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# On the Black Hole – Bulge Mass Ratios in Narrow-Line Seyfert 1 Galaxies *

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**Abstract** We present estimated ratios of the central black hole mass to the bulge mass ($M_{\rm bh}/M_{\rm bulge}$) for 15 Narrow Line Seyfert 1 galaxies (NLS1s). It is found that NLS1s apparently have lower mass ratios: the average mass ratio is about $1 \times 10^{-4}$ with a spread of 2, which is one order of magnitude lower than for Broad Line AGNs and quiescent galaxies. This lower value, as compared to that established essentially for all other types of galaxies, can be accounted for by an underestimation of the black hole masses and an overestimation of the bulge masses in the NLS1s.

**Key words:** galaxies: active — galaxies: nuclei — galaxies: bulges — quasars — galaxies: Seyfert

## 1 INTRODUCTION

Massive black holes (MBH) are believed to exist in the center of both quiescent and active galaxies. The central MBH masses have been estimated for about 37 nearby quiescent galaxies (Kormendy & Gebhardt 2001). Using the reverberation mapping techniques (Wandel et al. 1999; Ho 1999; Kaspi et al. 2000), the central MBH masses for 37 AGNs have been evaluated. Using the broad H$\beta$ emission line and the BLR size derived from the continuum at 5100 Å (Kaspi et al. 2000), many central MBH masses in AGNs have been estimated in the literature (Kaspi et al. 2000; Laor 2001; McLure & Dunlop 2002; Wandel 2002).

It is found that there is a strong connection between the active galactic nuclei and their host galaxies. Magorrian et al. (1998) suggested that, for some nearby galaxies, the MBH mass is proportional to the luminosity of the host bulge with an average MBH/bulge ratio about 0.006. Laor (1998) also found a relation between the central MBH mass and the host bulge luminosity in a sample of 14 bright quasars. Recent research using higher quality HST data and a more careful treatment of the modelling uncertainties showed that the bulge luminosity is overestimated using the Hubble type correction, with an average MBH/bulge mass ratio about

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0.001 (Merritt & Ferrarese 2001; Kormendy & Gebhardt 2001). However, Laor (2001) suggested a nonlinear MBH/bulge mass relation, $M_{\rm BH} \sim M_{\rm bulge}^{1.54}$. For a larger sample of 72 AGNs and 20 nearby inactive galaxies, McLure & Dunlop (2002) found a mean MBH/bulge ratio of 0.0012, consistent with the value for inactive galaxies. Wandel (2002) showed that the AGNs have the same MBH/bulge relation as the inactive galaxies. He found the broad line (BL) AGNs to have an average MBH/bulge mass ratio of $\sim 0.0015$, while for a few narrow line (NL) AGNs the average ratio was substantially lower, at $\sim 10^{-4} - 10^{-3}$. Mathur (2000) suggested that NLS1s are likely to be active galaxies at an early stage of evolution. Mathur et al. (2001) estimated the MBH mass for 15 NLS1s by fitting their spectral energy distributions with an accretion disk and corona model (Kuraskiewicz et al. 2000) and found their mean MBH/bulge ratio to be 0.00005, lower by a factor of 30 compared to that for broad line AGNs.

The theory of MBH/bulge relation is discussed by several authors (Silk & Rees 1998; Wang 2000; Mathur 2000; Adams et al. 2001). In the framework of the hierarchical dark-matter cosmology, the formation and evolution of galaxies and their active nuclei are intimately related (Fabian 1999; Haehnelt et al. 1998; Mathur 2000). Adams et al. (2001) and Wang et al. (2000) theoretically clarified that the black hole to bulge mass ratio is not a constant. Loar (2001) suggested the mass ratios in late-type spirals and NLS1s are lower than in bright elliptical galaxies and in broad line AGNs.

NLS1s are supposed to have a smaller central MBH mass and a higher accretion rates close to the Eddington limit. Many evidences suggest that NLS1s are likely to be active galaxies at an early stage of evolution (Mathur 2000). The NLS1s could play a particular role in our understanding of the formation of the bulge and the central MBH in the galaxies, hence it is important to investigate their MBH/bulge mass ratios.

In this paper, we examine the MBH/bulge mass ratio for the NLS1s as compared to the BL AGNs. In Section 2 we present the sample used and their calculated MBH/bulge ratios. The result and a discussion are presented in Section 3, and in Section 4 we summarize our conclusion. All the cosmological calculations in this paper assume $H_0 = 75\,{\rm km\ s^{-1}}$, $\Omega = 1.0, \Lambda = 0$.

