SDSS J160531.84+174826.1: A DWARF DISK GALAXY WITH AN INTERMEDIATE-MASS BLACK HOLE

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Received 2006 September 3; accepted 2006 November 9

ABSTRACT
We report the discovery of a dwarf Seyfert 1 active galactic nucleus (AGN) with a candidate intermediate-mass black hole, hosted by the dwarf galaxy SDSS J160531.84+174826.1 at $z = 0.032$. A broad component of the H$\alpha$ line with FWHM = 781 km s$^{-1}$ is detected in its optical spectrum, and a bright, pointlike nucleus is evident from a Hubble Space Telescope (HST) imaging observation. Nonthermal X-ray emission is also detected from the nucleus. The black hole mass, as estimated from the luminosity and width of the broad H$\alpha$ component, is about $7 \times 10^4 M_\odot$. The host galaxy appears to be a disk galaxy with a boxy bulge or nuclear bar. With an absolute magnitude of $M_R = -17.8$ ($M_B = -16.4$), it is among the least luminous host galaxies ever identified for a Seyfert 1.

Subject headings: galaxies: active — galaxies: dwarf — galaxies: individual (SDSS J160531.84+174826.1) — galaxies: nuclei — galaxies: Seyfert

1. INTRODUCTION

Supermassive black holes (SMBHs) with masses $M_{BH} \gtrsim 10^6 M_\odot$ have been convincingly inferred to be present in the centers of nearby galaxies (see Kormendy 2004 for a review) and are generally believed to reside in most, if not all, galaxies with a spheroidal stellar component (Kormendy & Gebhardt 2001; Ferrarese & Ford 2005). However, little is known about their low-mass counterparts, i.e., black holes with masses in the range of $10^3$–$10^6 M_\odot$, presumably in the centers of (dwarf) galaxies. These intermediate-mass black holes (IMBHs) may provide the “missing link” in understanding the formation and evolution of SMBHs seen today. In current models of galaxy evolution in a hierarchical cosmology, SMBHs must have formed from much less massive “seed” black holes and grown up by accretion and/or merging. It is likely that there exists a population of IMBHs in the present universe that have not had the opportunity to become full-grown (e.g., Islam et al. 2004).

The search for IMBHs turns out to be a difficult task, however, since IMBHs are beyond the reach of direct measurement using star/gas dynamics, by which most nearby SMBHs are unveiled (see Merritt & Rerrarese 2001; van der Marel 2004 for reviews). The most promising approach is to search for dwarf active galactic nuclei (AGNs) that are hosted in small galaxies—a scaled-down version of typical Seyfert galaxies and quasars. So far, convincing evidence for the existence of IMBHs has been found in only two AGNs, NGC 4395 [Filippenko & Ho 2003; $M_{BH} = (3.6 \pm 1.1) \times 10^5 M_\odot$, Peterson et al. 2005] and POX 52 ($M_{BH} \approx 1.6 \times 10^5 M_\odot$, Barth et al. 2004), with NGC 4395 being the only one with an accurate black hole mass measurement, found via reverberation mapping. In addition, Greene & Ho (2004) found 19 IMBH candidates from the Sloan Digital Sky Survey (SDSS; Stoughton et al. 2002) First Data Release (Abazajian et al. 2003), whose black hole masses were estimated using the linewidth-luminosity-mass scaling relation (Kaspi et al. 2000). All these objects, except NGC 4395, have a very high accretion rate, close to the Eddington limit.

In this paper, we report the discovery of a dwarf AGN with an estimated black hole mass as low as $\sim 10^5 M_\odot$, hosted by SDSS J160531.84+174826.1 (hereafter J1605+1748), a dwarf (most likely disk) galaxy at redshift $z = 0.032$. It was found from our on-going program of a systematic search for AGNs either with candidate IMBHs or hosted in dwarf galaxies from the SDSS Fifth Data Release. We assume a cosmology with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$.

