbp emitters with partly obscured disc-like BLRs. There might be different cases for partly obscured BLRs of dbp emitters, those in which a small part of the BLRs are obscured and those where a large part of the BLRs are obscured. If the central ring of BLRs is obscured, the expected result is that the peak position should have a small shift velocity, because the rotation velocity of the emission clouds in the outer rings is smaller than that in the inner rings. Furthermore, if the obscured part is not seriously obscured by the dust torus, the observed line profile should be seriously asymmetric.

3 OBSERVATIONAL RESULTS FROM SDSS DATA RELEASE 4

In this section, we discuss properties of some AGN selected from SDSS Data Release 4 (DR4) with high-quality shifted standard Gaussian broad Hα, in order to test our partly obscured accretion disc model. We here focus on objects with higher S/N than 40 at r band in the main quasar list of SDSS DR4 (Adelman-McCarthy et al. 2006), and with redshift less than 0.37 (in order to ensure the existence of complete broad Hα). Then, about 225 objects are first selected from the SDSS according to criteria about S/N and redshift. We further check spectra of the selected objects and find that some of them have apparent stellar absorption features, such as absorption lines Mg i λ 5175, Ca ii λ 3934, 3974 and 4000 Å break. Thus, we make sure that before we measure line parameters, the stellar components in the observed spectrum are first subtracted.

Before proceeding further, we first give some descriptions of our strict selection criteria. In this paper, we mainly focus on properties of shifted broad Balmer emission lines. Thus, how to determine whether one broad emission line is shifted is the first question we should find an answer to. The common method is to calculate the relative shifted value between central wavelengths of broad and narrow emission lines. It is obvious that asymmetry in broad emission lines should have serious effects on the determination of central wavelengths of broad emission lines. Thus, less asymmetry in high-quality emission lines can lead to a better determination of shifted velocity. Besides the convenience of determining shifted velocity, shifted standard Gaussian broad emission lines can provide more information about the total isotropic radial motions of normal BLRs, if we accept that normal BLRs are located in the so-called ionization cone as described by the unified model for AGN. In order to confirm that observed broad Hα has a standard Gaussian line profile, objects with high quality (S/N > 40) are preferred. In order to confirm that the broad emission lines have reliable shifted velocities, objects with apparent shifted velocities (larger than 180 km s$^{-1}$, the SDSS spectral resolution) relative to the centre wavelength of narrow Hα are selected. Thus, the number of objects in our final sample should be small; however, a small number of objects still provides interesting and sufficient information about our final conclusion.

An efficient method to subtract the stellar light is the Principal Component Analysis (PCA) method described by Li et al. (2005) and Hao et al. (2005), using the eigenspectra from pure absorption galaxies from SDSS or the eigenspectra from stars in STELIB (a library of stellar spectra at $R \approx 2000$, Le Borgne et al. 2003), because the method of PCA provides a better way to constrict more favourable information from a series of spectra of stars or galaxies into several eigenspectra. Here, we used the method from Hao et al. (2005). The eigenspectra are calculated by Karhunen–Loève transformation for about 1500 pure absorption galaxies selected from SDSS DR4. Then, the first eight eigenspectra and the spectra of an A star (which is used to account for the young stellar population) selected from STELIB (a library of stellar spectra at $R \sim 2000$, Le Borgne et al. 2003) are used to fit the stellar properties of the observed spectra. After this, rather than a power law, a third-order polynomial function is used to fit the featureless AGN continuum, because the study of composite spectra of AGN shows that the AGN continuum should be best fitted by two power laws with a break at $\sim 5000$ Å (Francis et al. 1991; Zheng et al. 1997; Vanden Berk et al. 2001). After the last step, the featureless continuum and the stellar components are obtained based on the Levenberg–Marquardt least-squares minimization method applied to the observed spectrum with emission lines masked.

After the subtraction of stellar components and featureless continuum, the line parameters can be measured. Here, we focus on the region around Hα: broad and narrow components of Hα, [N ii]λ 6583, 6585 Å and [S ii]λ 6716, 6731 Å. Then, we measure the line parameters applying a Gaussian function to each line component. In the procedure, the second moment of broad Hα has a lower limit of 400 km s$^{-1}$; the second moments of narrow emission lines have the same value in velocity space. Once line parameters are measured, objects with shifted velocities larger than 180 km s$^{-1}$ relative to narrow Hα and/or the [N ii] doublet are selected. Then, we carefully check the selected objects by eye to reject those with double-peaked emission lines. We have about 20 objects, of which the broad component of Hα can be best fitted by a one-Gaussian function. Then, one criterion for $\chi^2$ is finally used to reject some objects. The parameter $\chi^2$ is commonly used to determine whether the model fit by one broad Gaussian function is the best choice for broad emission lines limited by $0.5 < \chi^2 < 2.5$, where $\chi^2$ is calculated by $\chi^2 = \sum \frac{(y - \text{model})^2}{\text{d.o.f.}}$, where d.o.f. is degrees of freedom. We end up with eight objects which have shifted standard Gaussian broad Hα, seven with redshifted broad Hα and one with blueshifted broad Hα. The best-fitting results for emission lines around Hα are shown in Fig. 3. In Table 1, we list the line parameters of the eight objects.

