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On Jet Opening Angle and Dynamical Evolution of Some Powerful Extragalactic Radio Sources

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Abstract: We used both analytical and statistical methods of analyses to find out if there is possible connection between jet opening solid angle and linear size evolution of some powerful extragalactic radio sources in our sample. Based on simple linear regression analyses of $D-\Omega$ data (where D is observed linear size and Ω is estimated jet opening solid angle), we found with a marginal correlation, that effects contributed by the opening angle may be overshadowed by other factors. A plausible interpretation of the result is that there is presence of appreciable ambient gases around these sources.

Keywords: Jet, Ambient Density, Opening Angle, Evolution, Galaxies, Radio Sources

1. Introduction

Active galactic nuclei have exceptionally high luminosities and radiate large amounts of non-stellar radiation. A typical AGN has an overall luminosity in excess of 10^{37}W [1,2,3,4].They consist of two main classes based on the magnitude of their radio luminosity [1,2,3]. These classes are radio-loud and radio-quiet sources. The former are generally referred to as extragalactic radio sources.

Extragalactic radio sources (EGRSs) include those sources with high ratio of radio to optical emission, commonly defined by the ratio of the two flux densities, $S_{5GHz}/S_{6\times10^5GHz} > 10$[1]. These sources comprise radio galaxies, quasars, etc [2,3]. On radio maps, they show three main components – core, jet and lobe (clouds of radio-emitting dust particles). The jet is believed to be the conduit through which jet materials reach the lobe. The hot spot in the lobe is believed to be the termination point of the jet materials. The structure of a typical EGRS usually takes the form of two-sided relativistic jets which connect the base of accretion disk to the two lobes that straddle the central component (the core) that is more or less coincident with the nucleus of the host galaxy [2,5,6].

Presence of jets suggestively indicates that EGRSs have dense gaseous media. Moreover, within the host galaxy, the ambient number density, n_e, has been reported to decline from the central core by $D \sim n_e^{-0.5}$(where D is linear size of the radio source) [5,7,8]. This shows that ambient density falls off according to the equation as distance increases from the central core. However, much has not been said concerning jet opening angle; especially, when it concerns effects it may have on the linear size evolution of a radio source. Therefore, the aim of this work is to ascertain if there is any relationship between linear size evolution and jet opening solid angle. The radio sources used in this work were collected from [9]. They are made up of 21 radio sources with linear sizes, $D > 30$ kpc. These sources are those whose jets have estimated velocities from [10].

2. Radio Source Expansion

Jets of relativistic plasma are ejected from the parent galaxy which plough their way through the ambient medium until they terminate with strong shocks (at the hotspots) which are thermalized to form lobes [6]. The evolution of a radio source component is therefore expected to depend (among other factors) on power supplied by the core to the jet, the source age and the ambient medium through which it propagates.

With an assumption that, in general, jets in EGRSs propagate through a homogenous dense medium, the linear size, D, of the source can be written according to the equation [8]:

$$D \approx \left(\frac{P_{bol}\mu^2}{m_H c^3 n_e \Omega \varepsilon}\right)^{0.5} \quad (1)$$

where P_{bol} is its bolometric luminosity, n_e is its external/ambient medium number density, Ω is its jet opening solid angle, $\varepsilon(\ll 1)$ is the conversion efficiency of the source for the kinetic power into radiation, m_H is proton mass, c is light speed, and μ is the ratio of lobe velocity to jet velocity.

3. Jet Opening Solid Angle

Assuming lobe confinement by ram-pressure balance with the external medium, then we have [11,12,13,14,15]:

$$n_e \approx \frac{P_i}{m_H V_L^2} \quad (2)$$

where P_i is lobe internal pressure, and V_L is lobe velocity. From the last equation, it can be shown that lobe's internal pressure depends among other factors on the kinetic power, P_{cj}, delivered by core to jet according to the relation:

$$\Omega = \frac{P_{cj}}{P_i}\frac{\mu^2}{cD^2} \quad (3)$$

However, by definition, P_{cj} and P_i can be expressed respectively by [8,15]

$$P_{cj} = \frac{M_j a D}{T} \quad (4)$$

and

$$P_i = \frac{M_j a}{4\pi r_L^2} \quad (5)$$

where M_j is mass of jet, a is acceleration, T is source age, and r_L is radius of lobe.

Putting the last two equations in equation (3), we obtain

$$\Omega = \frac{4\pi r_L^2 V_j \mu^3}{cD^2} \quad (6)$$

where T has been replaced with $T = D/\mu V_j$ for homogenous ambient media [8].For the radio source, 3C405 (i.e., Cygnus A), r_L can be written in terms of D by

$$r_L \approx 0.11D \quad (7)$$

Hence, jet opening solid angle becomes

$$\Omega = 0.152\frac{V_j \mu^3}{c} \quad (8)$$

This implies that jet opening solid angle can be estimated once lobe and jet velocities are known.

