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ASTRONOMY AND ASTROPHYSICS

The correlations between the core dominance parameter and the core and extended powers of quasars

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Abstract. We study the correlations between the core dominance parameter R and the core and extended powers P_{core} and P_{ext} in the case of quasars with four different samples. In some samples, $logP_{ext}$ is highly anti-correlated with $logR$ while $logP_{core}$ is not at all correlated with $logR$. This effect seems to be common in the case of quasars when R is not very small. It obviously contradicts the conventional hypothesis of the core and extended emissions of radio sources in accordance with unified schemes and beaming models. Our study also implies that when R becomes larger, the anti-correlation between $logP_{ext}$ and $logR$ becomes more obvious while the correlation between $logP_{core}$ and $logR$ becomes less obvious; when R becomes smaller, the above anti-correlation becomes less obvious while the correlation becomes more obvious. This effect can be interpreted by assuming that, for the lobe-dominated quasars, the emission of the core is beamed and oriented, while for core-dominated quasars, the emission of the core is unbeamed and isotropic.

Key words: quasars: general – radio continuum: galaxies

1. Introduction

In studying the structure of extragalactic radio sources, "unified schemes" have always played important roles. In a unified scheme, BL Lac objects are presumed to be intrinsically identical to Fanaroff-Riley type I (FR-I; Fanaroff & Riley 1974) radio galaxies with jets oriented close to the line of sight and FR-I galaxies being their parent population (Browne 1983; Wardle, Moore & Angel 1984; Urry & Padovani 1995). In another unified scheme, Fanaroff-Riley type II (FR-II) radio galaxies, steep spectrum quasars and compact radio quasars are presumed to be drawn from the same parent population, but oriented at varying angles to the line of sight [see Barthel (1989) and Antonucci (1993) for more details]. A common assumption of unified schemes is that some specific classes of extragalactic radio sources are intrinsically the same, with their apparent differences being due to varying observational angles. This assumption is always accompanied by "beaming models". In beaming models (Rees 1966; Blandford & Königl 1979; Orr & Browne 1982; Pearson & Zensus 1987), the cores of radio sources are presumed to be dominated by beamed emission with their fluxes being enhanced by Doppler boosting, and the extended emissions of the sources are always presumed to be unbeamed and isotropic. Hence, the ratio of the core power to the extended power $R \equiv P_{core}/P_{ext}$ (called "core dominance parameter") has often been used as a relative measure of orientation (Hine & Scheuer 1980; Orr & Browne 1982), where large R is due to Doppler boosting at a small angle to the line of sight and small R corresponds to a large inclination angle. In this scenario, one may naturally expect that the core dominance parameter R should statistically be correlated with the core power P_{core} but should not be correlated with the extended power P_{ext}. However, in a previous work we found that R is not correlated with P_{core} but is obviously anti-correlated with P_{ext} in the cases of RBLs and XBLs (Qin et al. 1997). In this paper, we attempt to find out if this effect is still held in the case of quasars.

In Sect. 2, we investigate the correlations between R and P_{core}, P_{ext} in four samples of quasars. The results are discussed and a summary of this work is presented in Sect. 3.

2. Samples and correlation analysis

In order to have a statistical study of the correlations of the core dominance parameter R and the core and extended powers P_{core} and P_{ext} in the case of quasars, we employ some samples from literature. The samples selected are under the following conditions: (1) the size of samples must be big enough (say, $N \geq 30$ or $N \sim 30$); (2) if there are several classes of quasars within a sample, the number of sources of each class must also be big enough; (3) the data should be new. In this way, we found four samples suitable for the study. These samples are from Punsly (1995) (Sample 1), Murphy et al. (1993) (Sample 2), Hooimeyer et al. (1992) (Sample 3) and Hough & Readhead (1989) (Sample 4). The correlations are studied with these samples in the following.

