Original Research Article

Radio-Loud Quasars and Expansion of Universal Space-time

ABSTRACT

We have employed both analytical methods and statistical methods to find possible constraints that may be imposed by the observed accelerated expansion of the space-time on radio-loud quasars. We have done this by carrying out linear regression analysis on large-sized (linear size, $D > 30\,kpc$) quasars and on their smaller (more compact) (linear size, $D < 30\,kpc$) counterparts in our sample. On the linear size/redshift plane for the larger quasars, we find that these sources expand as space-time expands. Though they show similar trend on the $(D - z)$ plot, their more compact counterparts however, indicate difference in their gradient. The result of the more compact sources shows steeper slope (2.3), while that of the more extended sources indicates a flatter slope (1.5).This discrepancy must have originated from the ambient environments in which they are sited since the two sub-classes of objects have been shown to be situated in different ambient media. So, their observable physical processes should not be expected to be precisely the same. Therefore, since the compact sources are generally sub-galactic in dimensions (i.e. linear sizes are below $30kpc$), they are affected more by their denser ambient media. Also, gravity is more noticeable within a typical galaxy (and diameter of a typical galaxy is about $30kpc$) than within the intergalactic medium; so, space expansion should unsurprisingly yield little or null effect on the evolution of these compact sources. This is shown in our obtained relation, $D{\sim}\dot{R}^{-2.3}$. It indicates that the observed universal space-time expansion causes little or no effects on the sizes of these more compact quasars, and hence, their evolution is largely dynamical; while the converse may be the case for the more extended quasars.Conclusively, we state that large-sized radio-loud quasars are intergalactic which implies they are neither held by gravity nor dense media, but more possibly affected by creation of more spaces due to dark energy accelerating expansion of the universe. In contrast with it, Compact Steep Spectrum (CSS) quasars which are generally sub-galactic possibly get affected by denser ambient gases and gravity within CSS quasars, have little or no effect on source growth by dark energy.

Keywords**:** Dark energy, expansion, extragalactic, evolution, linear size, quasars, radio sources, space-time

1. INTRODUCTION

1.1. Accelerating Expansion of the Space-time

Observationally, it has been shown that the universe is undergoing accelerating expansion. This was first pointed out by Edwin Hubble in 1929; even though, he did not fully understand the physical significance of his findings at the time. He was able to find a linear relationship between the velocity, $\dot{R}$, of recession of a galaxy and its distance, R. The equation is stated as

$$\dot{R} = HR \tag{1}$$

where H is Hubble parameter. Afterward, it was found through observation of Type 1A supernovae that these galaxies were actually accelerating away from one another; indicating that the universe is undergoing rapid expansion. Observation of cosmic microwave background anisotropy is another evidence of rapid expansion of the universe. Furthermore, use of voids and super-voids as standard rulers for measuring astronomical distances plausibly indicate that the universe is expanding rapidly [1-4].

Equation (1) simply states that if the velocity of a galaxy at distance, R_1, is $\dot{R}_1$ at that time, t_1; then at another distance, $R_2 > R_1$, and time, $t_2 > t_1$, the velocity will be $\dot{R}_2 > \dot{R}_1$. Hence, acceleration, $\ddot{R}$, becomes

$$\ddot{R} = (\dot{R}_2 - \dot{R}_1)(t_2 - t_1)^{-1} = \frac{\nabla \dot{R}}{\nabla t} \tag{2}$$

This shows that Hubble's law predicts accelerating expansion.

Besides, this acceleration is believed not to have been caused by the respective galactic dynamics of the galaxies; but, by the stuff of the space-time in which these galaxies are entrenched. This simply means that the space-time is undergoing expansion; and this makes all the galaxies appear as if they are individually withdrawing from each another. The energy in the substance of the free-space (or vacuum) which causes this expansion has been referred to by authors as dark energy. It has been plausibly assumed to be an essential property of the space-time. However, as it is now, very little is known about dark energy [1-4].

Two major models authors have used to explain dark energy include: cosmological constant, and quintessence. In 1917 Albert Einstein, in ad hoc consideration, attached cosmological constant to his mathematical relations in order to delineate his assumed static universe. During that time, expansion of the universe had not been discovered. He simply introduced the constant to ensure equilibrium state required for a static universe. Though he regretted his action, scientists later found the constant important in accounting for the observed universe expansion. As is understood in the now, cosmological constant, Λ, is constant ubiquitously in the universe at any time; and hence, supports the concept of dark energy – whose energy density has been observed to be constant as the universe undergoes rapid expansion. Actually, present observed data indicate that dark energy density is about $68\% - 73\%$ of the total energy density of the universe. The rest is composed of baryonic matter density, dark matter density, and energy density [1-4].

