On Extragalactic Radio Sources and Dark Energy

Abstract: In this work, we use statistical methods of analyses to find effects of the intergalactic medium (IGM) and interstellar medium (ISM) of some extragalactic radio sources on dark energy. We carry out linear regression analysis of observed source linear sizes (D) of the more extended radio quasars against their corresponding observed redshifts (z) in our sample. Also, we carry out similar analysis on the observed linear sizes of compact steep spectrum (CSS) quasars against their corresponding observed redshifts. Results of the regression indicate that if we take D to be distance between any two positions in the IGM/ISM, then cosmic evolution shows an inverse power-law function with the magnitude of the distance between the two positions according to the relation, $(1+z)\sim D^{-\psi}$; where $\psi = 0.6$ and 0.4 for the more extended quasars and CSS quasars respectively. Since "a higher redshift implies an earlier epoch", and redshift has a direct dependence on expansion velocity between any two points in space, the results of the analyses simply suggest that at earlier epoch, the expansion rate of the universe is higher. Our results also indicate that the effect of cosmic evolution in the extended quasars is more than the effect in the CSS quasars $\left(\text{i.e. } D_{z(EGRQ)} > D_{z(CSSQ)}\right)$. Since the linear sizes of the extended radio-loud quasars are projected into the IGM, while the linear sizes of the CSS radio-loud quasars are confined within their individual host galaxies, the result $\left(D_{z(EGRQ)} > D_{z(CSSQ)}\right)$ can be interpreted to mean that cosmic evolution shows greater effect in the IGM (i.e. more rarefied medium) than in the ISM (i.e. less rarefied medium). Hence, from the results of the analyses, we may state that if dark energy is defined as the intrinsic tendency of vacuum (or free space) to increase in volume, then the inconsistency in $D_{z(EGRQ)}$ and $D_{z(CSSQ)}$ is simply a manifestation of dark energy. Therefore, we may conclusively say that dark energy constitutes a driving parameter behind cosmic evolution. Moreover, we estimate the percentage dilution on dark energy caused by the presence of matter to be $\approx 33\%$. This implies that if we assume IGM to be approximately an ideal vacuum, then matter present in the ISM offers $\approx 33\%$ dilution effect on dark energy.

Keywords: dark energy; cosmic evolution; linear size; radio sources; quasars; redshifts.

1. Introduction

The building blocks of the Universe are the galaxies. In terms of their luminosities, galaxies can be classified into sub-groups: namely, normal galaxies and active galaxies. Active galaxies are those galaxies that radiate in excess of $10^{36} W$ [1-4]. Unlike the normal galaxy whose radiation comes from the constituent stars, an active galaxy radiates copious amounts of radiation from its three major components: they include, central core (believed to harbor a supper massive blackhole), two-sided jets emanating from the core, and two-sided lobes fed by the jets [1-4].

Active galaxies consist of radio-loud sources and radio-quiet sources. The former are commonly referred to as extragalactic radio sources (EGRS). EGRS emit large amount of radio emission. They show high ratio of radio to optical emission. This ratio is generally defined by the quotient of the two flux densities given by $S_{5\,\text{GHz}}/S_{6\times10^5\text{GHz}} > 10$ [1–7]. They comprise radio galaxies, radio quasars and BL Lacertae objects [4–8]. Observationally, radio radiation from these EGRS generally assumes the morphology of two opposite sided relativistic jets connecting the base of the accretion disk to two radio-emitting lobes straddling the central core [1–8]. The jet is believed to serve as a conduit through which jets materials reach the lobe. In some sources, the lobes contain hotspots believed to be the termination points of the jets [1–8].

Compact steep spectrum sources (CSSs), on the other hand, belong to this class of active galaxies known as extragalactic radio sources (EGRS) that radiate more in the radio wavelengths [9–14]. The major difference between the CSSs and the normal EGRSs (or extended radio sources) is their smallness but yet powerful in radiation [9–14]. They constitute a remarkable class of radio sources accounting for a substantial fraction of the extragalactic sources selected, especially, at high radio frequencies where the source counts are usually dominated by flat spectrum (spectral index, $\alpha < 0.5, S_\nu \propto \nu^{-\alpha}$; where S_ν is flux density). They are not just cores that show steep spectra, rather they are full-fledged radio galaxies and quasars complete with jets and lobes, but on small scale [9–14]. They have been shown to contain special characteristics that make them be considered as a separate class of objects in addition to lobe- and core-dominated Active Galactic Nuclei (AGNs). They are usually found at high redshifts (generally, they tend to have redshift distribution of $z \leq 4$), and are among high luminosity sources [9–14].

The more extended EGRSs have linear sizes, D, given by $D > 30\,\text{Kpc}$ assuming Hubble constant, $H_0 = 75\,\text{kms}^{-1}\text{Mpc}^{-1}$. In all cases, their linear sizes extend into intergalactic media. Their radio luminosity is in excess of $10^{26}\text{W at } 5\text{ GHz}$ and overall luminosities $(P_{bol} \geq 10^{37}\text{W})$ in common with the Compact Steep Spectrum Sources (CSS) [4– 14].

