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J.Phy.Ast.

Print-ISSN: 2320-6756
Online-ISSN: 2320-6764

Journal of
Physics &
Astronomy

WWW.MEHTAPRESS.COM

Full Paper

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Received: September 29, 2013
Accepted: November 12, 2013

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On the asymmetric and orientation effects in high luminosity radio sources

Abstract

We examine a simple statistical consequence of relativistic beaming model using the fractional separation distance (x) and projected linear size (D) as orientation indicators. Our analysis shows that the observed x - D intercept for high luminosity lobe-dominated radio source sample provides an upper limit to the value of the expansion speedsof $\beta \sim 0.58 \pm 0.12$, $r = -0.9$ and $\beta \sim 0.47 \pm 0.07$, $r = -0.9$ with an average speed of $\langle\beta\rangle \sim 0.23 \pm 0.12$ and 0.16 ± 0.08 respectively for quasars and galaxies. These values are consistent with the relativistic beaming scenario and orientation paradigm and indicate that relativistic motion persist at kiloparsec regions of extragalactic radio sources.

Key Words

Galaxies - Active, Jets; Methods - Statistical; Data analysis.

INTRODUCTION

The phenomenology of active galactic nuclei involves a supermassive black hole which releases relativistic outflows of energetic particles by accretion of matter through an accretion disk surrounded by an optically thick torus. These relativistic outflows form well-collimated symmetric twin jets or beams that feed the radio lobes[6,26]. The interaction of the head of the beams/jets with the intergalactic medium produces the observed synchrotron lobe emission[29]. The classification of AGNs depends on the power and geometry of the central engine as well as the jet/disk orientation with respect to our line of sight (e.g.[1,7,8,33]). Thus, many properties of quasars and AGNs can be attributed to relativistic Doppler and geometric projection effects at small angles to our line of sight.

There is observational evidence that the jets of double FR II radio sources are initially relativistic. On parsec scales this idea is supported by the observation of superluminal and relativistic motions, rapid variability and high brightness temperatures. On kiloparsec-scales the correspondence of jet-sidedness with depolarization asymmetry of FRII radio sources[10,15] is interpreted as the brighter jet approaching the observer, thus supporting the idea of relativistic beaming of the radiation of the jet. In most double radio sources in which one-sided parsec and kiloparsec-scale jets are observed, the parsec-scale jet points in the direction of a kiloparsec-scale jet, implying that relativistic speeds persist on kiloparsec scales[2,24,34]. Other observational data are consistent with this picture. Hardcastle et al.[12] found that relativistic beaming is needed to explain the relationship between core and jet prominences, with speeds between $\beta \sim 0.5 - 0.6$ on kiloparsec scales. Wardle & Aaron[34] analyzed the jet-counterjet flux ratios of 13 3CR FRII quasars. Their result showed that only modest intrinsic jet asymmetries are allowed and that the large jet-counterjet brightness ratios can be attributed almost entirely to the Doppler beaming due to relativistic motion and small angle to the line of sight.

In this article, using statistical analysis of the fractional separation difference (x) as asymmetry parameters and the source size (D) as orientation parameter, we constrained the advance speed of jets in high luminosity extragalactic radio sources. The simple statistical relation is established in section 2, in section 3 we present our result which are discussed and concluded in section 4.

THEORY OF RELATION

The simplest relativistic beaming of EGRS predicts that the projected linear size, (D), arm-length ratio, (D), and the apparent flux ratio should depend on the viewing angle (e.g.[11,27,31]. For a radio source of intrinsic linear size (D_0) whose jet axis makes an angle (θ) with respect to the line of sight, the projected linear size (D) of the of radio source is expected to be foreshortened due to geometrical projection effects and is given by

$$D = D_0 \sin \theta \qquad (1)$$

The arm-length ratio (Q) is defined as the ratio of core-to-lobe length on the approaching side (D_{app}) to that on the receding side (D_{rec}) given by $Q = \frac{D_{app}}{D_{rec}}$, and in framework of simple relativistic kinematic model is given by (e.g.[11]),

$$Q = \frac{1 + \beta \cos \theta}{1 - \beta \cos \theta} = \frac{1 + x}{1 - x} \qquad (2)$$

where β is the bulk speed of the jets and θ is the viewing angle with respect to the line of sight of a distant observer. From equation (2), we can follow Banhatti[3] to define the fractional separation distance as

$$x = \beta \cos \theta = \frac{Q - 1}{Q + 1} \qquad (3)$$

Equations (1) - (3) suggest that sources inclined at small angles to the line of sight should have higher values of x due to beaming and smaller projected sizes (D), which should be more pronounced for asymmetric sources. This anti-correlation can be used as a qualitative test for beaming models (e.g.[31]) of EGRS for a well-defined sample.