As the space expands with time, dark energy density remains constant while other forms of energy densities diminish in values. Fig. 1 is a diagrammatic sketch which shows that as dark energy density (dashed red horizontal line) remains stable in magnitude while the universe undergoes rapid expansion, other forms of energy densities (dotted green curved line) suffer decay in their magnitudes. This simply implies that as contribution to the total energy density by baryonic matter, dark matter, and energy decrease as the universe expands, the contribution made by dark energy automatically increases. Obviously, this means that the universe plausibly is expected to undergo indefinite continuous rapid expansion. This is true because the dark energy which causes the expansion will continue to overcome every possible dilution/opposition effects that may be posed by the matter-dominated energy densities.

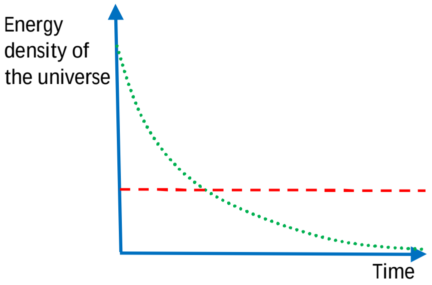

Fig. 1.Schematics (not to scale) comparing dark energy density and other densities (e.g. baryonic matter, dark matter, and energy). Dashed red horizontal line represents dark energy density; while dotted green curved line represents total density contributed by other entities. Source: The authors.

On the other hand, quintessence is a theoretical concept in which some dynamic field (scalar field) is assumed or believed to drive the observed accelerating expansion of the space-time. It varies in space and time in contrast to the cosmological constant, and must be light. Some scientists have suggested that quintessence could be the fifth fundamental force of interaction in the universe [1-4].

1.2. Quasars and Extragalactic Radio Sources

Usually, all extragalactic radio sources produce abundant radio radiation. They produce high percentage of radio to optical emission – generally given as [5–9]

$$\frac{S_{5\ GHz}}{S_{6\times10^5 GHz}} > 1 \tag{3}$$

where$S_{5\ GHz}$ is flux density at radio frequency; while $S_{6\times10^5 GHz}$ is flux density at optical frequency. They are situated far beyond the frontiers of our home galaxy – the Milky Way. Two main classes of extragalactic radio sources are radio galaxies and radio-loud quasars [8-9]. This classification is based on their structures on the radio maps. Moreover, based on their observed linear sizes, there are the large extended sources whose linear sizes, $D > 30kpc$; and their miniaturized/compact counterparts whose linear sizes are mostly well below $30kpc$. The latter are referred to as the compact steep spectrum (CSS) quasars [9-10]. While the sizes of the extended sources are inter-galactic, those of the CSS quasars are sub-galactic. This simply implies that these compact radio-loud quasars could suffer more drag than their large extended counterparts; as well as, overwhelmed more by their individual host galactic gravitational pull. The two aforementioned factors are expected to constrain their individual expansions. Hence, some observed physical properties of these two sub-classes of radio-loud quasars should probably differ.

On their radio maps, a typical structure of these two classes of quasars takes the form of two-opposite-sided relativistic radio-emitting jets that connect the base of the accretion disk to two radio-emitting lobes that are situated on both sides of the central component that is more or less coincident with the nucleus (or the central core) of the host galaxy [8, 11–12] (see figure 2). Usually, in some sources, the lobes may contain hotspots believed to be the destination points of the jets [8, 12–14].

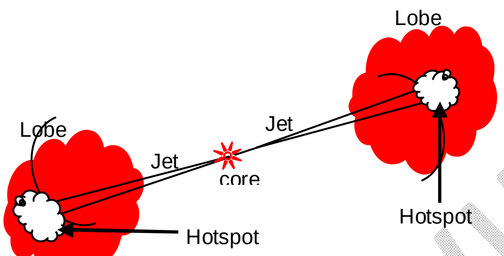

Fig. 2. The structure of a typical extragalactic radio source.
Source: The authors

On the other hand the more extended radio-loud quasars have linear sizes, D, greater than 30 Kpc if Hubble constant is assumed to be 75 $kms^{-1}Mpc^{-1}$. In all cases, their linear sizes extend into intergalactic media. It has been observed that their radio luminosity is in excess of $10^{26}W$ at $5GHz$ frequency; while, values of their overall luminosities start from $10^{37}W$. It is good to note that these values of luminosities arein consonance with the more compact quasars [8–16].

