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Spectral Indices of Core and Extended Components of Extragalactic Radio Sources *

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Abstract We use observed peak and total flux densities at 6 cm and 20 cm to determine the spectral indices separately for the core and extended components of QSOs and galaxies, as well as their core-dominance parameters. Our results indicate that 1) Nine QSOs show both greater than 1.0 core-dominance parameters (those objects should be blazars) and greater than 0.5 spectral indices. The average core spectral index is $\alpha_{\rm Core} = 0.85{\pm}0.21$ for the nine blazars, which implies that it is not reliable to use $\alpha_{\rm radio} = 0.0$ for blazars. For the different subclasses, the core and extended spectral indices are as follows: for the blazars, $\alpha_{\rm Core} = 0.22{\pm}0.06$ and $\alpha_{\rm Ext} = 0.77{\pm}0.12$; the galaxies, $\alpha_{\rm Core} = 1.01{\pm}0.13$ and $\alpha_{\rm Ext} = 0.83{\pm}0.21$, and for the QSOs, $\alpha_{\rm Core} = 0.28{\pm}0.10$ and $\alpha_{\rm Ext} = 0.68{\pm}0.08$. 2) The core spectral index and core dominance parameter (R) show an anti-correlation, $\alpha_{\rm C} = (-1.28{\pm}0.26)\log R + (0.65 \pm 0.11)$; 3) R is approximately linearly correlated with redshift (z).

Key words: galaxies: active — radio continuum: galaxies

1 INTRODUCTION

We now know the approximate structure of active galactic nuclei (AGNs), i.e., there is a supermassive black hole at the center surrounded by an accretion disk. However, the physical process of energy production and, especially, the nature of the central region, is still not very clear. The variations of AGNs are characterized by rapid variability superposed on a long-term variation. The intensive monitoring of the AGNs provide not only the rapid variability ('micro variability', the so called short-term variability, or intra-day variability) but also the long-term trends. The study of AGN variations can help us to probe and understand the nature of the central regions of AGNs. Radio observations of AGNs have been carrying on for decades. There are groups working on such monitoring in radio bands: Michigan (Aller et al. 1999), Metsahovi (Terasranta et al. 1999; Tonikoski et al. 2001), and IRAM (Steppe et al. 1995). Based on VLA and VLBI observations of the variations in the brightness, and superluminal motion in AGNs etc., the relativistic beaming model has been constructed. VLA and VLBI observations make it possible to separate the core and the extended components. Thus, the observed radio emissions of AGNs contain two components, a compact relativistically beamed core component and an unbeamed lobe component. From these authors have defined a core dominance parameter R

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(the ratio of the core to the extended component) as an indication of the beaming effect (e.g., Orr & Brown 1982). As we know, blazars are a subclass of AGNs, characterised by rapid brightness variation, being radio-loud (the radio to optical luminosity ≥ 10), core dominant ($R > 1$), highly polarized, and containing superluminal motion etc. Multiwavelength observational data show that the radio spectrum of most blazars are flat: usually $\alpha_{\rm radio} = 0.0$ ($S_\nu \propto \nu^{-\alpha}$). Is that always true? Do all blazars have the same radio spectral index? To answer this question, one should have simultaneous multiwavelength core and extended component data in radio band, and the data should satisfy two criteria: 1) The data should be observed simultaneously at, at least, two wavebands. 2) Both data of core and extended components should be available. High quality data at one band are available (e.g., Hough & Readhead 1989; Murphy et al. 1993; Zhang et al. 2003, also see Cao & Jiang 2001), but until now the data that satisfy the above two criteria are scanty. Fortunately, for a number of sources, Ulvestad et al. (1981) has given the total emission from the entire source and the peak flux density of the dominant component at two frequencies. If we take the peak flux density as that from the core, then we can calculate the spectral index using the Ulvestad data. That is the main aim of the present paper. The paper is arranged as follows: In Section 2, we compile a sample and give the result. In Section 3 we carry out a discussion and a brief conclusion is given in Section 4.

2 SAMPLE AND RESULTS

2.1 Sample

Ulvestad et al. (1981) provided observations at 6 cm and 20 cm of a number of sources, some of which are resolved and have more than two components. For those sources, we only consider the objects with one component with peak flux more than three times larger than any other component. We then have 74 resolved sources (47 QSOs, 18 galaxies and nine unidentified sources), for which peak and total flux densities at both frequencies are given. Here, the peak flux density is from the dominant component and the total flux density is from the entire source. These 74 sources are listed in Table 1, in which col. 1 gives the source name, col. 2 the classification, (uni for unidentified, GAL for galaxy, and QSS for QSO), cols. 3 and 4, the total and peak flux densities at 6 cm, and cols. 5 and 6, the same at 20 cm; all fluxes are in units of Jy.