Before the end of the section, we should note that the broad component of Hα in SDSS J1649 perhaps is not so secure, especially from the best-fitting results shown in Fig. 3. However, through the measured line parameters of the broad component of broad Hα of SDSS J1649 (listed in Table 1), we also keep the object in our sample according to the criteria above.

3.1 BH masses and size of BLRs

The most reliable method to estimate BH masses is based on the stellar velocity dispersion of the bulge of the host galaxy, the $M$–σ relation, first suggested by Ferrarese & Merritt (2000) and Gebhardt et al. (2000), then confirmed by Tremaine et al. (2002) and Merritt & Ferrarese (2001), etc.

$$M_{BH} = 10^{8.1 \pm 0.6} \left(\frac{\sigma}{200 \text{ km s}^{-1}}\right)^{4.02 \pm 0.32} M_\odot,$$

(1)

which indicates a strong correlation between BH masses and bulge masses (Wandel 1999; Kormendy 2001; Laor 2001; McLure & Dunlop 2002; Marconi & Hunt 2003; Haring & Rix 2004), etc. Furthermore, more recent results from a larger SDSS sample indicate that there is no significant evolution of the $M$–σ relation by Shen et al. (2008). Besides the results from observational work, Shankar, Bernardi & Haiman (2009) theoretically studied the evolution of
the $M-\sigma$ relation, and found that from $z \sim 0$ to 0.5 there is no significant evolution of the $M-\sigma$ relation, which is similar to the result found by Shen et al. (2008). Thus, although the eight objects in our sample have much different redshifts, we think that the BH masses from the $M-\sigma$ relation are still reliable.

However, how to accurately measure stellar velocity dispersion is an open question, because of known problems with the template mismatch. A commonly used method is to select spectra of several kinds of stars (commonly, G and K) as templates, and then broaden the templates by the same velocity to fit stellar features, leaving the contributions from different kinds of stars as free parameters (Rix & White 1992). However, more information about stars included by the templates should lead to more accurate measurement of stellar velocity dispersion. According to the above-mentioned method to subtract stellar components, we created a new template rather than several spectra of G or K stars as templates. Thus, we apply the PCA method for all 255 spectra of different kinds of stars in STELIB. Selecting the first several eigenspectra and a third-order polynomial function for the background as templates, the value of stellar velocity dispersion can be measured by the minimum $\chi^2$ method applied for the absorption features around Mg I $\lambda 5175$ Å within a rest wavelength range from 5100 to 5300 Å. The method to measure stellar velocity dispersion is similar to the method to subtract the stellar component discussed above. In Fig. 4, we show the best-fitting result for absorption features near Mg I $\lambda 5175$ Å for seven objects, except SDSS J1007+1246 because of the lack of Mg I $\lambda 5175$ Å. For SDSS J1007+1246, the linewidth of narrow emission lines is used as a substitute for stellar velocity dispersion (Nelson...
...of broad Hβ to broad Hα flux ratios of broad Hα are about 3.1. The flux ratios of broad Hα are estimated from continuum luminosity and size of the BLRs. Thus, the virial BH mass of the object SDSS J1649+3613, with $m_{\text{H}}^{\text{v}} \sim 10^{-6}$, should be smaller than the determined value because $R_{\text{BLR}}$, estimated from continuum luminosity should be smaller than the true size (see also Wang & Zhang 2003).

If the shifted standard Gaussian broad Hα comes from the partly obscured accretion disc, we should expect that the virial BH masses should be smaller than the more reliable BH masses estimated through stellar velocity dispersions, because of the smaller observed linewidth and smaller size of BLRs from smaller observed continuum luminosity than intrinsic ones from the partly obscured accretion disc model. Fig. 5 shows the comparison of the two kinds of BH masses of the eight objects. From the figure, we can see that BH masses estimated through the $M-\sigma$ relation are systematically larger than virial BH masses, $(M_{\text{vir}}/M_{\text{BH}})^{\text{true}} \sim 68$ for all the eight objects (if the object SDSS J1649 is rejected, the mean ratio of the two kinds of BH masses is 16). The result strongly indicates that the partly obscured accretion disc model is preferred for the objects in our sample, especially SDSS J1044, SDSS J1145 and SDSS J1715.