2. DATA ANALYSIS

2.1. Optical Spectrum

J1605+1748 was spectroscopically observed in the SDSS on 2005 June 12, with a 4048 s exposure, and was classified as a galaxy by the SDSS pipeline. It has a redshift of $z = 0.03167$, determined using the [O iii] $\lambda$5007 line. Figure 1 shows the rest-frame spectrum with Galactic reddening corrected ($E_B-V = 0.05$, Schlegel et al. 1998), which is dominated by the starlight of the host galaxy. To subtract the starlight and the nuclear continuum, we followed our method5 as described in detail in Zhou et al. (2006). The fit was good; the standard deviation of the distribution of the relative residuals $f_{\text{residual}}/f_{\text{SDSS}}$ in the emission line–free region around H$\alpha$ and H$\beta$ is $\approx 0.05$, just the noise level with respect to the signal. The left-over emission-line spectrum is plotted in Figure 1.

We fit the emission lines using the code described in detail in Dong et al. (2005). The peaks of the [N ii] $\lambda\lambda6548, 6583$ doublet are well separated from the H$\alpha$ line, which shows an apparent broad component, owing to the relatively high signal-to-noise (S/N) ratio (\geq 20) in this spectral range and the narrowness of the lines. We model the [N ii] doublet with two Gaussians, with the line ratio $6583/\lambda6548$ fixed to the theoretical value 2.96. We use two Gaussians to model the narrow and broad components of H$\alpha$, assuming the narrow component has the same profile and redshift as the [N ii] doublet (see Zhou et al. 2006 for a full account of this assumption).

5 Starlight is modeled with six spectral templates that were built up from the library of simple stellar populations of Bruzual & Charlot (2003) by using the Ensemble Learning Independent Component Analysis method (see Lu et al. 2006 for a detailed description).
A good fit is achieved, with a minimum reduced \( \chi^2 = 0.73 \) (92 degrees of freedom [dof]), yielding a line width of 794±42 km s\(^{-1}\) FWHM for the broad H\(\alpha\) component (see Fig. 1). It has been noted by Véron-Cetty et al. (2001) that the Lorentzian is a better profile to describe the broad lines in narrow-line Seyfert 1 galaxies with FWHM < 2000 km s\(^{-1}\). In view of this argument, we use a Lorentzian for the broad H\(\alpha\) component and repeat the above fit; this yields a similarly good fit with reduced \( \chi^2 = 0.71 \) (92 dof), but the model overpredicted in the [N\(\text{ii}\)] \(\lambda 6548\) region by 7\% of the [N\(\text{ii}\)] \(\lambda 6548\) peak height. So we adopt the Gaussian fit. To test the reliability of this broad H\(\alpha\) component, we model the whole H\(\alpha\) line with a single Gaussian with the center and width as free parameters; the result is unacceptable, with a reduced \( \chi^2 = 2.75 \) (95 dof) and large residuals remaining around H\(\alpha\). We therefore believe that the broad H\(\alpha\) line is real. For the H\(\beta\) line, since its S/N ratio is relatively low (\(~10\)), we fix the profile parameters to those of H\(\alpha\), for both the narrow and broad components. For the [O\(\text{iii}\)] \(\lambda 4959, 5007\) doublet, we only fit [O\(\text{iii}\)] \(\lambda 5007\) with a single Gaussian, because [O\(\text{iii}\)] \(\lambda 4959\) is jagged. We find that the fit is good and discover no extended wing for [O\(\text{iii}\)] \(\lambda 5007\). We fit other narrow lines with a single Gaussian profile. The results of emission-line fitting are listed in Table 1. The Balmer decrement is found to be 4.2 for the broad lines and 4.0 for the narrow lines, indicating an extinction color excess \( E_{B-V} = 0.36 \) and 0.31, respectively, assuming an intrinsic Balmer decrement of 3 (Dong et al. 2005; Zhou et al. 2006) and a SMC-like extinction curve. The ratios of the narrow lines [O\(\text{iii}\)] \(\lambda 5007\)/H\(\beta\) ≥ 3 and [N\(\text{ii}\)] \(\lambda 6583\)/H\(\alpha\) ≥ 0.6 place J1605+1748 into the AGN regime on the diagnostic diagram (Veilleux & Osterbrock 1987). It would be considered a Seyfert 1.8 in the Osterbrock (1981) classification scheme, just like NGC 4395 (Filippenko & Sargent 1989) and POX 52 (Barth et al. 2004).

