RADIO PROPERTIES OF LOW-REDSHIFT BROAD LINE ACTIVE GALACTIC NUCLEI

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ABSTRACT

The question as to whether the distribution of radio loudness in active galactic nuclei (AGNs) is actually bimodal has been discussed extensively in the literature. Furthermore, there have been claims that radio loudness depends on black hole mass ($M_{\text{BH}}$) and Eddington ratio ($L_{\text{bol}}/L_{\text{Edd}}$). We investigate these claims using the low-redshift broad line AGN sample of Greene & Ho, which consists of 8434 objects at $z < 0.35$ from the Sloan Digital Sky Survey Fourth Data Release (SDSS DR4). We obtained radio fluxes from the Very Large Array Faint Images of the Radio Sky at Twenty-centimeters (FIRST) survey for the SDSS AGN. Out of the 8434 SDSS AGNs, 821 have corresponding observed radio fluxes in the FIRST survey. We calculated the radio-loudness parameter ($\mathcal{R}$) for all objects above the FIRST detection limit (1 mJy), and an upper limit to $\mathcal{R}$ for the undetected objects. Using these data, the question of radio bimodality is investigated for different subsets of the total sample. We find no clear demarcation between the radio loud (RL; $\mathcal{R} > 10$) and radio quiet (RL < 10) objects, but instead fill in a more radio-intermediate population in a continuous fashion for all subsamples. We find that 4.7% of the AGNs in the flux-limited subsample are RL based on core radio emission alone. We calculate the radio-loud fraction (RLF) as both a function of $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$. The RLF decreases (from 13% to 2%) as $L_{\text{bol}}/L_{\text{Edd}}$ increases over 2.5 orders of magnitude. The RLF is nearly constant (~5%) over four decades in $M_{\text{BH}}$, except for an increase at $M_{\text{BH}} > 10^8 M_\odot$. We find for the FIRST detected subsample that 367 of the RL AGNs have $M_{\text{BH}} < 10^8 M_\odot$, a large enough number to indicate that RL AGNs are not a product of only the most massive black holes in the local universe.

Key words: galaxies: active -- galaxies: nuclei -- galaxies: Seyfert -- radio continuum: galaxies

Online-only material: machine-readable and VO tables

1. INTRODUCTION

The nomenclature for classifying active galactic nuclei (AGNs) relies on many different factors. The intrinsic power separates out the lower luminosity Seyfert galaxies from the higher luminosity quasars, whose optical spectra can be very similar. There is the separation of types 1 and 2 based on the presence or absence (respectively) of broad lines (BL), an effect presumably caused by the obscuration of the broad-line AGNs (Peterson et al. 2004; Kaspi et al. 2000, 2005) using

$$M_{\text{BH}} = \frac{f R_{\text{BLR}} \Delta V^2}{G},$$

where $f$ is a scaling factor that depends on the geometry and kinematics of the BLR and $\Delta V$ is the velocity dispersion. Empirical relations have been found to relate $R_{\text{BLR}}$ to the optical luminosity at 5100 Å ($L_\gamma[5100 \text{ Å}]$), allowing one simple measurement to be used as a proxy for $R_{\text{BLR}}$ (Peterson et al. 2004; Kaspi et al. 2005). There is some debate over the empirical power law that governs this relation, and a few different scalings are used, but recent studies have shown $R_{\text{BLR}} \propto (L_\gamma[5100 \text{ Å}])^\gamma$ where $\gamma \approx 0.5$ (Vestergaard & Peterson 2006). This is the (zeroth-order) theoretical expectation obtained by assuming a constant ionization parameter ($U$) and constant electron density ($n_e$) for the BLR in all AGNs (Peterson 1997). The FWHM of the BLs gives a measure of the velocity dispersion of the BLR clouds due to their assumed Keplerian orbits around the black hole (BH). These two combined measurements ($L_\gamma[5100 \text{ Å}]$, FWHM) from a single spectrum can give a relatively reliable estimate of $M_{\text{BH}}$ (Vestergaard & Peterson 2006).