This is true if we assume pure beaming as responsible for the observed asymmetries in EGRS. However, there are strong suggestions from literature that environmental effects may be important in the interpretations of observed asymmetries in EGRS (e.g.[5,13,14,17,22]), especially for smaller size sources[22]. In low frequency surveys, the emission from high luminosity extragalactic radio sources is usually dominated by the lobe which has steep spectra (spectral index, $\alpha \geq 0.5, S \sim \nu^{\alpha}$). These sources include the lobe-dominated quasars (LDQs) and Fanaroff & Riley (1974) FR II galaxies. The lobe emission is usually observed to be isotropic and less dependent on environment. By implication, for such large-sized radio source sample selected on the basis of their lobe emission, observed asymmetries and projected size foreshortening may be attributed to the relativistic/Doppler beaming. For such sample, we except the arm-length ratio and to be greater than unity (i.e. $Q \geq 1$). The notable exception include the compact steep spectrum sources which are of galactic dimensions and whose radio properties appear to be less dependent on orientation[9].

If we assume a linear regression equation for the x - D relation of the sort, then for the arm-length ratio, we have

$$x = x_m - mD \qquad (4)$$

Then the x - D anti-correlation can be used as a quantitative test for relativistic beaming and orientation scenario and for constraining the jet expansion speed. This is true, since as $\theta \to 0$, $D \to 0$ and $x \to x_m = \beta$.

ANALYSIS AND RESULTS

Our sample was selected based on high luminosity radio sources from Nilsson[20] with major selection criterion being $Q > 1$. We have excluded all the compact steep-spectrum sources in the sample. These are powerful sources with 178 MHz luminosity $P_{178MHz} \geq 10^{25}$ W/Hz (e.g.[32]), and linear dimension $D \leq 15$ kpc, spectral index $\alpha > 0.5$ and are usually located at high redshift ($z > 0.2$). Their small nature appears to be determined by their environments rather than orientation (e.g.[9,18,28]). The final sample consists of 126 radio quasars and 101 FR – II radio galaxies. We also tested these expectation on sources considered asymmetric ($Q \geq 1.2$ – 96 quasars and 48 FR II radio galaxies) and highly asymmetric sources ($Q \geq 1.5$ – 58 quasars and 25 FR II radio galaxies). These asymmetry selection criteria are arbitrary.

Results

Figure 1 shows the x - D plot for all the sourcesin our sample, for quasars. The plot shows no obvious general trend with correlation coefficient results of $r \sim -0.2$ and -0.3 for quasars and galaxies respectively, but the upper envelope x - D function (which shows the locus of the maximum x as a function of the projected linear size D) is well-defined. Theupper envelope function is usually attributed to relativistic beaming and geometric projection effects at small angles with respect to the line of sight (see[31,32]). Analysis using all the sources in our sample gives an average expansion speed of $\langle\beta\rangle \sim 0.23 \pm 0.12$ and 0.16 ± 0.08 respectively for quasars and galaxies. Figure 2 shows the plot of the upper envelope x - D data. Linear regression analysis of the upper envelope x - D data gives: for quasars we have $x_m = \beta = 0.55 \pm 0.18$, r = -0.8 and for galaxies we have $x_m = \beta = 0.44 \pm 0.13$, r = -0.8, where r is the regression coefficient result.

For asymmetric sources ($Q \geq 1.2$), the plot for the sub-sample is shown in figure 3, while the upper envelope x - D data plot is shown in figure 4. Regression analyses on the plots give an average expansion speed of $\langle\beta\rangle \sim 0.27 \pm 0.11$, r = -0.3 and $\langle\beta\rangle \sim 0.21 \pm 0.08$, r = -0.3 for quasars and galaxies respectively, with possible upper limit to the advance speed obtained from upper envelope x - D data of $\beta \sim 0.57 \pm 0.16$, r = -0.9 and $\beta \sim 0.42\ 0.13$, r = -0.8 respectively for quasars and galaxies.