Table 1 Radio Data of a Sample

Name	ID	$S_{6\rm cm}^{\rm Tot}$	$S_{6\rm cm}^{\rm Core}$	$S_{20\rm cm}^{\rm Tot}$	$S_{20\rm cm}^{\rm Core}$
0021–297	uni	0.9	0.1	1.7	0.4
0704–231	uni	1.5	1.0	3.6	1.9
0945+664	uni	1.2	0.8	2.3	1.9
1005+077	uni	2.1	1.0	5.9	4.7
1213–172	uni	1.9	1.5	1.6	1.2
1317+179	uni	0.6	0.1	1.7	0.6
1821–327	uni	0.6	0.1	4.0	0.5
1859–235	uni	1.1	0.6	2.9	1.8
2149–287	uni	1.2	0.5	2.8	1.6
0055–016	GAL	0.3	0.1	3.8	0.2
0114–211	GAL	1.1	0.9	3.7	2.8
0116+082	GAL	1.1	0.9	2.5	1.7
0347+057	GAL	1.0	0.3	2.8	1.3
0402+379	GAL	1.1	0.9	1.7	1.2
0453–206	GAL	1.5	0.1	4.4	1.4
0521–365	GAL	3.2	1.7	16.5	2.0
0604–203	GAL	0.4	0.1	3.1	0.5

Table 1 Continued

Name	ID	$S_{6\mathrm{cm}}^{\mathrm{Tot}}$	$S_{6\mathrm{cm}}^{\mathrm{Core}}$	$S_{20\mathrm{cm}}^{\mathrm{Tot}}$	$S_{20\mathrm{cm}}^{\mathrm{Core}}$
0614–349	GAL	1.3	0.9	2.8	2.7
0624–058	GAL	6.6	2.4	17.6	8.0
0755+379	GAL	0.3	0.2	2.2	0.2
1203+645	GAL	1.2	0.8	3.8	3.0
1221–423	GAL	1.0	0.3	2.3	1.8
1251+159	GAL	0.6	0.1	1.7	0.8
1434+036	GAL	1.2	0.4	2.8	1.0
1603+001	GAL	0.9	0.1	2.2	0.3
2314+038	GAL	1.4	0.4	3.7	2.9
2323–407	GAL	1.0	0.4	3.0	2.0
0003–003	QSS	1.5	0.6	3.8	2.0
0010+405	QSS	0.7	0.5	1.6	0.5
0118–272	QSS	0.9	0.8	1.1	0.8
0127+233	QSS	1.1	0.8	3.0	1.9
0218+357	QSS	1.2	0.6	1.7	1.0
0518+165	QSS	4.1	1.6	8.6	7.7
0539–057	QSS	1.5	1.4	1.3	0.7
0602–319	QSS	1.1	0.1	2.9	1.5
0741–063	QSS	3.0	2.6	8.0	6.4
0745+241	QSS	1.2	0.9	0.8	0.5
0805–077	QSS	1.0	0.9	1.3	1.0
0812+367	QSS	0.9	0.8	0.9	0.7
0820+225	QSS	1.8	1.5	2.2	1.8
0850+581	QSS	0.8	0.2	1.3	0.6
0858–279	QSS	1.7	1.6	2.4	1.8
0859+470	QSS	1.6	1.4	2.3	1.8
0906+430	QSS	1.8	1.0	4.2	3.1
0920–397	QSS	1.9	1.5	2.6	1.3
0954+556	QSS	2.1	1.8	3.2	1.4
1018–426	QSS	1.1	0.1	4.1	2.3
1045–188	QSS	0.7	0.6	1.1	0.4
1049+215	QSS	1.2	1.0	1.1	0.9
1055+201	QSS	1.5	0.4	2.0	1.2
1150+497	QSS	0.9	0.6	1.6	0.6
1222+131	QSS	0.6	0.2	4.0	0.4
1244–255	QSS	1.6	1.4	1.2	1.0
1253–055	QSS	11.7	10.5	11.0	6.2
1414–037	QSS	0.7	0.4	2.4	1.3
1424–418	QSS	2.1	1.0	3.7	2.1
1508–055	QSS	2.1	0.8	3.8	1.9
1538+149	QSS	1.5	1.2	1.7	1.2
1548+056	QSS	2.1	1.8	2.3	2.1
1550–269	QSS	1.5	1.2	1.4	1.0
1606+106	QSS	1.6	1.5	1.2	0.5
1622–253	QSS	3.4	3.1	1.9	1.0
1629+120	QSS	0.8	0.5	1.6	1.2
1655+077	QSS	1.8	1.5	1.6	1.0
1656+053	QSS	2.1	1.8	1.7	1.2
1800+440	QSS	0.9	0.7	0.9	0.5
1823+568	QSS	1.6	1.3	1.5	0.9
1828+487	QSS	6.0	2.4	14.6	7.0
1829+290	QSS	1.5	1.1	3.7	2.7
1954+513	QSS	1.4	1.1	4.0	0.6
2135–209	QSS	1.4	1.1	3.9	2.6
2201+315	QSS	2.2	1.7	2.2	1.0
2209+080	QSS	0.8	0.3	1.3	0.7
2226–411	QSS	1.0	0.5	2.7	1.5