It has been long claimed by previous studies that RL AGNs make up only about 5%–10% of the total AGNs population (Kellermann et al. 1989; Urry & Padovani 1995; Ivezić et al. 2002). This has led to the speculation that RQ AGNs are different from RL AGNs because of different physical accretion processes (Ho 2002; Sikora et al. 2007). The idea of two separate populations is based on the claim of a bimodal distribution in the
regulatory (VO) forms in the online journal. A portion is shown here for guidance (This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal). A portion is shown here for guidance (This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal). A portion is shown here for guidance (This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal).

| SDSS Name | FIRST Name | Flag | $F_{\text{int}}$ | Log($R$) |
|-----------|------------|------|-----------------|----------|
| J00202.95–103037.9 | 00015–10405G | 0 | 2.21 | 0.86 |
| J000710.01+005329.0 | 00075–01050E | 0 | 1.44 | 0.27 |
| J000813.22–005753.3 | 00075–01050E | 1 | 2.74 | 0.94 |
| J002141.01+003841.8 | 00225+00390E | 0 | 1.38 | 1.17 |

Notes. Col. (1): SDSS Name; Col. (2): FIRST Name; Col. (3): flag (1 = good flag); Col. (4): integrated radio flux at 1.4 GHz (mJy); Col. (5): radio-loudness parameter ($R$) of AGN (Kellermann 1999); $R$ is simply the ratio of the monochromatic radio luminosity to the monochromatic optical luminosity ($R \equiv \nu_{\text{radio}} L_{\text{radio}} / \nu_{\text{opt}} L_{\text{opt}}$). Historically, objects are considered to be RL if $R > 10$, and RQ if $R < 10$ (Kellermann et al. 1989). Typically, the radio luminosity is measured at 5 GHz, and the optical luminosity is measured at 4400 Å. One key difference in the current study is that the Very Large Array’s (VLA) Faint Images of the Radio Sky at Twenty-centimeters (FIRST) survey operates at 1.4 GHz, so the $R$ value will require a minor scaling. Corrections to account for different scalings will be discussed in Section 2. Several investigations into this claim of bimodality have yielded results that differ, based on the AGN sample, selection criteria, and the inclusion or exclusion of extended radio emission (White et al. 2000, 2007; Ivezić et al. 2002, 2004; Cirasuolo et al. 2003, 2004; Laor 2003).

The Sloan Digital Sky Survey (SDSS) allows the optical selection of a large number of AGNs with varying types of classifications over a large range in redshifts (Schneider et al. 2007). Large-scale radio surveys like the FIRST survey have allowed characterization of a large number of radio sources at a flux limit of 1 mJy and an angular resolution of 5″. Due to its high resolution, the FIRST survey is primarily sensitive to core emission. The number of objects with a resolved complex radio morphology (core-jet, core-lobe, double-lobed) in the FIRST survey with an SDSS optical counterpart is less than 10% (Ivezić et al. 2002), although it is likely that some of the unresolved sources have small, and presumably young, jet or lobe contributions.

In this paper, we take the Greene & Ho (2007) sample of low-redshift BL AGNs from the SDSS, from which $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$ can be calculated, and correlate them with their FIRST counterparts to test for bimodality in $R$ and the dependence of $R$ on $M_{\text{BH}}$. In this way, we can determine the radio properties of AGNs in the local universe and compare them with higher-redshift samples. We give a description of the SDSS and FIRST data samples in Section 2. In Section 3 we describe our data analysis and biases in the sample. We present conclusions in Section 4.

2. DATA SAMPLE

2.1. BL AGN Sample of Greene & Ho (2007)

The BL AGN sample and all optical data come from Greene & Ho (2007) and consist of 8434 AGNs, all with $z < 0.35$ to ensure the observation of Hα, taken from the SDSS Fourth Data Release (DR4). Greene & Ho subtract the stellar continuum from all spectra following their prescription (Greene & Ho 2004) to ensure that the AGN BLs are not masked or suppressed by host galaxy features. For this study the relevant data taken from the spectra consist of the FWHM of Hα ($\text{FWHM}_{\text{H} \alpha}$) and the luminosity of Hα ($L_{\text{H} \alpha}$). With the 35 or so reverberation-mapped AGNs, empirical relations between the continuum luminosity and broad Hβ FWHM have been calibrated to derive black hole masses of AGN’s central engines (Peterson et al. 2004). Other recent empirical relations have allowed the use of Hα to derive $M_{\text{BH}}$, because Hβ is usually about three times weaker and Hα has lower signal-to-noise requirements (Greene & Ho 2005). The following relations were used by Greene & Ho (2007) to calculate $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$ for all 8434 AGNs in their
To find $L_{bol}/L_{Edd}$, the bolometric luminosity ($L_{bol}$) is required. Greene & Ho (2005) find that $L_{Hα}$ scales with $L_{bol}$, which is then calculated using the following relation:

$$L_{bol} = (2.34 \times 10^{44}) \left(\frac{L_{Hα}}{10^{42}}\right)^{0.86} \text{ erg s}^{-1}. \quad (4)$$