For highly asymmetric sources ($Q \geq 1.5$), figure 5 shows the plot for the sub-sample, with the upper envelope x - D data plot shown in figure 6. The plot indicates absence of large sources for highly asymmetric sources especially for galaxies. Regression analyses on the plots give an average expansion speed of $\langle\beta\rangle \sim 0.35 \pm 0.09$, r = -0.3 and $\langle\beta\rangle \sim 0.31 \pm 0.07$, r = -0.3 for quasars and galaxies respectively, with possible upper limit to the advance speed obtained from upper envelope x - D data of $\beta \sim 0.58 \pm 0.12$, r = -0.9 and $\sim 0.47 \pm 0.07$, r = -0.9 respectively for quasars and galaxies.

DISCUSSION AND CONCLUSION

We have investigated a simple statistical consequence of the relativistic beaming model in which, due to relativistic beaming and geometric projection effects in high luminosity radio quasars and FR-II galaxies, the fractional separation distance (x) is expected to correlate inversely

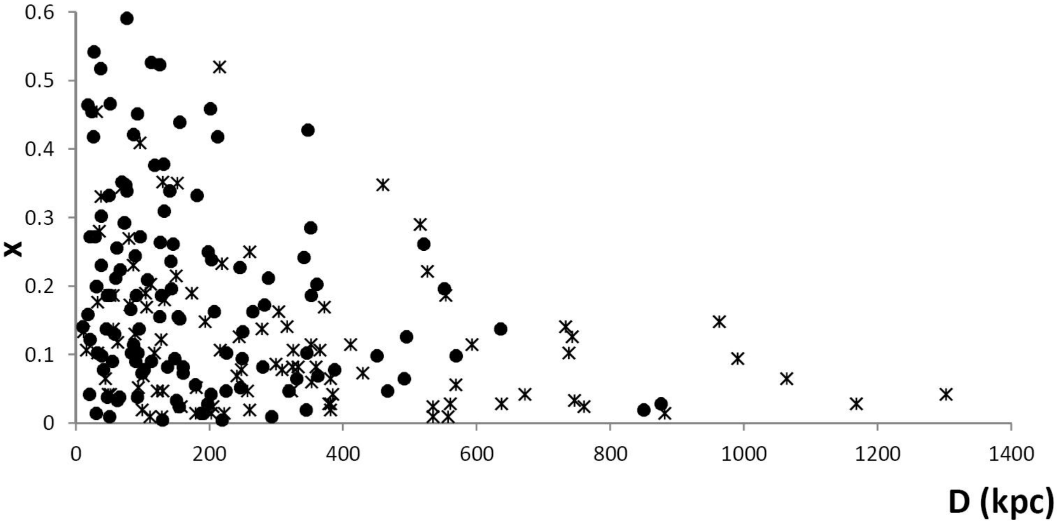

Figure 1 : Plot of fractional separation difference (x) against radio source size (D) for all the sources in our sample (Quasars-Solid Circle; Galaxies-Star).