It is obvious that we do not consider effects from internal redening on the results above. Commonly, effects of internal reddening can be corrected through Balmer decrements from broad Balmer emission lines, especially the flux ratio of broad Hα to broad Hβ, assuming that the internal Balmer decrement for broad Hβ to broad Hα is about 3.1. The flux ratios of broad Hα to broad Hβ are listed in Table 2 for the eight objects. According to observed flux ratios of Hα to Hβ, the internal luminosity of broad Hα is determined, after the correction of internal reddening effects. Then, according to the correlation between continuum luminosity and line luminosity for a sample of quasars (Greene & Ho 2005b), the internal AGN continuum luminosity is estimated...
for each object in our sample. In other words, after the correction of internal reddening effects, we ensure that the flux ratio of H\(\alpha\) to H\(\beta\) is 3.1, and the correlation luminosity of H\(\alpha\) and continuum luminosity obeys the one found by Greene & Ho (2005b). According to the AGN continuum luminosity after the correction of internal reddening effects, the virial BH masses are remeasured by equation (2) and reshowed in Fig. 6. We can clearly see that the effects of internal reddening cannot change the result: BH masses estimated through stellar velocity are systematically larger than virial BH masses.

If we assume that the broad H\(\alpha\) of each object in our sample is emitted from ‘normal’ BLRs, its distance to the BH (its size) can be estimated from the continuum luminosity after the correction of internal reddening (Bentz et al. 2006), \(R_{\text{BLRs}} \propto L_{5100}^{-0.5}\), except for SDSS J1649 which has a much smaller dimensionless accretion rate \(\dot{m}_{\text{H\(\alpha\)}} < -5.5\) (Zhang, Dultzin-Hacyan & Wang 2007a). The estimated size of BLRs of each object is listed in Table 2. If the shifted broad H\(\alpha\) are interpreted by emitting regions dominated by radial motions, it is clear that radial motions should lead to the change of size of BLRs, and then lead to the change of linewidth. There are seven out of eight objects which show redshifted broad profiles. The redshifted velocity indicates that the direction of the radial flows points to the central BH. The inferred ‘infalling times’ for such emission clouds were estimated and are listed in Table 2.
The implication is the following: if the shift of broad Hα is due to infalling emission clouds, after several years the broad line emission clouds would be accreted into the central accretion disc or into the central BH, and thus the observed broad Hα should have complex line profiles rather standard Gaussian profiles.

Finally, we want to point out that the smaller linewidth of broad Hα for objects in our sample is about 30 Å (second moment). It is necessary to check whether the partly obscured disc model can reproduce the outward shifted standard Gaussian broad Hα with small linewidth. If we select the following model parameters: \( R_{\text{in}} \sim 6286 \, R_\odot, R_{\text{out}} \sim 45 \, 000 \, R_\odot, i = 60^\circ, f_\epsilon = 0.8, \sigma_1 \sim 1550 \, \text{km s}^{-1} \) and \( \phi_0 \sim 55^\circ \), the outward Gaussian broad Hα line profile of SDSS J1715+5935 can be nearly reproduced with a second moment of 38.28 Å and with a central wavelength at 6577.92 Å. For this, we have to assume that half of the disc-like BLRs in accretion discs are obscured. This is, however, a very particular assumption.

Figure 5. The correlation between two kinds of BH masses: \( M_{\text{BH}}(\sigma) \) is estimated through stellar velocity dispersion and \( M_{\text{BH}}(\text{virial}) \) is estimated by the linewidth of broad Hα and continuum luminosity. The solid circle represents the object SDSS J1649 that indicates the actual virial BH mass should be larger than this one. The solid line represents \( M_{\text{BH}}(\sigma) = M_{\text{BH}}(\text{virial}) \).