### 2.2. Optical Image

We retrieved an archival Hubble Space Telescope (HST) image for J1605+1748, taken with the Wide Field Planetary Camera 2 (WFPC2) in 1995 June with a 500 s exposure. The galaxy fell in the view of the WFPC2 (0.1' pixel\(^{-1}\)) as a “bonus” in an observation of Mrk 298 (Malkan et al. 1998). The F606W filter was used,

| Table 1 | Fitted Emission-Line Parameters |
|---------|----------------------------------|
| Line    | Centroid\(^a\) (Å) | FWHM\(^b\) (km s\(^{-1}\)) | Flux (10\(^{17}\) erg s\(^{-1}\) cm\(^{-2}\)) |
| [O\(\text{ii}\)] \(\lambda 3727\) | 3728.47 ± 0.51 | 281 ± 102 | 28.0 ± 8.5 |
| H\(\alpha\) (narrow) | 4862.14 ± 0.24 | 137 | 17.0 ± 2.9 |
| H\(\alpha\) (broad)\(^c\) | 4860.93 ± 1.26 | 781 | 27.3 ± 5.8 |
| [O\(\text{iii}\)] \(\lambda 5007\) | 5008.25 ± 0.08 | 160 ± 12 | 53.7 ± 2.8 |
| [O\(\text{i}\)] \(\lambda 6301\) | 6302.83 ± 0.86 | 277 ± 84 | 9.3 ± 2.6 |
| H\(\alpha\) (narrow) | 6564.53 ± 0.06 | 137 ± 8 | 67.3 ± 4.1 |
| H\(\alpha\) (broad)\(^d\) | 6565.78 ± 0.30 | 781 ± 42 | 115.2 ± 5.3 |
| [N\(\text{ii}\)] \(\lambda 6583\)\(^e\) | 6585.22 | 137 | 38.4 ± 1.9 |
| [S\(\text{ii}\)] \(\lambda 6716\) | 6718.43 ± 0.18 | 142 ± 20 | 18.2 ± 1.9 |
| [S\(\text{ii}\)] \(\lambda 6731\)\(^f\) | 6732.81 | 142 | 14.6 ± 1.9 |

\(^a\) Vacuum rest-frame wavelengths.
\(^b\) Corrected for the instrumental broadening.
\(^c\) Adopting the profile of broad H\(\alpha\).
\(^d\) Adopting the profile of narrow H\(\alpha\).
\(^e\) Adopting the profile of [S\(\text{ii}\)] \(\lambda 6716\).
which has a mean wavelength of 5947 Å and a FWHM of 1500 Å (1997 May WFPC2 SYNPHOT update). The data reduction was carried out following Malkan et al. (1998). On the HST image, the galaxy is well resolved thanks to the superb spatial resolution. It is largely elongated with a major axis of about 6, and a bright, pointlike nuclear source is evident. We perform structural decomposition using a “two-step” strategy: first we fit the one-dimensional surface brightness profile, and then we fit the two-dimensional image using the GALFIT package (Peng et al. 2002). We construct surface brightness models for both the one-dimensional and two-dimensional cases with a combination of different structural components: a point source represented by a point-spread function (PSF) generated with the Tiny Tim software (ver. 6.3)6 for WFPC2, and galactic components parameterized by an exponential or a Sérsic function (Sérsic 1968; see Graham & Driver 2005 for a concise review) or a combination of these two functions. We start off the fitting procedure with the simplest one-component model and add in one more component only if the fit can be improved significantly by doing so. An additional constraint comes from the above optical spectral decomposition, which sets an upper limit on the contribution from a point source of (~15%) of the total flux at 6000 Å.