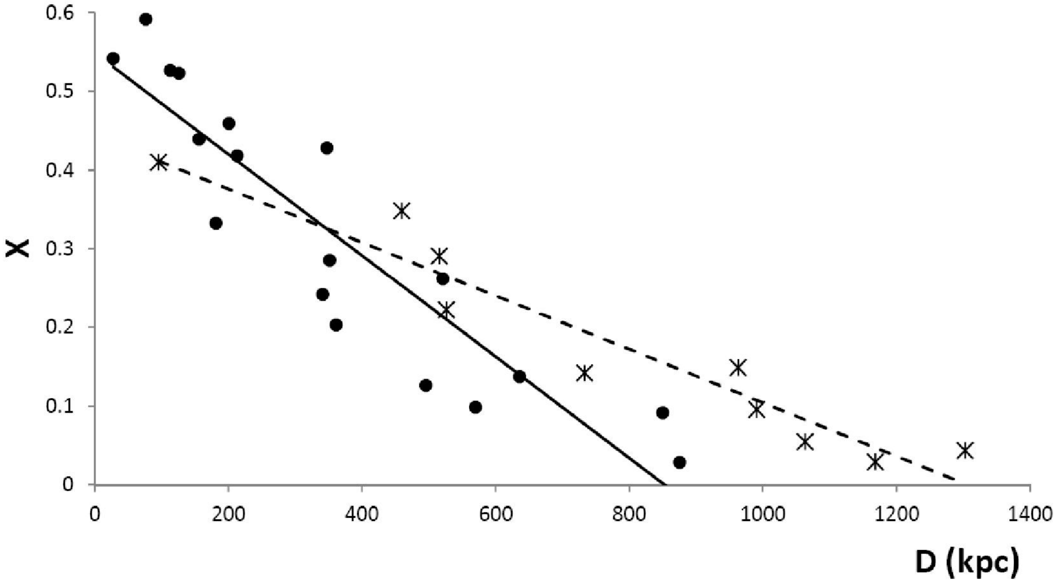

Figure 2 : Plot of upper envelope fractional separation difference (x) against radio source size (D) for all the sources in our sample (Quasars-Solid Circle; Galaxies-Star)

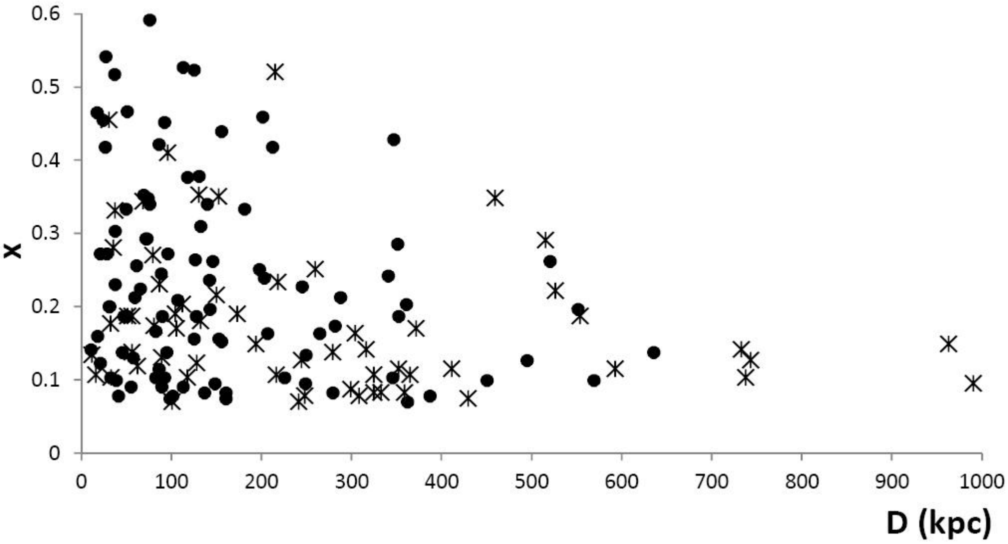

Figure 3 : Plot of fractional separation difference (x) against radio source size (D) for asymmetric sources (Q ≥ 1.2) (Quasars-Solid Circle; Galaxies-Star)