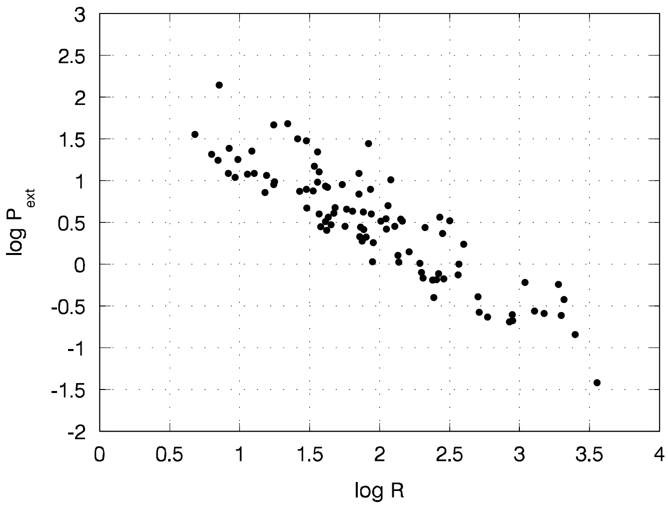

Fig. 1a. The plot of $logP_{ext} - logR$ for Sample 1.

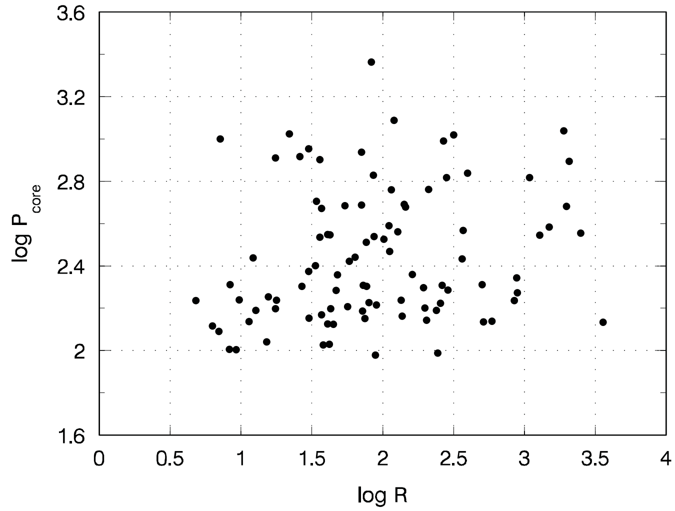

Fig. 1b. The plot of $logP_{core} - logR$ for Sample 1.

2.1. Sample 1

Sample 1 is from a large sample of 134 extremely powerful radio core quasars presented by Punsly (1995). An ultraluminous core was defined to have a core power, P_{core}, larger than $10^{46} ergs/s$ in the quasar rest frame between $10MHz$ and $250GHz$. The adopted cosmological parameters are $H_0 = 55kms^{-1}Mpc^{-1}$ and $q_0 = 0$. Only those sources with certain values of P_{ext}, P_{core} and R being presented are included in Sample 1. Thus, we have a powerful radio core quasar sample of 94 sources from the paper.

With Sample 1, a linear regression analysis gives:

$$logP_{ext} = (-0.91 \pm 0.05)logR + (2.26 \pm 0.10),$$
$$r = -0.889(N = 94)$$

and

$$logP_{core} = (0.09 \pm 0.05)logR + (2.26 \pm 0.10),$$
$$r = 0.196(N = 94),$$

where r is the correlation coefficient and N is the number of sources. The plots of $logP_{ext} - logR$ and $logP_{core} - logR$ for Sample 1 are shown in Fig. 1a and Fig. 1b, respectively. We find from these results that $logP_{ext}$ is highly anti-correlated with $logR$ while $logP_{core}$ is not correlated with $logR$ at all.

