A note on black hole masses estimated by the second moment in narrow-line Seyfert 1 Galaxies

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ABSTRACT
The second moment of the Hβ emission line is calculated for 329 narrow-line Seyfert 1 galaxies (NLS1s) selected from the Sloan Digital Sky Survey (SDSS), which is used to calculate the central supermassive black hole (SMBH) mass of each. We find that the second moment depends strongly on the broader component of the Hβ line profile. We find that for the NLS1s requiring two Gaussians to fit the Hβ line, the mean value of the SMBH mass from the Hβ second moment is larger by about 0.50 dex than that from the full width at half-maximum. Using the gas velocity dispersion of the core/narrow component of [O III]λ5007 to estimate the stellar velocity dispersion σ*, the new mass makes NLS1s fall very close to the MBH–σ* relation for normal active galactic nuclei. By using σ* measured directly from SDSS spectra with a simple stellar population synthesis method, we find that for NLS1s with mass lower than 10^7 M☉, they fall only marginally below the MBH–σ* relation considering the large scatter in the mass calculation.

Key words: black hole physics – galaxies: active – galaxies: nuclei.

1 INTRODUCTION
Narrow-line Seyfert 1 galaxies (NLS1s) are thought to be a special subclass of active galactic nuclei (AGN) harbouring relatively small but growing supermassive black holes (SMBHs, MBH), compared to other broad-line Seyfert 1 galaxies (BLS1s; e.g. Osterbrock & Pogge 1985; Boller, Brandt & Fink 1996; Mathur 2000). Whether NLS1s follow the well-known MBH–σ* (or MBH–Lbulge) relation defined in inactive galaxies is a question open for debate, where the stellar velocity dispersion (σ*) is measured at an eighth of the effective radius of the galaxies (e.g. Mathur, Kuraszkiewicz & Czerny 2001; Tremaine et al. 2002; Bian & Zhao 2004; Grupe & Mathur 2004; Barth et al. 2005; Botte et al. 2005; Komossa & Xu 2007; Ryan et al. 2007; Watson, Mathur & Grupe 2007). It also remains a question for other types of AGN (e.g. Nelson 2001; Greene & Ho 2006; Shen et al. 2008; Woo et al. 2008). In investigating the MBH–σ* relation for NLS1s or/and other AGN, the method of determining MBH–σ* is very important.

The central SMBH mass in AGN is a key parameter to understand the nuclear energy mechanism as well as the cosmic formation and evolution of SMBHs and their host galaxies (e.g. Rees 1984; Gebhardt et al. 2000; Ferrarese & Merritt 2000; Tremaine et al. 2002). In the past two decades, there has been striking progress in finding more reliable methods to calculate SMBHs masses in AGN through the linewidth, ΔV, of Hβ (or Hα, Mg II, C IV) from the broad-line region (BLR) and the BLR size, RBLR (e.g. Kaspi et al. 2000; Bian & Zhao 2004; McLure & Jarvis 2004; Peterson et al. 2004; Greene & Ho 2005b). Introducing the scaling factor f to characterize the nuclear kinematics and the geometry of the BLRs, the SMBH mass is calculated by

$$M_{\text{BH}} = f \frac{R_{\text{BLR}} \Delta V^2}{G}.$$  (1)

The uncertainties of SMBHs masses in AGN from equation (1) are mainly from the uncertainties in RBLR, f and ΔV.

