On Re-Acceleration Mechanism of the Radio Jets of Some Powerful Extragalactic Radio Sources

Jeremiah Chukwuemerie Ezeugo, Ph.D.

Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

E-mail: chuksemerie@yahoo.com

ABSTRACT

In this work, we have carried out linear regression analysis of observed source linear sizes, $\mathcal{D}$, of the more extended extragalactic quasars against their individual observed redshifts, z,. With appreciable correlation, result shows that D relates with redshift(z) according to the equation, $\mathcal{D} = \mathcal{K}(1+z)^{-1.5}$; where $\mathcal{K}$ is a constant. The relation shows that projected source size is smaller at earlier epoch in the evolution of the universe. In addition, if we take $\mathcal{D}$ to be distance between any two points in space, then the relation may mean that the diameter of the universe is smaller at earlier epoch of its evolution. With some plausible assumption, we show that jet velocity may be written as, $v_j \sim [\mathcal{P}_{BH}(1+z)^3]^{0.5}$, indicating that jet particles are driven by blackhole power, as well as, cosmic evolution. Since cosmic evolution is propelled by dark energy, the relation simply shows that dark energy enhances jet expansion more than blackhole power. Dark energy creates more empty space. It is anti-gravity in nature, and is believed to be the driving force behind the evolution (or expansion) of the universe. Moreover, we estimate the magnitude of the effect of dark energy on the jet expansion to be three times the effect caused by blackhole power. Therefore, this result suggests that in addition to other factors, a culprit for reacceleration mechanism for radio jets is dark energy.

In order to check the authenticity of the assertion, we carry out linear regression analyses of observed luminosities,$(\mathcal{P})$, against observed redshifts for both the extended extragalactic radio quasars and CSS quasars. With good correlations in both cases, we obtain $\mathcal{P} \sim (1+z)^a$; where $a = 0.04$ and 4.33 for the extended quasars and CSS quasars, respectively. The results show strong dependence of source luminosity on redshift. Moreover, the staggering difference in their indices suggestively implies that if we match the two samples at similar redshifts, luminosities of CSS quasars will be higher than those of the more extended sources. Hence, the results show that at similar epoch, luminosities of the more extended quasars are more extinguished (or more attenuated) than those of the CSS quasars.

The jets and lobes of the extended quasars are located in the intergalactic medium (IGM). This medium is very much rarefied and dark energy should be expected to exhibit more effect here than in the interstellar medium (ISM). On the other hand, the components of the CSS sources are sub-galactic. This means that they are buried in the dense ISM. In this medium, there is lesser manifestation of dark energy. Therefore, the disparity in the two indices (0.04 and 4.33) simply indicates manifestation of dark energy. Due to more rapid expansion of the IGM in which the jets and lobes of the extended sources are located, their luminosities are diluted more by increased spaces created by dark energy in that medium. This also shows that dark energy is a suspect in enhancement of re-acceleration of the extragalactic jets. In conclusion, our results suggest that a factor which fuels re-acceleration of extragalactic radio jets is dark energy.

(Keywords: cosmic evolution, linear size, astronomical distance, luminosity, radio sources, quasars, dynamical evolution, re-acceleration)

INTRODUCTION

Extragalactic radio sources (EGRS) emit large amounts of radio radiation. These are sources with a high ratio of radio to optical emission. This ratio is generally defined by the quotient of the two flux densities given by $S_{5\,\mathrm{GHz}}/S_{6\times10^5\mathrm{GHz}} > 10$ [1–5]. They are found outside the Milky Way galaxy. They are mainly made up of the following sub-classes: radio galaxies and radio-loud quasars [1–12]. Radio emission from these sources commonly takes the morphology of two opposite sided relativistic jets emanating from the central core presumed to harbor a supper massive blackhole. The jets terminate with strong shocks forming lobes. The two radio-emitting lobes straddling the central component which is more or less coincident with the nucleus of the host galaxy is irregular in shape [1,4,7]. In some sources, the lobes contain hotspots believed to be the termination points of the radio jets [1,4,7].

The more extended EGRS have linear sizes, D, given by $\mathcal{D} > 30$ Kpc assuming Hubble constant, $H_0 = 75\ \mathrm{kms^{-1}Mpc^{-1}}$. Since 30 Kpc is roughly the diameter of a typical galaxy, then it simply means that the jets and lobes of these sources are in the intergalactic media. Their radio luminosity is in excess of 10^{26}Wat, 5 GHz and overall luminosities are found to be $\geq 10^{37}$W [4–11].

