Journal of Basic Physical Research ISSN: 2141-8403 Prints, 2141-8411 Online
Vol.14, Issue 1, March, 2025, pp. 69 - 76. Available online at https://journals.unizik.edu.ng/jbpr/

MODELING SOME INTERGALACTIC RADIO COMPONENTS' AND COSMIC EXPANSIONS

Ezeugo, Jeremiah Chukwuemerie
Department of Physics and Industrial Physics, Nnamdi Azikiwe University,
Awka Anambra State, Nigeria

Abstract
Analytical and statistical methods are used to find a mathematical model that plausibly may connect cosmic expansion, and expansions of some intergalactic radio components (such as the extragalactic radio jets and lobes of some radio galaxies). These are done by carrying out some regression analyses on some measurable parameters of the more extended radio galaxies, as well as, on their more compact counterparts. Results of the size/redshift data for the more extended doubles indicate that these sources expand in size as cosmic expansion advances with time. However, this is in contrast with the results obtained for the more compact radio galaxies, and of course, this may have some physical implications. The more compact sources are remarkably sub-galactic in dimensions; which simply means they are domiciled in denser ambient media. Therefore, it should be expected that they would experience more drag than their more extended counterparts (as well as, experience more gravitational pull within their host galaxies) while undergoing their individual intrinsic dynamical expansions/growth. The disparity in the two results simply suggests that there are little or no connections of cosmic expansion with the sizes of these scaled-down versions of the more extended radio galaxies; while the sizes of the larger sources are boosted by cosmic expansion according to the relation $\mathfrak{L} \sim -\frac{1}{\mathcal{S}^{0.9}}$; where $\mathcal{S}$ is speed of recession of the radio galaxy, and $\mathfrak{L}$, its size/dimension. It shows that cosmic expansion plausibly influences the dimensions of the large extended extragalactic sources more than it does to the compact ones by factor of 1.3.
Keywords: Cosmic, extragalactic, radio sources, galaxies, expansion, dark energy

Introduction

Overview of Extragalactic Radio Sources and Radio Galaxies

Usually, extragalactic radio sources (EGRS) emit ample amount of radio waves. They display high proportion of radio to optical emission. The ratio is generally defined by (Rubin and Hayden 2016; Ezeugo 2021; Ubah and Ezeugo 2021; Urry 2004; Ezeugo 2015),

$$\frac{\mathcal{F}_{5\ GHz}}{\mathcal{F}_{6\times10^5 GHz}} > 1 \qquad (1)$$

where $\mathcal{F}_{5\ GHz}$ and $\mathcal{F}_{6\times10^5 GHz}$ are flux densities at radio and optical wavelengths respectively.

They are sited outside the boundaries of the Milky Way (which is our galaxy). Based on their morphologies, the main sub-classes of these objects include: radio galaxies and radio-loud quasars (Urry 2004; Ezeugo 2015). Also based on their observed linear sizes, there are the large extended sources whose linear sizes, $\mathfrak{L} > 30kpc$; and their miniaturized counterparts whose linear sizes are mostly well below $30kpc$. The latter are referred to as the compact steep spectrum (CSS) sources (O'Dea 1998; Ezeugo 2015). While the sizes of the extended sources are inter-galactic, those of the CSS sources are sub-galactic. This simply implies that the compact (CSS) sources could suffer more drag than their large extended counterparts; as well as, besieged more by their individual host galactic gravitational influences on their growth/expansion. Hence, some observed physical properties of these two classes of objects should be expected to differ.

Furthermore, on their radio maps, typical structure of these two classes of objects takes the form of bi-focal relativistic jets that connect the base of the accretion disk to two radio-emitting lobes that are located on both sides of the central component that is more or less coincident with the nucleus (or the central core) of the host galaxy (Urry 2004; Ezeugo 2015; Readhead

1995; Robson 1996) (see figure 1). In some sources, the lobes contain hotspots believed to be the termination points of the jets (Urry 2004; Robson 1996; Jackson 1999; Kawakatu and Kino 2007).

