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Luminosity Correlation of the X-Ray Selected Radio-Loud AGNs

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Abstract.

This paper presents a test of the luminosity correlation of the X-ray selected radio-loud Active Galactic Nuclei (AGNs), based on a large sample constructed by combining our cross-identification of southern sky sources with the radio-loud sources in the northern hemisphere given by Brinkmann et al. (1995). All sources were detected both by the ROSAT All-Sky Survey and the radio surveys at 4.85 GHz. The broad band energy distribution confirms the presence of strong correlations between luminosities in the radio, optical, and X-ray bands which differ for quasars, seyferts, BL Lacs, and radio galaxies. The tight correlations between spectral indices α_{ox} and monochromatic luminosities at 5500 Å and 4.85 GHz are also shown.

1. Introduction

The luminosity correlation of the Active Galactic Nuclei (AGNs) has been an appealing subject. It is widely appreciated that the correlations of the AGNs and active galaxies among luminosities emitted from radio, optical and X-ray energy bands can give insight into the relevant physical processes in AGNs and serve as a qualitative test for existing central engine models of AGNs. The subgroup of X-ray selected radio-loud AGNs is particularly useful in understanding the unification schemes (Barthel 1989; Padovani & Urry 1992) and cosmological and evolutionary effects for AGNs, since the radio-loud AGNs with strong X-ray emission are the most luminous objects with large look back times in the universe.

After the launch of the ROSAT satellite, the correlations of the ROSAT detected sources with existing compilations of radio catalogues were extensively investigated. Brinkmann et al. (1995) studied the bulk properties of previously optically identified AGNs which were detected by the ROSAT All-Sky Survey (hereafter RASS) (Voges 1992), by using the source list from the Green Bank 4.85 GHz Survey (refered to as GB6) (Condon et al. 1989). However, all radio galaxies and AGNs are limited to the northern hemisphere, and the sample seems to be not large enough in size enough to claim the luminosity correlations.

This paper presents a test of the luminosity correlations of the ROSAT selected radio-loud AGNs. The AGN sample is constructed by combining our

cross-identification list (Yuan et al. 1998) with the sources given by Brinkmann et al. (1995). Based on the larger sample, the luminosity correlations previously proposed can be verified in more details, and the implications relevant to AGN unification schemes can be also observed.

2. The Sample

The Parkes-MIT-NRAO (PMN) 4.85 GHz Radio Survey was conducted by Griffith & Wright (1993; 1991), using the Parkes 64m radio telescope with the NRAO multibeam receiver, with the same sensitivity as that of the GB6 survey. The PMN survey covers the southern hemisphere ($-87.°5 < \delta < +10°$) with a limiting flux of about 35 mJy at 4.85 GHz frequency, unlike the GB6 survey (also at the same frequency) covering a region of $0° < \delta < +75°$. A cross-identification of the southern-sky objects with the RASS and PMN surveys yields a list of 642 sources. Merely 311 (52%) coincidences were previously optically identified as extragalactic objects, using the NASA/IPAC Extragalactic Database (NED). A significant fraction of them are radio galaxies (129) and AGNs (183) (including 119 QSOs, 39 Seyferts, and 25 BL Lacs). The fluxes emitted from radio, optical, and X-ray bands and the other important parameters, such as redshift (or radial velocity) and power law index in soft X-ray band, are compiled in Yuan et al. (1998), in which the statistical properties of our source list can be also found.

A similar list of the northern-sky objects was given by Brinkmann et al. (1995). The combination of these two source lists generates a large sample, containing 367 quasars, 86 seyferts, 80 BL Lacertae objects, and 282 radio galaxies, which allows an investigation on broad band energy distribution and other possible correlations among the spectral indices and luminosities for various types of AGNs.

3. Luminosity Correlation

Our sample includes a large number of various types of AGNs, which allows an investigation of the luminosity correlations for AGNs. The derivation of luminosity from the observed flux is given by Schmidt & Green (1986).

