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The ratio $R_{\rm T}$ of the jet to the unbeamed luminosities for superluminal radio sources*

Fan Jun-Hui(樊军辉)[a)b)] and Lin Rui-Guang(林瑞光)[b)]

[a)] *National Astronomical Observatory, Chinese Academy of Sciences, Beijing* 100012, *China*

[b)] *Center for Astrophysics, Guangzhou University, Guangzhou* 510400, *China*

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Relativistic beaming model has been successfully used to explain the observational properties in active galactic nuclei. In this model the emissions are composed of two components, i.e. the boosted and the isotropic emissions. But how much is from each part is unknown. It has been assumed that the luminosity in the jet is proportional to the unbeamed in the comoving frame. However, the value of this ratio is not easy to determine. In this paper, we use the beaming model and the radio sources with superluminal motions to estimate the ratio, $R_{\rm T}$, for each source. We find $R_{\rm T} = 0.044 \pm 0.02$, which is consistent with that found by Orr and Browne.

Keywords: active galactic nuclei, superluminal motion, relativistic beaming
PACC: 9870J, 9890, 9850R

1. Introduction

Many active galactic nuclei contain compact radio sources with several components which appear to move apart in successive high-resolution images. When the apparent transverse velocity of separation exceeds the speed of light ($\beta_{\rm app} = {\rm v/c}$), the motion together with the object is called superluminal. Superluminal motion (SM) has now been observed in dozens of sources,[1−3] and it is consistent with the beaming model.[4−7]

The popular kinematic explanation for SM is that the nuclear region contains a narrow, nearly straight, expanding jet of plasma in a relativistic motion. If the jet is pointed close to the line of sight, then the contraction of the apparent time scale can give rise to a superluminal motion. It also produces Doppler boosting, which brings a relatively large number of these objects into the strong-source catalogues. Superluminal sources have been studied for over two decades, and their main observational properties are well established.[8] Many observations are consistent with the uniform outward motion, independent of wavelength.

From the synchrotron self-Compton (SSC) and the relativistic beaming models, the Doppler factor, Lorentz factor, brightness temperature and the viewing angle of the jet have been obtained for many radio sources, and the different beaming indicators (Doppler factor and superluminal motion, etc.) have been found to be associated with each other.[9] Vermeulen and Cohen[3] gave a compilation of superluminal motion sources, presented some statistical predictions from a simple relativistic beaming model and discussed the inferences in which a comparison of data and models allows for both relativistic jets and cosmology. Wu and Quirrenbach Witzel[10] obtained correlations between the apparent velocity and radio power at 10GHz for large and small sources. In our previous paper, we have shown an association between radio and optical enhancements and that the acceleration model is reasonable.[1] Later on, some statistical results have been obtained for a sample of superluminal radio sources.[2] If the SM is caused by the effect of the relativistic beaming, we can expect to have some information for the jet, for example, the Lorentz factor, viewing angle, the ratio of intrinsic jet and the unbeamed luminosity. Also we can investigate the cor-

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relation between the beaming parameters and other observational data. This paper is arranged as follows: in section 2, we give the results for superluminal radio sources; and in section 3, we give some discussions and finally a brief conclusion.

2.Result for SM sources

In the relativistic beaming model, the observed flux, $S^{\rm ob}$, is boosted to be $\delta^{\rm p}$ times the intrinsic flux, $S^{\rm in}$, i.e. $S^{\rm ob} = \delta^{\rm p} S^{\rm in}$. In principle, one can obtain the intrinsic flux from the above formula. Unfortunately, the Doppler factor is unobservable. In 1993, Ghisellini *et al*[9] compiled the known core size, radio, optical and x-ray fluxes, and used them to estimate the Doppler factor based on the relativistic beaming and the synchrotron self-Compton models for a large sample. They also obtained the Lorentz factor and the viewing angle for objects with SM. If the Doppler factor, the superluminal velocity, and the so-called core-dominance are adopted, one can gain some information of the ratio of the intrinsic to the unbeamed luminosities, as described in the following.