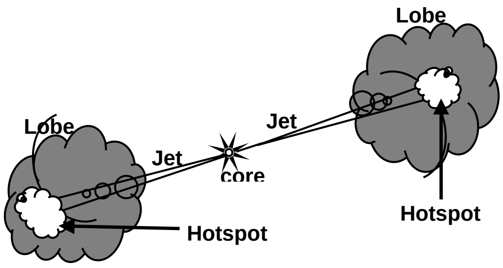

Fig.1. The structure of a typical radio galaxy.
Source: The author.

The more extended sources have linear sizes, $\mathfrak{L}$, greater than 30 Kpc. In all cases, their linear sizes jut into intergalactic media; hence, they are intergalactic. It has been observed that their radio luminosity is in excess of $10^{26}W$ at $5GHz$ frequency; while, values of their bolometric luminosities range from $10^{37}W$ and are in common with those of the CSS sources (Urry 2004; Ezeugo 2015; Readhead 1995; Robson 1996; Jackson 1999; Kawakatu and Kino 2007; Ezeugo and Ubachukwu 2010; O'Dea 1998).

Many authors have pointed out that presence of jets in extragalactic radio sources is simply an indication of tenuous ambient media (Jackson 1999; Kawakatu and Kino 2007; Ezeugo and Ubachukwu 2010; O'Dea 1998; Fanti *et al*., 1995; Ezeugo 2021a&b; Jackson 1999). Hence, a number of hydrodynamic computer simulations of jet propagations have been performed for their phenomenology (Fanti *et al*. 1995; Ezeugo 2021a&b; Jackson 1999; Mahatma *et al*. 2019; Mingo *et al*. 2019; Hardcastle *et al*. 2019; Dabhade *et al*. 2017). Results of these simulations indicate that the jet materials have smaller masses than those of its surrounding medium. In addition, Ezeugo and Ubachukwu (2010) created a mathematical model for evolution of the CSS sources and used the result to estimate their ambient densities.

Overview of Cosmic Expansion and Dark Energy

Results of some observations made by some authors show that the universe is truly expanding with acceleration. It was first found by Edwin Hubble (1929) who related the velocity of recession, $\mathcal{S}$, of a galaxy to its distance, $\mathfrak{X}$, according to the relation,

$$\mathcal{S} = \mathcal{H}\mathfrak{X} \qquad (2)$$

where $\mathcal{H}$ is Hubble parameter; though at the time he did not fully understand the real meaning of that equation. Later on, it was found through observation of type 1A supernovae that these galaxies were actually accelerating away from one another; and this indicates that the universe is undergoing accelerated expansion. Another evidence of this is from observation of the cosmic microwave background anisotropy. Moreover, use of voids and super-voids as standard rulers for measuring cosmic distances suggest that the universe is expanding with acceleration (Ellis *et al*. 1978; Padmanabhan 2002; Linder 2003; Riess 2020).

Still on Hubble's law, if the velocity of a galaxy at distance, $\mathfrak{X}_1$, is $\mathcal{S}_1$ at the time, $\mathfrak{T}_1$; then at distance, $\mathfrak{X}_2 > \mathfrak{X}_1$, and time, $\mathfrak{T}_2 > \mathfrak{T}_1$, the velocity will be $\mathcal{S}_2 > \mathcal{S}_1$. Hence, this gives

$$\frac{\mathcal{S}_2 - \mathcal{S}_1}{\mathfrak{T}_2 - \mathfrak{T}_1} = \frac{\delta\mathcal{S}}{\delta\mathfrak{T}} \qquad (3)$$

Since, $\frac{\delta \mathcal{S}}{\delta \mathfrak{T}}$ is recognized as acceleration, it shows that Hubble's law (equation (2)) predicts accelerating expansion.

Furthermore, It has been mentioned by authors that this acceleration is not brought about by the individual galactic motion; rather, by the fabric of the space-time in which these galaxies are embedded. This simply means that the fabric of the space-time is undergoing expansion; and this makes all the galaxies (which incidentally are domiciled in it) appear as if they are individually receding from one another. The energy in the space-time which causes this expansion has been termed dark energy. It has been taken to be an intrinsic property of the space-time. Very little is known about dark energy (Ellis *et al* 1978; Padmanabhan 2002; Linder 2003; Riess 2020).