2.2. Sample 2

There are 89 sources within the complete sample of core-dominated radio sources presented by Murphy et al. (1993). All these sources have $5GHz$ core flux densities $> 1Jy$. The maps of radio structure of the sources were made at a frequency of $1.64GHz$ from combined VLA A and B configuration data. Of the 89 sources, 19 are BL Lac objects while 70 are quasars. These 70 sources form a complete sample of core-dominated quasars. Within this sample, there are only 54 sources with their values of the core and extended powers being available, and these sources constitute Sample 2. We take the values of R_c and L_{ext} of the sources directly from Table 3 of the paper, where R_c is the ratio of core to extended luminosity at an emitted frequency equal to the observing frequency $1.64GHz$ and L_{ext} is the extended radio luminosity in WHz^{-1} at $1.64GHz$. The adopted cosmological parameters are $H_0 = 50kms^{-1}Mpc^{-1}$ and $q_0 = 0$, while the adopted core and extended spectral indices are $\alpha_{core} = 0$ and $\alpha_{ext} = 1$ ($S_\nu \propto \nu^{-\alpha}$), respectively. The core radio luminosity is calculated by $L_{core} = R_c L_{ext}$.

A linear regression analysis with Sample 2 gives:

$$logL_{ext} = (-0.88 \pm 0.11)logR_c + (27.82 \pm 0.14),$$
$$r = -0.739(N = 54)$$

and

$$logL_{core} = (0.12 \pm 0.11)logR_c + (27.82 \pm 0.14),$$
$$r = 0.150(N = 54).$$

The plots of $logL_{ext} - logR_c$ and $logL_{core} - logR_c$ for Sample 2 are shown in Fig. 2a and Fig. 2b, respectively. The results also show that $logL_{ext}$ is highly anti-correlated with $logR_c$ while $logL_{core}$ is not correlated with $logR_c$ at all.

2.3. Sample 3

Sample 3 is a sample of 30 quasars with extended radio structure observed with VLBI at $5GHz$, presented by Hooimeyer et al. (1992). The data of the total luminosity at $5GHz$, L_{tot}^{5000}, the core dominance parameter R and redshift z could be taken directly from Table 4 of the paper. The core dominance parameter R was defined as the ratio $L_{core}^{5000}/(L_{tot}^{5000} - L_{core}^{5000})$, where L_{core}^{5000} is the core luminosity at $5GHz$, divided by a K-correction factor $(1+z)^{\alpha}$, where a value of 0.7 was adopted for α ($S_\nu \propto \nu^{-\alpha}$). The adopted cosmological parameters are $H_0 = 100kms^{-1}Mpc^{-1}$ and $q_0 = 0.05$. According to the definition of R, we have $L_{core}^{5000} = RL_{tot}^{5000}/[R + (1+z)^{-\alpha}]$.

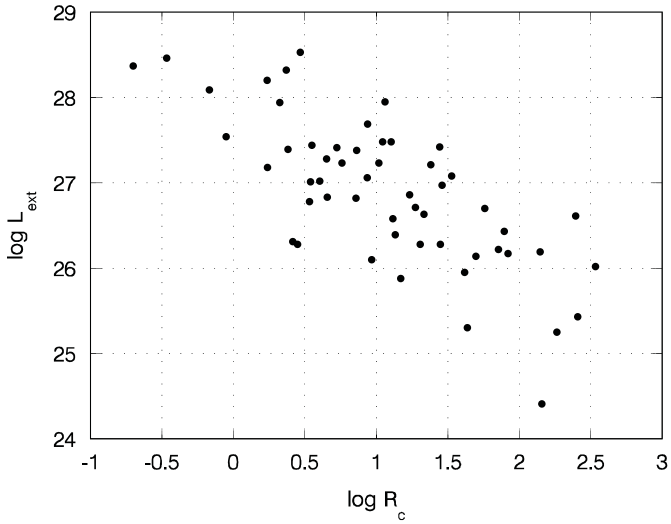

Fig. 2a. The plot of $logL_{ext} - logR_c$ for Sample 2.