However, the compact steep spectrum (CSS) sources are scaled-down versions of the more extended sources with projected linear sizes well below 30 Kpc. They comprise radio galaxies and radio-loud quasars but on sub-galactic dimensions. They show steep spectra ($\alpha \geq 0.5, S_\nu \sim \nu_P^\alpha$; where $S_\nu$is flux density, α, spectral index, and ν_P, spectral turnover) at high frequencies (e.g., ≥ 0.02 GHz) from the entire radio morphological structures; hence, their name. Their radio luminosities at 5 GHz are above 10^{21} W; while their bolometric luminosities are higher than 10^{37} W [12–18].

Several authors have wondered on the relationship between CSS sources and the more extended EGRS. Sequel to this, some authors have come up with some models for the evolution of these sources. These models include Youth Scenario (i.e., young evolving sources), Frustration Scenario (i.e., sources confined by dense gases in their respective interstellar media), and Relativistic Beaming and Orientation Effects (i.e., the source sizes are foreshortened by orientation and projection effects) [12–18].

It has been pointed out by some authors that presence of jets in radio sources generally depicts presence of gaseous ambient media [12-18]. Some hydrodynamic simulations of jet propagations in tenuous media have been carried out to investigate their properties and nature [5–6]. Some of the results in literature have shown that the jets are made up of fast-moving particles (presumably electrons) [12–13,19].

In addition to the foregoing, many authors have been puzzled on the mechanism behind the un-attenuated nature of the speeds with which the jet particles propagate through the immense distances from the central core to the radio-emitting lobes. Some authors have suggested that there must be some reacceleration mechanisms. This shows that the particles' kinetic energies may be boosted by some mechanisms while on their way to the lobes [4]. It is generally believed that if this is true, then layers of magnetic fields present in the intergalactic media should be a suspect [4]. However, this has been a presumption and there is no concrete evidence for the assertion. Therefore, in this paper, we seek to find, with some plausible assumptions, effect of dark energy in the overall jet expansion.

In order to achieve this, we carry out some regression analyses using some powerful extragalactic radio source samples. The first sample list contains the more extended extragalactic radio-loud quasars obtained from [20]. Their projected linear sizes are well above 30 Kpc, and are 170 in number. The second sample list contains 27 CSS quasars obtained from O'Dea (1998) [15].

SIZE/REDSHIFT $(\mathcal{D}/z)$ RELATION

In this section, we carry out linear regression analysis of source projected linear sizes of quasars and observed redshifts (see Figure 1).

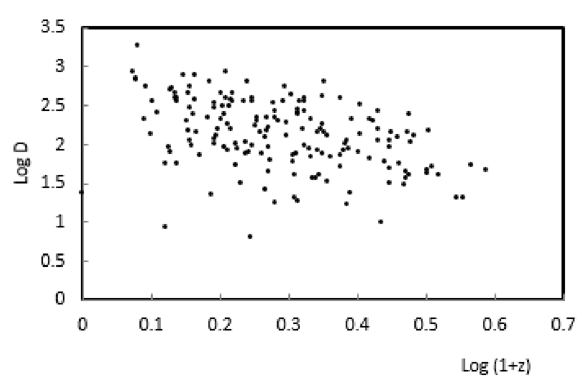

Figure 1: Scatter Plot of Source Observed Linear Sizes against Observed Redshifts for Extended Quasars.

Results from the $\mathcal{D} - z$ plane shows that projected linear size and source redshift are connected according to the following relation:

$$\text{Log}\mathcal{D} = 2.562 - 1.522\text{Log}(1 + z) \quad (1)$$

If we assume that the correlation is appreciable (with correlation coefficient given as 0.41), we may rewrite Equation (1) to be:

$$\mathcal{D} = \mathcal{K}(1 + z)^{-1.5} \quad (2)$$

where, $\mathcal{K}$ is a constant. Or evaluating further, we obtain:

$$z \sim \mathcal{D}^{-2/3} - 1 \quad (3)$$

The last equation shows that projected source size is smaller at earlier epoch. In addition to that, if we take $\mathcal{D}$ to be distance between any two points in space, then Equation (3) may mean that the diameter of the universe is smaller at earlier epoch.