## 2 THE DATA

In order to investigate the MBH/Bulge mass ratio in NLS1s, we collected the available data in the literature on the bulge luminosity (Mackenty 1990; Whittle 1992; Bahcall et al. 1997; Malkan et al. 1998) and the central MBH mass (Veron-Cetty et al. 2001; Wang & Lu 2001). We selected those NLS1s with available data of both BMH mass and bulge luminosity. Veron-Cetty et al. (2001) have compiled 83 objects known to us before January 1998 either to be NLS1s or to have a "broad" Balmer component narrower than $2000\,{\rm km\ s^{-1}}$; these objects are located north of $\delta = -25°$, bright than $B = 17.0$ and with $z < 0.1$. Measurements at a moderate resolution of 3.4 Å for 59 NLS1s of the instrument-subtracted [OIII] and H$\beta$ widths as well as the optical magnitudes at the B band are listed in Tables 2 and 3 in Veron-Cetty et al.(2001); these were used to calculate the MBH masses. We obtained the absolute B magnitude of the bulge ($M_B^{\rm bulge}$) and calculated the mass of the bulge. The number of NLS1 suitable for our study is limited because there is so little information about NLS1s bulge luminosity. We obtained a sample of 15 NLS1s (Table 1). Wandel (2002) derived the MBH/bulge relation for 46 BL AGNs, nine NL AGNs and 35 quiescent galaxies. Two NLS1s (Mrk 335, NGC 4051) are common to Wandel (2002) sample and our sample.

### 2.1 Determination of the MBH Mass

Only two NLS1s (Mrk 335, NGC 4051) in our sample have been estimated before for the central MBH mass by the reverberation mapping method. For the other 13 NLS1s we evaluated the size of the BLR using the empirical correlation between the size and the monochromatic luminosity at 5100 Å (Kaspi et al. 2000):

$$R_{\rm BLR} = 32.9\Big(\frac{\lambda L_\lambda(5100\,\text{Å})}{10^{44}{\rm erg\cdot s^{-1}}}\Big)^{0.7} \quad {\rm lt \;\; days.} \tag{1}$$

Here $\lambda L_\lambda(5100\,\text{Å})$ is estimated from the B-magnitude by adopting an average optical spectral index of –0.5 and after correcting for Galactic reddening and applying the K-correction. If the H$\beta$ width reflects the keplerian velocity, $V$, of the line-emitting BLR material around the central MBH, then the so-called virial mass estimated for the central MBH is given by

$$M_{\rm bh} = R_{\rm BLR} V^2 G^{-1}, \tag{2}$$

$G$ being the gravitational constant. Assuming random orbits, Kaspi (2000) related the $V$ to the FWHM of the H$\beta$ emission line by $V = (\sqrt{3}/2){\rm FWHM}_{[{\rm H}\beta]}$. The calculated central MBH masses for the 15 NLS1s are listed in Table 1 (Wang & Lu 2001).

### 2.2 Determination of the Bulge Mass

We evaluate the bulge masses for 15 NLS1s from the absolute B magnitude of the bulge ($M_B^{\rm bulge}$) of the host galaxies (Laor 1998; Wandel et al. 1999; Mathur 2000). $M_B^{\rm bulge}$ is calculated from the galaxy's total B bulge magnitude ($M_B^{\rm total}$) by the equation in Simien & de Vaucouleurs (1986):

$$M_B^{\rm bulge} = M_B^{\rm total} - 0.324\tau + 0.054\tau^2 - 0.0047\tau^3, \tag{3}$$

where $\tau = T + 5$ and $T$ is the Hubble type of the galaxy. We adopted a canonical Hubble type of Sa for Mrk734, Mrk486, and Mrk1239. For Mrk1044, Mrk382, and Mrk493 we took the host galaxy magnitude from MacKenty (1990), who included nuclear emission in the total blue magnitude. Hence, in Table 1, we quote the blue magnitude as an upper limit. Then we use the relation between the bulge $B$ and $V$ magnitude $B - V = 0.8$ and calculate the bulge luminosity from the empirical formula:

$$\log(L_{\rm bulge}/\,L_\odot) = 0.4(-M_V^{\rm bulge} + 4.83). \tag{4}$$

Finally, using the relation between the bulge mass and the bulge luminosity for normal galaxies from Magorrian et al. (1998),

$$\log(M_{\rm bulge}/\,M_\odot) = 1.18\log(L_{\rm bulge}/\,L_\odot) - 1.11\ , \tag{5}$$

we calculated the bulge masses of 15 NLS1s given in Table 1. Table 1 lists, in turn, Col.1: name, Col.2: Hubble type of the host galaxy, Col.3: log of the estimated MBH mass in $M_\odot$, Col.4: log of the estimated bulge mass in $M_\odot$, Col.5: log of the MBH/bulge mass ratio. [a]: the bulge absolute blue magnitude from Malkan et al. (1998), [b]: the bulge absolute blue magnitudes are adopted from MacKenty (1990), the others are adopted from Whittle (1992). [c]: the Hubble type is unknown and we adopt a canonical Hubble type of Sa.