Much effort has been focused on determining RBLR from the reverberation mapping method or empirical size–luminosity relations (e.g. Kaspi et al. 2000, 2005; Bentz et al. 2006; Vestergaard & Peterson 2006). There are mainly two ways to parametrize the line widths of broad emission lines, i.e. the full width at half-maximum (FWHM) and the second moment (σ line). For a Gaussian line profile, FWHM/σ line = √8 ln 2 ≈ 2.35; while for a Lorentzian profile, σ line → ∞. However, people usually find that one-Gaussian component provides a poor fit to the Hβ emission-line profile after subtracting the contribution from narrow-line region (NLR), especially for NLS1s (e.g. Rodriguez-Ardila et al. 2000; Dietrich, Crenshaw & Kraemer 2005; Mullaney & Ward 2008). Salviander
et al. (2007) used a Gauss–Hermite function to measure the Hβ FWHM (also see McGill et al. 2008). Netzer & Trakhtenbrot (2007) measured FWHM from the two-Gaussian fits to the Hβ profile (see also Mullaney & Ward 2008). For 12 NLS1s, Dietrich et al. (2005) suggested that their broad emission-line profiles are well represented by employing two-Gaussian components, while the Lorentzian profile does not do as well for the core and wing of the Hβ profile simultaneously. Based on the analysis of reverberation mapping data, it was suggested that σ line rather than FWHM be used to characterize the linewidth (Frommelt & Melia 2000; Krolik 2001; Peterson et al. 2004).

For 16 AGN with BLRs sizes from the reverberation mapping and possessing reliable σ line measurements, Onken et al. (2004) determined the scaling factor f to make the reverberation-based SMBH masses consistent with the well-known $M_{\text{BH}}$–σ line relation of inactive galaxies (Tremaine et al. 2002). They found that f is $5.5 \pm 1.8$ when σ line from rms spectra is adopted as $\Delta V$. Collin et al. (2006) proposed different scaling factors for emission lines with different ratios of FWHM to σ line. They suggested f = 3.85 ± 1.15 when σ line from mean spectra is adopted as $\Delta V$. It is also often assumed that the BLR gas has random orbits. Netzer (1990) suggested that f = 3 when FWHM/2 is adopted as $\Delta V$ (e.g. Kaspi et al. 2000, 2005; Greene & Ho 2006).

Although σ line is difficult to measure for AGN because the nuclei outline their hosts; there are a larger number of AGN from the Sloan Digital Sky Survey (SDSS) with obvious stellar-absorption features within 3 arcsec aperture spectra, which can be used to measure σ line (e.g. Greene & Ho 2006; Shen et al. 2008). About the method to measure σ line, refer to Bian et al. (2007), and the references therein. The gaseous velocity dispersion (e.g. σ core (O III)/σ line (N II)) is often used as a proxy for σ star (e.g. Nelson & Whittle 1996; Greene & Ho 2005a).

In our previous work based on NLS1s selected from the SDSS early data release (EDR), using Hβ FWHM to calculate the mass and [O III] narrow/core FWHM to give the σ line, we found that the SMBH masses of NLS1s deviated significantly from the well-known $M_{\text{BH}}$–σ line relation (Bian & Zhao 2004; Bian, Yuan & Zhao 2006). Here, we use the second moment of the broad Hβ profile to reinvestigate the SMBHs masses in NLS1s. All of the cosmological calculations in this paper assume $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$ and $\Omega_{\Lambda} = 0.7$.

2 SAMPLE AND DATA ANALYSIS

We use the largest sample of about 2000 NLS1s from SDSS Data Release 3 (DR3) (Zhou et al. 2006). Zhou et al. (2006) presented this sample of NLS1s selected from the objects assigned as ‘quasi-stellar objects’ and ‘galaxies’ in the spectroscopic data base of SDSS DR3. The only criterion is that the broad component of Hγ or Hδ is detected and is narrower than 2200 km s$^{-1}$ in FWHM. Using a Lorentzian function to model the broad Hβ profile, Zhou et al. (2006) obtained the FWHM and calculated SMBHs masses from the $R_{\text{BLR}}$–$L_{5100}$ relation of Kaspi et al. (2000). We use the latest SDSS spectra from Data Release 6 (DR6).