2.1. Orr and Browne model

Following Hine and Scheuer,[11] Orr and Browne[12] defined a core-dominance parameter $R(\theta)$

$$R(\theta) = \frac{\text{flux density of beamed CC}}{\text{flux density of unbeamed components}},$$

$$R_{\rm T} = R(90^\circ),$$

where θ is the viewing angle, the CC (compact core) is assumed to be produced by emissions from the unresolved bases of two oppositely directed jets, which move with a speed β_c. If the jet spectra is flat, one can have the following relation,

$$R(\theta) = 1/2 R_{\rm T}[(1-\beta\cos\theta)^{-2} + (1+\beta\cos\theta)^{-2}]. \quad (1)$$

Therefore, $R_{\rm T}$ corresponds to the value of $R(\theta)$ when $\theta = 90^\circ$. From the beaming model, the Doppler factor and the superluminal velocity can be expressed as

$$\delta = [\Gamma(1-\beta\cos\theta)]^{-1}, \ \beta_{\rm app} = \frac{\beta\sin\theta}{1-\beta\cos\theta},$$

which suggest that the Lorentz factor (Γ) and the viewing angle (θ) can be expressed as

$$\Gamma = \frac{\beta_{\rm app}^2 + \delta^2 + 1}{2\delta}, \quad (2)$$

$$\tan\theta = \frac{2\beta_{\rm app}}{\beta_{\rm app}^2 + \delta^2 - 1}. \quad (3)$$

Thus, given the Doppler factor (δ) and the superluminal velocity ($\beta_{\rm app}$) of a source, Γ and θ can be obtained from Eqs.(2) and (3). Furthermore, if the core-dominance (R) is known, then $R_{\rm T}$ can be obtained from Eq.(1). This is the aim of this paper.

2.2. Data

From Ref.[9], in which the SSC model was used to estimate the Doppler factor and other parameters were compiled, we can find the Doppler factor, the superluminal velocity (H_0=100 km/Mpc$\cdot$s^{-1}), and the core-dominance for a sample of 38 objects. Then we calculate the relevant parameters (Γ, θ) and finally, obtain the parameter $R_{\rm T}$. They are listed in Table 1, in which column 1 gives the name; column 2 is the identification, CQ denotes the core-dominated quasars, G denotes galaxies, BL denotes the BL Lacertae objects, and LQ denotes the lower-polarized quasars; column 3 lists Doppler factor (δ); column 4 gives the superluminal velocity ($\beta_{\rm app}$); column 5 presents the core-dominance ($R(\theta)$); column 6 gives the maximum optical polarization ($P_{\rm opt}\%$); column 7 lists the Lorentz factor (Γ); column 8 gives the viewing angle (θ); and column 9 gives $R_{\rm T}$.

3. Discussion

SM has been observed from dozens of objects. A variety of models have been proposed to explain it, (see Ref.[2] and references therein), but the popular model is the relativistic beaming model, which has explained the extreme observation properties of extragalactic radio sources with rapid variation, SM, and core-dominance parameter, etc.

Core-dominance parameter R (or expressed as $R(\theta)$) is an important parameter and has been proposed as the orientation of the emission,[12] and an indicator of relativistic beaming.[14] In our previous papers, we found that the core-dominance parameter and the optical polarization are also indicators of beaming effect.[15,16] In the present paper, we also find that the polarization is associated with the core-dominance parameters, and the higher the polarization, the higher the core-dominance, as shown in Fig.1. We have found that the data points are mainly concentrated in the region bounded by $c(m)$=0.01 and $c(m)$=1.0. Here $c(m) = \frac{k}{R_{\rm T}} 10^{0.4m}$, k is a constant and m the magnitude.[16] This means that the difference in $R_{\rm T}$ is 4 magnitude. It is interesting to

find that the points in the corresponding region shows $\frac{R_{\rm T}(\max)}{R_{\rm T}(\min)} = 3.0\times10^4$. These two values are quite consistent with each other. For objects with $R_{\rm T}$ greater than unity, $R_{\rm T} > 1.0$ suggests that the jet luminosity is greater than the extended luminosity in the objects mentioned above, or the jet is brighter than the extended component when these objects are observed edge on.

