Black Hole – Bulge Relation for Narrow-Line Objects

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(Received 2002 October 23; accepted 2002 November 20)

Abstract

It has been thought that narrow-line Seyfert 1 galaxies are likely to be in the early stages of the evolution of active galaxies. To test this suggestion, the ratios of the central massive black hole (MBH) mass to the bulge mass ($M_{\text{bh}}/M_{\text{bulge}}$) were estimated for 22 Narrow Line AGNs (NL AGNs). It is found that NL AGNs appear to have genuinely lower MBH/Bulge mass ratio ($M_{\text{bh}}/M_{\text{bulge}}$). The mean $\log(M_{\text{bh}}/M_{\text{bulge}})$ for 22 NL AGNs is $-3.9 \pm 0.07$, which is an order of magnitude lower than that for Broad Line AGNs and quiescent galaxies. We suggest a nonlinear MBH/Bulge relation and find there exists a relation between the $M_{\text{bh}}/M_{\text{bulge}}$ and the velocity dispersion, $\sigma$, derived from the [O III] width. A scenario of MBH growth for NL AGNs is one of our interpretations of the nonlinear MBH/Bulge relation. The MBH growth timescales for 22 NL AGNs were calculated, with a mean value $(1.29 \pm 0.24) \times 10^{8}$ yr. Another plausible interpretation is also possible: that NL AGNs occur in low-$M_{\text{bulge}}$ galaxies and that in such galaxies $M_{\text{bh}}/M_{\text{bulge}}$ is lower than that in galaxies with a higher $M_{\text{bulge}}$, if we consider that NL AGNs already have their “final” $M_{\text{bh}}/M_{\text{bulge}}$. More information of the bulge in NL AGNs is needed to clarify the black hole – bulge relation.

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

1. Introduction

Evidence shows that there is a strong connection between active galactic nuclei and their host galaxies. Within the framework of the hierarchical dark-matter cosmology, the formation and evolution of galaxies and their active nuclei is intimately related (Fabian 1999; Haehnelt et al. 1998; Mathur 2000).

Magorrian (1998) found that the central massive black hole (MBH) mass is proportional to the mass of the host bulge in a sample of nearby galaxies, hereafter referred to as the MBH/Bulge relation, with the MBH mass being about 0.006 of the bulge mass. Laor (1998) also found this relation for 14 bright quasars. Recent research using higher quality HST data and a more careful treatment of the modelling uncertainties give lower values of the central MBH masses in nearby galaxies, with an average MBH-to-bulge mass ratio of about 0.001 and a nearly linear MBH – Bulge relation, $M_{\text{bh}} \propto L_{\text{bulge}}^{0.05}$ (Merritt, Ferrarese 2001; Kormendy, Gebhardt 2001; McLure, Dunlop 2001, 2002).

However, Laor (2001) suggested a nonlinear MBH/Bulge mass relation, $M_{\text{bh}} \sim M_{\text{bulge}}^{1.54}$, and showed that the mean MBH-to-bulge mass ratio is therefore not a universal constant, which is related to the bulge masses. The bulge information of late-type spirals and of narrow line Seyfert 1 galaxies (NLS1s) (both predicted to have low $M_{\text{bh}}$) can test the MBH/Bulge nonlinear relation. Wandel (2002) revised the MBH/Bulge relation for a sample of 55 AGNs and 35 inactive galaxies. He found that broad-line AGNs (BL AGNs) have an average MBH/Bulge mass ratio of $\sim 0.0015$ and strong correlations, $M_{\text{bh}} \propto L_{\text{bulge}}^{0.9}$, $M_{\text{bh}} \propto \sigma^{3.5-5}$. For a few narrow-line AGNs (NL AGNs) in Wandel (2002), the average MBH/Bulge mass ratio is really lower, $\sim 10^{-4}$.