2.2 RESULTS

According to the two-component model, the total radio emission ($S^{\rm tot}$) is the sum of a core component ($S^{\rm C}$) and and extended component ($S^{\rm E}$) component: $S^{\rm tot} = S^{\rm C} + S^{\rm E}$. The extended flux can be obtained from the total and core emissions, $S^{\rm E} = S^{\rm tot} - S^{\rm C}$. Let the core and extended spectral indices be $\alpha_{\rm C}$ and $\alpha_{\rm E}$ ($S_\nu \propto \nu^{-\alpha}$). We K-correct the fluxes using $S = S^{\rm ob}(1+z)^{\alpha-1}$. Then the spectral indices can be calculated using

$$\alpha_{\rm C} = \frac{\log(S^{\rm C}_{6\,{\rm cm}}/S^{\rm C}_{20\,{\rm cm}})}{\log(6/20)}$$

and

$$\alpha_{\rm E} = \frac{\log(S^{\rm E}_{6\,{\rm cm}}/S^{\rm E}_{20\,{\rm cm}})}{\log(6/20)}\,.$$

Taking the peak flux density by Ulvestard et al. (1981) as the core flux density, we found, for the whole sample of ($N = 74$), $\alpha_{\rm C} = 0.53{\pm}0.08$, $\alpha_{\rm E} = 0.70{\pm}0.08$.

To investigate the spectral index difference between the two classes, we consider galaxies and QSOs separately and find, for the 18 galaxies, $\alpha_{\rm C} = 1.01{\pm}0.13$ ($N = 18$), $\alpha_{\rm E}{=}0.830{\pm}0.20$, and for the 47 QSOs, $\alpha_{\rm C} = 0.28{\pm}0.10$ ($N = 47$), $\alpha_{\rm E}{=}\ 0.68{\pm}0.08$.

The corresponding histograms are shown in Figs. 1, 2 and 3.

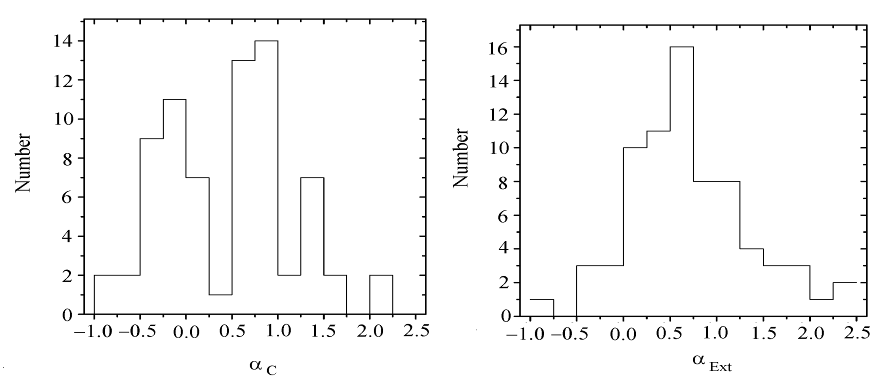

Fig. 1 Distribution of radio spectral index (whole sample).