We briefly outline our steps to do the SDSS spectral analysis. (i) We use simple stellar population (SSP) synthesis to model the stellar contribution in the Galactic extinction-corrected spectra in the rest frame (Cid Fernandes et al. 2005; Bian et al. 2007). We include 45 templates from Bruzual & Charlot (2003; hereafter BC03) and one power-law component (representing the AGN continuum emission). During the stellar-population synthesis, we put twice the weight in the fit for strongest stellar-absorption features, such as Ca II K, G band and Ca II λ 4227, 8498, 8542, 8662 triplet. For details, see Bian et al. (2007) and the references therein. (ii) The optical and ultraviolet Fe template from the prototype NLS1 I Zw 1 is used to subtract the Fe emission from the residual spectra after the above step. (iii) Four Gaussians are used to model the Hβ profile, and two sets of two Gaussians are used to model the [O III]λ 4959, 5007 lines. We take the same linewidth for each component, and fix the flux ratio of [O III]λ 4959 to [O III]λ 5007 to be 1:3. Two components of Hβ (from the NLR) are set to have the same linewidth of each component of [O III]λ 5007 and their flux are constrained to be less than 1/2 of each component of [O III]λ 5007. Two broad components are used to model broad Hβ profile from the BLR contribution (broad component and intermediate component, BC and IC, respectively).

We present our spectral fitting method in detail in Hu et al. (2008). In the above three steps, the best fit is reached by minimizing $\chi^2$. $\chi^2 = \sum_i \left( \frac{y_i - \bar{y}_i}{\sigma_i} \right)^2 / N$, where $\sigma_i$ is the error of the data set ($x_i, y_i$) and $N$ is the degrees of freedom.

Objects without clear Hβ or [O III] lines are eliminated. In order to obtain a reliable spectral fit, we carefully select objects for analysis. We select objects by the following criteria: (i) the signal-to-noise ratio (S/N) is larger than 15. The S/N is measured in the wavelength 4800–5040 Å, covering the range for line fitting. (ii) $\chi^2$ in the above three steps (SSP, Fe subtraction and Hβ and [O III] lines fitting) is less than 2.5. (iii) The FWHM errors of BC and IC of Hβ from BLR and [O III]λ 4959, 5007 are less than 100 per cent. (iv) The height of one component of [O III] is less than the height of one component of [O III] by 30 per cent. The first criterion leads to about 900 NLS1s. The second and third criteria make sure that we have a good fitting of Hβ and [O III]. The fourth criterion makes us reliable to obtain the core/narrow component of [O III] line, and their linewidth is used to trace the σ line. Then, we visually check these spectra one by one. In the end, we have a sample of 329 NLS1s.

The first moment of the line profile is

$$\lambda_0 = \int \frac{\lambda P(\lambda) d\lambda}{\int P(\lambda) d\lambda}. \quad (2)$$

The second moment of the line profile is

$$\sigma_{\text{line}}^2 = \int \frac{\lambda^2 P(\lambda) d\lambda}{\int P(\lambda) d\lambda} - \lambda_0^2. \quad (3)$$

We use the BC and IC to reconstruct the broad Hβ profile as $P(\lambda)$. Then, we use the method of Peterson et al. (2004) to measure the FWHM and $\sigma_{\text{Hβ}}$ from the reconstructed broad Hβ profile (equations 2 and 3). The error of $\sigma_{\text{Hβ}}$ is calculated from the error of FWHM for BC and IC in the line fit. The FWHM measurement is not sensitive to the broad wing of Hβ, while the measurement of Hβ second moment is. We have to make sure the necessity of using BC and IC in the Hβ fitting (see also Dietrich et al. 2005). We use one broad component to model the Hβ profile from the BLR at the same time. When the $\chi^2$ in the fitting is decreased by 20 per cent with two Gaussian with respect to one Gaussian, we have to make sure that it is necessary to use BC and IC, and we use the result of two-Gaussian fitting, otherwise we use the result of one-Gaussian fitting. For Hβ profile with one-Gaussian fitting, the second moment is directly from our fitting and not from equations (2) and (3). For all objects, the measurement of FWHM is adopted from the two-Gaussian reconstructive profile. Hereafter, we call the total 329 NLS1s as sample A, 209 NLS1s with two-Gaussian fitting as sample B and the other 120 NLS1s with one-Gaussian fitting as sample C.
Figure 1. Top panel: an example fit for SDSS J123831.34+644356.5. The black line is the original spectrum after Galactic-extinction correction in the rest frame. The red line is the contribution from the host galaxy. The green line is the Fe II emission. The residual is shown at the bottom. The left-hand upper panel shows the region around Ca H+K λλ 3969, 3934 and G band. In the right-hand upper panel, we show the Hβ and [O iii] line fits, where the blue one with the highest peak is the IC, the blue one with the second highest peak is the BC, the two blue ones with the lower peaks are the components from NLRs. Bottom panel: another example of line fit for SDSS J084716.88+334858.9. The black line is the original spectrum after Galactic-extinction correction, star light subtraction, and the Fe II subtraction in the rest frame. The bottom panel is the residual. The multiple-Gaussian components are in blue and the sum of them is in red. The fitting window is in green.