First, the azimuthally averaged one-dimensional radial profile of surface brightness is extracted using the IRAF ELLIPSE task. The best-fit model, plotted in Figure 2 along with the measured profile, is composed of a central point source plus two Sérsic components, one dominating the inner part of the galaxy and the other dominating the outer part. Leaving off the point source or one of the two Sérsic gives rise to unacceptable fits with significant and strongly structured residuals. The need for a central point source is not surprising, as revealed from the HST image (Fig. 3). The presence of the second galactic component is found to be significant, as shown in Figure 2. Secondly, we perform two-dimensional image decomposition using GALFIT, taking the results of the one-dimensional fits as initial values for the fitting parameters. The best-fit model turns out to be the same as for the one-dimensional fitting, but with somewhat different parameter values, especially for the central point source. We adopt the result from the two-dimensional fitting (Table 2) in this paper, because two-dimensional modeling can recover a nuclear source much more reliably than one-dimensional fitting (Peng et al. 2002). Also displayed in Figure 3 are the images of the residuals and the model components. The fit is good in general, with the standard deviation of the distribution for the fractional residuals $\text{residuals}/\text{model} \sim 0.1$ within the sky region 10 times or more brighter than the sky level. In comparison, other models with the same or a smaller number of model components give rise to unacceptable fitting results that have much larger $\chi^2$ and structures in the residuals.

For easy comparisons with NGC 4395 and POX 52, we derive the Johnson magnitudes from the F606W flux using the IRAF/SYNPHOT package. We assume a continuum similar to that of NGC 4395 ($f_\nu \propto \nu^{-1.5}$, Filippenko et al. 1993) for the central point source, and a template bulge spectrum (Kinney et al. 1996) for the inner Sérsic. We further make use of the SDSS spectrum (§ 2.1) for the outer Sérsic, since it accounts for ~90% of the total F606W flux. The results are given in Table 2.

2.3. X-Ray Data

As a remote member of the cluster Abell 2151, J1605+1748 was observed serendipitously several times by Röntgensatellit (ROSAT) and XMM-Newton. We retrieved from archives the observations with good effective exposures, one with the ROSAT Position Sensitive Proportional Counter (PSPC) in 1993, one with the ROSAT High Resolution Imager (HRI) in 1997, and one with the XMM-Newton EPIC-PN7 in 2003. X-ray data reduction were performed following the standard procedures, using the FTOOLS (ver. 6.1) utilities and the Science Analysis System (SAS, ver 6.0.0) for the ROSAT and XMM-Newton data, respectively. Table 3 lists some relevant parameters for the X-ray observations and data.

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6 See http://www.stsci.edu/software/tinytim/.

7 The source position falls into a gap between CCD chips on the two EPIC-MOS detectors.
Fig. 3.—Two-dimensional decomposition of the HST/WFPC2 F606W image. Top: The original data (left panel) and the residual from the best-fitting PSF + two Sérsic model (right panel). The standard deviation of the distribution for the fractional residuals $f_{\text{residual}}/f_{\text{HST}} \sim 0.1$ within the sky region 10 times or more brighter than the sky level. Bottom: The best-fit inner Sérsic component (left panel) and outer Sérsic component with the contours of the original image overlaid (right panel). Images have the same size.