Assuming that the radio jet is confined by ram-pressure balance with the ambient medium, we have [16, 21]

$$\mathcal{P}_j \approx \eta m_h v_j^2 \quad (4)$$

where $\mathcal{P}_j$ = jet internal pressure
η = particle number density of the source ambient medium
m_h = hydrogen mass, and
v_j = jet velocity.

From (4), we derive blackhole power, $\mathcal{P}_{\mathcal{BH}}$, (i.e., power supplied by the blackhole to the jet). This is given by:

$$\mathcal{P}_{\mathcal{BH}} \approx \eta m_h c v_j^2 \Gamma \mathcal{D}^2 \quad (5)$$

Evaluating for jet velocity, we obtain:

$$v_j \approx \left(\frac{\mathcal{P}_{\mathcal{BH}}}{\eta m_h c \Gamma \mathcal{D}^2}\right)^{\frac{1}{2}} \quad (6)$$

Combining Equations (2) and (6), we get:

$$v_j \approx \left(\frac{\mathcal{P}_{\mathcal{BH}}}{\eta m_h c \Gamma [\mathcal{K}(1 + z)^{-1.5}]^2}\right)^{\frac{1}{2}} \quad (7)$$

This implies:

$$v_j \sim [\mathcal{P}_{\mathcal{BH}}(1 + z)^3]^{\frac{1}{2}} \quad (8)$$

This therefore indicates that jet expansion is powered by both blackhole and cosmic evolution. Since cosmic evolution is propelled by dark energy (i.e., the intrinsic tendency of vacuum/free space to expand in volume), Equation (8) simply states that dark energy enhances jet expansion more than blackhole power. Dark energy creates more empty spaces. It is anti-gravity and is believed to be the driving force behind the evolution (or expansion) of the universe [22]. Using the indices in the equation, we estimate the magnitude of the effect of dark energy on the jet expansion to be three times the effect caused by blackhole power. Therefore, we suggest that in addition to other factors, a culprit for reacceleration mechanism for radio jets may be dark energy.

LUMINOSITY/REDSHIFT $(\mathcal{P}/z)$ RELATION

We also carry out linear regression analyses of observed luminosities, $\mathcal{P}$, against observed redshifts for both the extended extragalactic radio quasars (Figure 2) and CSS quasars (Figure 3).

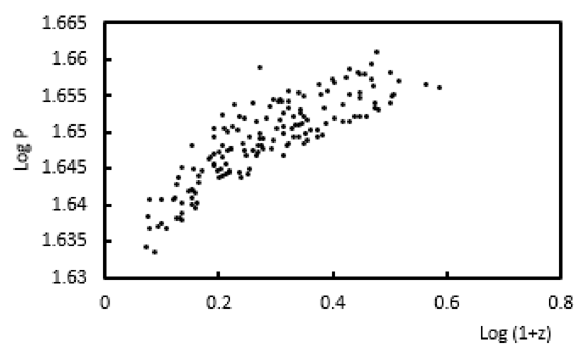

Figure 2: Scatter Plot of Source Observed Luminosities against Observed Redshifts for the Extended Quasars.

From $\mathcal{P} - z$ data (Figure 2), we find the relation:

$$\text{Log}\,\mathcal{P} = 1.64 + 0.04\text{Log}\,z \quad (9)$$

With correlation coefficient given as $r = 0.8$, we see that source luminosity shows strong correlation with redshift. Transforming the equation, we obtain:

$$\mathcal{P} \sim (1 + z)^{0.04} \quad (10)$$

Moreover, from $\mathcal{P}-z$ plane for CSS quasars (Figure 3), we obtain similar relation. This is given by:

$$\text{Log}\,\mathcal{P} = 26.46 + 4.33\text{Log}\,z \qquad (11)$$

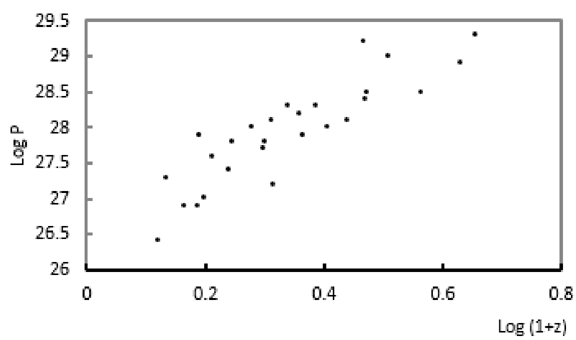

Figure 3: Scatter Plot of Source Observed Luminosities against Observed Redshifts for the CSS Quasars.