As the strongest forbidden line in the SDSS spectral wavelength coverage, we use the gas velocity dispersion of the narrow/core [O III] component from NLRs to trace $\sigma_*$, $\sigma_{\text{core}}^{\text{O III}} = \sqrt{\sigma_{\text{obs}}^2 - [\sigma_{\text{inst}}/(1+z)]^2}$, where $z$ is the redshift. For SDSS spectra, the mean value of instrumental resolution $\sigma_{\text{inst}}$ is 60 km s$^{-1}$ for [O III] (e.g. Greene & Ho 2005a). We also reliably obtain $\sigma_*$ (correction of the resolutions of the SDSS spectra and BC03 templates) from our SSP synthesis for about 98 NLS1s. The error of $\sigma_*$ is given by different typical errors for different effective S/N at 4020 Å (Bian et al. 2007).

3 MASS FROM $\sigma_{\text{H}}$ AND FWHM

3.1 Mass estimation

With our measurement of $\sigma_{\text{H}}$, we use the more recent $R_{\text{BLR}}$–$L_{5100}$ relation (which seems to hold for NLS1s; Peterson et al. 2004) of Bentz et al. (2006) and $f = 3.85$ (Collin et al. 2006) to calculate the SMBHs masses in NLS1s. We also calculate the mass from our FWHM for the Hβ profile from the BLR by $R_{\text{BLR}}$–$L_{5100}$ relation of Bentz et al. (2006) and $f = 3$ (Netzer 1990). In Fig. 2, we
compare these two masses. For sample B, the best linear fit with fixed slope of 1 gives $y = x - 0.49$, the mass from $\sigma_{\text{H} \beta}$ is on average larger by 0.49 dex than that from FWHM. In Fig. 2(a), we show the distribution of FWHM $\sigma$, $1.33 \pm 0.36$, which deviates from 2.35 for a Gaussian profile. Our mass correction from $\sigma_{\text{H} \beta}$ with respect to mass from FWHM is mainly due to the H$\beta$ emission-line profile deviation from the Gaussian profile. For six NLS1s in Peterson et al. (2004), we find that the mass based on $\sigma_{\text{H} \beta}$ is on average larger by 0.46 dex with respect to that from FWHM, which is consistent with our calculation.

By using the FWHM derived from the Lorentzian profile, Zhou et al. (2006) calculated SMBHs masses from the $R_{\text{BLR}}-L_{5100}$ relation of Kaspi et al. (2000, $R_{\text{BLR}} \propto L_{5100}^{0.7}$) and $f = 3$. For comparison with the results of Zhou et al. (2006), we use the updated $R_{\text{BLR}}-L_{5100}$ relation of Bentz et al. (2006, $R_{\text{BLR}} \propto L_{5100}^{0.515}$) and $f = 3$ to calculate the mass. For the FWHM from Zhou et al. (2006), the updated $R_{\text{BLR}}-L_{5100}$ relation of Bentz et al. (2006) would lead the masses of Zhou et al. (2006) to be larger by 0.1–0.3 dex for NLS1s with mass less than $10^7 M_\odot$ (see Fig. 2b). By the best linear fit through zero, we find that FWHM in Zhou et al. (2006) derived from the Lorentzian profile is $0.84 \pm 0.01$ of our FWHM for objects in sample B, which leads to the decrease in SMBH mass by 0.15 dex if we use the FWHM of Zhou et al. (2006).