Mathur (2000) has proposed that the NLS1s are likely to be active galaxies in an early stage of evolution, and therefore have a lower MBH/Bulge mass ratio than BL AGNs. Mathur et al. (2001) have estimated the central MBH mass for 15 NLS1s by fitting their spectral energy distributions with the accretion disk and corona model (Kuraskiewicz et al. 2000), and found the mean mass ratio of the MBH/Bulge to be 0.00005, lower by a factor of 30 compared to that for broad-line AGNs.

It is found that the central MBH mass is not only related to the bulge luminosity, but also to the bulge velocity dispersion. Ferrarese and Merritt (2000) and Gebhardt et al. (2000a) have found that the MBH mass of inactive galaxies is better correlated with the stellar velocity dispersion in the host bulge than with the bulge luminosity, and that the relations are respectively $M_{\text{bh}} \propto \sigma^{4.80}$ and $M_{\text{bh}} \propto \sigma^{3.75}$. Gebhardt et al. (2000b) and Ferrarese et al. (2001) showed that the MBH masses of a few Seyfert galaxies from reverberation mapping are consistent with the relation between the MBH mass and galaxy velocity dispersion which they have found in inactive galaxies.

The theoretical interpretation for the MBH/Bulge relation is discussed based on several models. One model is about merger-driven starbursts with black hole accretion (Kauffmann, Haehnelt 2000). Some models are based on black hole accretion influencing the star formation and gas
dynamics in the host galaxies (Silk, Rees 1998; Blandford 1999). Adams et al. (2001) presented an idealized model of the collapse of the inner part of protogalaxies, and assumed the MBH mass is determined when the centrifugal radius of the collapse flow exceeds the capture radius of the central MBH. They produced the observed relation between the MBH mass and the galactic velocity dispersion, and predicted the mass ratio of the MBH/Bulge: \( M_{bh}/M_{bulge} \approx 0.004(\sigma/200 \text{ km s}^{-1}) \). Wang et al. (2000) presented a model which could explain the MBH/Bulge relation in AGNs and the dependence on the environmental parameters of the host galaxies, such as the gas or stellar velocity dispersion, as well as the relation of the central star burst and accretion process during galactic interaction. They also discussed the mass ratio of MBH/Bulge based on a unified formation scheme, where the bulge formation and nucleus activity are triggered by galaxy mergers or tidal interactions, and found a correlation of the mass ratio of the MBH/Bulge to be roughly \( M_{bh}/M_{bulge} \propto \sigma^{-4} \).

It is important to investigate the lower limit of the MBH/Bulge mass ratio because it will reveal physical links between the bulge and the MBH. There has been a progress concerning the estimation method of the central MBH mass in AGNs (Wandel et al. 1999; Ho 1999; Kaspi 2000; Wang, Lu 2001). NLS1s are suggested to have smaller central MBH masses with higher accretion rates close to the Eddington limit. Therefore, NLS1s could play a particular role to understand the formation of the bulge and central MBH in galaxies.

In this paper, we investigate the MBH/Bulge relation in NL AGNs compared with BL AGNs using the recent estimation of MBH masses of NL AGNs. In section 2 we present a sample of the NL AGNs, along with the estimated mass of the central MBH and the bulge. In section 3 we explore the MBH/Bulge relation for the BL AGNs and NL AGNs. The result and a discussion are presented in section 4, and in section 5 we summarize our conclusion. All of the cosmological calculations in this paper assume \( H_0 = 75 \text{ km s}^{-1}, \Omega = 1.0, \Lambda = 0 \).