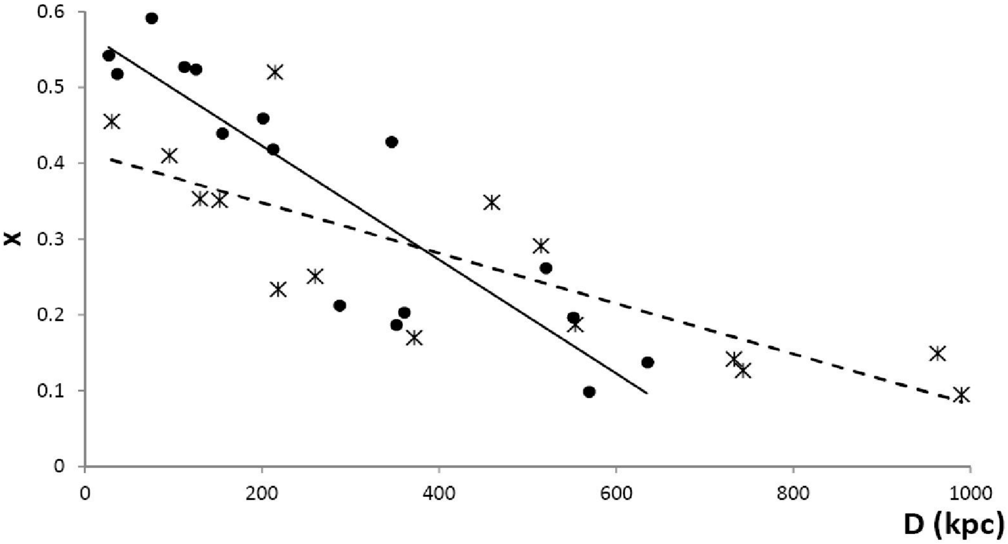

Figure 4 : Plot of upper envelope fractional separation difference (x) against radio source size (D) for asymmetric sources (Q ≥ 1.2) (Quasars-Solid Circle; Galaxies-Star)

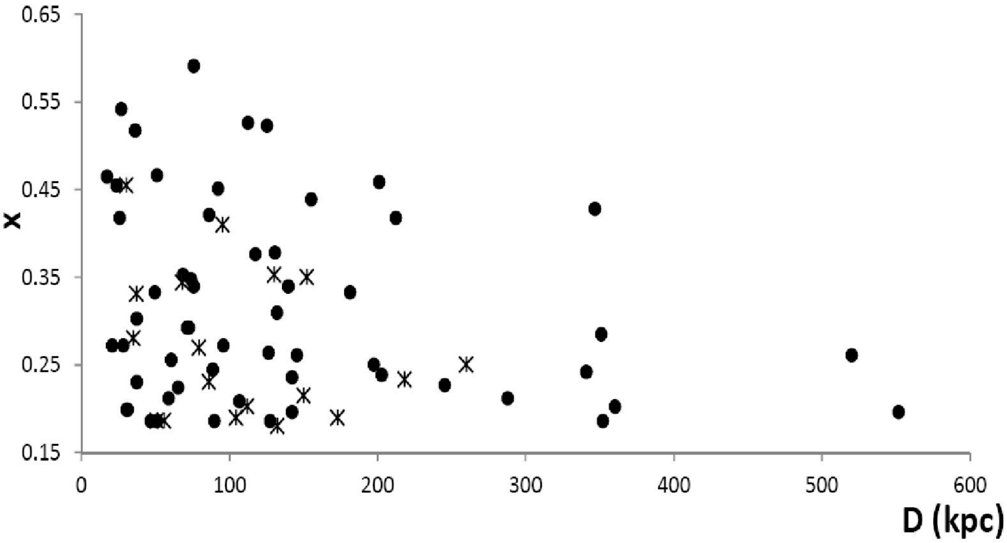

Figure 5 : Plot of fractional separation difference (x) against radio source size (D) for highly asymmetric sources (Q ≥ 1.5) (Quasars-Solid Circle; Galaxies-Star)