Some major models of dark energy include: cosmological constant, and quintessence. It was Albert Einstein (1917), in ad hoc consideration, who attached cosmological constant to his equations for describing his assumed static universe. At that time, it had not been discovered that the universe was expanding. He introduced the constant to ensure equilibrium state required for a static universe. Though he regretted introducing the constant, authors latter found the constant important in the observed cosmic expansion. As is understood in the now, cosmological constant, Λ, is constant everywhere in the universe at any time; and hence, supports the concept of dark energy – whose energy density is observed to be constant as the universe undergoes rapid expansion. In fact, current observations show that about $68\% - 73\%$ percentage composition of the total energy density of the universe is dark energy density; while the rest is composed of baryonic matter density, dark matter density, and electromagnetic energy density (Ellis *et al*. 1978; Padmanabhan 2002; Linder 2003; Riess 2020).

Dark energy density remains constant as others decrease in value due to the accelerating expansion of the universe (see Fig. 2). This clearly shows that as contribution to the total energy density by baryonic matter, dark matter, and electromagnetic radiation decrease as the universe expands, the contribution by dark energy automatically increases. Of course, the implication is that the universe will continue to undergo accelerating expansion indefinitely, since dark energy which causes the expansion will continue to overcome possible dilution/opposition effects that may originate from matter-dominated energy densities.

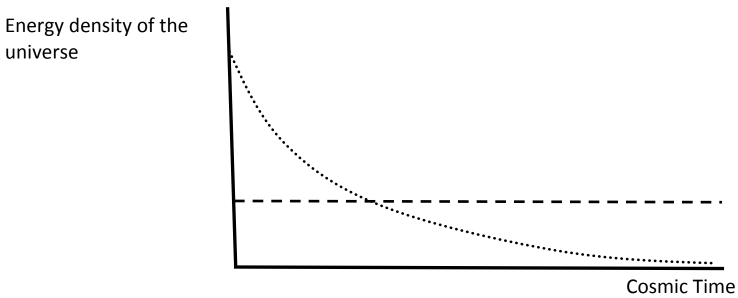

Fig. 2 Schematics (not to scale) comparing dark energy density, and the energy density contributed by baryonic matter, dark matter, and electromagnetic radiation. Dashed horizontal line represents dark energy density; while dotted curved line represents total energy density contributed by other entities.

Source: The author.

Quintessence, on the other hand, is an analytical model in which some dynamic field (scalar field) is believed to drive the observed accelerating expansion of the universe. It varies in space and time unlike the cosmological constant, and must be light. Some authors have proposed that quintessence could be the fifth fundamental force/interaction (Ellis *et al*. 1978; Padmanabhan 2002; Linder 2003; Riess 2020).

The purpose of this work is to find a mathematical model (relation) that may connect cosmic expansion and expansion of extragalactic radio jet-lobe systems of the radio galaxies in our sample lists. These samples are of two groups. The first group contains the large extended radio galaxies whose jet-lobe systems are located in the intergalactic media. Some authors refer to them as the conventional radio galaxies; while some call them 'the extended doubles' because each is immediately recognized by its prominent double lobes. Ninety nine (99) of them are selected from Nilsson (1998). This number is selected because their linear sizes show that their jet-lobe systems are largely intergalactic. The second group contains the more compact radio galaxies. They are completely sub-galactic in contrast to the previous group, and are generally referred to as the compact steep spectrum (CSS) sources. They are obtained from O'Dea (1998). The intergalactic group and the sub-galactic group used in this work have observed linear sizes, $\mathfrak{L} \geq 60kpc$ and $\mathfrak{L} < 30kpc$ respectively.