2. The Sample of Narrow Line AGNs

In order to investigate MBH/Bulge relation in NL AGNs, we used available data of the bulge luminosity (Mackenty 1990; Whittle 1992; Bahcall et al. 1997; Malkan et al. 1998) and central MBH mass (Veron-Cetty et al. 2001; Wang, Lu 2001) for NL AGNs in the literature. We selected NL AGNs with the BH mass and the bulge luminosity. Veron-Cetty et al. (2001) have compiled 83 objects known to us before 1998 January either to be NLS1s or to have a “broad” Balmer component narrower than 2000 km s\(^{-1}\), north of \( \delta = -25^\circ \), bright than \( B = 17.0 \) and with \( z < 0.1 \). The measurement with a moderate resolution of 3.4 \( \AA \) for 59 NLS1s of the instrument-subtracted [O III] and H\( \beta \) widths as well as the optical magnitude at \( B \) band are listed in table 2 and table 3 in Veron-Cetty et al. (2001), which are used to calculate MBH masses. We obtained the bulge absolute blue magnitude \( (M_B^{\text{bulge}}) \) to calculate the mass of the bulge. The number of NLS1 suitable for studying the NLS1s MBH/Bulge relation is limited because there is so little information about the NLS1 bulge luminosity. We obtained a sample of 22 NL AGNs (table 1). Wandel (2002) derived the MBH/Bulge relation for 46 BL AGNs, 9 NL AGNs, and 35 quiescent galaxies. Our sample includes all 9 NL AGNs in the Wandel (2002) sample.

2.1. Determination of the MBH Mass

The central MBH masses of only 6 NL AGNs (Mrk 335, NGC 4051, 3C 120, Mark 110, Mrk 590, PG 1704) in our sample were estimated from the reverberation mapping method. For the other 16 NL AGNS, we estimated the size of the broad line region (BLR) using an empirical correlation between the size and the monochromatic luminosity at 5100 \( \AA \) (Kaspi et al. 2000),

\[
R_{BLR} = 32.9 \left( \frac{\lambda L_{\lambda}(5100 \ \text{\AA})}{10^{44} \text{erg s}^{-1}} \right)^{0.7} \text{ lt} - \text{d},
\]

where \( \lambda L_{\lambda}(5100 \ \text{\AA}) \) was estimated from the \( B \)-magnitude by adopting an average optical spectral index of -0.5 and accounting for the galactic redding and \( k \)-correction. If the H\( \beta \) widths reflect the Keplerian velocity of the line-emitting BLR material around the central MBH, then the so-called virial mass estimated for the central MBH is given by

\[
M_{bh} = R_{BLR} V^2 G^{-1},
\]

where \( G \) is the gravitational constant, and \( V \) is the velocity of the line-emitting material. \( V \) can be estimated from the H\( \beta \) width. Assuming random orbits, Kaspi (2000) related the \( V \) to the FWHM of the H\( \beta \) emission line by \( V = (\sqrt{3}/2) \text{FWHM}_{\text{H}\beta} \). The calculated central MBH masses for 15 NLS1s are listed in table 1 (Wang, Lu 2001).

2.2. Determination of the Bulge Mass

We estimate the bulge masses of the NLS1s from the bulge absolute blue magnitude \( (M_B^{\text{bulge}}) \) of the host galaxies (Laor 1998; Wandel 1999; Mathur 2000). \( M_B^{\text{bulge}} \) was calculated from the galaxy’s total bulge blue magnitude \( (M_B^{\text{total}}) \) by the Simien and de Vaucouleurs (1986) equation,

\[
M_B^{\text{bulge}} = M_B^{\text{total}} - 0.324 \tau + 0.054 \tau^2 - 0.0047 \tau^3,
\]

where \( \tau = T + 5 \) and \( T \) is the Hubble-type of the galaxy. We adopted a canonical Hubble-type of Sa for Mrk 734, Mrk 486, and Mrk 1239. For Mrk 1044, we took the host galaxy magnitudes 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. We then use the relation between the bulge \( B \) and \( V \) magnitudes. We used \( B - V = 0.8 \), and calculated the bulge luminosity from the empirical formula,

\[
\log(L_{\text{bulge}}/L_{\odot}) = 0.4(-M_B^{\text{bulge}} + 4.83).
\]

Finally, we used the mass and luminosity relation for normal galaxies from Magorrian et al. (1998),
The calculated bulge masses of NLS1s are listed in table 1.