Furthermore, it has been well noted that presence of jets in radio sources simply suggests presence of gaseous ambient media [15-18]. A number of hydrodynamic simulations of jet propagations have been performed to examine their physical properties [15–16]. These studies show that jet materials have smaller masses than those of the ambient medium. Besides, Ezeugo J.C. and Ubachukwu A.A. (2010) [13] created a model for evolution of compact steep spectrum (CSS) sources (which is a subclass of EGRSs) and used it to estimate their ambient densities. In this work, we use statistical methods of analyses to find effects of the intergalactic medium (IGM) and interstellar medium (ISM) of some extragalactic radio sources on dark energy. Moreover, dark energy is simply the intrinsic tendency of vacuum (or free space) to increase in volume. It brings more space into existence. This energy is anti-gravity, and is believed to be the driving force behind the evolution (expansion) of the universe [19].

The extragalactic radio sources used in the analyses are obtained from [15]. They are made up of 170 extended radio-loud quasars with observed linear size, $D > 30Kpc$. The second sample contains 31 CSS radio-loud quasars obtained from [12]

2. Dependence of Cosmic Evolution on a Distance in the Intergalactic Medium (IGM)

In this section we use the more extended radio-loud quasars in the analyses. The projected linear sizes of these sources are of extragalactic dimension $(D > 30Kpc)$ – their components (jets and lobes) are located in the IGM. This is because the size of a typical galaxy is $\approx 30Kpc$. Therefore, whatever result obtained in this section has been affected by the most rarefied medium – the IGM. We carry out linear regression analysis of observed source linear sizes, D, of the more extended radio-loud quasars against their corresponding observed redshifts, z, (Figure 1) in our sample.

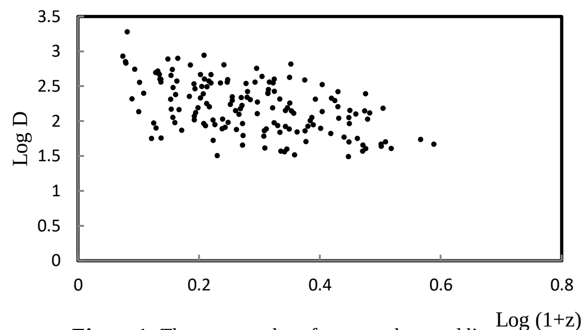

Figure 1: *The scatter plot of source observed linear sizes against observed redshifts for the more extended quasars*

Results of the regression show that D relates with z according to the equation:

$$\mathrm{Log}D = -1.595\mathrm{Log}(1+z) + 2.657 \qquad (1)$$

The correlation is good with coefficient, $r = 0.50$; therefore, equation (1) may be rewritten as

$$D \sim (1+z)^{-1.6} \qquad (2)$$

Or making $(1+z)$ subject, we obtain

$$(1+z) \sim D^{-0.6} \qquad (3)$$

This shows that

$$z = z(D) \qquad (4)$$

Therefore, if we take D to be distance between any two positions in the IGM, then equation (3) shows that cosmic evolution has an inverse power-law function with the distance between the two positions. This implies that at earlier epoch, the expansion rate of the universe was higher.

3. Dependence of Cosmic Evolution on a Distance in the Interstellar Medium (ISM)

In this section, we use the CSS radio-loud quasars in the analyses. The projected linear sizes of these sources are of sub-galactic dimension $(D < 30Kpc)$ – their components (jets and lobes) are located in the ISM. Therefore, whatever result obtained in this section has been affected by the dense gases in the interstellar medium. Ezeugo J.C. and Ubachukwu [13] have shown that these radio sources are evolving in dense interstellar media unlike their extended counterparts.

On the $D - z$ plane (Figure 2), we obtain the relation:

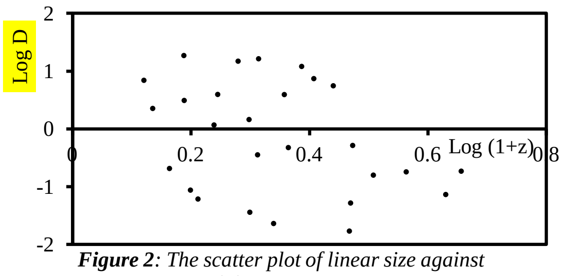

***Figure 2**: The scatter plot of linear size against redshift for the CSS quasars*

$\text{Log}D = -2.49\text{Log}(1 + \text{z}) + 0.89$ (5)

with correlation coefficient, $r = 0.4$. Even though the correlation is marginal, it is still in consonance with the result obtained for the more extended quasars. So, if we assume it is good enough for observed physical parameters such as these, we transform (5) to obtain

$D \sim (1 + z)^{-2.5}$ (6)

Or, as before, making $(1 + z)$ subject, we find

$(1 + z) \sim D^{-0.4}$ (7)

This shows that

$z = z(D)$ (8)

Therefore, just as pointed out earlier, if we take D to be distance between any two positions in the ISM, then equation (7) shows that cosmic evolution has an inverse power-law function with the distance between the two positions. This also implies that at earlier epoch, the expansion rate of the universe was higher.