The use of $R_{\text{BLR}}-L_{5100}$ Relation of Kaspi et al. (2005) will decrease $M_{\text{BH}}$ by 0.17 dex with respect to that of Kaspi et al. (2000). If we use $f = 3.85$ instead of 3, the mass will increase by 0.11 dex. The uncertainty of the mass calculation from the H$\beta$ line is mainly from the systematic uncertainties, up to about 0.5 dex, which is due to the unknown kinematics and geometry in BLRs, and perhaps the effects of radiation pressure (e.g. Krolik 2001; Peterson et al. 2004; Decarli et al. 2008; Marconi et al. 2008).

### 3.2 The $M_{\text{BH}}-\sigma_{\text{H} \beta}$ Relation

In Fig. 3, we show the SMBH mass from $\sigma_{\text{H} \beta}$ versus $\sigma_{\text{[O III]}}$. In Fig. 3(a), we show the mass derived from our FWHM versus $\sigma_{\text{[O III]}}$. It is obvious that the mass from FWHM deviates from Tremaine et al. relation (solid line in Fig. 3a), which is consistent with the result of Zhou et al. (2006). In Fig. 3(a), we have shown the SMBH mass from $\sigma_{\text{H} \beta}$ versus $\sigma_{\text{H} \beta}$ that from our FWHM. The SMBH masses based on $\sigma_{\text{H} \beta}$ in 209 NLS1s of sample B are larger by about 0.5 dex with respect to that from FWHM.

For the solid line in Fig. 3, the $M_{\text{BH}}-\sigma_{\text{H} \beta}$ relation, $M_{\text{BH}}(\sigma_{\text{H} \beta}) = 10^{8.13} (\sigma_{\text{H} \beta}/(200 \text{ km s}^{-1}))^{1.12} M_\odot$ (Tremaine et al. 2002), we calculate the deviation of mass (see Table 1). In Fig. 3(b), we show the mass deviation from the Tremaine et al. relation versus the redshift. The dashed line is for no deviation and the solid line is the relation found by Woo et al. (2008). For redshifts of NLS1s larger than 0.4, their mean mass deviation is 0.28 $\pm$ 0.82 with respect to Tremaine et al. relation, and for NLS1s with redshift less than 0.4, the mean mass deviation is $-0.04 \pm 0.58$ (Woo et al. 2008). We calculate the Eddington ratio, i.e. the ratio of the bolometric luminosity ($L_{\text{bol}}$) to the Eddington luminosity ($L_{\text{edd}}$), where $L_{\text{edd}} = 1.63 \times 10^{38} (M_{\text{BH}}/M_\odot) \text{ erg s}^{-1}$. The bolometric luminosity is calculated from the monochromatic luminosity at 5100 Å, $L_{\text{bol}} = c^2 \lambda L_\lambda(5100 \text{ Å})$, where we adopt the correction factor $c_B$ of 9 (Kaspi et al. 2000; Richards et al. 2006; Netzer & Trakhtenbrot 2007). We do not find larger mass deviations for objects with larger Eddington ratio. In Table 1, we give the mass, Eddington ratio and the mass deviation from the $M_{\text{BH}}-\sigma_{\text{H} \beta}$ relation for A, B, C samples. For sample B, mass from $\sigma_{\text{H} \beta}$ can be increased by $\sim 0.5$ dex with respect to that from FWHM. For sample C, mass from $\sigma_{\text{line}}$ can be increased by 0.13 dex with respect to that from FWHM, which is due to the values of $f$. 