The monochromatic continuum luminosity at 5100 Å ($\lambda L_{\lambda} [5100 \text{ Å}]$) is found to scale with $L_{bol}$ (McLure & Dunlop 2004; Greene & Ho 2005), but because the typical $R$-value is based on $L_\lambda (4400 \text{ Å})$, it is necessary to scale $L_\lambda (5100 \text{ Å})$ using a typical optical spectral index of 0.5 (Sikora et al. 2007), so that

$$L_\lambda (4400 \text{ Å}) = (L_\lambda [5100 \text{ Å}]) \left(\frac{5100 \text{ Å}}{4400 \text{ Å}}\right)^{-0.5} = (2.59 \times 10^{43}) \left(\frac{L_{Hα}}{10^{42}}\right)^{0.86} \text{ erg s}^{-1}. \quad (5)$$

Our final optical data set consists of redshifts, FWHM $H\alpha$, $L_{H\alpha}$, $L_\lambda (5100 \text{ Å})$, and $L_\lambda (4400 \text{ Å})$, along with calculated $M_{BH}$ and $L_{bol}/L_{Edd}$ for all objects in the sample (see Greene & Ho 2007 for a more complete description of the optical data set). The full sample has 7565 AGNs with $M_{BH} < 10^8 M_\odot$, and 858 AGNs with $M_{BH} > 10^8 M_\odot$. The advantage of using this sample is that it is complete to a given limiting magnitude, and hence a limiting 5100 Å flux ($\sim 1 \times 10^{-17} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Å}^{-1}$), as shown by the solid line in Figure 1. Furthermore, this is a spectroscopic sample of BL AGNs from which $M_{BH}$ and $L_{bol}/L_{Edd}$ can be calculated. Finally, the AGNs in this sample were not, in general, selected on the basis of their radio properties, and thus we can determine the true fraction of AGNs at low redshift that are RL.

2.2. FIRST Data

The FIRST survey was designed to cover a large portion of the SDSS coverage area (Becker et al. 1995). The FIRST survey operates at 1.4 GHz with an angular resolution of 5′′ and has a
limiting flux of 1 mJy. We obtained radio fluxes based on the correspondence in position with the optical data. The search radius was only 4″ from the optical counterpart to ensure that the radio emission at the sample redshift limit was still within the host galaxy. The 4″ search radius may, however, exclude objects with weak core emission and extended radio structures, such as double lobes or long knotty jets. Figure 2 shows a histogram of the position offset (indicating the accurate astrometry in both SDSS and FIRST databases). Only 3% of the FIRST sources are off by more than 2″ from the SDSS optical counterpart (which corresponds to ∼14 kpc at the $z = 0.35$ sample limit). For each object the integrated flux ($F_{\text{int}}$) given in mJy was taken. Out of the 8434 AGNs, there were 832 sources with radio flux above the FIRST limit. Table 1 gives the SDSS and FIRST names of these 832 AGNs, along with the side lobe flag indication, integrated flux, and calculated $\log(R)$. We removed 11 radio sources with a side lobe flag in the FIRST data due to possible contamination from another nearby source, leaving 821 detected objects. All objects that did not have a FIRST counterpart were given an upper limit flux of 1 mJy. For consistency, we converted $F_{\text{int}}$ into a luminosity using the usual flux-luminosity relation with the same cosmology and redshifts used by Greene & Ho (2007) from Spergel et. al. (2003; $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$). We conform to the standard definition of $R$ so that comparisons could be made with previous work, where $L_{\text{radio}}$ is at 5 GHz. Since the radio flux in AGN is

**Figure 4.** Radio-loudness ($R$) histogram: the solid line is for the 821 objects in the detected subsample and the dashed line is a cumulative upper limit for the entire sample using a FIRST flux limit of 1 mJy at 5 GHz. The inset shows the peak of the upper-limit histogram. Both peak at $\log(R) \approx 0.9$.