4. Dark Energy and Cosmic Evolution

As stated earlier, dark energy is the intrinsic tendency of vacuum (or free space) to increase in volume. It brings more space into existence. This energy is anti-gravity, and is believed to be the driving force behind the evolution (expansion) of the universe [19].

From (3) and (7), we have

$D_{z(EGRQ)} > D_{z(CSSQ)}$ (9)

where $D_{z(EGRQ)}$ represents cosmic evolution effect in the extended quasars, and $D_{z(CSSQ)}$ represents the effect in CSS quasars. Since the linear sizes of the extended radio-loud quasars jut into the IGM, while the linear sizes of the CSS radio-loud quasars are located within their individual host galaxies, therefore, equation (9) can be interpreted to mean that cosmic evolution shows greater effect in the IGM (more rarefied medium) than in the ISM (less rarefied medium). Hence, from the foregoing, we may state that if dark energy is defined as the intrinsic tendency of vacuum (or free space) to increase in volume [19], then the inconsistency in $D_{z(EGRQ)}$ and $D_{z(CSSQ)}$ is simply the manifestation of dark energy.

Moreover, we estimate the percentage dilution of dark energy caused by presence of matter. The positive difference of the indices of equations (3) and (7) yields 0.2; hence, percentage dilution becomes $\frac{0.2}{0.6} \times 100\% = 33.3\%$. The implication of this is that if we assume IGM to be roughly an ideal vacuum, then matter present in the ISM offers ≈ 33% dilution to dark energy. The particle number density of the ISM of CSS sources has been estimated by Ezeugo J.C. and Ubachukwu A.A. [13].

5. Discussion and Conclusion

We have carried out linear regression analysis of observed source linear sizes (D) of the more extended radio quasars against their corresponding observed redshifts, z, (Figure 1) in our sample. Results of the regression analysis show that D relates with z according to the equation (1) with correlation coefficient, $r = 0.50$. This correlation is good. Rewriting equation (1), we have $(1 + z) \sim D^{-0.6}$; indicating that $z = z(D)$. Therefore, if we take D to be distance between any two positions in the IGM, then the relation shows that cosmic evolution has an inverse power-law function with the distance between the two positions. Since "a higher redshift implies an earlier epoch", and redshift has a direct dependence on expansion velocity between any two positions (according to Hubble's law), then the results of the analyses simply suggest that at earlier epoch, the expansion rate of the universe was higher.

Moreover, on the $D - z$ plane (Figure 2), we obtain a relation (equation (5)) which connects the observed linear sizes of CSS quasars and their respective redshifts. The correlation is marginal with, $r = 0.4$. Even though it is marginal, it is still in consonance with the result obtained for the more extended quasars. So, if we assume it is good enough for observed physical data such as these, we may transform (5) to obtain $(1 + z) \sim D^{-0.4}$ which also implies that $z = z(D)$. Therefore, just as pointed out earlier, if we take D to be distance between any two positions in the ISM, then equation (7) shows that cosmic evolution has an inverse power-law function with the distance between the two positions. This also shows that since "observation of a higher redshift implies observation of an earlier epoch" (and as pointed out earlier – according to Hubble's law, redshift has a direct dependence on expansion velocity between any two points in space), then the results of the analyses simply suggest that at earlier epoch, the expansion rate of the universe was higher.

From equations (3) and (7), we find that the effect of cosmic evolution in the extended quasars is more than the effect in the CSS quasars $\left(D_{z(EGRQ)} > D_{z(CSSQ)}\right)$. Since the linear sizes of the extended radio-loud quasars are projected into the IGM, while the linear sizes of the CSS radio-loud quasars are confined within their individual host galaxies, therefore, equation (9) can be interpreted to mean that cosmic evolution shows greater effect in the IGM (more rarefied medium) than in the ISM (less rarefied medium). Hence, from the results of the analyses, we may state that if dark energy is defined as the intrinsic tendency of vacuum (or free space) to increase in volume, then the inconsistency in $D_{z(EGRQ)}$ and $D_{z(CSSQ)}$ is simply the manifestation of dark energy. Therefore, we may conclusively say that dark energy constitutes a driving parameter behind cosmic evolution.

In addition to the foregoing, we estimate the percentage dilution of dark energy caused by presence of matter. The estimate is 33.3%. The implication of this is that if we assume IGM to be approximately an ideal vacuum, then matter present in the ISM offers $\approx 33\%$ dilution effect to dark energy. The particle number density of the ISM of CSS sources has been estimated by Ezeugo J.C. and Ubachukwu A.A. [13]. Their results show that the estimated ambient (ISM) densities of CSS sources generally, by far, outweigh those of their extended counterparts.

References

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

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

[3]. 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.

[4]. 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.

[5]. 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.

[6]. 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.

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

[8]. 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.

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

[10]. 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.

[11]. 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.

[12]. 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.

[13]. 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.

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

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

[16]. 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.

[17]. 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.

[18]. 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.

[19]. Friedman, J.A., Turner, M.S. Huterer, D. (2008) Dark Energy and the Accelerating Universe. Annual Review of Astronomy. 46: 385–432.