3. MBH – Bulge Relation

3.1. \( M_{bh}/M_{bulge} \) Distribution

For 22 NL AGNs we found the mean \( \log(M_{bh}/M_{bulge}) \) to be \(-3.9 \pm 0.07\), which is an order of magnitude lower than that of BL AGNs. Mathur et al. (2001) found a smaller \( M_{bh}/M_{bulge} \) value of 0.00005. The difference is due to their underestimated MBH masses from the spectral fitting. Wandel (2002) also found a smaller \( M_{bh}/M_{bulge} \) value for 9 NL AGNs \((-3.9 \pm 0.27)\), which is consistent with our results.

3.2. The Nonlinear \( M_{bh} – M_{bulge} \) Relation

In figure 1 we plot the bulge mass vs. the MBH mass for 22 NL AGNs. There is a significant correlation with a correlation coefficient of \( R = 0.74 \), corresponding to a probability of \( P = 1.23 \times 10^{-4} \) that the correlation is caused by a random factor. The best linear fit is

\[
\log(M_{bulge}/M_\odot) = 1.18 \log(L_{bulge}/L_\odot) - 1.11. \tag{5}
\]

The calculated bulge masses of NLS1s are listed in table 1.

### Table 2. Central MBH and the bulge properties of AGNs (Wandel 2002), except our 22 NL AGNs.

| Name            | \( \log M_{bulge} \) | \( \log M_{bh} \) | \( \log M_{bh}/M_{bulge} \) | \( [\text{O III}] \) |
|-----------------|---------------------|-----------------|-----------------------------|---------------------|
| (1)             | (2)                 | (3)             | (4)                         | (5)                 |
| 0736+017        | 11.46               | 7.99            | -3.47                       | 540                 |
| 0953+41         | 11.08               | 8.39            | -2.69                       | 640                 |
| 1004+13         | 11.70               | 9.09            | -2.61                       | 470                 |
| 1020-103        | 11.36               | 8.35            | -3.01                       | 430                 |
| 1116+215        | 11.51               | 8.22            | -3.29                       | 380                 |
| 1202+28         | 11.08               | 8.29            | -2.79                       | 500                 |
| 1217+023        | 11.55               | 8.40            | -3.15                       | 380                 |
| 1226+02         | 11.84               | 8.61            | -3.23                       | 470                 |
| 1302-10         | 11.41               | 8.30            | -3.11                       | 710                 |
| 1425+267        | 11.36               | 9.32            | -2.04                       | 310                 |
| 1444+40         | 11.13               | 8.06            | -3.07                       | 540                 |
| 1545+21         | 11.32               | 8.93            | -2.39                       | 610                 |
| 2135-14         | 11.41               | 8.94            | -2.47                       | 360                 |
| 2141+175        | 11.55               | 8.74            | -2.81                       | 1120                |
| Mrk79†          | 10.15               | 8.02            | -2.13                       | 350                 |
| Mrk817†         | 10.33               | 7.56            | -2.77                       | 330                 |
| NGC2327†        | 9.47                | 7.69            | -1.78                       | 485                 |
| NGC3516†        | 10.69               | 7.36            | -3.33                       | 250                 |
| NGC4151†        | 9.31                | 7.08            | -2.23                       | 425                 |
| NGC4593†        | 10.21               | 6.91            | -3.30                       | 255                 |
| NGC5548†        | 10.31               | 7.83            | -2.48                       | 410                 |
| NGC6814†        | 9.81                | 7.08            | -2.73                       | 125                 |

* Col1, name; Col2, \( \log \) of the estimated bulge mass in \( M_\odot \); Col3, \( \log \) of the estimated MBH mass in \( M_\odot \); Col4, \( \log \) of the MBH/Bulge mass ratio; Col5, FWHM (in \( km/s \)) of [O III]. The MBH and bulge mass are all adopted from Wandel (2002).

† Seyfert galaxies, the others are PG quasars. The FWHM of [O III] for PG quasars are adopted from Marziani et al. (1996) and that for Seyfert galaxies are from Whittle (1992).