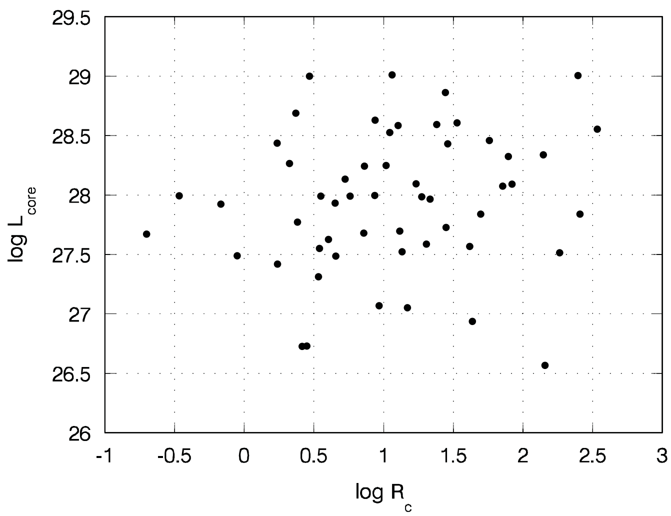

Fig. 2b. The plot of $logL_{core} - logR_c$ for Sample 2.

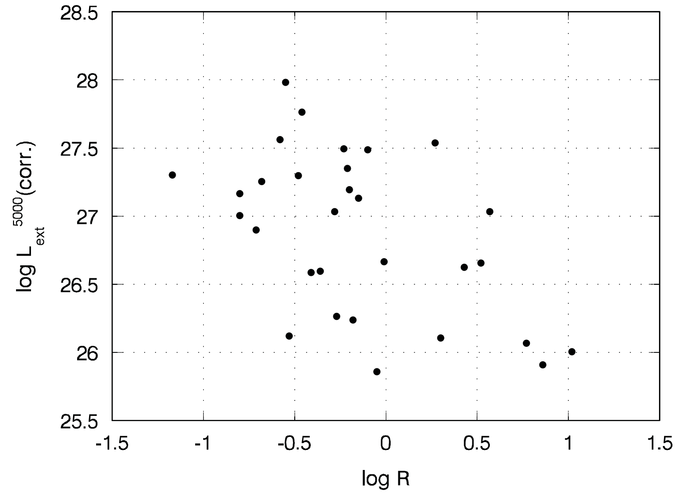

Fig. 3a. The plot of $logL^{5000}_{ext}(corr.) - logR$ for Sample 3.

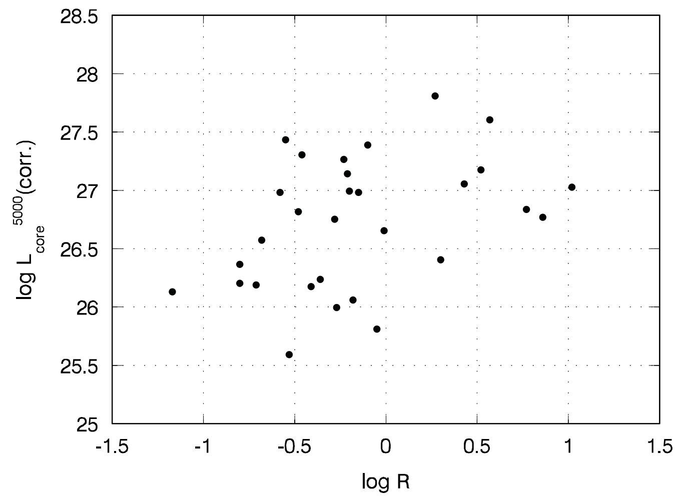

Fig. 3b. The plot of $logL^{5000}_{core}(corr.) - logR$ for Sample 3.

The extended luminosity at $5GHz$ could be calculated by $L^{5000}_{ext} = L^{5000}_{tot} - L^{5000}_{core}$.

