On Size Evolution / Radiated Power of Extragalactic Radio Sources and Implication

Abstract: We have applied in this work, statistical methods of analyses to find empirically some effect posed by source expansion on radiated power of extragalactic radio sources. The subclasses of the sources used are radio-loud quasars and radio galaxies. We have done this by carrying out linear regression analyses of observed source angular sizes (θ) of the quasars against their respective observed redshifts (z); as well as, observed source luminosities (P) against their respective observed redshifts. For the quasars, result indicates that with good correlation coefficient $(r \approx 0.5)$, observed angular size shows an inverse relationship with observed redshift, and is given by $\theta \sim (1+z)^{-1.9}$. For the galaxies, the result indicates similar trend; we obtain $\theta \sim (1+z)^{-3.7}$, where $r \approx 0.6$ (which is also a good correlation). Moreover, on the $P-z$ plane, we obtain a direct relationship given by $P \sim (1+z)^{0.04}$ for the quasars; where $r \approx 0.8$ (which is a good correlation). However, for the galaxies, luminosity/redshift relationship is poor (with $r \approx 0.1$). This poor correlation may possibly have stemmed from lack of observation of galaxies at high redshifts unlike observation of their quasar counterparts. The θ/z relationships for the quasars and the galaxies simply indicate positive source size evolution with time. However, the converse is the case for P/z relationship – it shows negative source luminosity evolution with time. These results suggestively indicate that extragalactic radio sources, though small scaled at earlier epoch, were more powerful sources than what they are at present epoch. Their luminosity/angular size relation is given by $P \sim \theta^{-0.01}$. Therefore, conclusively the results suggestively indicate that the mechanisms of size evolution of these sources simply bring about diminution effect on their radiated power.

Keywords: angular size; luminosity; redshift; radio sources; quasars; galaxies; extragalactic; epoch; evolution.

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1. Introduction

Extragalactic sources are sources that are located beyond the confines of the Milky way galaxy – our home galaxy. They can be classified into two groups; namely, active and non-active galaxies. The active galaxies are further sub-divided into radio-loud sources and radio-quiet sources. The radio-loud sources are generally referred to as extragalactic radio sources (EGRS). They radiate more copious amount of radio emission than their radio-quiet counterparts. They are sources that have high radio radiation to optical radiation ratio; and conventionally, it is defined by, $S_{5\,\mathrm{GHz}}/S_{6\times10^5\mathrm{GHz}} > 10$ (where S is flux density) [1–11].

Based on their observed linear sizes, they have been classified into two sub-groups; namely, the large extended sources – their observed linear sizes (D) are in the range, $D > 30$ Kpc; and the compact steep spectrum sources – whose observed linear sizes are less than 30 Kpc [1,2,4–6]. Usually, the radio morphology of the EGRS assumes the form of two opposite sided relativistic jets of plasma that connect the base of the accretion disc to two radio-emitting lobes that sandwich the nucleus. The nucleus or central core is believed to host a super massive blackhole and is taken to be the central engine that fuels the activities that characterize any active galaxy. [1–11]. In some sources, the lobes contain hotspots which are generally assumed to be the termination points of the radio jets; while the observed jets are assumed to be the conduits through which the lobes are fed with jet materials [1, 4,5]. Figure 1 shows the schematic structure of a typical EGRS; while, Figure 2 shows Cygnus A – an example of EGRS.

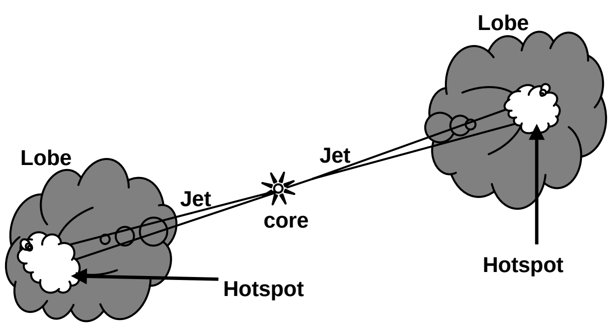

Figure 1: *The schematic structure of a typical EGRS.*
Source: The author

As mentioned earlier, the more extended EGRS have linear sizes well above 30 Kpc assuming Hubble constant is $75\ \mathrm{kms^{-1}Mpc^{-1}}$. This simply means that their linear sizes extend into intergalactic media since the size of a typical galaxy is around 30 Kpc [5]. Their radio luminosity is in excess of 10^{26}W at 5 GHz with bolometric luminosities given as 10^{37}W – which is still common with those of the CSS sources [1,5].