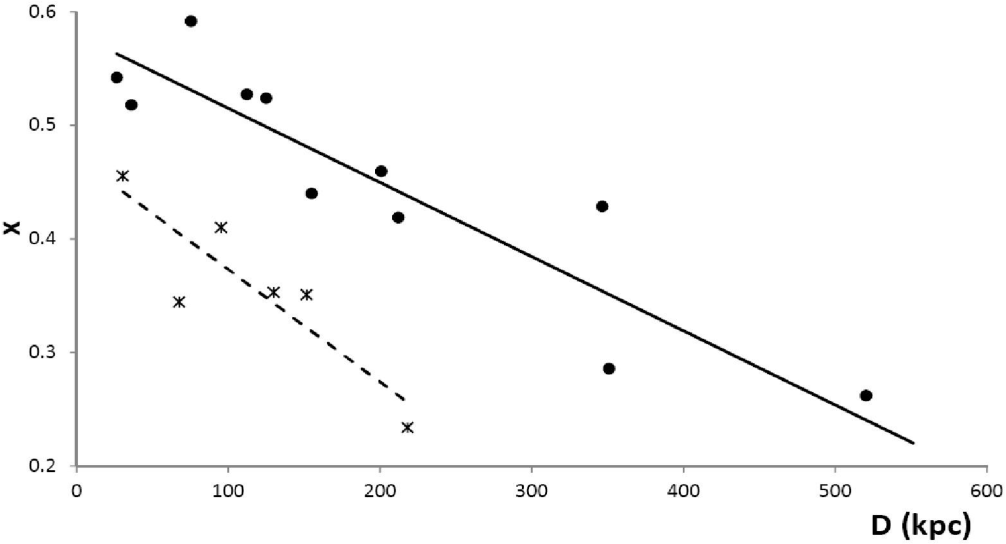

Figure 6 : Plot of upper envelope fractional separation difference (x) against radio source size (D) for highly asymmetric sources (Q ≥ 1.5) (Quasars-Solid Circle; Galaxies-Star)

with the projected linear size (D). Our results showed a strong anti-correlation in the x - D upper envelope data which offers both qualitative and quantitative support to the hypothesis that in high luminosity radio quasars and FR-II galaxies relativistic motion though mildly persist at kiloparsec regions.

The plots indicate that quasars are more asymmetric than galaxies, our analysis indicated that quasars have higher average advance speed of $\langle\beta\rangle \sim 0.23 \pm 0.12 - 0.35 \pm 0.09$, and $\langle\beta\rangle \sim 0.16 \pm 0.08 - 0.31 \pm 0.07$. This is consistent with the orientation-dependent relativistic beaming and unification paradigm for high luminosity radio sources in which the FR II radio galaxies form the parent population of the lobe-dominated quasars (e.g.[4,31-33]). Here, galaxies are more oriented on the plane of the sky are expected to be less asymmetric than quasars. The advance speed estimated from the upper envelope x - D data gives $\beta \sim 0.6$ for quasars and $\beta \sim 0.5$ for galaxies. This result indicates that intrinsically, the jet advance speed in quasars and FR II galaxies are mildly relativistic and similar, any difference may be attributed to orientation.

The average advance speed we estimated $\langle\beta \sim 0.16 - 0.31$ are in reasonable agreement with other works found in literature. Observations of the synchrotron radiation spectrum of extragalactic radio sources (assuming equipartition magnetic field) have led to estimate of the advance speed of the hotspots for most powerful sources as $\beta \sim 0.2 - 0.3$[19]. Using the prevalence of long lobe of radio sources, Longair & Riley[16] estimated that the expansion speed of the lobes in general cannot be more than $\beta = 0.25$. Furthermore, Best et al.[5] showed that a hotspot speed in the range $\beta = 0.2 - 0.3$ would be required to reproduce the Q – distribution for the 3CRR sample. More recently, Stanghellini et al.[30] in their study of three compact radio sources obtained hotspot speed which lies in the range $\beta = 0.2 - 0.4$

The upper limit to the advance speed we estimated from the upper envelope data ($\beta \sim 0.6$ and $\beta \sim 0.5$ for quasars and galaxies) is in reasonable agreement $\beta \sim 0.6$ obtained for low redshift quasars by Arshakian & Longair[2] and also in agreement with range of speeds obtained from the analysis of jet prominences ($\beta \sim 0.5 - 0.7$) by Hardcastel et al.[12]. Orienti&Dallacasa[23] reported a mean apparent expansion speed in intrinsically compact radio sources of $\beta = (0.39 \pm 0.18)$ which is in agreement with the values obtained by Polatidis & Conway[25] who studied a dozen of the most compact radio sources, while for O'Dea et al.[21] who obtained an upper limit of $\beta = 0.7$, these values are generally in reasonable agreement with the limits of our result.

In conclusion, we have used a sample of high luminosity EGRS to investigated a simple statistical consequence of the relativistic beaming model and orientation paradigm in radio sources. Due to Doppler beaming and geometric projection effects, fractional separation parameter (x) is expected to correlate inversely with the projected linear size (D). Our result shows a strong anti-correlation in the x - D upper envelope data which offers both qualitative and quantitative support to the hypothesis that relativistic motion persist in kiloparsec regions of EGRS and enabled us to constrain the upper limit of expansion speed in high luminosity EGRS.

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