3.3. \( M_{bh}/M_{bulge} – \sigma \) Relation

Nelson and Whittle (1995) found that the stellar velocity dispersion in the host galaxy can be converted from the [O III] FWHM in AGNs by \( \sigma = \text{FWHM}_{[\text{O III}]} / 2.35 \). Nelson (2001) has shown that the relation between MBH mass and the bulge velocity dispersion derived from the FWHM of [O III] in AGNs is in good agreement with the \( M_{bh} – \sigma \) relation defined by nearby inactive galaxies. Wang & Lu (2001) also show that it is the same for NLS1s. We here use FWHM of the narrow line [O III] as a representation of the bulge velocity dispersion. The available FWHM of [O III] and \( M_{bh}/M_{bulge} \) except our 22 NL AGNs, are listed in table 2. In figure 2 we plot the MBH/Bulge mass ratio vs. the velocity dispersion for all available data. We find that there is a moderately strong correlation between them with \( R = 0.55 \) (\( P = 2.25 \times 10^{-4} \)). NGC 6814 is excluded in our fit because of its departure too much from the trend. The MBH mass of NGC 6814 may be overestimated from the overestimation of FWHM.
Table 1. Central MBH and the bulge properties of 22 NL AGNs.

| Name        | log $M_{bh}$ | log $M_{bulge}$ | log $M_{bulge}/M_{bh}$ | log $L_{bol}$ | log $L_{bol}/L_{Edd}$ | [O III] | $t_s$ |
|-------------|--------------|-----------------|------------------------|--------------|------------------------|---------|-------|
| Mrk 335     | 6.80         | 10.56           | -3.76                  | 44.79        | -0.12                  | 245     | 1.67  |
| Mrk 359     | 6.23         | 10.11           | -4.59                  | 44.66        | 0.32                   | 180     | 0.75  |
| Mrk 705     | 6.92         | 11.11           | -4.20                  | 44.79        | -0.24                  | 365     | 2.06  |
| Mrk 124     | 7.20         | 10.51           | -3.31                  | 45.17        | -0.15                  | 380     | 0.51  |
| Mrk 142     | 6.67         | 10.59           | -3.91                  | 44.77        | -0.02                  | 260     | 0.96  |
| Mrk 42      | 6.00         | 9.70            | -3.70                  | 44.40        | 0.28                   | 220     | 0.38  |
| NGC 4051    | 6.11         | 10.05           | -3.94                  | 43.56        | -0.66                  | 200     | 4.36  |
| Mrk 766     | 6.63         | 10.62           | -3.99                  | 44.51        | -0.24                  | 220     | 1.73  |
| Akn 564     | 6.46         | 10.62           | -4.16                  | 45.04        | 0.47                   | 220     | 0.39  |
| Mrk 486     | 7.03         | 10.66           | -3.63                  | 44.65        | -0.11                  | 400     | 0.85  |
| Mrk 734     | 7.34         | 11.27           | -3.93                  | 45.37        | -0.08                  | 180     | 1.14  |
| Mrk 1239    | 6.38         | 10.40           | -4.02                  | 44.65        | 0.16                   | 400     | 0.71  |
| Mrk 382     | 6.61         | 10.82           | -4.21                  | 44.78        | 0.43                   | 155     | 1.31  |
| Mrk 493†    | 6.11         | 10.07           | -3.96                  | 44.74        | 0.01                   | 315     | 0.81  |
| Mrk 1044‡   | 6.23         | 10.76           | -4.53                  | 44.52        | 0.29                   | 335     | 0.30  |
| 3C 120      | 7.36         | 10.72           | -3.36                  | 45.34        | -0.13                  | 230     | 0.56  |
| Mrk 110     | 6.75         | 10.74           | -3.99                  | 44.71        | -0.15                  | 290     | 1.42  |
| Mrk 590     | 7.25         | 11.03           | -3.78                  | 44.63        | -0.73                  | 400     | 4.34  |
| 0157+001    | 7.7          | 11.79           | -4.09                  | 45.62        | -0.19                  | -       | 1.70  |
| 1402+26     | 7.28         | 10.61           | -3.33                  | 45.13        | -0.26                  | -       | 0.70  |
| 1704+60     | 7.57         | 11.13           | -3.56                  | 46.33        | 0.65                   | 440     | 0.13  |
| 2247+140    | 7.59         | 11.55           | -3.96                  | 45.47        | -0.23                  | -       | 1.66  |

