Is the Radio Dichotomy of AGNs Real?

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Abstract AGNs are traditionally divided into radio-loud and radio-quiet. Optically selected AGN samples usually show bimodal distributions in radio-loudness. However, recent radio selected AGN samples do not have this radio dichotomy and contained a large number of radio-intermediate objects. To avoid the apparent selection effects in optically and radio selected AGN samples, we use an X-ray selected sample to revisit this question and find no clear bimodality in radio-loudness. On the other hand, when the X-ray-loudness and radio-loudness are both been taken into consideration, two populations of AGNs are well separated. This result might be used in the unification scheme of AGNs.

1 Introduction

AGNs are usually classified as radio-loud (hereafter RL) and radio-quiet (hereafter RQ). Although this classification is of some historical reason, the optically and X-ray selected samples do show a bimodal distribution in radio-loudness, with one peak corresponds to the RL and the other to the RQ (see Fig. 1 in Della Ceca et al. 1994, Fig.3 in Kellermann et al. 1989, and Fig. 3 in Visnovsky et al. 1992; Stocke et al. 1992). The distinction in radio-loudness has been attributed to the difference in central black hole mass or spin rate, say, the black holes in radio-loud objects have much higher mass or much higher spin rate than the black holes in radio-quiet objects(e.g. Loar 2000; Wilson & Colbert 1995).

However, it has recently been found that the ROSAT All-Sky Survey (RASS) and the Faint Images of the Radio Sky at Twenty-centimeters (FIRST) correlated quasars do not illustrate bimodal distribution in radio-loudness (Brinkmann et al. 2000). What's more, the quasars discovered in the FIRST Bright Quasar Survey (hereafter FBQS) have a smooth change in number from the traditionally RL to the traditionally RQ (White et al. 2000). If there is indeed no radio dichotomy in AGNs, AGNs should be classified in another way and the unified scheme should be reconsidered. Therefore, whether there is a radio dichotomy in AGNs is an essential question in AGN classification and unification.

It is well known that the optically and radio selected AGN samples suffer from significant selection effects. However, X-ray emission has been found to be nearly the definitive characteristic of AGNs, hence X-ray selected AGN samples are believed to be more complete than optically and radio selected samples. Here we use an X-ray selected sample to study the radio-loudness of AGNs.

2 The Samples

2.1 The X-ray Sample

The complete sample of X-ray AGNs resulted from the optical follow-up observations of the RASS sources in six areas (Appenzeller et al. 1998; Zickgraf et al. 1997). The total sky coverage is 685 deg^2 and there are 674 X-ray sources down to a ROSAT count rate limit

0.03 cts s^{-1}. Optical identifications led to the discovery of 166 Seyferts and 71 quasars.

2.2 The Radio Sample

The NRAO VLA Sky Survey (NVSS, Condon et al. 1998) sample is selected as our radio sample. The NVSS used the D configuration of the VLA to survey the entire sky north of -40 deg declination at a frequency of 1.4 GHz. Over 1.8 million sources were detected to a flux density limit of about 2.5 mJy. The NVSS reaches well into the RQ population of AGNs.

3 Cross Correlation

The X-ray AGN sample gives only the X-ray positions. Taking their uncertainty as $20''$ (Zickgraf et al. 1997) and the NVSS's positional uncertainty as $5''$ (Condon et al. 1998), we searched the AGNs in the NVSS catalog with a searching radius of $40''$. The cross correlation resulted in 32 (45%) radio detections in 71 quasars and 34 (20%) detections in 166 Seyferts.

4 Statistics on Radio-Loudness

4.1 Definition of Radio- and X-ray-Loudnesses

Sometimes the radio-loudness of AGNs is defined directly by their radio luminosities, but the more generally used definition is the radio-to-optical flux ratio, $R^* = f(5GHz)/f(2500\text{Å})$ (Stocke et al. 1992).