It shows good correlation too with $r \approx 0.8$. rewriting the equation, we have:

$$\mathcal{P} \sim (1+z)^{4.33} \qquad (12)$$

Generally, the results (10) and (12) obtained from the analyses of the two samples simply indicate strong dependence of source luminosity on redshift. Moreover, the staggering difference in their indices suggestively implies that if we match the two samples at similar redshifts, luminosities of CSS quasars will be higher than those of the more extended sources just as is roughly shown in Figure 4.

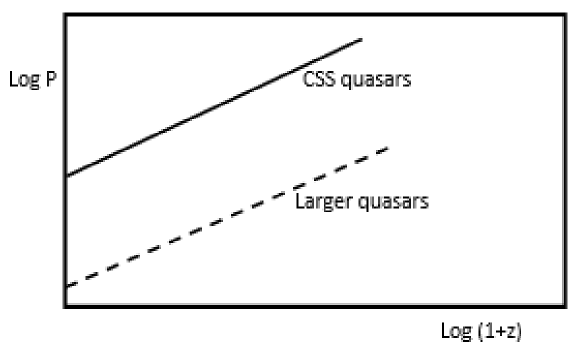

Figure 4: Schematic Diagram of Variation of Luminosities of CSS Quasars and Larger EGR Quasars when Matched at Similar Redshifts (Solid line represents CSS quasars' luminosities while broken line shows luminosities of the more extended EGRSs).

This result shows that at similar epoch, luminosities of the more extended sources are more extinguished/attenuated than those of the CSS sources. It is good to note that components (jets and lobes) of the larger sources are in the intergalactic medium (IGM). This medium is very much rarefied and dark energy shows more effect here. However, the components of the CSS sources are sub-galactic. This means that they are encapsulate by the dense gases in the interstellar media (ISM). In this medium, there is lesser manifestation of dark energy. Therefore, the disparity in the two indices simply indicates manifestation of dark energy. Due to more rapid expansion of the IGM in which the jets and lobes of the larger sources are located, their luminosities are diluted more by more spaces created by dark energy in that medium. This also shows that dark energy is a suspect in enhancement of re-acceleration of the extragalactic jets.

DISCUSSION AND CONCLUSION

We have carried out linear regression analysis of observed source linear sizes, $\mathcal{D}$, of the more extended extragalactic quasars against their individual observed redshifts, z, (see Figures 1). Result shows that D relates with redshift(z) according to the equation, $\mathcal{D} = \mathcal{K}(1+z)^{-1.5}$; where $\mathcal{K} =$ a constant and $r = 0.4$ is the correlation coefficient.

Even though the correlation is marginal, we consider it good enough for observed data in the field of astronomy. The relation shows that projected source size is smaller at earlier epoch in the evolution of the universe. Moreover, if we take $\mathcal{D}$ to be distance between any two points in space, then the relation may mean that the diameter of the universe is smaller at earlier epoch of its evolution.

If we assume jet confinement by ram-pressure balance with the particles of the medium through which it propagates [16,21], then jet velocity may be given by, $v_j \sim [\mathcal{P}_{BH}(1+z)^3]^{0.5}$. This indicates that jet velocity is powered by blackhole and cosmic evolution. Since cosmic evolution is propelled by dark energy Equation (8) simply states that dark energy enhances jet expansion more than blackhole power. Dark energy creates more empty spaces. It is anti-gravity in nature and is believed to be the driving force behind the evolution (or expansion) of the universe [22]. Using the indices in the equation, we estimate the magnitude of the effect of dark energy on the jet expansion to be three times the effect caused by blackhole power. Therefore, this result suggests that in addition to other factors, a culprit for reacceleration mechanism for radio jets may be dark energy.

In addition, we carry out linear regression analyses of observed luminosities,$(\mathcal{P})$, against observed redshifts for both the extended extragalactic radio quasars (Figure 2) and CSS quasars (Figure 3).

From $\mathcal{P} - z$ data (Figure 2) for the more extended sources, we find the relation, $\mathcal{P} \sim (1 + z)^{0.04}$, with correlation coefficient given as 0.8. This shows that source luminosity shows strong correlation with redshift. Moreover, from $\mathcal{P} - z$ plane for the CSS quasars (Figure 3), we obtain similar relation, $\mathcal{P} \sim (1 + z)^{4.33}$, with 0.8 as the correlation coefficient.