* Col.1: name, Col.2: log of the estimated MBH mass in $M_\odot$, Col.3: log of the estimated bulge mass in $M_\odot$, Col.4: log of the MBH/Bulge mass ratio, Col.5: log of the the bolometric luminosity in unit of erg s$^{-1}$, Col.6: log of the ratio of the bolometric luminosity to the Eddington luminosity, Col.7: FWHM (in km s$^{-1}$) of [O III], Col.8: growth timescale for NLS1s in unit of $10^8$ yr.
† The bulge absolute blue magnitude from Malkan (1998).
‡ The bulge absolute blue magnitudes are adopted from MacKenty (1990), the others are adopted from Whittle (1992).

In this subsection, we calculated the ratio of the bolometric luminosity, $L_{bol}$, to the Eddington luminosity, $L_{Edd}$. $L_{bol}$ is usually calculated by $L_{bol} = 10\lambda L_{5100}$, where $L_{5100}$ is the monochromatic luminosity at 5100 Å (Wandel et al. 1999). Here, we adopt the bolometric luminosity from Woo and Urry (2002), which was taken from the spectral energy distribution (SED). The result of the cal-

![Fig. 2. MBH/Bulge mass ratio versus the stellar velocity dispersion derived from FWHM of [O III]. The solid squares denote NL AGNs and the open circles denote BL quasars. The thick solid line is the best fit to all objects with the available FWHM of [O III] (table 1 and table 2). The dashed line is the theoretical line predicted by Adams et al. (2001) and the dotted line is that from Wang et al. (2000).](image-url)
3 we plot the central MBH mass against the calculated Eddington ratio is presented in table 1. In figure 3 we find there is a correlation between the MBH mass and the bulge absolute magnitude with the Eddington limit. 22 NL AGNs are shown as filled squares. The location of the Eddington limit is shown by the vertical dash line. The best-fit relation for 72 objects found by McLure & Dunlop (2001) is shown by the solid line.

4. Discussion

If the relation of the MBH mass to the bulge luminosity is given by $M_{bh} \propto L_{bulge}^\alpha$, the mass-to-light ratio for the bulge is parameterized as $M_{bulge} \propto L_{bulge}^\beta$, and the MBH/Bulge mass ratio is given by $M_{bh} \propto M_{bulge}^\alpha$. Some authors give the relation between the MBH mass and the bulge absolute V magnitude with $M_{bh} \propto (M_{V}^{bulge})^{\delta}$ and $\alpha = 2.58$ (equation 4). The value of $\beta$ that is commonly adopted is 1.18 (Magorrian 1998) or 1.31 (Jorgensen et al. 1996). Our result and other authors’ results for $\alpha, \beta, \gamma$ are list in table 3. For the same MBH masses (figure 1), the NL AGNs have larger bulge masses compared to the other BL AGNs and inactive galaxies. NL AGNs are special, and should be dealt with separately in a study of the MBH/Bulge relation.

Although we obtained the MBH/Bulge mass ratios for 22 NL AGNs, we should noticed that there are some uncertainties in the estimation of the MBH/Bulge mass ratios. There are mainly several opinions concerning the origin about the narrow width of H$\beta$ in NLS1s. One is the small inclinations in NLS1s (figure 1 in McLure, Dunlop 2002; Bian, Zhao 2002); the second is the long distance of the BLRs emitting line of H$\beta$ in NLS1s; the third is their higher value of $L/L_{Edd}$ because of their low central black hole masses. The second option is more plausible considering the other properties in NLS1s (Turner et al. 2002). The uncertainties in the $B$ magnitude, continua, and the empirical equation 1 would lead to an uncertainty of about 0.5 index in the MBH mass estimation (Wang, Lu 2001).