![Figure 2. The mass from the H$\beta$ FWHM versus the mass from the H$\beta$ second moment. The blue circles denote objects in sample B where the H$\beta$ from BLRs can be fitted well by two Gaussian with $\chi^2$ decreased by at least 20 pcen with respect to that by one Gaussian. The red circles denote objects in sample C with the H$\beta$ from BLRs can be fitted well by one Gaussian in order to avoid the broad wing effect in measurement of the second moment. The solid line is 1:1, and the red line is the best linear fit with the fixed slope of 1 for sample B, $y = x - 0.49$. Then FWHM and $\sigma_{\text{H} \beta}$ are measured from the reconstructed broad H$\beta$ profile. For sample C, there is a scatter from 1:1. For sample C, mass from $\sigma_{\text{line}}$ can be increased by 0.13 dex with respect to that from FWHM. (a) The distribution of FWHM $\sigma$ (H$\beta$) for 209 NLS1s in sample B. (b) SMBH mass from Zhou et al. (2006) versus that with updated the $R_{\text{BLR}}-L_{5100}$ relation of Bentz et al. (2006).]
that we are using for sigma \( (f = 3.85) \); and FWHM/2 \( (f = 3) \) are not exactly consistent with a single Gaussian, whereas in order to get the same mass for a single Gaussian the ratio of \( f \) values is 1.38. We also note that for NLS1s with mass larger than \( 10^9 \) \( M_\odot \), they tend to fall above the Tremaine et al. relation.

### 4 DISCUSSION

#### 4.1 Large SMBH masses in NLS1s?

In Fig. 3, we find that for some NLS1s mass from \( \sigma_{H\beta} \) is very large, up to \( 10^8-10^9 \) \( M_\odot \), which is due to their obvious broad wings in their \( H\beta \) profiles. With the near-infrared imaging data, Ryan et al. (2007) found that the average SMBH mass in their NLS1s sample is \( 10^{7.9} \) \( M_\odot \), where the mass is calculated from the mass and host galaxy luminosity relation. The mass is typical for BLS1s. They find that it is larger by 1.5 dex with respect to the mass calculated from the FWHM of Veron-Cetty, Veron & Goncalves (2001). We note that these objects have broad wings in their \( H\beta \) profile, especially in their \( H\alpha \) profile (fig. 2 in Veron-Cetty et al. 2001). It is possible that the sample of Zhou et al. (2006) has some objects that should not be classified as NLS1s. Considering the effects of the random velocity and the inclination in SMBH mass estimation of NLS1s, Decarli et al. (2008) found that these effects would increase the mass for NLS1s by 0.84 dex, which can account for the mass difference between NLS1s and BLS1s. The definition of NLS1s needs to be re-examined if we think that NLS1s harbour rapidly growing small SMBH with high accretion rate.

#### 4.2 \( \sigma_{H\beta} \) and FWHMs of BC, IC

The flux ratio of \( H\beta \) to [O\textsc{iii}]\( \lambda5007 \) from NLRs is often taken to be around 10 per cent (e.g. Osterbrock & Pogge 1985; McGill et al. 2008). Rodriguez-Ardila et al. (2000) suggested that this ratio is about 20–100 per cent due to which they just used two Gaussian to model the total \( H\beta \) profile and assumed the narrow \( H\beta \) component is from NLRs. The flux ratio of \( H\beta \) to [O\textsc{iii}]\( \lambda5007 \) from NLRs depends on the physics of the low-density gas found in NLRs photoionized by AGN, which is beyond the scope of this paper (e.g. Groves, Heckman & Kaufmann 2006; Kewley et al. 2006). During our fitting procedure of the \( H\beta \) and [O\textsc{iii}] lines, we add a conservative constraint to the \( H\beta \) contribution from NLRs, less than a half of [O\textsc{iii}]\( \lambda5007 \) flux.

For 209 NLS1s in sample B, the second moment \( \sigma_{H\beta} \) is calculated from the reconstructed \( H\beta \) profiles from BC and IC. We did a comparison between \( \sigma_{H\beta} \) and the FWHM of IC/BC. In Fig. 4, we show \( \sigma_{H\beta} \) versus FWHM of IC and BC. The dashed line is the relation of FWHM = 2.35 \( \times \sigma \) when a Gaussian profile is measured. We find that there is a much stronger correlation between the \( \sigma_{H\beta} \) versus FWHM of BC with respect to that for IC (see Fig. 4). If \( \sigma_{H\beta} \) is used to calculate the SMBH masses, the result depends much more on the BC FWHM than on the narrower IC FWHM. We think that if the \( H\beta \) profile from BLRs can be fitted well by one Gaussian,
for mass, there is no difference for the usage of Hβ FWHM and $\sigma_{H\beta}$.