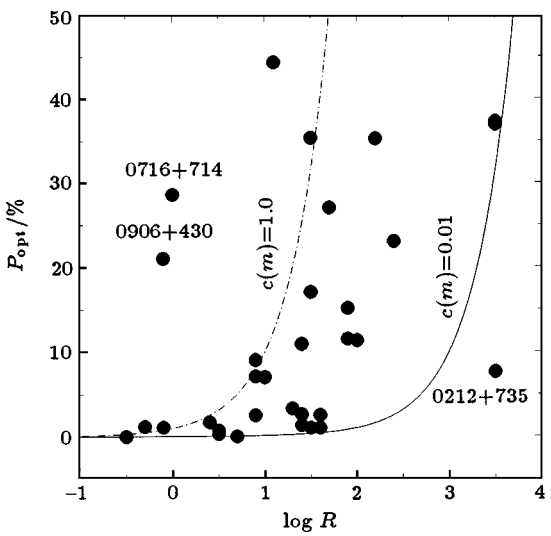


Fig.1. A plot of polarization ($P_{\rm opt}$%) against core-dominance parameter (log$R$).

Polarization is found to be correlated to Doppler factor (δ) for BL Lacertae objects.[15] But the dependence of polarization on the Doppler factor in BL Lacertae objects is different from that in optically violently variable quasars (OVVs), implying that the intrinsic polarization and the ratio of the intrinsic to unbeamed luminosities in OVVs are smaller than those in BL Lacertae objects.[17] This is not contradictory to the results shown in the present paper.

In BL Lacertae objects, the fact that there is no, or only very weak, emission-line emission means that the Doppler boosted emissions dominate the isotropic emission from the emission materials. This also means that the ratio of the intrinsic to the unbeamed luminosities is large. In OVVs, on the contrary, there are strong emission-line emissions and sometimes SMs. Therefore, the beaming effect should be strong in OVVs because of the superluminal phenomenon, and the unbeamed emissions are also strong since emission lines are observed. In this sense, the ratio of intrinsic to the isotropic luminosities should be smaller in OVVs than in BL Lacertae objects.

From Table 1 we can see that $R_{\rm T}$ satisfies $R_{\rm T} < 0.1$ for most objects. From the histogram of $R_{\rm T}$ (Fig.2), one can obtain that $R_{\rm T}$ reduces in the range of 0.044 ± 0.02, which is not in conflict with the averaged value of $R_{\rm T} = 0.024$ found by Orr and Browne.[12] There are also some objects whose $R_{\rm T}$ is very large. This comes partially from the facts: 1) The Doppler factors given by Ghisellini *et al*[9] are the lower limits. 2) The core sizes used by Ghisellini *et al* are larger than the true values. 3) The turnover frequency is not the real frequency. 4) The core-dominance used is smaller.

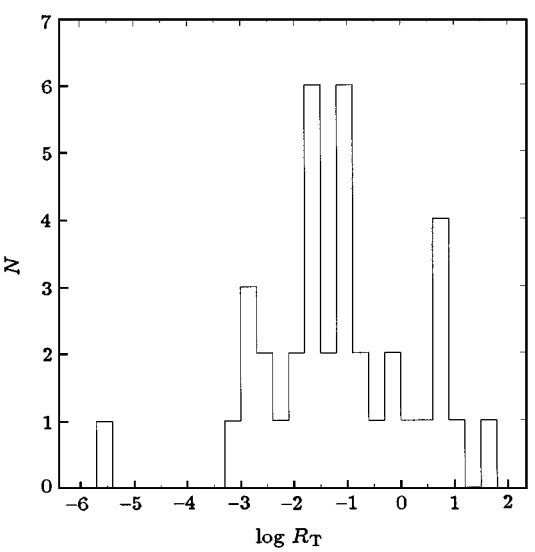


Fig.2. The histogram of $R_{\rm T}$.