As Fig. 3 shows, the core spectral index for QSOs has two peaks, so we divide the results ($\alpha_{\rm C}$) into two groups, one for $\alpha_{\rm C}$ greater than 0.5 ($N = 19$), one for less than 0.5 ($N = 28$). For the latter group, we obtain: $\alpha_{\rm C} = -0.21 \pm 0.06$ ($N = 28$), and for the former, $\alpha_{\rm C} = 1.00 \pm 0.12$ ($N = 19$). We also calculate the core dominance parameter using the formula, $R = (1+z)^{\alpha_{\rm C}-\alpha_{\rm E}} S^{\rm C}_{\rm ob}/S^{\rm E}_{\rm ob}$. Here, we K-correct the fluxes using $S = S^{\rm ob}(1+z)^{\alpha-1}$ with the redshift from Veron-Cetty & Veron (1998). The sources with known redshift and the corresponding core-dominance parameter (R) are listed in Table 2, in which col. 1 gives the name, col. 2 the identification, col. 3, the redshift, col. 4 the core spectral index, and col. 5 the core-dominance parameter.

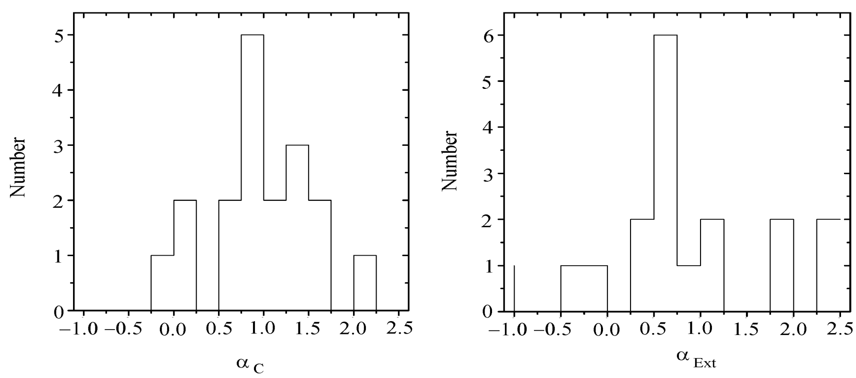

Fig. 2 Distribution of radio spectral index (Galaxies).

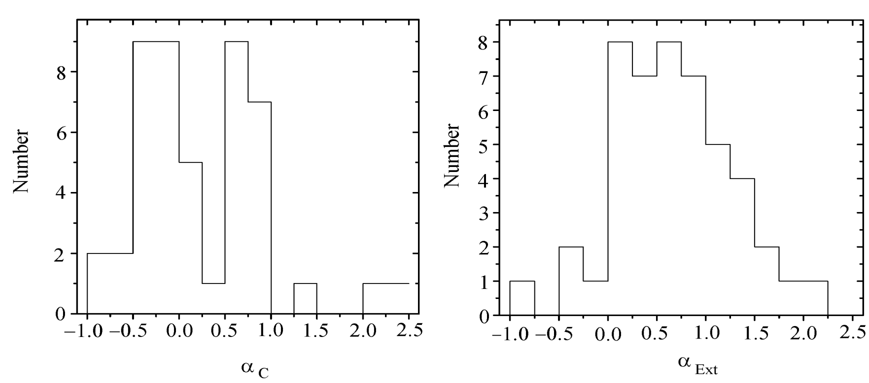

Fig. 3 Distribution of radio spectral index (QSOs).

The results show that most of the QSOs near the first peak (about –0.2) are blazars ($R > 1$). Of those near the second peak (1.0), however, there are just nine QSOs with core dominance parameters greater than 1 (blazars). In general, core-dominance quasars belong to flat spectral radio quasars, i.e., belong to blazars. However, the core-dominated sources on VLA scale are not necessarily blazars. They could be compact symmetrical objects (CSOs), which have typical size of hundred parsecs, and would appear compact on VLA scale. The corresponding diagram is shown in Fig. 4. For the nine blazars, we have $\alpha_{\rm C} = 0.85 \pm 0.21$. In this sense, it is not quite reliable to use $\alpha_{\rm C} = 0.0$ for blazars.