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 obtained by a bulge/disk decomposition of the galaxy images tends to be systematically lower than that from the empirical formula for the bulge/total ratio, depending on the Hubble type (Simien, de Vauculours 1986; Wandel 2002). Wandel (2002) found a bulge luminosity correction based on the width line of H$\beta$, which is derived from 15 Seyfert 1 galaxies common to the Wandel et al. (1999) sample and the McLure and Dunlop (2001) sample. We don’t use this bulge luminosity correction because we find it larger than the value of the bulge luminosity for the NL AGNs. Accurate values of the bulge luminosity for NL AGNs is necessary in a study of the MBH/Bulge relation in NL AGNs. In the mass – light relation, $M_{bulge} \propto L_{bulge}^\beta$, $\beta$ is usually adopted as 1.18 since it is was determined through stellar dynamics (Magorrian 1998). However, McLure and Dunlop (2001) assumed the relation $M_{bulge} \propto L_{bulge}^\beta$, which is from the Gunn-r fundamental plane study (Jorgensen 1996). In this paper we adopt $\beta = 1.18$.

In figure 2, we find there is a correlation between the MBH/Bulge mass ratio to the available velocity dispersion (from the FWHM of [O III]) for 22 NL AGNs and 22 BL AGNs, $M_{bh}/M_{bulge} \propto \sigma^{1.18 \pm 0.54}$. We notice that the relation is mainly due to the smaller MBH/Bulge mass ratio and the smaller velocity dispersion for the NL AGNs. This relation can be expected from the relation between the MBH mass and the bulge mass and the relation between MBH mass and stellar velocity dispersion. Our result gives $M_{bulge} \propto M_{bh}^{0.6}$ and $M_{bh}/M_{bulge} \propto M_{bh}^{0.4}$. If $M_{bh} \propto \sigma^{\alpha}$, then $M_{bh}/M_{bulge} \propto \sigma^{a_{2}}$ [$a_{2} = 4.80$, Ferrarese et al. 2001], $M_{bh}/M_{bulge} \propto \sigma^{-0.50}$ [$a_{2} = 3.75$, Gebhardt et al. 2000b]. We suggested the nonlinear MBH/Bulge relation (Laor 2001). This relation is consistent with some theoretical work (Wang et al. 2000; Adams et al. 2001). We can’t distinguish these two models for their idealization. Mathur (2000) has proposed that NLS1s are likely to be active galaxies in an early stage of evolution. The mean MBH/Bulge mass ratio of NLS1s will be significantly smaller than that of BL AGNs and normal galaxies. A scenario of MBH growth is his preferred interpretation. The accretion process determines the MBH mass (Haelmelt et al. 1998). The Salpeter time for the growth of MBH, i.e. the e-folding time, is $t_{e} = 4 \times 10^{7}(L_{Edd}/L) \eta_{0.1}$ yr, where $\eta_{0.1}$ is the radiative efficiency normalized to 0.1.

Let us assume the calculated MBH masses to be the initial MBH masses. The MBH would grow to a “final” Seyfert mass, which is estimated from the MBH/Bulge mass ratio in BL AGNs and the bulge masses. We adopt the MBH/Bulge mass ratio in BL AGNs is 0.0012 (McLure, Dunlop 2002). The “final” Seyfert mass is 0.0012$M_{bulge}$. The growth time for NLS1s to a “final” Seyfert galaxy is $t_{e} = \log_{10}(0.0012M_{bulge}/M_{bh}) \times 10^{7}(L_{Edd}/L_{bol}) \eta_{0.1}$ yr. Our calculated growth times of 22 NLS1s are listed in
Table 3. The MBH/Bulge relation, where $M_{\text{bh}} \propto L_{\text{bulge}}^\alpha$, $M_{\text{bulge}} \propto L_{\text{bulge}}^\beta$, $M_{\text{bh}} \propto M_{\text{bulge}}^\gamma$.