The existence of BC and IC in the Hβ profile from BLRs have been investigated by many people (Baldwin et al. 1998; Brotherton et al. 1994; Rodriguez-Ardila et al. 2000; Wills et al. 1993; Leighly 2004; Dietrich et al. 2005), and it is suggested that BC and IC are emitted from two distinct emission regions. For 12 NLS1s, Dietrich et al. (2005) found that FWHM$_{BC} = 3275 \pm 800 \text{ km s}^{-1}$ and FWHM$_{IC} = 1200 \pm 300 \text{ km s}^{-1}$. For our 209 NLS1s in sample B, we also found that FWHM$_{BC} = 4098 \pm 1751 \text{ km s}^{-1}$ and FWHM$_{IC} = 1385 \pm 492 \text{ km s}^{-1}$.

Therefore, it is clear that there exists a BC in NLS1s that is typical for BLRs, and the IC displays typical Hβ FWHM in NLS1s. The equivalent width (EW) of BC for our 209 NLS1s in sample B is $19.4 \pm 8.6$ and $16.1 \pm 8.0$ Å for IC EW. There is no correlation between them.

### 4.3 $M_{BH} - \sigma_*$ relation

With FWHM from the Hβ Lorentzian profile, Zhou et al. (2006) used $R_{BLR-L_{5100}}$ relation of Kaspi et al. (2000) and $f = 3$ to calculate the mass. The updated $R_{BLR-L_{5100}}$ relation of Bentz et al. (2006) would lead to the mass of Zhou et al. (2006) larger by 0.1–0.3 dex for NLS1s with mass less than $10^7 M_\odot$ (see Fig. 2b), which would place NLS1s close to the Tremaine et al. $M_{BH} - \sigma_*$ relation when $\sigma_*$ is adopted from $\sigma_{[NII]}$ (see fig. 29 in Zhou et al. 2006). For a sample of 58 NLS1s selected from the 11th edition of the 'Catalogue of Quasars and AGN' (Veron-Cetty & Veron 2003) and SDSS DR3 by the $R_{BLR-L_{5100}}$ relation of Kaspi et al. (2005), Komossa & Xu (2007) suggested that NLS1s do follow the $M_{BH} - \sigma_*$ relation found in the inactive galaxies after excluding 'blue outliers' (see Bian, Yuan & Zhao 2005).

Using the second moment of broad Hβ profile, we find that the SMBH mass would be larger by ~0.5 dex with respect to that from Hβ FWHM in sample B with necessary two-Gaussian fitting. The larger masses make NLS1s follow the Tremaine et al. relation when the $\sigma_{[OIII]}$ is used as a surrogate for the bulge velocity dispersion. In Fig. 5, we find that some AGN lie far below the $M_{BH} - \sigma_*$ relation and we tried to determine if they are 'blue outliers'. No 'blue outliers' were found or it is impossible to measure the [O III] blueshift due to the low S/N in [S II] or [O II]. We also use [N II] FWHM (Zhou et al. 2006) as the $\sigma_*$, and find a similar result to that shown in Fig. 5, but with more scatter. The [N II] FWHM measurement depends on the H$\alpha$ profile fitting. And the [N II] FWHM is consistent with FWHM of [O III] core component, although the correlation is very weak (Komossa & Xu 2007).