Table 2 The Core Spectral Index and Core Dominance Parameter

Name	ID	z	α_C	$R_{6\,cm}$	Name	ID	z	α_C	$R_{6\,cm}$
0116+082	GAL	0.59	0.53	3.37	1055+201	QSS	1.11	0.91	0.88
0347+057	GAL	0.34	1.22	0.51	1150+497	QSS	0.33	0.0	1.5
0402+379	Gal	0.05	0.24	4.38	1222+131	QSS	1.25	0.58	0.18
1203+645	Gal	0.37	1.10	2.36	1244–255	QSS	0.64	–0.28	6.1
1251+159	Gal	0.77	1.73	0.41	1253–055	QSS	0.54	–0.44	4.42
0003–003	QSS	1.04	1.0	0.9	1414–037	QSS	1.41	0.98	1.22
0010+405	QSS	0.26	0.00	1.81	1424–418	QSS	1.52	0.62	1.21
0127+233	QSS	1.47	0.72	1.93	1508–055	QSS	1.19	0.72	0.84
0218+357	QSS	0.94	0.42	1.22	1548+056	QSS	1.42	0.13	9.05
0518+165	QSS	0.76	1.31	2.16	1550–269	QSS	2.15	–0.15	2.56
0539–057	QSS	0.84	–0.58	3.98	1606+106	QSS	1.23	–0.91	1.98
0602–319	QSS	0.45	2.25	0.21	1622–253	QSS	0.79	–0.94	3.53
0745+241	QSS	0.41	–0.49	2.54	1629+120	QSS	1.79	0.73	2.75
0805–077	QSS	1.84	0.09	3.81	1655+077	QSS	0.62	–0.34	3.22
0812+367	QSS	1.03	–0.11	4.93	1656+053	QSS	0.88	–0.34	3.71
0850+581	QSS	1.32	0.91	0.65	1800+440	QSS	0.66	–0.28	2.27
0858–279	QSS	2.15	0.1	3.24	1828+487	QSS	0.69	0.89	0.77
0859+470	QSS	1.46	0.21	4.26	1829+290	QSS	0.84	0.75	2.73
0906+430	QSS	0.67	0.94	1.77	1954+513	QSS	1.22	–0.5	0.49
0920–397	QSS	0.59	–0.12	2.25	2135–209	QSS	0.64	0.71	2.86
0954+556	QSS	0.9	–0.21	2.02	2201+315	QSS	0.30	–0.44	2.51
1018–426	QSS	1.28	2.6	0.57	2209+080	QSS	0.48	0.7	0.75
1045–188	QSS	0.6	–0.34	2.41	2226–411	QSS	0.45	0.91	1.07
1049+215	QSS	1.3	–0.09	4.65	2314+038	QSS	0.22	1.65	0.58

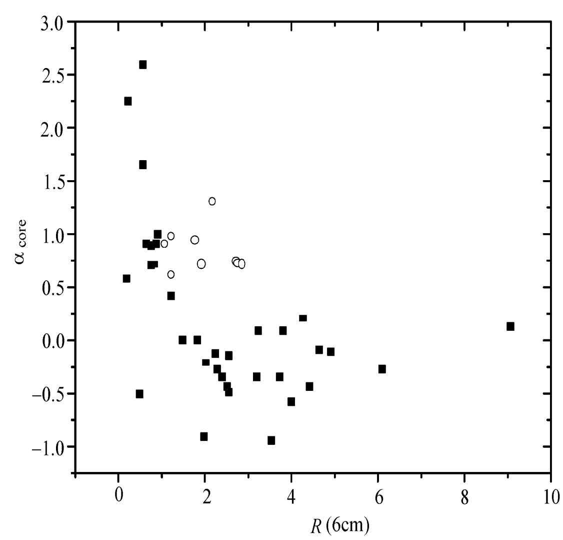

Fig. 4 Core dominance parameter and the core spectral index (The hollow circles represent sources with core dominance parameters greater than 1.0 and core spectral indices greater than 0.5).

3 DISCUSSION

Extragalactic sources show strong radio emission, which is composed of two components, a core and an extended emission. The core emission is generally beamed and it is possible that the emissions from the two components are from different mechanisms. This argument should be tested using the spectral index, for which one needs data that satisfy the two criteria stated in the Introduction. Such data are very scarce at present. In 1981, Ulvestard et al. gave both peak and total flux densities at 6 cm and 20 cm for a number of sources. Form this we chose 74 resolved sources, with the peak flux density from a dominant component. If we take the peak flux density as the core flux density a in Cao & Jiang (2001) and Kleun et al. (2002), then we can obtain the extended flux density from the total and peak flux densities. However, we should point out that taking the peak flux as the core flux will result in some uncertainty in the evaluation of the core-dominance parameter.