The correlation between the luminosities of X-ray and radio bands which has been emphasized in many previous studies strongly suggests a similar origin of the radiation in all radio sources. Figure 1b confirms the correlation between the monochromatic X-ray luminosity at 2 keV and radio luminosity at 4.85 GHz. The galaxies populate the low luminosity region and quasars locate the high luminosity end. The regression analysis for subsamples of galaxies and quasars shows that both of the linear correlation coefficients are significant at very high confidence level. The hypothesis that the slopes of the linear regressions are the same for galaxies and quasars can be ruled out with nearly 100% confidence. Compared with the previous studies by Fabbiano et al. (1984), our correlation is somewhat similar to that of the flat spectrum objects, hinting that radio-loud objects at high frequency band (4.85 GHz) seem to be enriched with flat radio spectrum objects. The quasar population seems to have a good proportionality between X-ray and optical emission, indicating a common radiation mechanism.

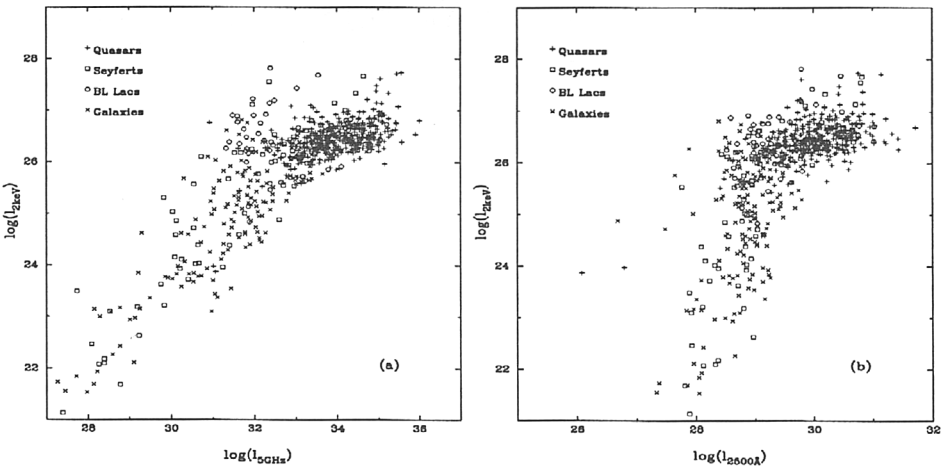

Figure 1. Monochromatic X-ray luminosity at 2 keV as a function of the monochromatic luminosites at 4.85 GHz (left panel) and at 2500 Å(right panel) (in erg s^{-1} Hz^{-1}), for all types of objects in our sample.

Figure 1b shows the monochromatic X-ray luminosity at 2 keV as a function of the optical luminosity at 2500 Å. However, it can be seen that the distribution of galaxies and Seyferts are completely different from that of quasars. Quasars have a typical monochromatic X-ray luminosity of 10^{27} erg s^{-1} Hz^{-1}, and cover a relatively wide region of optical luminosity. The slopes of the linear regressions for galaxies and quasars are significantly diverse.

Note that it is still uncertain about the extent of selection effects in observation and biases in measurements.

4. Correlations Between Spectral Index α_{ox} And Luminosities

Based mainly on geometrical and orientation arguments, unification schemes have been proposed for more than a decade to explain the connection of AGN properties. It is of great interest to analyze the probable correlations between the optical-to-X-ray spectral index α_{ox} and the monochromatic luminosities, since the spectral index α_{ox} may be sensitive to the structures and physical conditions of the outer regions, spanning from the accretion disk to the broad emission-line region (BELR), of different types of AGNs. The two-point spectral index α_{ox} is defined as: $\alpha_{ox} = -log(S_{\nu_x}/S_{\nu_{opt}})/log(\nu_x/\nu_{opt})$. The diagram of α_{ox} versus monochromatic luminosities might provide some clues to physical conditions of the BELR.