In Fig. 5, we plot $M_{BH}$ from $\sigma_{H\beta}$ versus $\sigma_*$ for 37 NLS1s. For $\sigma_*$ from SSP synthesis, its uncertainty based on effective S/N at 4020 Å is typically about 24 km s$^{-1}$ at S/N = 5; 12 km s$^{-1}$ at S/N = 10; 8 km s$^{-1}$ at S/N = 15, where the effective S/N is the S/N (measured between 4010 and 4060 Å) multiplied by the stellar fraction (Cid Fernandez et al. 2005; Bian et al. 2007). The mass is calculated for AGN that satisfy the first two criteria in Section 2. The blue circles denote AGN with necessary two-Gaussian fits and the red circles denote AGN with one-Gaussian fits, which is the same as that in Fig. 2. For the total 37 NLS1s in Fig. 5, the mass is between 10$^6$ and 10$^8$ $M_\odot$, and the distribution of the mass deviation is $-0.24 \pm 0.46$. For 14 AGN with two-Gaussian fits, the distribution of the mass deviation is $-0.14 \pm 0.50$, and for 23 AGN with one Gaussian, the distribution is $-0.29 \pm 0.43$. If these 23 NLS1s follow Tremaine et al. relation, we need $f = 7.7$. The $\sigma_{[OIII]}$ is slightly larger than $\sigma_*$ for these 37 NLS1s (see Botte et al. 2005). For about 3000 type II Seyfert galaxies, Zhou et al. (2006) also found that $\sigma_{[NII]} = \sigma_* \times (2.62/2.35)$ and overestimate the $\sigma_*$ (also see Onken et al. 2004). Therefore, using the gas velocity dispersion to trace $\sigma_*$ will place NLS1s close to the $M_{BH} - \sigma_*$ relation and make the mass deviation smaller by 0.19 dex.

![Figure 4](image_url)  
**Figure 4.** The FWHM of BC (top panel) and IC (bottom panel) versus the Hβ second moment for sample B of 209 NLS1s. The dashed line is the relation between FWHM and the second moment, FWHM = $\sigma_{H\beta} \times 2.35$, for a Gaussian line profile.

![Figure 5](image_url)  
**Figure 5.** The $M_{BH} - \sigma_*$ relation for 37 AGN with reliable measurements of $\sigma_*$. The BC and IC have the same meaning as in Fig. 2. The solid line is the $M_{BH} - \sigma_*$ relation of Tremaine et al. (2002). The green dashed line is the $M_{BH} - \sigma_*$ relation of Ferrarese & Ford (2005). The line in the left-hand corner denotes the typical error in mass calculation.
For the total 37 NLS1s, there exists marginal evidence that they deviate from the $M_{\text{BH}}-\sigma_*$ relation found in the inactive galaxies. For 23 NLS1s with mass lower than $10^7\,M_\odot$, the deviation becomes much larger, up to $-0.46 \pm 0.40$ (also see Fig. 3), which is consistent with the result of Botte et al. (2005, their fig. 3), although it is not the case for the sample of Greene & Ho (2006) (also see Barth et al. 2005). If these 23 NLS1s follow the Tremaine et al. relation, we need $f = 11.1$. It is possible that the sample of Zhou et al. (2006) has some objects that cannot be classified by NLS1s. It is possible that there exists true NLS1s with rapidly growing small SMBH. The reliable measurements of mass and $\sigma_*$ are important for this kind of work.

5 CONCLUSIONS

The second moment of H$\beta$ line from BLRs is calculated to derive the SMBHs masses for a sample of 329 NLS1s selected from SDSS. The main conclusions can be summarized as follows: (i) for objects with necessary two-Gaussian fitting, the mean value of SMBH masses from the H$\beta$ second moment is larger by about 0.5 dex with respect to that from the H$\beta$ FWHM; (ii) using the narrow/core [O III] velocity dispersion as a surrogate for the stellar velocity dispersion, we find that the new masses based on the H$\beta$ broad emission-line second moment bring them to the Tremaine et al. relation; (iii) the H$\beta$ second moment is more strongly correlated with the BC FWHM rather than the IC FWHM; (iv) using $\sigma_*$ measured from SSP synthesis, we find that for NLS1s with masses lower than $10^7\,M_\odot$, they are marginally below the Tremaine et al. relation considering the larger scatter in mass calculation. If these 23 NLS1s follow Tremaine et al.’s relation, we need $f = 11.1$.

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