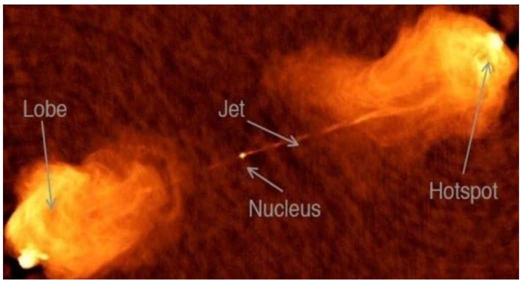

***Figure 2:** Cygnus A – An EGRS.*

Source: slideplayer.com

The CSS source is a sub-class of EGRS [12–19]. The major difference between a typical CSS source and a large extended EGRS is easily seen in their little sizes, even though they are as powerful in radiation as the more extended ones [12–19]. Generally, their spectral indices show steep spectra (spectral index, $\alpha < 0.5$, $S_\nu \propto \nu^{-\alpha}$; where S_ν is flux density). They are full-fledged radio galaxies and quasars complete with jets and lobes [12–19] (see Figures 1 and 2). They are normally seen at high redshifts (usually, they tend to have redshift distribution of $z \leq 4$), and are among high luminosity sources [12–19]. In addition, it has been well mentioned in literature that observation of jets in EGRS should mean presence of gaseous ambient media [5,7,12,15]. Moreover, some hydrodynamic simulations of jet propagations through the source ambient media have been carried out in order to study their observed properties [5–11]. These studies show that jet materials have smaller masses than those of the ambient medium. This simply implies that jet particles are less massive particles; such as, electrons / and positrons. In addition, Ezeugo and Ubachukwu [12] wrote on dynamical evolution of CSS sources; and using the result, they obtained estimates of their individual ambient medium particle number densities. This shows that CSS sources are surrounded by dense gases in their host galaxies.

In this paper, we use samples of extragalactic radio sources to find empirically effects posed by source expansion on their radiated power. The samples of EGRS used in the analyses are obtained from Nilson (1998) [13]. They comprise 226 quasars and 276 radio galaxies.

2. Observed Source Angular Size and Redshift (Quasars)

We carry out linear regression analysis of observed source angular sizes, θ, of the quasars against their corresponding observed redshifts, z, in the sample (Figure 3).

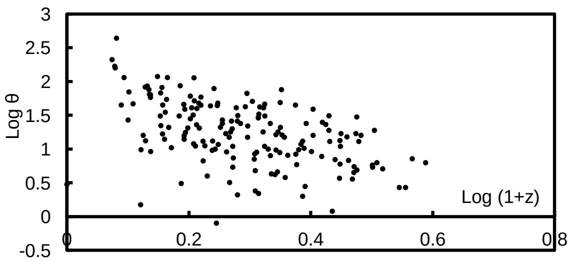

***Figure 3**: The scatter plot of angular size against redshift for the quasars*

On the $\theta - z$ plane (Figure 3), we obtain the relation:

$$\text{Log}\theta = -1.897\text{Log}(1+\text{z}) + 1.785 \qquad (1)$$

with correlation coefficient, $r = 0.5$. The correlation is good. We may transform equation (1) to obtain

$$\theta \sim (1+z)^{-1.9} \qquad (2)$$

This indicates an inverse power-law relationship between angular size and redshift.

3. Luminosity and Redshift (Quasars)

Moreover, from luminosity/redshift $(P - z)$ data for the quasars (Figure 4), we obtain a relation given by

$$\text{Log}\, P = 0.039\text{Log}\,(1+\text{z}) + 1.637 \qquad (3)$$

(with good correlation coefficient given as $r = 0.8$), which connects the source luminosity, P, and redshift, z. Transforming the equation, we obtain

$$P \sim z^{0.04} \qquad (4)$$

This indicates that observed luminosity shows a direct power-law function with observed redshift.

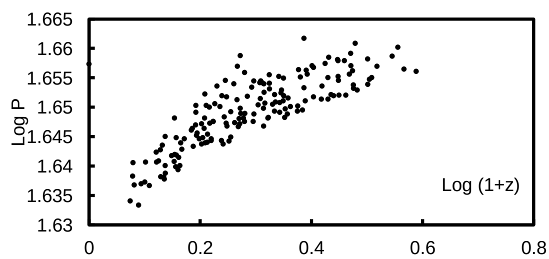

***Figure 4**: The scatter plot of luminosity against redshift for the quasars*

4. Luminosity and Angular Size (Quasars)

Moreover, from luminosity/angular size $(P - \theta)$ data for the quasars (Figure 5), we obtain a relation given by,

$$\text{Log}\, P = -0.007\text{Log}\,\theta + 1.658 \qquad (5)$$

The correlation is good and the value of its coefficient is $r = 0.6$). The relation connects the source luminosity, P, and angular size, θ. Transforming the equation, we obtain

$$P \sim \theta^{-0.01} \quad (6)$$

This indicates that observed luminosity shows an inverse power-law relationship with observed angular size – in other words, it means that brighter sources appear smaller in angular sizes than dimmer sources at the same epoch.