Analyses and Results

$(\mathfrak{L} - \mathfrak{z})$ ***Data for the More Extended Radio Galaxies***

Linear regression analysis of observed source linear sizes, $\mathfrak{L}$, of the more extended radio galaxies and their corresponding observed redshifts, $\mathfrak{z}$, (Figure 3) in our sample is carried out. Correlation coefficient is ≈ 0.3 for the $(\mathfrak{L} - \mathfrak{z})$ data. Assuming this marginal correlation is appreciable enough for the observed physical data, then following relation is satisfied:

$$\mathrm{Log}\mathfrak{L} = 2.632 - 0.897\mathrm{Log}(1 + \mathfrak{z}) \qquad (4)$$

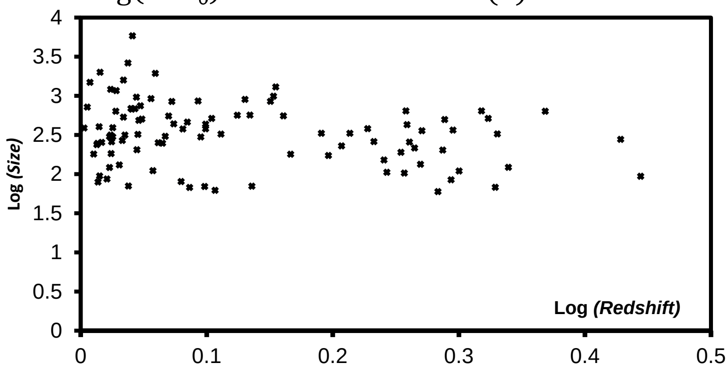

Fig. 3. The scatter plot of size versus redshift for the intergalactic radio galaxies

Rewriting it yields

$$\mathfrak{L} \sim \mathfrak{z}^{-0.9} \qquad (5)$$

The redshift relation with source velocity of recession, $\mathcal{S}$, is written by

$$\mathfrak{z} = \frac{\mathcal{S}}{\mathfrak{C}} \qquad (6)$$

where $\mathfrak{C}$ is speed of light. Combining equations (2) and (6) gives

$$\mathfrak{z} = \frac{\mathcal{H}\mathfrak{X}}{\mathfrak{C}} \qquad (7)$$

Therefore, equation (5) may be written as

$$\mathfrak{L} \sim \left(\frac{\mathfrak{C}}{\mathcal{H}\mathfrak{X}}\right)^{0.9} \qquad (8)$$

In terms of $\mathfrak{X}$ only, the last equation becomes

$$\mathfrak{L} \sim \frac{1}{\mathfrak{X}^{0.9}} \quad (9)$$

This shows that the source size scales as $\mathfrak{X}^{-0.9}$; where $\mathfrak{X}$ has already been defined as distance to the source.

In terms of time, equation (2) becomes,

$$\mathcal{H} = \frac{\mathcal{S}}{\mathfrak{X}} \quad (10)$$

which, by dimensional analysis, gives

$$\mathfrak{T} = \frac{\mathfrak{X}}{\mathcal{S}} \quad (11)$$

$\mathfrak{T}$ is recognized as the cosmic time. Solving equations (9) and (11) simultaneously, yields

$$\mathfrak{L} \sim \frac{1}{(\mathfrak{T}\mathcal{S})^{0.9}} \quad (12)$$

Notably, the velocity, $\mathcal{S}$, is velocity of recession, implying it is a negative quantity. Hence, attaching a minus sign to $\mathcal{S}$, and rewriting equation (12) in terms of velocity only, gives

$$\mathfrak{L} \sim -\frac{1}{\mathcal{S}^{0.9}} \quad (13)$$

Noting that $\mathcal{S}$ is not an intrinsic velocity of the source, rather it is the rate at which the space-time expands. Therefore, the last equation suggests that the linear sizes, $\mathfrak{L}$, of the large extended doubles may be boosted by the accelerating expansion of the space-time. This should be expected because the sources' components are intergalactic; and the space-time expansion is actually brought about by dark energy (Ellis *et al.*1978; Padmanabhan 2002; Linder 2003; Riess 2020). Dark energy is expected to manifest more in the intergalactic medium because it is very much rarefied. So, equation (13) tells us that as long as the source components; namely, the jets and the lobes, are not held by gravity, the source linear sizes may scale up as more spaces are created in the intergalactic media.