### Table 2

| Function       | $m_{606}$ | $M_B$ | $M_B$ | $r_e$ | $n$ | $b/a$ | PA | $c$ | Notes |
|----------------|-----------|-------|-------|-------|-----|-------|----|-----|-------|
| PSF            | 21.1      | −14.6 | −14.6 | ...   | ... | ...   | ...| ... | ...   |
| Sérsic         | 21.9      | −13.9 | −12.4 | 0.18  | 0.4 | 0.28  | 82 | +0.6| Bar?  |
|                | 18.1      | −17.8 | −16.4 | 1.58  | 0.8 | 0.37  | 65 | −0.1| Disk  |

**Note.**—Col. (1): Components used in the fit. Col. (2): F606W integrated magnitudes on the Vega system. Col. (3): Absolute Johnson $R$ magnitudes. Col. (4): Absolute Johnson $B$ magnitudes. Col. (5): Effective radius of the Sérsic law, in arcseconds. Col. (6): Sérsic exponent. Col. (7): Axis ratio. Col. (8): Position angle, in degrees. Col. (9): Diskiness (negative)/boxiness (positive) parameter, defined in eq. (3) of Peng et al. (2002). All the magnitudes are corrected for Galactic extinction; see the text for the transformation from mag$_{606}$ to Johnson $B$ and $V$ magnitudes.

* In good agreement with the SDSS r-band absolute magnitude derived from the fit with an exponential model, $M_r = −17.8$.

### Table 3

| Parameter                      | XMM-Newton/EPIC-PN | ROSAT/HRI | ROSAT/PSPC  |
|--------------------------------|--------------------|-----------|-------------|
| ObsID                          | 0147210301          | RH 703861A01 | RP 800517N00 |
| Good exposure (ks)              | 5.7                 | 54.9      | 12.1        |
| $R_{\text{source extraction}}$ (arcsec) | 30                  | 25        | 45          |
| Net count rate$^a$              | $1.2 \pm 0.2$       | $0.12 \pm 0.02$ | $0.35 \pm 0.08$ |
| Flux$^a$                       | $3.4 \pm 0.6$       | $4.2 \pm 0.7$  | $7.1 \pm 1.4$ |

* Measured in the 0.3–2.4 keV range. Count rate in units of $10^{-2}$ counts s$^{-1}$, and flux (without Galactic-absorption correction) in units of $10^{-14}$ ergs s$^{-1}$ cm$^{-2}$. 
reduction. For the XMM-Newton data, exposure periods that suffered from high-flaring background caused by soft protons are removed. Source counts are extracted from a circle (see Table 3), and background events are extracted from source-free regions using a concentric annulus for PSPC and HRI, and two circles at the same CCD read-out column as the source position for PN. In each of these observations, an X-ray source was detected at $\lesssim 6\sigma$ significance levels at a position coincident with the optical point source of the galaxy, within a 1 $\sigma$ positional error. The position of the X-ray source detected with XMM-Newton is R.A. = 16$^h$05$^m$31.87$^s$ and decl. = $+17^\circ$48$'$26.11$''$ (J2000.0), with an error circle of 0.9$''$ (1 $\sigma$) in radius.

The spectral fitting is carried out using XSPEC (ver. 12.2.1). Due to the small number of source counts, 58 for PSPC (0.1–2.4 keV) and 79 for PN (0.3–8 keV), the spectra are rebinned to have a minimum of 6 counts in each energy bin, and the Cash-statistic is adopted in the minimization instead of $\chi^2$. We fit the two spectra simultaneously, assuming the same spectral models with the parameters tied together except for the normalizations. The spectra can be fitted with a power law with a photon index $\Gamma = 2.1 \pm 0.3$ and an absorption column density close to the Galactic value ($3.5 \times 10^{20}$ cm$^{-2}$). The unabsoved 2–10 keV flux is $3.0 \times 10^{-14}$ ergs s$^{-1}$ cm$^{-2}$, measured by XMM-Newton, corresponding to a luminosity of $7.0 \times 10^{40}$ ergs s$^{-1}$. The best-fit normalization at 1 keV is a factor of 2 higher for ROSAT than for XMM-Newton. To test the significance of this variation, we search for the maximum confidence contours in the parameter space of the two normalizations (two free parameters) within which they differ from each other; we find that the variation is marginaly significant at the $\sim$90% level. The HRI flux is found to be roughly consistent with the XMM-Newton value, assuming the same spectral shape.