**Figure 5.** Flux-limited radio-loudness ($R$) histogram: the solid line is for the AGN in the detected subsample after the optical flux limit is imposed and the dashed line is an upper limit for all AGNs with the optical flux limit imposed. The inset shows the peak of the upper-limit histogram.

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generally characterized by a power law where $F_\nu \propto \nu^{-\alpha}$, the luminosity was scaled by $(15 \mathrm{GHz}/1.4 \mathrm{GHz})^{-\alpha_R} = 0.361$, where the most common radio spectral index, $\alpha_R = 0.8$, is used (Sikora et al. 2007). So the assumed upper limit assigned to undetected objects of 1 mJy at 1.4 GHz corresponds to 0.361 mJy at 5 GHz.

The total sample can be broken into subsets and analyzed separately based on detections and flux limits. The first subset is the 821 objects that have measured FIRST fluxes. This subset will be referred to as the “detected” sample. The detected sample is advantageous in that all $R$-values will be uniquely determined for each object. In this subsample, log($R$) ranges from $-0.68$ to $4.47$, spanning over 5 orders of magnitude, and has 683 AGNs with $M_{\mathrm{BH}} < 10^8 M_\odot$, and 138 AGNs with $M_{\mathrm{BH}} > 10^9 M_\odot$. The next subset is found by setting an optical flux limit of $F_{\lambda} (4400 \ \AA) = 5.6 \times 10^{-17} \ \text{ergs} \ \text{s}^{-1} \ \text{cm}^{-2} \ \text{Å}^{-1}$ ($F_{\nu} [4400 \ \AA] = 0.0361 \ \text{mJy}$). The practical reason for the optical flux-limited sample is that for an object not detected by FIRST, we cannot uniquely determine if it is RL or RQ if $F_{\nu} (4400 \ \AA) < 0.0361 \ \text{mJy}$. All AGNs designated RL with an $R$ upper limit are cut when this optical flux limit is set. Some of these may be true RL AGNs, but since they lack a FIRST counterpart (i.e., too faint for the FIRST detection and have a $F_{\nu} [5 \ \text{GHz}] < 0.361 \ \text{mJy}$) they do not make the cut. Some objects from the detected subsample, and some that are designated RQ with an $R$ upper limit are cut as well. This subset will be referred to as the “flux-limited” sample and consists of 5477 objects. The dashed line in Figure 4 shows the optical flux limit used to make this cut.

The last subset is from the flux-limited sample and is found by imposing even more stringent flux limits following Ivezić et al. (2002). This last flux imposition takes into account that a large number of objects in a radio versus optical flux plot will tend to overpopulate the region of the plot just above each respective flux limit. Ivezić et al. (2002) claim that to get a true representation of the $R$ distribution, this must be taken into account. Figure 3 is a plot of the radio flux (at 5 GHz) as a function of the optical flux (at 4400 Å), both given in mJy. The horizontal and vertical lines indicate the FIRST and SDSS flux limits, respectively. The region just above both of these limits is the most populated, as shown by the dots. The positively sloped dot-dashed lines are lines of constant log($R$) = 2, 1, 0 from the top down, respectively. According to Ivezić et al. (2002), it is necessary to take samples in regions that are perpendicular to these lines and well away from the flux limits. The square symbols are the ones that are in the region of interest. This “stringently flux-limited” sample has 234 objects.

3. RESULTS

In this section, we perform our analysis based on different subsamples. The detected sample is useful when plotting $R$ as a function of $M_{\mathrm{BH}}$ and $L_{bol}/L_{Edd}$, since $R$ is uniquely determined for all AGNs in this subsample. It is however highly biased when calculating the radio-loud fraction (RLF), in that the number of RQ AGNs is significantly underestimated due to the FIRST flux limit. The flux-limited sample is not as affected by this bias, since many of the RQ AGNs still make the optical flux cut and remain in the subsample, and is therefore used to determine the RLF. The statistical errors in the RLF plots are calculated from Poisson statistics.