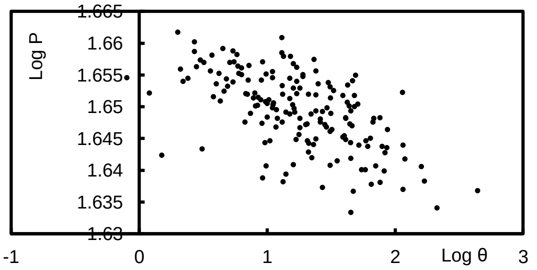

Figure 5*: The scatter plot of luminosity against angular size for the quasars*

5. Observed Angular Size and Redshift (Radio Galaxies)

In addition to the foregoing, we obtain $\theta - z$ data (Figures 6) for the radio galaxies in our sample.

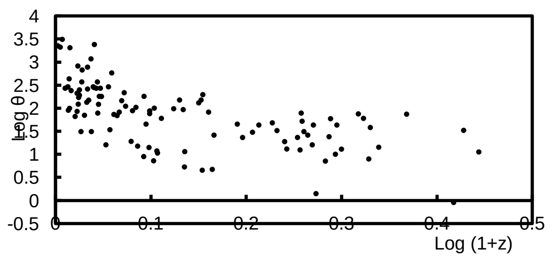

Figure 6: *The scatter plot of langular size against redshift for the radio galaxies*

We obtain a relation given by,

$$\text{Log}\,\theta = -3.728\text{Log}\,(1+z) + 2.34 \quad (7)$$

The correlation is good and the value of its coefficient is $r = 0.6$). The relation connects the source angular size and redshift. Transforming the equation, we obtain

$$\theta \sim (1+z)^{-3.7} \quad (8)$$

This indicates that observed angular size shows an inverse power-law relationship with observed redshift for the galaxies.

However, there is poor correlation on the $P - z$ plane for the galaxies. The correlation coefficient is given by $r \approx 0.1$. This poor correlation may possibly have stemmed from lack of observation of galaxies at high redshifts unlike observations of their quasar counterparts.

6. Discussion and Conclusion

We have carried out linear regression analyses of observed source angular sizes, θ, of the quasars against their corresponding observed redshifts, z, in our sample. On the $\theta - z$ plane (see Figure 3), we obtain the relation, $\theta \sim (1+z)^{-1.9}$ with good correlation coefficient, $r = 0.5$. The expression indicates an inverse power-law relationship between angular size and redshift.

Moreover, from luminosity/redshift $(P - z)$ data for the quasars (see Figure 4), we obtain a relation given by $P \sim (1+z)^{0.04}$. Correlation coefficient is 0.8. This is a good correlation and shows a direct relationship between source luminosity and redshift.

Also, from luminosity/angular size $(P - \theta)$ data for the quasars (Figure 5), we obtain a relation given by, $P \sim \theta^{-0.01}$. The correlation is also good with coefficient, $r = 0.6$. The relation connects the source luminosity and angular size. It shows that observed luminosity has an inverse power-law relationship with observed angular size. This, therefore, may be interpreted to mean that sources with higher radiated power appear smaller in angular sizes than those with lower radiated power when they are observed at the same epoch.

We also obtain $\theta - z$ data (Figures 6) for the radio galaxies in our sample. We obtain a relation given by, $\theta \sim (1+z)^{-3.7}$. The correlation is good and the value of its coefficient is 0.6. The relation connects the source angular size and redshift. This indicates that observed angular size shows an inverse power-law relationship with observed redshift for the galaxies.

However, we observe poor correlation on the $P - z$ plane for the galaxies. The correlation coefficient is given by $r \approx 0.1$. This poor correlation may possibly have originated from lack of observation of galaxies at high redshifts unlike observations their quasar counterparts.