It is well pointed out by scientists that jet presence in the extragalactic sources simply signifies presence of tenuous ambient media [13-20]. In addition, a number of hydrodynamic computer simulations of jet propagations have been carried out to ascertain their properties [17–24]. Of course, results of these simulations indicate that masses of the jet materials are smaller than those of the external media. In addition, Ezeugo J.C. and Ubachukwu A.A. [15] created a mathematical model for evolution of the more compact sources and used the result to estimate their ambient densities.

The purpose of this work is to find out whether there is any influence imposed by space-time expansion on the sizes of quasars in our samples. These samples are of two groups – the large extended quasars (170 in number) selected from Nilsson 1998 [25], and 31 more compact quasars (i.e. the CSS quasars) obtained for O'Dea 1998 [16]. Observed linear sizes of the more extended quasars are greater than $30kpc$; while those of the more compact quasars are well below 30kpc.

2. DATA ANALYSES

2.1. SIZE/REDSHIFT RELATIONFOR THE EXTENDED RADIO-LOUD QUASARS

We carry out linear regression analysis of observed source linear sizes, D, of the quasars and their corresponding observed redshifts, z, (Figures 3) in our sample.

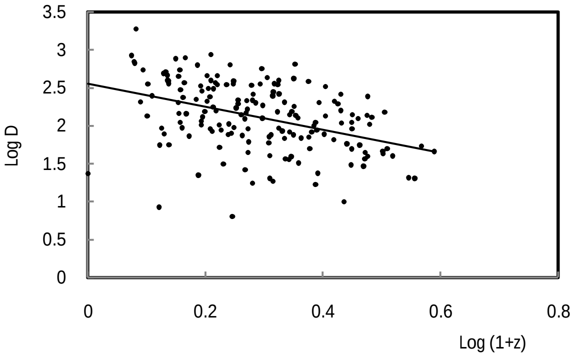

Fig. 3. The scatter plot of source observed linear sizes against observed redshifts for the more extended quasars

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

$$\mathrm{Log}D = 2.562 - 1.522\mathrm{Log}(1 + \mathrm{z}) \tag{4}$$

The correlation is appreciable (correlation coefficient, $r = 0.41$); hence, equation (4) may be transformed to be

$$D \sim z^{-1.5} \tag{5}$$

Generally, the redshift relation with source velocity of recession is written by

$$z = \frac{\dot{R}}{c} \tag{6}$$

where$c$ is speed of light. Combining equations (1) and (6) gives

$$z = \frac{HR}{c} \tag{7}$$

Therefore, equation (5) becomes

$$D \sim \left(\frac{c}{HR}\right)^{1.5} \tag{8}$$

In terms of R only, the last equation becomes

$$D \sim \frac{1}{R^{1.5}} \tag{9}$$

This shows that the observed linear size scales as $R^{-1.5}$; and we have already define R as distance between the observer and the source.

In terms of time, we have from equation (1),

$$H = \frac{\dot{R}}{R} \tag{10}$$

which becomes

$$t = \frac{R}{\dot{R}} \tag{11}$$

$t$is time. Solving equations (9) and (11) simultaneously, we obtain

$$D \sim \frac{1}{\left(t\dot{R}\right)^{1.5}} \tag{12}$$

which shows that

$$D \sim \frac{1}{\dot{R}^{1.5}} \tag{13}$$

The mechanism that brings about this velocity,$\dot{R}$, is not from the quasar itself, instead, it originates from the space-time. Therefore, equation (13) suggests that the linear sizes, D, of the large extended radio-loud quasars are affected by the accelerated expansion of the space-time. We expect this since the sources' components (jets and lobes) are located in the intergalactic media where particle number densities and gravitational effects are minimal. The space-time expansion is actually caused by dark energy and effects of dark energy are expected to manifest more in the intergalactic media. So, equation (13) states that as long as the source components are not held by gravity, the source linear sizes in intergalactic media are possibly affected as more spaces pop up in the media.

2.2. SIZE/REDSHIFT RELATION FOR CSS QUASARS

Furthermore, we carry out linear regression on linear size and redshift for the more compact (CSS) quasars in our sample (Figure 4).

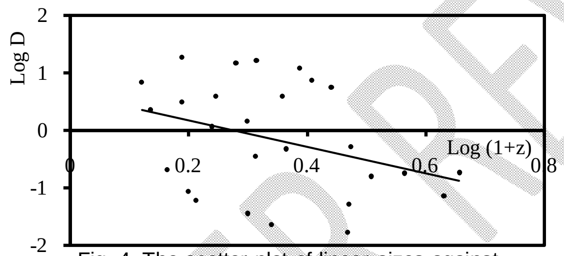

Fig. 4. The scatter plot of linear sizes against redshifts for the more compact quasars

The following relation is obtained:

$$\mathrm{Log}D = -2.301\mathrm{Log}(1 + z) + 0.637 \qquad (14)$$

with correlation coefficient,0.4. Even though the correlation is marginal, if we assume it is good enough for observed physical parameters such as those in the field of astronomy, we may transform equation (14) to obtain

$$D \sim z^{-2.3} \qquad (15)$$

We notice that this is in order with result obtained for the more extended quasars (see equation (5)); except it shows steeper slope.