2.2 $(\mathfrak{L} - \mathfrak{z})$ *Data For The More Compact Radio Galaxies*

Figure 4 shows $(\mathfrak{L} - \mathfrak{z})$ data for the more compact (CSS) radio galaxies in our sample. Results of the linear regression show that some marginal relationship exists between the source linear size and redshift (correlation coefficient, $r \approx 0.4$). However, assuming (just as before), that this marginal relationship is significant enough for the observed physical data, then the following expression for the scaled-down versions of radio galaxies is satisfied:

$$\mathrm{Log}\mathfrak{L} = -0.581 + 2.921\mathrm{Log}(1 + \mathfrak{z}) \quad (14)$$

Making $\mathfrak{L}$ subject, yields

$$\mathfrak{L} \sim (1 + \mathfrak{z})^{2.9} \quad (15)$$

It is easily noticeable that this is out of order with results obtained for the more extended radio galaxies (see equation (5)).

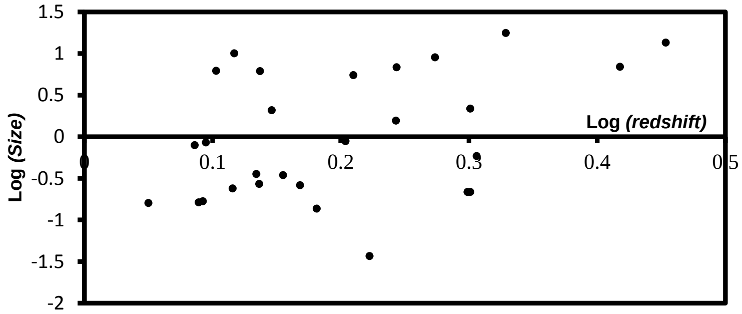

Fig. 4. The scatter plot of size versus redshift for the subgalactic radio galaxies

Now the question is 'what causes this disparity?' It is noted earlier that these two sub-classes of objects are embedded in different ambient media. So, their observable physical processes should not be expected to be exactly the same. Therefore, since the CSS sources are sub-galactic in dimensions, they are affected more by their denser ambient media. Moreover, gravity is more pronounced within a typical galaxy than within the intergalactic medium; so, space expansion is expected to yield little or no positive result in the CSS source growth.

Solving for $\mathfrak{L}$ in terms of cosmic time and cosmic expansion velocity just as it is done in the previous section, gives

$$\mathfrak{L} \sim -(\mathfrak{T}\mathcal{S})^{2.9} \qquad (16)$$

which shows that

$$\mathfrak{L} \sim -\mathcal{S}^{2.9} \qquad (17)$$

This suggestively shows that the observed ubiquitous cosmic expansion poses little or no effects on sizes of these scaled-down versions of the more extended doubles.

Discussion and Conclusion

The sources used in this work are two sub-classes of radio galaxies; and usually show similar properties as mentioned earlier on the radio maps, except on their observed sizes. The more extended radio galaxies are intergalactic while the more compact (CSS) radio galaxies are sub-galactic in dimensions. In this work, linear regression analyses of observed source linear sizes, $\mathfrak{L}$, and their corresponding observed redshifts, $\mathfrak{z}$, (Figure 3) of the more extended radio galaxies; as well as, those of the CSS radio galaxies (Figure 4) are carried out.

For the larger radio galaxies, correlation coefficient is ≈ 0.3. Assuming this marginal correlation is good enough for the observed physical data, especially in the field of astrophysics, the relation, $\mathfrak{L} \sim \mathfrak{z}^{-0.9}$, is obtained. Combining this result and Hubble's law, yields $\mathfrak{L} \sim -\left(\frac{\mathfrak{C}}{\mathcal{H}\mathfrak{X}}\right)^{0.9}$. This shows that observed linear size scales with source distance $(\mathfrak{X})$ as $\mathfrak{X}^{-0.9}$. Also, in terms of velocity of recession the relation, $\mathfrak{L} \sim -\frac{1}{\mathcal{S}^{0.9}}$, is obtained.