The θ/z relationships for the quasars and the galaxies simply suggest positive source size evolution with time (since redshift relates inversely with time). However, the converse is the case for P/z relationship – it shows negative source luminosity evolution with time. These results suggestively indicate that extragalactic radio sources, though small scaled at earlier epoch, were more powerful sources than what they are at present epoch. Their luminosity/angular size relation is given by $P \sim \theta^{-0.01}$. Therefore in conclusion, we may state that the mechanisms of size evolution of these sources simply bring about diminution effect on their radiated power.

References

[1]. Ezeugo, J.C. (2021) Jet in the More Extended Radio Sources and Unification with Compact Steep Spectrum Sources. The Pacific Journal of Science and Technology. 22: 14 – 19.

[2]. Ubah, O.L., Ezeugo, J.C. (2021) Relativistic Jet Propagation: Its Evolution and Linear Size Cosmic Dilation. International Astronomy and Astrophysics Research Journal. 3(3): 1–6.

[3]. Urry, C.M. (2004) AGN Unification: An Update. Astronomical Society of the Pacific conference series 1. No vol.

[4]. Readhead, A.C. (1995) Evolution of Powerful Extragalactic Radio Sources. In proc. Colloquium on Quasars and Active Galactic Nuclei, ed. Kohen, M., and Kellermann, K. (USA: National Academy of Sciences, Berkman Center, Irvine), 92, 11447–11450.

[5]. Robson, I. (1996) Active Galactic Nuclei, John Wiley and Sons Ltd, England.

[6]. Jackson, J.C. (1999) Radio Source Evolution and Unified Schemes. Publications of Astronomical Society of the Pacific. 16: 124–129.

[7]. Kawakatu, N. and Kino, M. (2007) The Velocity of Large-scale Jets in a Declining Density Medium. In Serie de Conferencias. Triggering Relativistic Jets, ed. W.H. Lee and E. Ramirez-Ruiz. 27: 192–197.

[8]. Mahatma, V.H., Hardcastleand, M.J. Williams, W.L. (2019). LoTSS DR1: Double-double Radio Galaxies in the HETDEX Field. Astronomy and Astrophysics .622:A13.

[9]. Mingo, B., Croston, J.H. and Hardcastle, M. J. (2019). Revisiting the Fanaroff-Riley Dichotomy and Radio Galaxy Morphology with the LOFAR Two-Meter Sky Survey (LoTSS). Monthly Notices of the Royal Astronomical Society. 488:2701–2721.

[10]. Hardcastle, W.L., Williams W.L. and Best, P.N. (2019) Radio-loud AGN in the First LoTSS Data Release — The Lifetimes and Environmental Impact of Jet-Driven Sources. Astronomy and Astrophysics. 622: A12.

[11]. Dabhade, P., Gaikwad, M and Bagchi, J. (2017). Discovery of Giant Radio Galaxies from NVSS: Radio and Infrared Properties. Monthly Notices of the Royal Astronomical Society. 469 (3): 2886–2906.

[12]. Ezeugo, J.C. and Ubachukwu, A.A. (2010) The Spectral Turnover–Linear Size Relation and the Dynamical Evolution of Compact Steep Spectrum Sources. Monthly Notices of the Royal Astronomical Society. 408: 2256–2260.

[13]. Nilson, K. (1998) Kinematical Models of Double Radio Sources and Unified Scheme. Monthly Notices of the Royal Astronomical Society.132: 31–37.

[14]. Fanti, C., Fanti, R. Dallacasa, D. Schillizzi, R.T. Spencer, R.E. and Stanghellini, C. (1995) Are compact steep spectrum sources young? Astronomy and Astrophysics. 302: 317–326.

[15]. Ezeugo, J.C. (2021) On the Intergalactic Media Densities, Dynamical Ages of Some Powerful Radio Sources and Implications. Journal of Physical Sciences and Application. 11 (1): 29–34.

[16]. Ezeugo J.C. (2021) Compact Steep Spectrum Source Size and Cosmological Implication. Journal of Research in Applied Mathematics. 7(2): 1–4.

[17]. Ezeugo, J.C. (2015) Compact Steep-Spectrum Radio Sources and Ambient Medium Density. International Journal of Astrophysics and Space Science. 3(1): 1–6.

[18]. Ezeugo J.C. (2015) On the Dependence of Spectral Turnover on Linear Size of Compact Steep-Spectrum Radio Sources. International Journal of Astrophysics and Space Science. 3(2): 20–24.

[19]. Ezeugo, J.C. (2021) On Cosmic Epoch and Linear Size/Luminosity Evolution of Compact Steep Spectrum Sources. American Journal of Astronomy and Astrophysics. 9(1): 8–12.