### 3. RESULTS AND DISCUSSION

In summary, observations of J1605+1748 reveal the presence of an optical bright point source based on its HST image, a broad H$\alpha$ component with FWHM = 781 km s$^{-1}$ (after correcting for the instrumental broadening of 141 km s$^{-1}$ FWHM), and AGN-like narrow emission line ratios, a nonthermal X-ray luminosity ($7.0 \times 10^{40}$ ergs s$^{-1}$ in 2–10 keV), and possible X-ray variability. All these observational facts point to the presence of a Seyfert 1 type dwarf active nucleus in J1605+1748. This can be further supported by the striking similarities between J1605+1748 and the two well-known dwarf AGNs NGC 4395 and POX 52, whose properties are summarized in Table 4. In fact, the AGN in J1605+1748 lies in between NGC 4395 and POX 52 in terms of the observed luminosities of both H$\alpha$ and the optical continuum. Furthermore, J1605+1748 is more luminous at hard X-rays than NGC 4395 (no data available for POX 52 so far). The equivalent width of its broad H$\beta$ component ($\sim$20 A, relative to the nuclear continuum calculated from the HST F606W flux of the point source) is typical of Seyfert 1.8/1.9 nuclei and similar to that of NGC 4395 (Filippenko & Sargent 1989).

We estimate the mass of its central black hole following the widely used linewidth-luminosity-mass scaling relation (e.g., Vestergaard 2002; McLure & Jarvis 2002; Greene & Ho 2004). The intrinsic monochromatic luminosity at 5100 $\AA$ is estimated to be $L_{5100} = 3L_{\nu}(5100) = 4.0 \times 10^{41}$ ergs s$^{-1}$ from the H$\beta$ luminosity, using the $L_{\text{H}\beta}$-$L_{5100}$ relation given by Greene & Ho (2005), incorporating the extinction correction that is derived from the Balmer decrement for the broad lines (§ 2.1). Using equation (6) in Greene & Ho (2005), we find a black hole mass of $6.9 \times 10^{4}$ $M_\odot$. The uncertainty of the black hole mass thus estimated is not well understood, however. As pointed out by Vestergaard & Peterson (2006), the statistical accuracy of the masses from such a scaling relationship is a factor of $\sim$4 (1 $\sigma$), and for individual mass estimates, the uncertainty can be as large as 1 order of magnitude. Using the BLR-size–luminosity relations from Kaspi et al. (2005) and Bentz et al. (2006), we find black hole masses of $5.8 \times 10^{4}$ and $2.6 \times 10^{4} M_\odot$, respectively; here we adopt the formalism and scale factor from Peterson et al. (2004) and Onken et al. (2004), with $L_{5100} = 4.0 \times 10^{41}$ ergs s$^{-1}$ and $\sigma_{\text{line}} = 332$ km s$^{-1}$ estimated from the broad H$\beta$ component. Using the scaling relationships calibrated by Vestergaard & Peterson (2006) based on the H$\beta$-line luminosity or $L_{5100}$, we find a black hole mass of $5.4 \times 10^{4}$, $3.1 \times 10^{4} M_\odot$, respectively.

Assuming a spectral energy distribution (SED) similar to that of NGC 4395, the bolometric luminosity $L_{\text{bol}}$ for J1605+1748 is estimated to be $\approx 3.7 \times 10^{42}$ ergs s$^{-1}$ by scaling their $L_{5100}$ luminosities using the NGC 4395 data in Peterson et al. (2005). This is consistent with the bolometric correction $L_{\text{bol}}/L_{\text{edd}} \approx 9.5 \times 10^{3}$ used for normal QSOs (Kaspi et al. 2000). Then the Eddington ratio $L_{\text{edd}}/L_{\text{bol}} \approx 0.3$ for a black hole mass of $6.9 \times 10^{4} M_\odot$. This indicates that J1605+1748 is at a high accretion state, similar to POX 52. The broadband spectral index $\alpha_{\text{ox}} = -0.3838$ log $\left( F_{\nu}[2\text{keV}]/F_{\nu}[2500\text{A}] \right) \approx -1.1$ agrees well with the extrapolation down to low luminosity of the $\alpha_{\text{ox}}$-luminosity relation given by Strateva et al. (2005); see also Yuan et al. 1998) for radio-quiet AGNs, similar to the result for a small sample of IMBH AGNs (Greene & Ho 2006).