Based on that consideration, we calculated the spectral index and our statistical results show that, for the QSOs, the spectral indices are different (at 3σ) for the core from the extended components. For the galaxies, however, the difference between the two components is not clear. Between the cores of quasars and galaxies, the difference in the spectral index is nearly 7σ the galaxies having steeper core indices than the QSOs. Does that mean that the emissions or the relative electron distributions are different in QSO cores and in galaxy cores? Moreover, it is known that the core emissions in blazars are strongly beamed and their spectra are flat, can we then say that the steeper spectra in galaxies suggest that the beaming effect is not so strong in galaxy cores than in QSO cores? From Ulvestard et al. (1981) which contains 360 observed sources, we chose only 74 resolved sources, only a quart of the whole sample. This selection should not result in any selection effect on our results from the following considerations. 1) Ulvestard et al. (1981) also obtained the spectral index difference between quasars and galaxies based on the total flux density for the whole sample, our results are consistent with theirs. 2) For the R and α calculation, their values only depend on the observational data. Our finding that blazars ($R > 1$) have non-zero spectral indices is not from selection effect. We should mention that, however, the core flux density used in the present paper may be greater than the true one, which will make the obtained core-dominance parameter greater than the real core-dominance parameter. Therefore, more new data would be useful. Furthermore, the difference in the spectral index between the extended components of the quasars and galaxies is not large (near 1σ). This implies that the environment is similar in both types of objects.

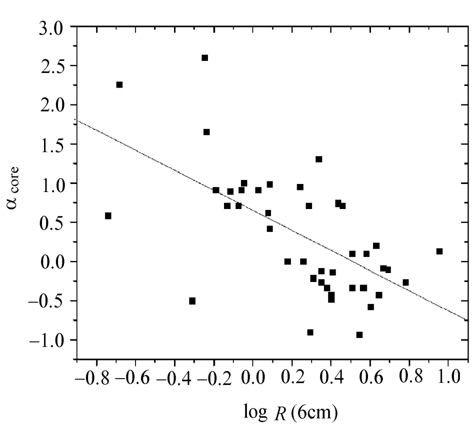

Fig. 5 Core dominance parameter (log) and the core spectral index.

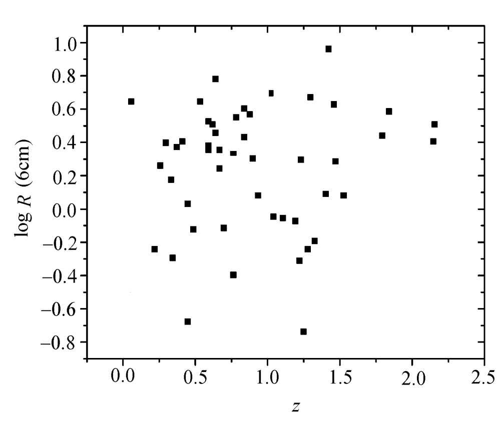

Fig. 6 Core dominance parameter (log) and redshift.

From Fig. 4, a correlation between $\alpha_{\rm C}$ and $\log R_\nu$ can be seen. This is shown in Fig. 5, in which the straight line is a best fit, $\alpha_{\rm C} = (-1.28 \pm 0.26) \log R + (0.65 \pm 0.11)$ with a correlation coefficient $r = -0.62$ and a chance probability of $p < 0.0001$. It shows that $\alpha_{\rm C}$ is anti-correlated with $\log R_\nu$.

Observations of distant objects imply they are strong sources. Theoretical work reveals that such sources have relativistic jet pointing to us, then they should have a large core dominance parameter. If this is true, we would expect that the core dominance parameter should be correlated with distance (or redshift). Our result (see in Fig. 6) has borne out this expectation in some sense, and that the core dominance parameter seems to have a tendency of being linearly correlated with the redshift.

4 CONCLUSION

Based on our calculation, we have come to the following conclusions: 1) It is not reliable to use $\alpha_{\rm radio} = 0.0$ for all blazars. 2) The core dominance parameter is anti-correlated with the spectral index and is approximately linearly correlated with the redshift (z). 3) For different subclasses, the averaged core and extended spectral indices are $\alpha_{\rm Core} = 1.01 \pm 0.13$ and $\alpha_{\rm Ext} = 0.83 \pm 0.21$ for galaxies, $\alpha_{\rm Core} = 0.28 \pm 0.10$ and $\alpha_{\rm Ext} = 0.68 \pm 0.08$ for QSOs, and $\alpha_{\rm Core} = 0.22 \pm 0.06$ and $\alpha_{\rm Ext} = 0.77 \pm 0.12$ for blazars.

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