3.1. Radio-Loudness Results

Figure 4 shows a histogram of the radio loudness, $R$. The solid line is for all 821 AGNs detected by the FIRST survey. The dashed line in Figure 4 shows the total sample with upper limits on $R$ calculated for all AGNs undetected by FIRST. The inset shows the peak of the total sample. In both histograms, there is a smooth distribution about log($R$) $\approx 0.9$ and no clear evidence for two distinct populations. The dashed line histogram could always move farther to the left in Figure 4 as indicated by the arrows. In fact, to actually see a bimodal distribution, the upper-limit histogram peak would have to shift very far to
Figure 7. $R$ vs. $L_{\text{bol}}/L_{\text{Edd}}$. The dashed line shows the division between RL and RQ. There is clearly a lack of points in both the lower left and upper right of this plot, indicating the paucity of RL AGNs that have high accretion rates and of RQ AGNs that have low accretion rates.

Figure 8. $L_{1.4\,\text{GHz}}$ vs. $L_{\text{bol}}/L_{\text{Edd}}$. The crosses have $R > 10$ and the diamonds have $R < 10$.

The key points are as follows:

- **Figure 7**: The dashed line marks the division between RL and RQ AGNs. The plot shows a clear lack of points in both the lower left and upper right regions, indicating a paucity of RL AGNs with high accretion rates and of RQ AGNs with low accretion rates.

- **Figure 8**: The crosses represent AGNs with $R > 10$, and the diamonds represent those with $R < 10$. The plot shows a clear lack of points in the lower left and upper right regions, similar to Figure 7.

The R histogram is shown in Figure 5 for the optically flux-limited sample. The solid line is for all AGNs above the optical flux limit and detected by the FIRST survey. The dashed line is for the total sample (undetected FIRST sources included) after the optical flux limit is imposed, with the inset showing the peak. The sharp cutoff at $\log(R) = 1$ for the total sample is due to the flux limits imposed. In both cases there is still no evidence for bimodality in this sample. The peak for the flux-limited histogram is at $\log(R) \approx 0.75$. We find that $4.7\%$ of the AGNs in this subsample are RL. This percentage is similar to roughly the $5\%–10\%$ that have been found in other studies based primarily on higher-redshift AGN (Kellermann et al. 1989; Urry & Padovani 1995).

The same plot is shown in Figure 6 for the stringently flux-limited sample, with the inset showing the peak of the total sample. The cutoff at $\log(R) = 0$ and 2 are due to the limits imposed following Ivezić et al. (2002). The peak for the stringently flux-limited sample is again at $\log(R) \approx 0.75$. Including objects at higher and lower $R$-values, outside the flux
cut prescription followed here, does not shift the location of the peak or introduce a bimodal distribution with another peak at higher $\mathcal{R}$-values.

### 3.2. Radio Loudness, Eddington Ratio, and Luminosity

Figure 7 shows a plot of $\mathcal{R}$ as a function of $L_{\text{bol}}/L_{\text{Edd}}$ for the detected sample. There are no AGNs with $\log(L/L_{\text{Edd}}) < -2.8$ due to the SDSS limiting magnitude. Although there are broad distributions in both properties, there is a scarcity of AGN in the high accretion rate, high-$\mathcal{R}$ regime, and also in the low accretion rate, low-$\mathcal{R}$ regime, which is consistent with previous studies that find a global trend of decreasing radio loudness with an increasing Eddington ratio (Ho 2002; Nagar et al. 2005; Sikora et al. 2007). Figure 7 does not show two distinct populations of AGNs at a given Eddington ratio as found by Sikora et al. (2007). The two distinct populations in that paper at intermediate Eddington ratio values (0.01–0.1) likely represent the upper radio-loudness limits of two separate populations—the upper population consisting of broad-line radio galaxies (BLRGs) hosted by giant elliptical galaxies with $M_{\text{BH}} > 10^8 M_\odot$, and the lower mostly being the most RL Seyferts, hosted by spiral galaxies, and with $M_{\text{BH}} < 10^8 M_\odot$. Instead we find a continuous distribution from RQ to RL where the radio-intermediate (RI) objects ($\log(\mathcal{R}) \approx 1$) are the most numerous.