With the above data, we have

$$logL^{5000}_{ext} = (-0.57 \pm 0.19)logR + (26.84 \pm 0.10),$$
$$r = -0.501(N = 30)$$

and

$$logL^{5000}_{core} = (0.43 \pm 0.21)logR + (27.01 \pm 0.11),$$
$$r = 0.368(N = 30).$$

We learn from the definition of R that the values of L^{5000}_{tot} and L^{5000}_{core} (hence L^{5000}_{ext}) had not been K-corrected. To meet $\alpha = 0.7$ ($\alpha \equiv \alpha_{ext} - \alpha_{core}$), we adopt $\alpha_{core} = 0.1$ and $\alpha_{ext} = 0.8$ for K-corrections. Therefore we have $L^{5000}_{core}(corr.)$ from L^{5000}_{core} and $L^{5000}_{ext}(corr.)$ from L^{5000}_{ext} by K-corrections. A linear regression analysis with these new data gives

$$logL^{5000}_{ext}(corr.) = (-0.57 \pm 0.18)logR + (26.79 \pm 0.10),$$
$$r = -0.514(N = 30)$$

and

$$logL^{5000}_{core}(corr.) = (0.43 \pm 0.18)logR + (26.79 \pm 0.10),$$
$$r = 0.405(N = 30).$$

The plots of $logL^{5000}_{ext}(corr.) - logR$ and $logL^{5000}_{core}(corr.) - logR$ for Sample 3 are shown in Fig. 3a and Fig. 3b, respectively. These results are different from that of Sample 1 and Sample 2. While $logL^{5000}_{ext}(corr.)$ is still anti-correlated with $logR$, there is also an obvious correlation between $logL^{5000}_{core}(corr.)$ and $logR$.

2.4. Sample 4

Sample 4 is the complete, flux-density-limited sample of double-lobed radio quasars defined by Hough & Readhead (1989). In their definition, nuclei of the sources were bright

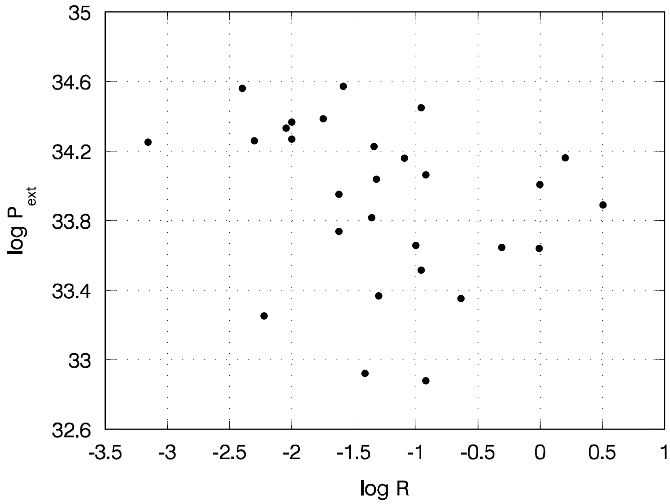

Fig. 4a. The plot of $logP_{ext} - logR$ for Sample 4.

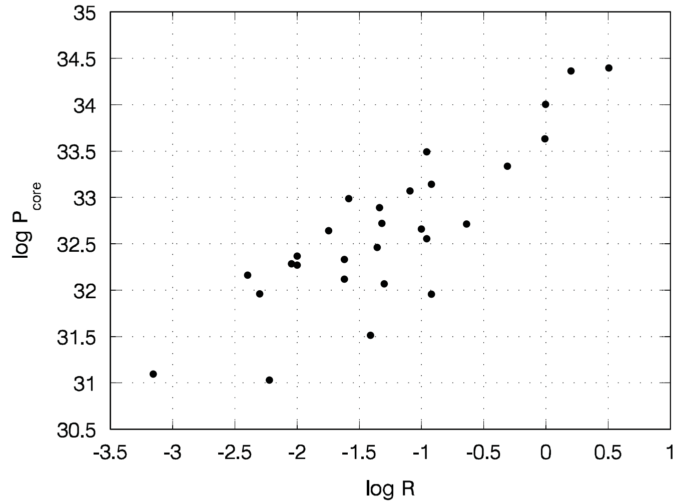

Fig. 4b. The plot of $logP_{core} - logR$ for Sample 4.