Another equivalent parameter is the two point radio-to-optical spectral index $\alpha_{\rm ro}$. It is defined as

$$\alpha_{\rm ro} = -\frac{\log \dfrac{L_{2500\text{Å}}}{L_{5\,\rm GHz}}}{\log \dfrac{\nu_{2500\text{Å}}}{\nu_{5\,\rm GHz}}} = \frac{\log R^*}{5.38}. \tag{1}$$

Similarly, the two point X-ray-to-optical spectral index or X-ray-loudness can be defined as

$$\alpha_{\rm ox} = -\frac{\log \dfrac{L_{2\,\rm keV}}{L_{2500\,\text{Å}}}}{\log \dfrac{\nu_{2\,\rm keV}}{\nu_{2500\,\text{Å}}}}. \tag{2}$$

It should be noted that a smaller value of $\alpha_{\rm ox}$ corresponds to a relatively higher X-ray luminosity, or in other words, an X-ray-loud AGN has a relatively lower $\alpha_{\rm ox}$, contrary to radio-loudness.

When calculating the fluxes and luminosities, we adopted a Hubble constant of 50 km s^{-1} Mpc^{-1} and a deceleration factor as $q_0 = 0.5$. Power laws were assumed for the radio, optical, and X-ray spectra of quasars and Seyferts and their radio and optical spectral indices were both adopted as 0.5 ($S \propto \nu^{-\alpha}$). All AGNs were assumed to have an X-ray photon index as $\Gamma = 2.3$ ($F_{\rm photon} \propto E^{-\Gamma}$) (Brinkmann et al. 1997; Rush et al. 1996; Yuan et al. 1998).

4.2 The Radio and X-ray Properties of AGNs

The X-ray photon index is slightly different for different kind of objects and varies with redshift. The generally accepted values are: $\Gamma \approx 2.5$ for RQ quasars, $\Gamma \approx 2.1$ for RL quasars, and $\Gamma \approx 2.3$ for Seyferts. For simplicity, we adopted 2.3 for all three kinds of objects.