Figure 8 shows a plot of the 1.4 GHz radio luminosity as a function of $L_{\text{bol}}/L_{\text{Edd}}$. The crosses are objects that are RL (defined by $\mathcal{R} > 10$) and the diamonds are objects that are RQ ($\mathcal{R} < 10$). There is significant overlap in the RL/RQ populations.
around $L_\nu(1.4 \text{ GHz}) = 10^{23} \text{ W Hz}^{-1}$, which has previously been used as an alternative division line between RL and RQ sources (e.g., Best et al. 2005). We find that 20% of the objects that have $L_\nu(1.4 \text{ GHz}) > 10^{23} \text{ W Hz}^{-1}$ are classified as RQ by $R$, and that 13% of these that have $L_\nu(1.4 \text{ GHz}) < 10^{23} \text{ W Hz}^{-1}$ are classified as RL by $R$. No obvious trends exist in Figure 8, but it clearly shows the ambiguity that can be involved when these two different definitions of RL and RQ are used.

In Figure 9, we show the RLF as a function of $\log(L_{bol}/L_{Edd})$ for the optically flux-limited sample with assumed upper limits. The RLF is the ratio of the number of RL objects to the total number of AGNs, and is plotted in bins of 0.25 dex. Although the trend is mostly flat over a range of Eddington ratio, the global trend is that the RLF decreases from $\sim 13\%$ to $\sim 2\%$ with an increasing Eddington ratio, in a manner similar to that found in the previous studies mentioned above. The stringently flux-limited sample shows a similar trend, but with a much higher overall RLF in each bin, due to the flux limits cutting out all of the RQ objects with upper limits on $R$.

3.3. Radio Loudness and Black Hole Mass

In some studies of AGN at higher luminosities, the degree of radio loudness was suggested to be dependent on $M_{BH}$, where RL quasars are typically found to have $M_{BH} > 10^8 M_\odot$ (Laor 2000; McLure & Jarvis 2004). Figure 10 shows a plot of $R$ versus $M_{BH}$ for our detected subsample. We find a significant number of RL AGNs with $M_{BH} < 10^8 M_\odot$. We find that 367
(53\%) of the objects with $M_{\text{BH}} < 10^8 M_\odot$ are RL, compared to 55 (40\%) objects with $M_{\text{BH}} > 10^8 M_\odot$ that are RL. Figure 10 shows that 11 AGNs with $M_{\text{BH}} < 10^8 M_\odot$ are extremely RL ($\log(R) > 3$). These outliers do not result from underestimating their H\alpha (and hence continuum) fluxes. Their radio fluxes are truly high, in the range 136–1213 mJy, whereas their H\alpha fluxes have a distribution similar to that of the entire sample.

Figures 11 and 12 show the $\mathcal{R}$ distribution for the high-and low-mass populations for the detected and flux-limited subsamples, respectively. In these figures, the solid lines are for the higher mass population and the dashed lines are for the lower mass population. Both distributions cover the same range and peak in about the same place. A Kolmogorov–Smirnov (K–S) test shows that two samples drawn from the same population would differ this much 56\% of the time for the detected sample and 84\% of the time for the flux-limited sample, indicating that the two distributions are not statistically different. This is consistent with the findings of Woo & Urry (2002) and Ho (2002) that radio loudness is not intrinsically dependent on $M_{\text{BH}}$.

Figure 13 shows the RLF as a function of $M_{\text{BH}}$, for the optically flux-limited subsample. The RLF here is the ratio of the number of RL AGNs to the total number of AGNs in mass bins of $\log(M_{\text{BH}}) = 0.5$. The distribution is essentially flat at the low mass end although there is evidence for an increase in the highest mass bin.

In Figure 14 we show $L_\nu(1.4 \, \text{GHz})$ as a function of $M_{\text{BH}}$ with symbols same as those in Figure 8. As in Figure 8 we see a lot of overlap between the RL and RQ AGN, as defined by $\mathcal{R}$ around $L_\nu(1.4 \, \text{GHz}) = 10^{23} \, \text{W} \, \text{Hz}^{-1}$. This figure is more ordered than
Figure 8 in that there are a paucity of points in the low (high) $L_{1.4\ GHz}$, high (low) $M_{\text{BH}}$ range. Thus, the most powerful radio-core sources tend to have higher black hole masses, but we find little evidence that the radio loudness depends strongly on mass.