4. Analyses and Results

For simplicity, we assume a constant ratio of $\mu \approx 0.837$ for lobe to jet velocities. This is estimated by dividing the lobe velocity, $0.251c$, of the radio source, 0710+439, observed by [16] by the speed, $0.3c$, of jet at 1pc [3]. In this paper, we have assumed for simplicity that the quotient is approximately constant for the sources in our sample.

However, jet velocities for the sources were obtained from [10] for $b = 1$ (where b is ratio of magnetic field strength to minimum energy). Putting these values in equation (8), we estimated jet opening solid angles, Ω, for each source (see Table 1).

Table 1. *Estimated jet opening solid angle, Ω.*

S/n	Source name	Linear size, D(kpc)	Jet velocity, $V_j(c)$	Opening angle, $\Omega(10^{-11}$sr)
1	3C 239	93.7	0.29	6.3
2	3C 322	278.6	0.26	5.65
3	3C 194	122.2	0.16	3.48
4	3C 267	326.6	0.2	4.34
5	3C 356	642.7	0.27	5.86
6	3C 280	109.8	0.13	2.82
7	3C 268.1	365	0.205	4.45
8	3C 289	84.8	0.135	2.93
9	3C 325	133.4	0.255	5.54
10	3C 265	643.3	0.16	3.48
11	3C 247	105.4	0.145	3.15
12	3C 55	556.8	0.33	7.17
13	3C 337	333.2	0.085	1.85
14	3C 427.1	172.9	0.07	1.52
15	3C 405	183.4	0.07	1.52
16	3C 6.1	215.9	0.215	4.67
17	3C 34	380.9	0.135	2.93
18	3C 41	189.7	0.12	2.61
19	3C 114	429.3	0.145	3.15
20	3C 441	260.6	0.1895	4.12
21	3C 469.1	636.7	0.445	9.66

Moreover, we carried out regression analyses of $D - \Omega$ data (figure 1). Result yields

$$\log D = 0.36\log\Omega_2 + 6.16 \quad (9)$$

with marginal correlation coefficient, r, given by $r \approx 0.3$. This gives a power-law function of the form:

$$D \sim \Omega^{0.4} \quad (10)$$

5. Discussion

Equation (1) points out that the observed linear size, D, may depend, among other factors (e.g. P_{bol} andn_e,), on Ω according to the equation,

$$D \sim \Omega^{-0.5} \quad (11)$$

However, comparing (10) with (11) shows there is disparity between the theoretical relation (11) and the semi-empirical relation (10) for $D-\Omega$ relationship. This disagreement suggestively indicates that other factors which affect dynamical evolution of extragalactic radio sources overshadow the effects caused by Ω.

Furthermore, it has been mentioned by some authors [3,14,17,18] that presence of jets indicates presence of gases around radio sources. Therefore, we may state that among the parameters/factors in (1), the biggest culprit which affects jet opening angle is source ambient medium density. Therefore, (1) can be rearranged to give

$$n_e \approx K\Omega^{-1} \quad (12)$$

where $(P_{bol}\mu^2)/(m_H c^3 \varepsilon D)$ has been replaced with K. The last equation simply shows that jet opening angle decreases with an increase in the source ambient density. In addition, it has been pointed out by some authors [3,8,12] that linear size depends on the source ambient density according to the relation,

$$D \sim n_e^{-0.5} \quad (13)$$

Therefore since D and Ω both show inverse dependence on n_e, the discrepancy between the theoretical and the semi-empirical relations for the two parameters may be attributed to the presence of significant ambient gases around each radio source.

6. Conclusion

The results of our analyses shows dissimilarity between the theoretical and semi-empirical relations for linear size (D) and jet opening solid angle (Ω). Based on these relations, (10) and (11), we have shown that the dissimilarity between the two indices (i.e. 0.4 and -0.5 respectively for the two equations) might have stemmed from the presence of considerable ambient gases around the sources. Hence, the inconsistency in the two results possibly is an indication of appreciable ambient density.

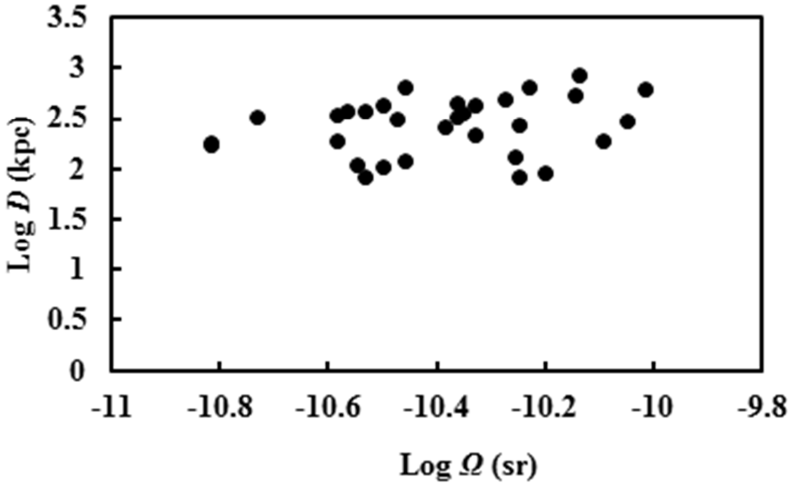

Figure 1. *The scatter plot of linear size (D) against jet opening solid angle (Ω).*