| Sample          | Type     | N  | $\alpha$ | $\beta$ | $\gamma$ | $R$  | $\log(M_{\text{bh}}/M_{\text{bulge}})$ |
|-----------------|----------|----|----------|---------|----------|------|---------------------------------------|
| Our NLS1s       | NL AGNs  | 22 | $1.90 \pm 0.70$ | $1.18$ | $1.61 \pm 0.59$ | $0.74$ | $-3.90 \pm 0.27$                     |
| Wandel 2002     | NL AGNs  | 9  | $0.99 \pm 0.13$ | $1.18$ | $0.84 \pm 0.22$ | $0.82$ | $-3.85 \pm 0.29$                     |
| Wandel 2002     | BL AGNs  | 46 | $0.90 \pm 0.11$ | $1.18$ | $0.76 \pm 0.09$ | $0.78$ | $-2.81 \pm 0.45$                     |
| McLure 2002     | AGNs     | 72 | $1.15 \pm 0.08$ | $1.31$ | $0.85 \pm 0.06$ | $0.77$ | $-2.90 \pm 0.45$                     |
| Laor 2001       | AGNs     | 24 | $1.60 \pm 0.25$ | $1.18$ | $1.36 \pm 0.21$ | $0.80$ |                                       |
| Kormendy 2001†  | Inactive | 35 | $0.96 \pm 0.13$ | $1.18$ | $0.81 \pm 0.10$ | $0.80$ | $-2.77 \pm 0.50$                     |
| Mathur 2001     | NLS1s    | 15 | -         | -       | -         | -    | $-4.33 \pm 0.47$                     |

* Col. 1 gives the sample. Col. 2 gives the class of the objects. Col. 3 gives the number of objects in the sample. Col. 4-6 give the $\alpha$, $\beta$, $\gamma$. Col. 7 is the correlation coefficient ($R$). Col. 8 gives the mean MBH/Bulge mass ratio and the standard deviation.
† Exclude NGC 4486B and NGC 5845 for their larger uncertainty in the MBH mass (Wandel 2002).

Table 1. Since the accretion rate decreases with time, the growth time is the lower limit. The mean growth time is $(1.29 \pm 0.24) \times 10^8$ yr, which is close to the upper limit, $4.5 \times 10^8/0.1 \text{ yr}$ calculated for $L_{\text{bol}}/L_{\text{Edd}} = 1$ (Haehnelt et al. 1998; Mathur et al. 2001).

5. Conclusion

New MBH/Bulge mass ratios were calculated for a sample of 22 NL AGNs using the FWHM of H$\beta$, nuclear $B$ magnitude and the bulge $B$ band magnitude. We obtained the mean MBH/Bulge mass ratio and the MBH/Bulge relation. The main conclusions can be summarized as follows:

- The mean of $M_{\text{bh}}/M_{\text{bulge}}$ for 22 NL AGNs is $-3.9 \pm 0.07$, which is lower by one order of magnitude compared to that of BL AGNs.
- A correlation is found between the bulge mass and the MBH mass for 22 NL AGNs (the correlation coefficient is $R = 0.74$), $M_{\text{bulge}} \propto M_{\text{bh}}^{0.62 \pm 0.13}$, which is higher compared to that for BL AGNs. We suggest the nonlinear MBH/Bulge relation. A correlation is found between the MBH/Bulge mass ratio and the velocity dispersion converted from the FWHM of [O III] for 22 NL AGNs and 22 BL AGNs, which is consistent with some recent theoretical studies.
- A scenario of MBH growth for NL AGNs is one of our interpretations of the nonlinear MBH/Bulge relation. The mean MBH growth time for NLS1s to a “final” Seyfert galaxy is $(1.29 \pm 0.24) \times 10^8$ yr. Another interpretation of the nonlinear MBH/Bulge relation is also possible, that NL AGNs occur in low $M_{\text{bulge}}$ galaxies if we consider that NL AGNs already have their “final” $M_{\text{bh}}/M_{\text{bulge}}$.

Acknowledgements

We thank the anonymous referee for the valuable comments. We thank the financial support from Chinese Natural Science Foundation under contract 10273007.

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