4. CONCLUSIONS

We have taken 8434 optically selected BL AGNs from the SDSS and estimated $M_{\text{BH}}$ and $L_{\text{bol}}/L_{\text{Edd}}$ for them. Using fluxes taken from the FIRST survey we compute $\mathcal{R}$, the radio-loudness parameter, where the radio emission is thought to be mostly from the core. We note that because of the resolution of the FIRST survey and our small search radius (4'), we miss AGNs with extended radio structures that have very weak core emission. We note that $\sim90\%$ of all SDSS/FIRST matched AGNs have only central core radio emission (Ivezić et al. 2002), although because of the resolution limit of FIRST, many of these “core” sources will include compact jets and lobes. Furthermore, the higher-redshift samples with which we are comparing our results (White et al. 2000; Ivezic et al. 2002; Cirasuolo et al. 2004) are also based on core radio emission from FIRST. In the flux-limited subsample we find that 4.7% of the AGNs are RL. This is similar to the approximately 5% found for higher-redshift quasars, but may be coincidental in that the distribution of radio loudness likely depends on the available range of Eddington ratio and host galaxy morphology in the sample. The issue of extended radio structure and its impact on the radio-loudness distribution will be addressed in a forthcoming paper.

The radio-loudness histograms in Figures 4 and 5 both peak in the same place, at $\log(\mathcal{R}) \approx 0.75$. We find no evidence for a bimodal histogram for any subset of the total sample. We do note that the upper limit (dashed line) histograms could be pushed farther to the left to reveal a bimodal distribution, but at much lower $\mathcal{R}$-values than previously found by Ivezić et al. (2004) and Cirasuolo et al. (2004), who find peaks at $\log(\mathcal{R}) \ll 1$, and $\log(\mathcal{R}) \approx 2–3$. After we apply various flux limits to our total sample, we still cannot reproduce a local minimum at $\log(\mathcal{R}) \approx 1$. In all our subsamples we fill in a substantial number of RI objects. The minimum in the $\mathcal{R}$ histogram could be shifted to lower values or could just not be present at all at these low redshifts. Nevertheless, we still see a RL tail. Compared to higher-redshift samples, the $\mathcal{R}$ distribution in the local universe for detected sources is narrower and shifted to lower values (Ivezić et al. 2004; White et al. 2007). This may indicate that the radio luminosity function has a stronger evolution than the optical luminosity function to the current epoch, as suggested by Jiang et al. (2007). White et al. (2007) find for their sample a similar effect of evolution of the $\mathcal{R}$ histogram with redshift. Our plot is in good agreement with their low-redshift ($z < 0.5$) quasars, where there is a peak at low values of $\mathcal{R}$, and a tail that falls off over four orders of magnitude, with no indication of two separate populations.

Our plot of $\mathcal{R}$ as a function of $L_{\text{bol}}/L_{\text{Edd}}$ lacks points in the low accretion/RQ and high accretion/RL regimes. We also see a trend of higher RLF at the low values of $L_{\text{bol}}/L_{\text{Edd}}$. This matches the general trend seen by Ho (2002) and Sikora et al. (2007) of decreasing $\mathcal{R}$ with increasing $L_{\text{bol}}/L_{\text{Edd}}$, based on AGNs that extend to much lower $L_{\text{bol}}/L_{\text{Edd}}$ ($\sim10^{-7}$).

We do not find two separate populations at a given $L_{\text{bol}}/L_{\text{Edd}}$, but again fill in a more RI population. This may be due to the homogeneous optical selection of our data set, as opposed to the admittedly heterogeneous selection criteria of AGN in Sikora et al. (2007), which includes AGN from various samples, where objects were selected in very different ways. We do note however that we do not cover nearly as much parameter space as Sikora et al. who get up to an $\mathcal{R}$ of $\sim10^2$ and down to an $L_{\text{bol}}/L_{\text{Edd}}$ of $\sim10^{-7}$. Our sample does not go down to the very low $L_{\text{bol}}/L_{\text{Edd}}$ values due to the SDSS flux limit. Homogeneous samples like ours that extend to much fainter radio and optical fluxes would be extremely useful for further studies. In fact, going deeper in both the radio and optical fluxes is necessary if one wants to search for AGN in the very lowest $L_{\text{bol}}/L_{\text{Edd}}$ and $\mathcal{R}$ regimes.

We find a substantial number of RL AGNs with $M_{\text{BH}} < 10^8 M_\odot$, as seen in Figure 10 (although the fraction of RL sources is the largest for the most massive BHs in our sample as shown in Figure 13). This clearly shows that in the local universe it is not only massive BHs ($M_{\text{BH}} > 10^9 M_\odot$) that are responsible for RL AGNs, which is consistent with the findings of Ho (2002) and Woo & Urry (2002).

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