Here, it is noted that this velocity of recession is not propelled by intrinsic source kinetic energy; instead, it is brought about by creation of more spaces in the fabric of the space-time. Therefore, equation (13) proposes that the linear sizes of the large extended radio galaxies may possibly be boosted by the accelerating expansion of the space-time. This is expected because both the twin jets and lobes straddling the central cores of the extended sources used in our analyses are (i) intergalactic in dimensions, with linear sizes, $\mathfrak{L} \geq 60kpc$ (Readhead 1995; Robson 1996; Ezeugo 2021a); and (ii) not gravitating about each other and about the central core; instead, the jets and lobes are receding from the central core (Readhead 1995; Robson 1996; Ezeugo 2021a). An implication of these is that since these components are not held by gravity and are located in the intergalactic media (which are very much rarefied), the source linear size (defined by the distance between the ends of the two lobes; see Fig.1) are likely to be boosted by the creation of more spaces in the intergalactic media which drives the observed accelerating expansion of the universe.

The cosmic expansion is actually brought about by dark energy – it is an intrinsic property of the space-time (Ellis, Maarteens and Nel 1978; Padmanabhan 2002; Linder 2003; Riess 2020). Effects of dark energy are expected to manifest most in the intergalactic media because they are among the most rarefied environments in the universe. So, equation (13) tells us that as long as the source components; namely, the jets and the lobes, are not held by gravitational pull, the source size is scaled up as more spaces appear in the intergalactic media.

$(\mathfrak{L} - \mathfrak{z})$ data (Figure 4) for the sub-galactic versions in our sample lists are also obtained. Results of the linear regression show that some border-line correlation exists between the source linear size and redshift ($r \approx 0.4$). Assuming just as before, that this marginal relationship is adequate for the observed physical data, the expression, $\mathfrak{L} \sim (1 + \mathfrak{z})^{2.9}$, is obtained. However, it is visible that this is not in agreement with the result obtained for the more extended radio galaxies.

This inconsistency must have originated from the surrounding media in which these compact sources are domiciled, since the two sub-classes of radio galaxies have been shown to be situated in different ambient media (Ezeugo and Ubachukwu 2010). So, their observable physical processes should not be expected to be just the same as mentioned earlier. Therefore, since the CSS sources are sub-galactic in dimensions (linear sizes are below $30kpc$), they are affected more by their denser ambient gases (Ezeugo and Ubachukwu 2010; O'Dea 1998; Fanti C, *et al.*, 1995). Also, gravity is more conspicuous within a typical galaxy (diameter of a typical galaxy is roughly $30kpc$) than within the intergalactic medium; so, cosmic expansion should predictably yield little or no positive result in enhancement of the CSS source dynamical growth. This is shown in the expression, $\mathfrak{L} \sim -\mathcal{S}^{2.9}$; and demonstrates that the observed universal cosmic expansion has little or no effects on these sub-galactic radio galaxies. However, it boosts the dimensions of the more extended radio galaxies according to the relation, $\mathfrak{L} \sim -\frac{1}{\mathcal{S}^{0.9}}$. Moreover, from the indices of the two results (equations (13) and (17)), it may be concluded that cosmic expansion plausibly influences the dimensions of the large extended radio galaxies more than it does to the compact ones by a factor of 1.3.

References

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.

Ellis G.F.R, Maarteens R., and Nel S.D. (1978). The Expansion of the Universe. Monthly Notices of the Royal Astronomical Society. 184, 439–465.

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

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.

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

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.

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.

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.

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

Hardcastle W.L., Williams W.L., 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.

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

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

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.

Linder E.V. (2003). Exploring the Expansion History of the Universe. Physical Review. 90 (9), 091301.

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

Mingo B., Croston J.H., 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.

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

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.

Padmanabhan T. (2002). Accelerating Expansion of the Universe driven by Tachyonic Matter. Physical Review. D 66 (2), 021301.

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.

Riess A.G. (2020). The Expansion of the Universe is Faster than Expected. Nature Reviews. 2(1), 10-20.

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

Rubin D. and Hayden B. (2016). Is the Expansion of the Universe Accelerating? All Signs Point to Yes. The Astrophysical Journal Letters. 833 (2), L30.

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

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