Table 1. Results for a sample of superluminal sources.

Source	ID	δ	$\beta_{\rm app}$	log R	$P_{\rm opt}/\%$	Γ	θ	$R_{\rm T}$
0016+731	CQ	10.30	8.30	0.50	0.3	8.54	0.0951	0.0008195
0106+013	CQ	18.90	8.20	0.90	7.1	11.26	0.0387	0.0003577
0108+388	G	0.90	2.14	2.20		3.55	0.7727	30.0153796
0153+744	CQ	2.30	1.30	0.40	1.7	1.73	0.4101	0.3090467
0212+735	CQ	9.20	3.10	3.50	7.6	5.18	0.0664	2.7787983
0234+285	CQ	16.60	9.30	2.00	11.3	10.94	0.0515	0.0060946
0333+321	CQ	16.60	5.20	1.60	1.0	9.14	0.0345	0.0034593
0430+052	CQ	5.30	3.21	1.40	2.6	3.72	0.1700	0.1294783
0552+398	CQ	2.80	1.72	0.40		2.11	0.3377	0.1430238
0615+820	CQ	2.00	1.70	0.70	0.0	1.97	0.5235	0.6303477
0710+439	G	0.50	1.25	0.80		2.81	0.0010	0.0537524
0711+356	CQ	8.30	5.50	0.50	0.7	6.03	0.1116	0.0025113
0716+714	BL	2.10	2.30	0.00	28.6	2.55	0.4863	0.0691451
0735+178	BL	7.30	5.00	3.50	36.9	5.43	0.1287	4.0249395
0836+710	CQ	8.70	7.30	1.50	1.0	7.47	0.1136	0.0149728
0850+581	CQ	3.30	3.90	0.30		4.11	0.3013	0.0217494
0851+202	BL	8.80	2.95	3.50	37.2	4.95	0.0692	3.3289895
0906+430	LQ	43.40	5.23	–0.10	21.0	22.03	0.0055	0.0000016
1039+81	CQ	0.90	2.50	1.60	2.5	4.48	0.6899	4.8084968
1040+123	LQ	1.80	3.10	–0.50	0.0	3.85	0.4820	0.0132666
1101+384	BL	0.50	1.64	1.00	7.0	3.94	0.0010	0.0215115
1150+812	CQ	1.90	3.50	1.40	1.3	4.44	0.4403	0.7041722
1156+295	CQ	6.40	5.20	0.90	9.0	5.39	0.1540	0.0133786
1226+023	CQ	6.00	6.20	0.90	2.5	6.29	0.1672	0.0111230
1253–055	CQ	18.00	3.98	1.10	44.3	9.47	0.0235	0.0008690
1308+326	BL	6.80	10.80	1.70	27.0	12.05	0.1326	0.0147939
1618+117	LQ	0.40	1.88	–0.70		5.89	0.9490	0.0676384
1641+399	CQ	5.30	6.83	1.50	35.3	7.15	0.1831	0.0439085
1721+343	LQ	0.20	3.10	–0.10	1.1	26.63	0.6219	0.0551303
1749+701	BL	1.10	2.35	1.90	11.5	3.51	0.6868	10.3988778
1803+784	BL	8.50	8.40	2.20	35.2	8.46	0.1180	0.0612870
1830+285	LQ	0.50	2.50	–0.30	1.2	7.50	0.7378	0.0694510
1928+738	CQ	4.40	6.68	1.30	3.3	7.38	0.2090	0.0377455
2007+777	BL	4.70	2.32	1.90	15.1	3.03	0.1735	0.7834174
2200+420	BL	4.40	2.39	2.40	23.0	2.96	0.1960	2.9524962
2223–052	CQ	20.90	3.35	1.50	17.0	10.74	0.0150	0.0012310
2230+114	CQ	1.90	16.87	1.40	10.9	76.11	0.1170	0.0024169

Now we can conclude that the ratio of the luminosity in the jet to the unbeamed luminosity, $R_{\rm T}$, is scattered but satisfies $R_{\rm T} < 0.1$ for most objects.

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