The question now is,'what must have triggered off this discrepancy'. We have mentioned previously that these two sub-classes of quasars are situated in different surroundings. So, their observable physical phenomena should not be expected to be exactly the same. Therefore, since the sizes of these compact quasars show that they are embedded in their respective galaxies, they are affected more by denser ambient media than their more extended counterparts. Also, gravitational attraction is felt more inside a galaxy than outside it. Therefore, we expect space expansion to exert little or no influence on the source evolution.

We obtain D in terms of time and space expansion velocity just as we did in the previous section, and have

$$D \sim \frac{1}{\left(t\dot{R}\right)^{2.3}} \tag{16}$$

This shows that

$$D \sim \frac{1}{\dot{R}^{2.3}} \tag{17}$$

In comparison with equation (13), equation (17) states that if there are effects of the observed space-time expansion on CSS quasars, they may be smaller than the effects on the larger quasars.

3. DISCUSSION OF RESULTS AND CONCLUSION

We have tried to find (if any) effects imposed on the size evolution of extragalactic radio-loud quasars by the observed expansion of the space-time. We use two sub-classes of extragalactic radio-loud quasars; and usually they show similar properties, as mentioned earlier, on the radio maps except on their observed sizes. The more extended radio-loud quasars are intergalactic while the more compact (CSS) ones are sub-galactic in sizes. We have carried out linear regression analyses of observed source linear sizes, D,and their corresponding observed redshifts, z,(Figures 3) of the more extended radio-loud quasars; as well as those of the CSS quasars (Figure 4) in our sample.

For the larger quasars, correlation coefficient, r,shows $r \approx 0.4$. If we assume this correlationis considerably enough for the observed physical data, especially in the field of astronomy, we will have the following relation, $D \sim z^{-1.5}$. Combining this result and Hubble's law yields $D \sim \left(\frac{c}{HR}\right)^{1.5}$ (see equation (8)). This shows that observed linear size increases with source distance (R)as $R^{-1.5}$. Also, in terms of velocity of recession, we obtain $D \sim \frac{1}{\dot{R}^{1.5}}$ (i.e. equation (13)).

Here, we need to understand 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) states that the linear sizes of the larger quasars may be affected by the accelerated expansion of the space-time. We expect this because both the radio-emitting jets and lobes straddling the central core of a typical extended radio-loud quasars are (i) intergalactic in dimensions [11-12,18]; and (ii) not gravitating about each other and about the central engine/core [11-12,18]. An implication of these is that since these components are not held by gravity and are located in the intergalactic medium, the source linear size (defined by the distance between the ends of the two lobes; (Fig. 2)) are likely to be affected by the creation of more spaces in the intergalactic media which drives the observed accelerated expansion of the universe.

The space-time expansion is actually brought about by dark energy [1-4]. Effects of dark energy are expected to manifest most in the intergalactic media because they are 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 gravity, the source linear sizes are affected as more spaces are created in the intergalactic media.

We also obtain $D - z$ data (Figures 4) for the more compact (CSS) radio-loud quasars in our sample. Results of the linear regression show that some borderline correlation exists between the source linear size and redshift ($r \approx 0.4$). If we assume just as before, that this marginal relationship is substantial enough for the observed physical data, we may have the expression, $D \sim (1 + z)^{-2.3}$ (i.e. equation (15)). We notice that this result is in harmony with result obtained for the more extended quasars (see equation (5)); except that the result of the larger quasars shows flatter slope.

This discrepancy must have originated from the nature of the ambient environments in which they are sited, since the two sub-classes of objects have been shown to be situated in different ambient media [15]. So, their observable physical processes should not be expected to be precisely the same. Therefore since the CSS quasars are generally sub-galactic in dimensions (i.e. linear sizes are below $30kpc$), they are affected more by their denser ambient gases [15-17]. Also, gravity is more noticeable within a typical galaxy (diameter of a typical galaxy is $30kpc$) than within the intergalactic medium; so, space expansion should unsurprisingly yield little or no effect on the source growth. This is shown in the relation, $D{\sim}\dot{R}^{-2.3}$ (i.e. equation (17)). This suggestively establishes that the observed universal space-time expansion causes little or no effects on size evolution of these CSS quasars; whereas it shows more profound effects on that of their more extended counterparts according to the relation, $D{\sim}\dot{R}^{-1.5}$.

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