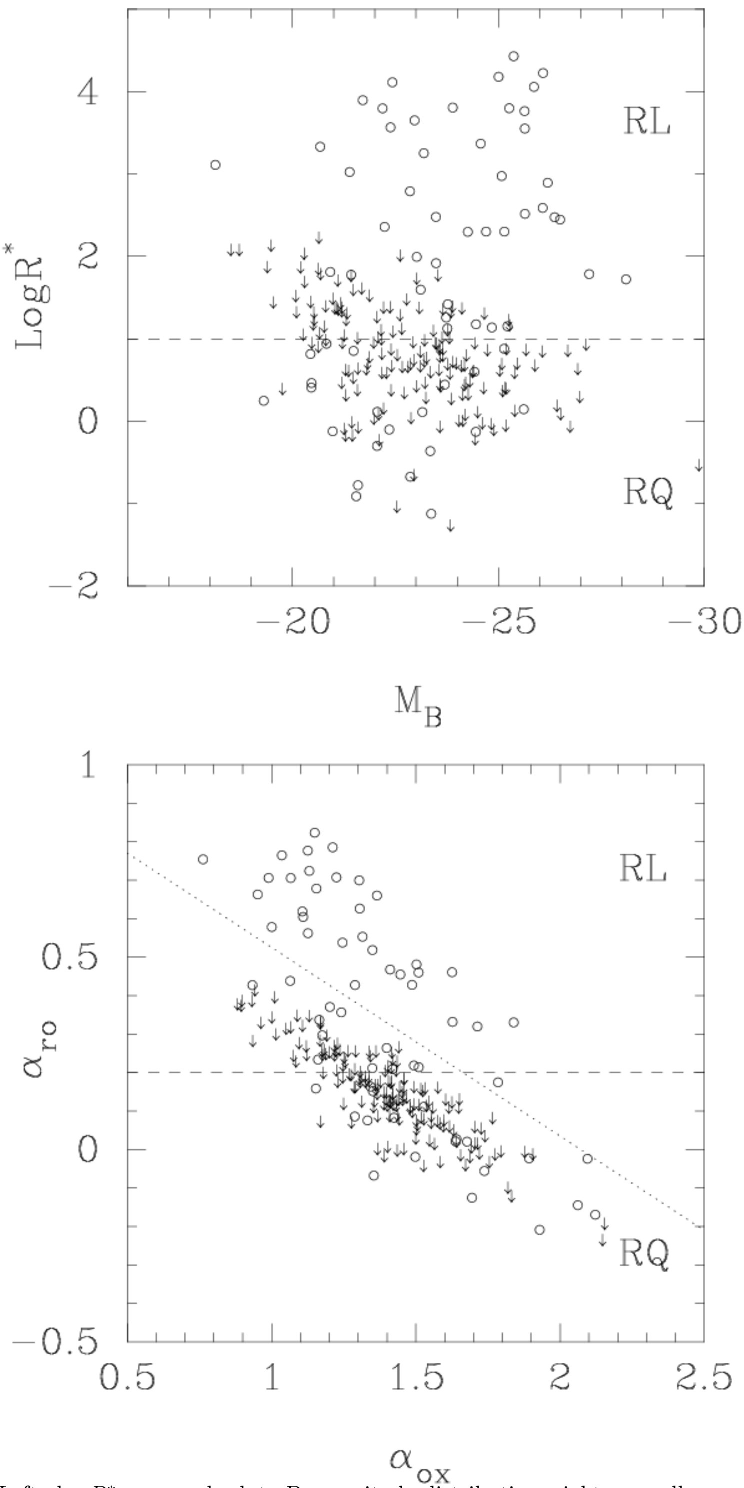

Fig. 1 Left: $\log R^*$ versus absolute B magnitude distribution; right: overall energy distribution. Quasars and Seyferts are taken as a whole. The radio detections are denoted in open circles and the upper limits in downward arrows. The dashed line marks the generally adopted boundary between RL and RQ.

Fig. 1 demonstrates the radio-loudness versus absolute B magnitude distribution and broad-band spectral index distribution. Quasars and Seyferts are taken as a whole. There is no clear deficiency of objects towards the dashed lines, the commonly adopted boundaries between RL and RQ. Fig. 1. suggest that there is no radio dichotomy for AGNs. This result is in agreement with recent conclusions (Brinkmann et al. 2000; White et al. 2000). And because our sample is X-ray selected and hence involves less selection effects, the result is of higher confidence.

What is interesting in the right panel of Fig. 1 is that there seems to be a gap extending from the upperleft to the lowerright (marked by the dotted line). If it is the case, it would be that the dividing line of $\alpha_{\rm ro}$ between 'RL' and 'RQ' decreases with increasing optical-to-X-ray energy ratio. In other words, the AGNs should be classified not only by their radio-loudness ($\alpha_{\rm ro}$), but also by their X-ray-loudness ($\alpha_{\rm ox}$).

In fact, a similar phenomenon has been observed by Stocke et al. (1991) when carrying out a similar statistics on the X-ray AGNs selected in the EINSTEIN Extended Medium Sensitivity Survey (EMSS). In their Fig. 6, both 'RL' AGNs and 'RQ' AGNs have an inclined distribution in $\alpha_{\rm ox} - \alpha_{\rm ro}$ plane, from high $\alpha_{\rm ro}$, low $\alpha_{\rm ox}$ to low $\alpha_{\rm ro}$, high $\alpha_{\rm ox}$, similar as in Fig. 1 in our statistics. But the 'RL' AGN band has a clear shift in $\alpha_{\rm ox}$ with respect to the 'RQ' AGN band, the former being more X-ray-quiet (larger $\alpha_{\rm ox}$) than the latter. The only difference between Stocke et al. statistics and ours is that their sample have a lower cutoff in $\alpha_{\rm ro}$ for the 'RL' AGNs and a upper cutoff in $\alpha_{\rm ro}$ for the 'RQ' AGNs. Both cutoffs might be based on the early classification of AGNs just after their discoveries. Our result is different from most previous results.

5 Conclusions

Based on the statistics of an X-ray selected sample, we found no radio dichotomy in AGNs. This result is in agreement with some recent results (Brinkmann et al. 2000; White et al. 2000), but, of course, has higher confidence. The radio dichotomy of AGNs might be totally of historical reason.

An interesting result of our study is that AGNs can be classified both in radio-loudness and X-ray-loudness. This result may have some implication in unifying the AGNs since the present unification scheme of AGNs is based in part on the radio dichotomy of AGNs. Of course, the NVSS, the radio survey used by us, is of limited sensitivity, making the radio detection relatively low for the X-ray AGNs. A deeper radio survey is desired to carry out the same statistics as in this paper.

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