The results (10) and (12) obtained from the analyses of the two samples simply shows strong dependence of source luminosity on redshift. Moreover, the staggering difference in their indices suggestively implies that if we match the two samples at similar redshifts, luminosities of CSS quasars will be higher than those of the more extended sources (Figure 4). This result shows that at similar epoch, luminosities of the more extended quasars are more extinguished (or more attenuated) than those of the CSS quasars.

The components (i.e., jets and lobes) of the larger sources are located in the intergalactic medium (IGM). This medium is very much rarefied and dark energy should be expected to exhibit more effect here than in the interstellar medium (ISM). On the other hand, the components of the CSS sources are sub-galactic. This means that they are buried in the dense ISM. In this medium, there is lesser manifestation of dark energy. Therefore, the disparity in the two indices in (10) and (12) simply indicates manifestation of dark energy.

Due to more rapid expansion of the IGM in which the jets and lobes of the larger sources are located, their luminosities are diluted more by more spaces created by dark energy in that medium. This also shows that dark energy is a suspect in enhancement of re-acceleration of the extragalactic jets.

In conclusion, our results suggest that a factor which fuels re-acceleration of extragalactic radio jets is dark energy.

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 (1): 14 – 19.

2. Ubah, O.L. and J.C. Ezeugo. 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*.

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

5. Robson, I. 1996. *Active Galactic Nuclei*. John Wiley and Sons Ltd.: London, UK.

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 M. Kino. 2007. “The Velocity of Large-scale Jets in a Declining Density Medium”. *In Serie de Conferencias. Triggering Relativistic Jets.* W.H. Lee and E. Ramirez-Ruiz. 27: 192–197.

8. 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.

9. Mahatma, V.H., M.J. Hardcastle, and W.L. Williams. 2019. “LoTSS DR1: Double-Double Radio Galaxies in the HETDEX Field”. *Astronomy and Astrophysics.* 622:A13.

10. Mingo, B., J.H. Croston, and M.J. Hardcastle. 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.

11. Hardcastle, W.L., W.L. Williams, and P.N.Best. 2019. “Radio-loud AGN in the First LoTSS Data Release — The Lifetimes and Environmental

Impact of Jet-Driven Sources”. *Astronomy and Astrophysics.* 622: A12.

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

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

14. 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.

15. Ezeugo, J.C. and A.A. Ubachukwu. 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.

16. O’Dea, C.P. 1998. “The Compact Steep Spectrum and Gigahertz Peaked Spectrum Radio Sources”. *Publications of the Astronomical Society of the Pacific*. 110: 493–532.

17. Fanti, C.R., D. Fanti, R.T. Dallacasa, R.E. Schillizzi, C. Spencer, and C. Stanghellini. 1995. “Are Compact Steep Spectrum Sources Young?” *Astronomy and Astrophysics*. 302: 317–326.

18. Ezeugo, J.C. 2021. “Compact Spectrum Source Size and Cosmological Implication”. *Journal of Research in Applied Mathematics*. 7(2): 1–4.

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.

20. Ezeugo, J.C. 2021. “Intergalactic Media Densities of Extragalactic Radio Sources and Source Ages”. *American Journal of Astronomy and Astrophysics*. 9(2): 13–17.

21. Nilsson, K. 1998. “Kinematical Models of Double Radio Sources and Unified Scheme”. *Monthly Notices of the Royal Astronomical Society.* 132: 31–37.

22. Ezeugo, J.C. 2021. “On the Components of Large Extended Extragalactic Radio Sources”. The Pacific *Journal of Science and Technology.* 22 (1): 20–23.

23. Frieman, J.A., M.S. Turner, and D. Huterer. 2008. “Dark Energy and the Accelerating Universe” *Annual Review of Astronomy*. 46: 385–432.

ABOUT THE AUTHOR

Dr. Jeremiah Chukwuemerie Ezeugo, is a Lecturer in the Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. He holds a Ph.D. degree in Astrophysics from the University of Nigeria, Nsukka. His research interests are in the areas of Extragalactic Radio Astronomy and Cosmology.

SUGGESTED CITATION

Ezeugo, J.C. 2022. “On Re-Acceleration Mechanism of the Radio Jets of Some Powerful Extragalactic Radio Sources”. *Pacific Journal of Science and Technology*. 23(1): 28-33.

Pacific Journal of Science and Technology