Figure 2 gives a global picture of correlations between the spectral index α_{ox} and luminosities emitted at 4.85 GHz (left panel), 5500 Å(middle panel), and 2 keV (right panel). It is interesting that radio galaxies adn Seyferts have a decreasing tendency systematically with increasing luminosities, which is completely different from quasars. A good linear correlation can be found for galaxies and Seyferts in Fig. 2c. As a sharp contrast, the quasars show a tight corre-

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lation between spectral indices α_{ox} and optical luminosities in Fig. 2b. Such a good correlation in Fig. 2b can be used to predict the X-ray luminosities of quasars according to their optical emissions. Similarly, Fig. 2c can be utilized to estimate the optical luminosities of radio galaxies and Seyferts with given X-ray emissions. Our results hint that the structure and physical conditions in outer regions are significantly different from galaxies to quasars.

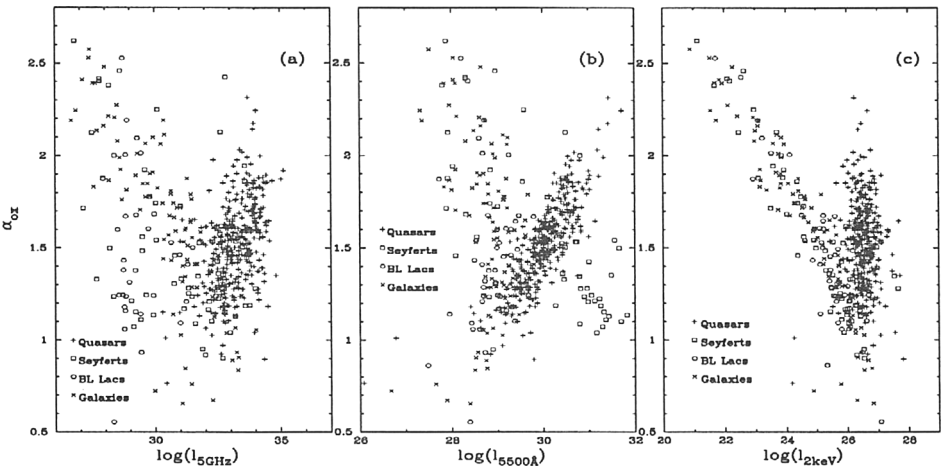

Figure 2. Plots of the spectral indices α_{ox} versus monochromatic luminosities at 4.85 GHz (left panel), 5500 Å(middle panel), and 2 keV (right panel), for all types of objects in our sample.

5. Discussion

To understand the intrinsic mechanisms and the mutual relations between the different categories of extragalactic objects, we constructed a large sample of X-ray selected radio-loud AGNs. This sample is inhomogenous and the selection is mainly a result of the X-ray flux limitation. The luminosity correlations given above strongly suggest that the radio, optical, and X-ray emission are essentially physically connected. Browne & Murphy (1987) presented a model of a 'canonical quasar' where the optical and X-ray emission both contain beamed and unbeamed contributions. The nuclear origin of the X-ray emission seems to be established (Fabbiano et al. 1984) even for radio galaxies, which indicates that the apparently different source types are intrinsically the same kind of objects, but seen under different geometric viewing conditions.

The impressive correlation between radio and X-ray luminosities, seen from Fig. 1a, confirms a similar origin for the radiation in all radio sources. However, it should be not easy for orientation-related unification schemes of AGNs to accommodate the fact that the slope of the correlation for radio galaxies and Seyferts is not so compatible with that for quasars.

We also find a tight correlation between spectral indices α_{ox} and optical luminosities for quasars, which is significantly different from the characteristics

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of the radio galaxies and Seyferts. According to the definition of spectral index α_{ox}, for quasars with a typical value of X-ray luminosity, the larger the optical luminosity is, the steeper the energy distribution between the optical and X-ray bands. The correlation might indicate that the core regions of quasars emit energy at X-ray energies of the same magnitude. On the other hand, the spectral indices α_{ox} of radio galaxies and Seyferts are found to be counter-correlated with X-ray luminosities. These findings do not seem to be the result of observational selection effects and measurement bias.

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