As results from the above HST image decomposition analysis (§ 2.2), the galaxy is composed of three components: a central...
point source as the AGN, an inner Sérsic with \( r_e = 0.18'' \) (114 pc), and an outer Sérsic with \( r_e = 1.58'' \) (1 kpc), which account for 6.0, 2.6, and 91.4\% of the total F606W light, respectively. We tend to identify the outer Sérsic as a galactic disk, because of (1) its exponential-like radial profile with the Sérsic index, \( n = 0.8 \), close to 1 for exponential,\(^9\) (2) the disky isophote shape (\( c = -0.1 \)), (3) the apparent extreme flattening (Hubble type E6.3, based on the axis ratio), which is very unlikely for an elliptical (Binney & de Vaucouleurs 1981), and particularly (4) the existence of the additional inner Sérsic component.

With an effective radius of 0.18'', the inner Sérsic is barely resolved by the WFPC2; however, fits without this component result in large residuals and an overpredicted point source, as displayed in Figure 2. Its size is too large for it to be a nuclear star cluster. The fitted image has a boxy shape (\( c = 0.6 \)) and a rather flat profile (\( n = 0.4 \)), suggesting a box- or peanut-shaped bulge or an edge-on nuclear bar—their presence in disk galaxies has been known for many years (e.g., Burbidge & Burbidge 1959; Evans 1951; de Vaucouleurs 1975). We prefer the nuclear bar speculation because there is a \( \sim 17'' \) misalignment between its major axis and that of the disk, which is more natural for the bar scenario; moreover, a bar can provide an efficient mechanism of fueling the AGN with gas, but a bulge cannot (e.g., Shlosman et al. 1989). In fact, a boxy bulge may evolve from a bar, or may simply be (part of) a bar viewed edge-on (see Kormendy & Kennicutt 2004 for a review). Regardless of its nature, we predict the mass of the central black hole based on the empirical \( M_{\text{BH}}-L_{\text{bol}} \) correlations, using the absolute magnitudes (Table 3, corrected for the internal extinction \( E_B-V = 0.36 \)). Using the formalism from Marconi & Hunt (2003) and McLure & Dunlop (2002), we find \( 2.5 \times 10^8 \) and \( 2.6 \times 10^8 \) \( M_{\odot} \), respectively, roughly consistent with our estimate from the scaling relation, considering the large uncertainties. Furthermore, following the empirical relation between \( M_{\text{BH}} \) and bulge concentration (Graham et al. 2001, 2003), we obtain \( M_{\text{BH}} = 1.6 \times 10^8 \) \( M_{\odot} \), also consistent with the virial mass estimate. Either bars or boxy bulges (as a kind of “pseudobulge” ;Kormendy 1993) form out of disk material (Kormendy & Kennicutt 2004). So, probably just as stated by Carollo (2004), “the requirement for making a supermassive central black hole is that the galaxy is capable of reaching sufficiently high central baryonic densities.”

This work is supported by Chinese NSF grants NSF-10533050 and NSF-10573015. X. B. D. is partially supported by a postdoctoral grant from Wang Kuan-Cheng Foundation. We wish to thank the anonymous referee for constructive comments and suggestions, and thank Alister Graham for helpful comments. X. B. D. thanks Robert Kennicutt, Jr., for valuable suggestions and insightful discussions during his visit to USTC this summer, and thanks Zhenlong Zou for helpful comments and suggestions. Funding for the Sloan Digital Sky Survey (SDSS) has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the US Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions.

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