**Table 1** Central MBH and the Bulge of 15 NLS1s

| Name | Type | $\log(M_{\rm bh})$ | $\log(M_{\rm bulge})$ | $\log(\frac{M_{\rm bulge}}{M_{\rm bh}})$ |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| Mrk 335 | S0/a | 6.80 | 10.73 | –3.93 |
| Mrk 359 | SB0 | 6.23 | 10.82 | –4.59 |
| Mrk 705 | S0 | 6.92 | 11.11 | –4.20 |
| Mrk 124 | Sb | 7.20 | 10.51 | –3.31 |
| Mrk 142 | S | 6.67 | 10.59 | –3.91 |
| Mrk 42 | SBb | 6.00 | 9.70 | –3.70 |
| NGC 4051 | SABbc | 6.11 | 10.43 | –4.32 |
| Mrk 766 | SBa | 6.63 | 10.62 | –3.99 |
| Akn 564 | SBb | 6.46 | 10.62 | –4.16 |
| Mrk 486 | Sa[c] | 7.03 | 10.66 | –3.63 |
| Mrk 734 | Sa[c] | 7.34 | 11.27 | –3.93 |
| Mrk 1239 | Sa[c] | 6.38 | 10.40 | –4.02 |
| Mrk 382 | Sc | 6.61 | 10.82 | –4.21 |
| Mrk 493[a] | SBb | 6.11 | 10.07 | –3.96 |
| Mrk 1044[b] | SB0 | 6.23 | 10.76 | –4.53 |

### 2.3 $M_{\rm bh}/M_{\rm bulge}$ Distribution

For the 15 NLS1s we find a mean $\log(M_{\rm bh}/M_{\rm bulge})$ of $-4.02 \pm 0.33$, which is one order of magnitude lower than for BL AGNs. Mathure et al. (2001) found a smaller $M_{\rm bh}/M_{\rm bulge}$ value of 0.00005. The difference is due to their underestimated MBH masses from spectral fitting. Wandel (2002) also found smaller $M_{\rm bh}/M_{\rm bulge}$ values for nine NL AGNs.

## 3 DISCUSSION

Although the calculated mean $M_{\rm bh}/M_{\rm bulge}$ is about $10^{-4}$, which is an order of magnitude lower than that of BL AGNs and quiescent galaxies, we should note that there are systematic errors in the calculations of the black hole masses and the bulge masses.

The errors in the central MBH masses calculated with Eqs.(1), (2) are from systematic errors in the BLR size and virial mass calculation, and from random measurement errors. The former depends on the geometry and dynamics of the BLR, and could amount to a factor of 3 in either direction (Krolik 2001). McLure & Dunlop (2002) considered a model in which the orbits of the line-emitting material have a flattened geometry rather than randomly orientated. With this modification in the MBH mass calculation, McLure & Dunlop (2002) found the scatter around the $M_{\rm bh} - L_{\rm bulge}$ relation is significantly reduced. The inclination factor is sensitive to the FWHM of H$\beta$ especially for NLS1s (fig.1 in McLure & Dunlop 2002; Bian & Zhao 2002). So it is necessary to calculate the MBH mass of NLS1s taking into account the inclination factor. This means that the black hole masses on average have been underestimated, quite plausibly by a factor about 1.5.

The errors in the calculated bulge masses are mainly related to the calculation of the bulge magnitude and the mass-light relation for the bulge. The bulge luminosity for NLS1s is based on the total galaxy and nuclear luminosity. For the available data we used we cannot reliably remove the nuclear component and the estimation of the bulge luminosity will be biased toward a higher value by at least a factor of 2. The bulge luminosity obtained by bulge/disk decomposition of the galaxy images tends to be systematically lower than that from the empirical formula relating the bulge/total ratio to the Hubble type( Simien & de Vauculours 1986). The latter has an average bulge luminosity typically lower by a factor of 3 (McLure & Dunlop 2001). The bulge luminosity deduced here is likely to have been overestimated by a factor of about 6. In the mass-light relation, $M_{\rm bulge} \propto L_{\rm bulge}^{\beta}$, $\beta$ is usually adopted as 1.18 since this value was determined through stellar dynamics (Magorrian et al. 1998). However, McLure & Dunlop (2001) assumed the relation $M_{\rm bulge} \propto L_{\rm bulge}^{1.31}$ (Jorgensen et al. 1996). In the present paper we adopt $\beta = 1.18$. So we should consider the difference in the mass-light relation when we compare different results of the MBH/bulge mass ratio. The calculated bulge mass from the luminosity is likely to have been overestimated by a factor of about 6, or more.

Considering the biases in the estimations of the bulge masses and the black hole masses, the MBH/bulge mass ratio should be increased by a factor of about 10. This is enough to account for all of the discrepancy in the MBH/bulge mass ratio between NLS1s and all the other types of galaxies. Careful bulge/disc decomposition from HST images is needed to yield reliable bulge luminosities and hence bulge masses, rather than using the corrections from the Hubble type.

## 4 CONCLUSIONS

We have calculated the MBH/bulge mass ratios for a sample of 15 NLS1s using the FWHM of H$\beta$, nuclear B magnitude and the bulge absolute B band magnitude. We obtained a mean MBH/bulge mass ratio $1 \times 10^{-4}$ with a spread of 2, which is lower by one order of magnitude compared to BL AGNs. However, biases in the calculations of the black hole masses and the bulge masses will lead to an underestimation of the mean MBH/bulge mass ratio in NLS1s. Careful bulge/disc decomposition from HST images instead of the corrections from the Hubble type is necessary for this research.

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