References

[1] H. Meusinger, and V. Weiss, "Ultraviolet variability of quasars: dependence on the accretion rate," Astron. and Astrophy., vol. 560, pp. 1-16, 2013

[2] A. C. Readhead, "Evolution of powerful extragalactic radio sources," in Quasars and Active Galactic Nuclei, vol. 92, M. Kohen, and K. Kellermann, Eds. U.S.A: National Academy of Sciences, 1995, pp.11447-11450

[3] I. Robson, Active Galactic Nuclei, England: John Wileyand Sons, 1996, pp. 232 – 234

[4] G. Lanzuisi, P. Ranalli, I. Georgantopoulos, A. Georgakakis, I. Delvecchio, T. Akylas, S. Berta, A. Bongiorno, M. Brusa, N. Cappelluti, F. Civano, A. Comastri, R. Gilli, C. Gruppioni, G. Hasinger, K. Iwasawa, A.Koekemoer, E. Lusso, S. Marchesi, V. Mainieri, A. Merloni, M. Mignoli, E. Piconcelli, F. Pozzi, D. J. Rosario, M. Salvato, J. Silverman, B. Trakhtenbrot, C. Vignali and G. Zamorani, "Compton thick AGN in the XMM-COSMOS survey" Astron. and Astrophy.vol.573, pp.137-160, 2015

[5] C. A. Jackson,"Radio source evolution and unified schemes," Publ. Astron. Soc. Aust., vol. 16,pp.124-129, 1999

[6] N. Kawakatu, M. Kino, "The velocity of large-scale jets in a Declining Density Medium", in Triggering relativistic jets, vol. 27, W. H. Lee & E. Ramirez-Ruiz, Eds. Instituto de Astronomia, UNAM, 2007,pp. 192-197

[7] C. P. O'Dea, "The compact steep-spectrum sources and Gigahertz peaked-spectrum radio sources", Pub. Astron. Soc. Ppacific, vol. 110, pp. 493-532, 1998

[8] J. C. Ezeugo, and A. A. Ubachukwu, "The spectral turnover-linear size relation and the dynamical evolution of compact steep spectrum sources", Mon. Not. Roy. Ast. Soc, vol. 408, pp. 2256-2260, 2010

[9] K. Nilsson, “Kinematical Models of Double Radio Sources and the Unified Scheme”, Mon. Not. Roy. Ast. Soc., vol. 132, pp. 31-37, 1998

[10] C. P. O'Dea, R. A. Dally, P. Kharb, and K. A. Freeman, “Physical properties of very powerful FRII radiogalaxies”, Astro. and Astrophys., vol. 494, pp. 471,2009

[11] C. Fanti, R. Fanti, D. C. Dallacasa, R. T. Schilizzi, R.E. Spencer, and C. Stanghellini, “Are compact steep-spectrum sources young?”Astron. and Astrophy., vol. 302, pp. 317-326,1995

[12] A. C. S. Readhead, G. B. Taylor, W. Xu, T. J. Pearson, P. N. Wilkinson, A. G. Polatidis, “The statistics and ages of compact symmetric objects, ”The Astrophy. Journ., vol. 460, pp. 612-633, 1996

[13] J. C. Cavalho, “The evolution of GHz-peaked-spectrum radio sources,” Astronomy and Astrophysics, vol. 329,pp. 845-852, 1998

[14] A. Labiano, “Tracing jet-ISM interaction in young AGN: correlations between [O III] λ500 Å and5GHzemission”, Astron. and Astrophy., 488, vol.L59-L62, 2008

[15] J. C. Ezeugo, “Compact Steep-Spectrum Radio Sources and Ambient Medium Density, ”Intn’l Journal of Astrophy. and Space Sc. Vol. 3, 2015, pp. 1-6, 2015

[16] I. Owsianik, and J. E. Conway, “First detection of hotspot advance in a compact symmetric object” Astron. and Astrophy., vol. 337, pp. 69-79, 1998

[17] F. Mantovani, W. Junor, M. Bondi, W. Cotton, R. Fanti, L. Padrielli, G. D. Nicolson, E. Salerno, “Large Bent Jets in the Inner Region of CSSs,” Astron. and Astrophy., vol.332, pp. 10–18, 1998

[18] F. Santoro, J. B. R. Oonk, R. Morganti, and T. Oosterloo, “The jet-ISM interaction in the outer filament of Centaurus A, ”Astron. and Astrophy., vol. 574, A89, 2015