The ID number and name for each object are listed in the first and second columns. The third column gives the value of stellar velocity dispersion in units of km s\(^{-1}\). The fourth column is the dimensionless accretion rate by luminosity of Hα (BD, Balmer decrement \( \sim 200 \)). The flux ratio of broad Hα to broad Hβ (BD, Balmer decrement for BLRs) is listed in column 5. Then, the internal logarithmic continuum luminosity at 5100 Å in units of erg s\(^{-1}\) is shown in the next column, after consideration of the effects of internal reddening. Columns 7 and 8 are the two kinds of logarithmic BH masses in units of M\(_\odot\): \( M_{\text{BH}}(\sigma) \) is estimated from stellar velocity dispersion, \( M_{\text{BH}}(V) \) is the virial BH mass through the linewidth of broad Hα and continuum luminosity listed in column 6. For SDSS J1649, the listed virial BH mass in the table is the lower limit one. The last two columns are the size of BLRs in units of light days estimated by the continuum luminosity listed in column 6 and the infalling time in units of years.

Table 2. Parameters of emission lines.

| ID | Name             | \( \sigma \) | \( \sigma_{\text{in}} \) | BD | \( L_{5100\AA} \) | \( M_{\text{BH}}(\sigma) \) | \( M_{\text{BH}}(V) \) | \( R_{\text{BLRs}} \) | \( t_{\text{in}} \) |
|----|------------------|--------------|---------------------------|----|-------------------|--------------------------|---------------------|------------------|----------------|
| 0  | J093943.74+560230.4 | 165.52±26.62  | -3.5                      | 3.67 | 43.85             | 7.79                     | 7.9               | 20.24            |
| 1  | J100726.10+124856.2 | 226.37±7.17   | -3.0                      | 5.14 | 44.94             | 8.34                     | 8.89               | 80.49            |
| 2  | J102044.43+013048.4 | 137.64±15.36  | -3.9                      | 3.89 | 43.23             | 7.47                     | 7.71               | 9.23             |
| 3  | J104451.73+063548.6 | 148.48±11.53  | -4.9                      | 15.13 | 43.29         | 7.61                    | 6.88               | 9.96             |
| 4  | J145706.79+494008.4 | 140.43±12.26  | -5.1                      | 4.14 | 42.29             | 7.51                     | 6.45               | 2.81             |
| 5  | J146009.58+361325.8 | 264.23±15.46  | -5.9                      | 12.68 | 42.98         | 8.61                    | 6.82               | 6.72             |
| 6  | J171322.58+325628.0 | 171.56±20.50  | -4.1                      | 3.64 | 43.38             | 7.86                    | 7.68               | 11.15            |
| 7  | J171550.49+593548.7 | 151.30±16.15  | -4.4                      | 4.31 | 43.01             | 7.64                    | 7.33               | 6.98             |

The correlation between two kinds of BH masses after the correction of internal reddening effects: \( M_{\text{BH}}(\sigma) \) is estimated through stellar velocity dispersion and \( M_{\text{BH}}(\text{virial}) \) is estimated by the linewidth of broad Hα and continuum luminosity. The solid circle represents the object SDSS J1007, for which the stellar velocity dispersion is substituted by the linewidth of narrow emission lines. The upward arrow for object SDSS J1649 indicates that the actual virial BH mass should be larger than this one. The solid line represents \( M_{\text{BH}}(\sigma) = M_{\text{BH}}(\text{virial}) \).

Figure 6. The correlation between two kinds of BH masses after the correction of internal reddening effects: \( M_{\text{BH}}(\sigma) \) is estimated through stellar velocity dispersion and \( M_{\text{BH}}(\text{virial}) \) is estimated by the linewidth of broad Hα and continuum luminosity. The solid circle represents the object SDSS J1007, for which the stellar velocity dispersion is substituted by the linewidth of narrow emission lines. The upward arrow for object SDSS J1649 indicates that the actual virial BH mass should be larger than this one. The solid line represents \( M_{\text{BH}}(\sigma) = M_{\text{BH}}(\text{virial}) \).

3.2 Number ratio of objects with redshifted velocities to objects with blueshifted velocities

In this section, we will discuss the number ratio of objects with redshifted observed broad standard Gaussian Hα to objects with...
blueshifted observed broad standard Gaussian Hα, $N_{\text{obs}}$, under the partly obscured accretion disc model, which will provide more evidence for the model.

As we have done in Section 2, we can find that under the partly obscured accretion disc model, the value of $N_{\text{obs}}$ is about 25/55. It is clear that the value should depend on the location of the central BH in the accretion disc model, if the radius of one particle is described by

$$r = \frac{r_*(1 + e)}{1 + e \cos(\phi - \phi_0)}$$

(where $r_*$ and $e$ are the pericentre distance and eccentricity of one elliptical ring), rather than by

$$r = r_*(1 + e)$$

(in other words, the new orientation angle $\phi^*$ is described as $\phi^* = \phi + \pi$), the value of $N_{\text{obs}}$ should be 55/25. Especially, if the eccentricity is around zero, i.e. circular disc-like BLRs, it is obvious that the number ratio of $N_{\text{obs}}$ should be 1. Thus, the number ratio from the partly obscured accretion disc model is around 1.