enough to be mapped with the Mark III VLBI system. A "double-lobed" quasar was defined as one in which the central component (coincident with the optical object) is straddled by two roughly symmetrical lobes. There are 28 sources within the sample. The values of the core dominance parameter R of the sources were presented in Table II of the paper, where K-corrections had been made. The adopted cosmological parameters are $H_0 = 100kms^{-1}Mpc^{-1}$ and $q_0 = 0.5$. All the core spectral indices of the sources were presented. They are: for 0127+233 and 1458+718, $\alpha_{core} = 0.7$ ($S_\nu \propto \nu^{-\alpha}$); for 0133+207 and 1100+772, $\alpha_{core} = 0.0$; for 1040+123, $\alpha_{core} = 0.5$; for 1137+660, $\alpha_{core} = -0.5$; for 1218+339 and 1241+166, $\alpha_{core} = 0.1$; for other sources, $\alpha_{core} = 0.2$. The values of the core flux density at $5GHz$, S_{core}, and redshift z are available from Table I of the paper. The core power P_{core} could therefore be calculated with these values (i.e., the values of H_0, q_0, z, α_{core} and S_{core}). Once the values of P_{core} have been determined, that of the extended power P_{ext} could be calculated by $P_{ext} = P_{core}/R$.

With these data, a linear regression analysis gives:

$$logP_{ext} = (-0.16 \pm 0.10)logR + (33.72 \pm 0.16),$$
$$r = -0.286(N = 28)$$

and

$$logP_{core} = (0.84 \pm 0.10)logR + (33.72 \pm 0.16),$$
$$r = 0.848(N = 28).$$

The plots of $logP_{ext} - logR$ and $logP_{core} - logR$ for Sample 4 are shown in Fig. 4a and Fig. 4b, respectively. These results are significantly different from that of the previous samples. $logP_{ext}$ is not at all correlated with $logR$, while $logP_{core}$ is highly correlated with $logR$.

3. Discussion and conclusions

We have studied the correlations between the core dominance parameter R and the core and extended powers P_{core} and P_{ext} in the case of quasars with four different samples. For the core-dominated quasars, $logP_{ext}$ is highly anti-correlated with $logR$ while $logP_{core}$ is not at all correlated with $logR$. For the lobe-dominated quasars, $logP_{ext}$ is not at all correlated with $logR$ while $logP_{core}$ is highly correlated with $logR$. The confidence levels of the correlations are different for varying classes of quasars. We notice that the mean values of R are different for the four adopted samples. They are: for Sample 1, $\overline{R} = 296.14$; for Sample 2, $\overline{R} = 39.68$; for Sample 3, $\overline{R} = 1.57$; for Sample 4, $\overline{R} = 0.30$. It implies that when R becomes larger, the anti-correlation between $logP_{ext}$ and $logR$ becomes more obvious while the correlation between $logP_{core}$ and $logR$ becomes less obvious; when R becomes smaller, the above anti-correlation becomes less obvious while the correlation becomes more obvious. The effect of the anti-correlation between $logP_{ext}$ and $logR$ and the non-correlation between $logP_{core}$ and $logR$ is common in the case of quasars when R is not very small, which is similar to that of the cases of XBLs and RBLs found in our previous work (Qin et al. 1997). Therefore, while the conventional interpretation of the core and extended emissions is true when R is very small, it may not be held in many cases (especially when R is big).

This effect is rather confused when interpreted by unified schemes and beaming models. If this effect is true, we suggest that the conventional beaming models should be revised. For the lobe-dominated quasars, the emission of the core is beamed and oriented, while for core-dominated quasars, the emission of the core is unbeamed and isotropic. With this model, the above effect can be simply explained.

We observe that the data of the four samples are based on different means of observations, different observing frequencies, different adopted parameters and even different definitions of luminosities (or powers) (some are monochromatic while others are not). This in one aspect implies that, though there are so many differences, the above effect is rather common in the case of quasars. In other aspect it suggests that the results from the four samples could not be compared quantitatively. We also observe that, some of the samples are not at all complete. Thus, the above results and interpretation are not conclusive. They need to be confirmed by further investigations.

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