However, there is only one object with blueshifted standard broad Gaussian Hα. Perhaps the weird number ratio is due to the strict selection criteria. Fig. 7 shows the distribution of shifted velocities for the objects in our sample. Thus here we do not give the precession period of BLRs into the accretion disc for dbp emitters, because we only have single-epoch spectra, it is difficult to determine the model parameters for the objects in our sample. Thus here we do not give the precession period of BLRs into the accretion disc for dbp emitters, but the line profile should keep its form. As shown in Table 2, the infalling times for several objects are around 10 years, thus it should be possible to determine whether radial motions are dominant in these objects by observational spectroscopic monitoring. On the other hand, if our model of partly obscured BLRs of dbp emitters is correct, we should expect that line profiles should be varying with the passage of time, especially for objects with short precession period. Because we only have single-epoch spectra, it is difficult to determine the model parameters for the objects in our sample. Thus here we do not give the precession period of BLRs into the accretion disc for dbp emitters, and cannot give a clear time prediction for observing the change in line profiles. Thus, the long-period monitoring of these objects is an interesting observational project to confirm our model.

Furthermore, besides the shifted standard broad Gaussian emission lines, it is interesting to discuss the objects with asymmetric broad emission lines. Commonly, the asymmetry is considered as the effect of radial motions in part of normal BLRs. However, the asymmetric non-virialized components in broad emission lines should lead to overestimated virial BH masses. Thus, it is clear that there are obviously different characters of virial BH masses estimated from the radial motions in BLRs model and the partly obscured accretion disc model. The radial motions in BLRs always indicate overestimated virial BH masses, however, the partly obscured accretion disc model leads to underestimated virial BH masses.

4 DISCUSSION

In this paper, we present a new and interesting model to explain the appearance of shifted broad emission lines, besides the radial motions of broad emission line clouds in BLRs. The scenario considers the partial obscuration of disc-like BLRs in the accretion disc of dbp emitters. From the shift velocity of broad lines, we cannot determine the velocity field of the broad line clouds in BLR. We cannot firmly discard radial motions into the BH or away from it. But we can predict that if the shifted standard Gaussian broad lines are emitted from a ‘normal’ BLR in an ionization cone, we expect the linewidth to change with time (BLRs near the central BH produce broader emission lines), but the line profile should keep its form. As shown in Table 2, the infalling times for several objects are around 10 years, thus it should be possible to determine whether radial motions are dominant in these objects by observational spectroscopic monitoring. On the other hand, if our model of partly obscured BLRs of dbp emitters is correct, we should expect that line profiles should be varying with the passage of time, especially for objects with short precession period. Because we only have single-epoch spectra, it is difficult to determine the model parameters for the objects in our sample. Thus here we do not give the precession period of BLRs into the accretion disc for dbp emitters, and cannot give a clear time prediction for observing the change in line profiles. Thus, the long-period monitoring of these objects is an interesting observational project to confirm our model.

Furthermore, besides the shifted standard broad Gaussian emission lines, it is interesting to discuss the objects with asymmetric broad emission lines. Commonly, the asymmetry is considered as the effect of radial motions in part of normal BLRs. However, the asymmetric non-virialized components in broad emission lines should lead to overestimated virial BH masses. Thus, it is clear that there are obviously different characters of virial BH masses estimated from the radial motions in BLRs model and the partly obscured accretion disc model. The radial motions in BLRs always indicate overestimated virial BH masses, however, the partly obscured accretion disc model leads to underestimated virial BH masses.
Finally, we can summarize our conclusions as follows. We present a model to explain the appearance of shifted Balmer broad emission lines which does not need to involve radial motions dominating the emission line clouds. We show that partly obscured BLRs of dbp emitters can also produce shifted standard Gaussian broad emission lines. Then, we select eight high-quality objects (with S/N at r band larger than 40) with shifted broad Hα (the shifted velocity larger than 180 km s$^{-1}$) from SDSS DR4 (seven of them have observable stellar absorption features). Reliable BH masses determined using stellar velocity dispersions result in systematically larger than virial BH masses estimated by the linewidth of broad Hα and continuum luminosity. We further estimate the size of BLRs for the objects from continuum luminosity and show that internal reddening has no important influence on our final results. Finally, we make predictions about the variation of shifted broad Hα with time for the two models: broad Hα from ‘normal’ radially moving clouds or broad Hα from dbp BLRs in a partly obscured accretion disc.

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