*Original Research Article*

Universal Space-time Accelerated Expansion and Luminosities of Some Extragalactic Radio Sources

**Abstract**

We have used both analytical methods and statistical methods to find if there is anypossible effect of observedspace-time expansion on some extragalactic sources – the radio-loud quasars.This is done by carrying out linear regression analysis on larger radio-loud quasars and on smaller radio-loud quasars.On the luminosity$\left(P\right)$/redshift$\left(z\right)$ plane for the more extendedquasars, we find that the luminosities of these sources are attenuated as space-time expansion proceeds.Though their more compact counterparts show similar trend on the $\left(P-z\right)$ plot, however, they indicate dissimilarity in their gradient.The result of the more compact sources shows steeper slope $\left(4.33\right)$, while that of the more extended sourcesindicates a flatter slope $\left(0.04\right)$. This indicates that the more compact quasars have higher luminosities at earlier epoch than the more extended quasars.This disagreement must have originated from the ambient environments in which they are located, 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 more compactquasars are generally sub-galactic in dimensions, they are affected more by their denser ambient gases; as well as the gravitational pull within the galaxies they are residing. This is not the case with the intergalactic media. In this medium, ambient density is very much smaller than that of the interstellar medium; and the components (jets and lobes) are not held by gravitational pull, so, space expansion should unsurprisingly attenuate the luminosities of the more extended radio-loud quasars. This is shown in the obtained relation, $P\~-v^{4.33}$. The results simply establishes that the observed universal space-time expansion may pose a threat to the luminosities of the more extended radio-loud quasars.If this is true, the implication is that photons in the intergalactic media would suffer more delay in their propagation as ‘elements of space-time’ pop in between them.

(Keywords: space-time, linear size, quasars, luminosity,radio sources, extragalactic, expansion)

**1. Introduction**

**1.1 Space-time Expansion**

Based on observations, it has beenfound that the universe is undergoing cosmic expansion. It was first found by Edwin Hubble in 1929. He found a direct positive linear relationship between the velocities with which galaxies recede from each other and their distances of separation. As standard candles (cosmic objects with high and constant luminosity), the Type 1A supernovae have been used to measure distances. Matching their distances with their redshifts indicates that galaxies are actually accelerating away from one another; hence, indicating that the size of the universe is expanding rapidly. Another evidence of accelerated expansion of the universe is from observation of the cosmic microwave background anisotropy. Also, use of voids and super-voids as standard rulers for measuring cosmic distances shows that the universe is expanding with acceleration [1-4]. This lastapproach is quite different from the previously mentioned evidences; and hence, confirms accelerating expansion of the universe.

Mathematically, Hubble’s law is expressed as $v=Hr$; where $v$ is velocity of recession of galaxy, $r$ distance to the galaxy, and $H$ Hubble’s constant. The relation suggests that if the velocity of a galaxy at distance, $r\_{1}$, is $v\_{1}$ at time $t\_{1}$; thenat distance, $r\_{2}>r\_{1}$, and time, $t\_{2}>t\_{1}$, the velocity will be $v\_{2}>v\_{1}$. Hence, acceleration, $a$, becomes, $a={\left(v\_{2}-v\_{1}\right)}/{\left(t\_{2}-t\_{1}\right)}={∆v}/{∆t}$. This shows that Hubble’s law predicts accelerated expansion.

Furthermore, it has been pointed out by authors that this acceleration is not brought about by the individual galactic dynamics; but rather, by the fabric of the space-time in which these galaxies arelocated. This simply means that the space-time is undergoing expansion; and this makes all the galaxies appear as if they are individually receding from one another. The energy in the space-time which causes this expansion has been referred to as dark energy. It has been taken to be an intrinsic property of the space-time. Very little is known about dark energy [1-4].

Some modelsintroduced inorder to explain dark energy include: cosmological constant, andquintessence. It was Albert Einstein (1917), who attached cosmological constant to his equations for describing his assumed static universe.There was no mathematical proof for attaching it, and it had not been discovered that the universe was expanding at the time.He only introduced the constant to ensure equilibrium state required for a static universe. Though he felt sorry introducing the constant, authors later found the constant important in the observed universe expansion. As is understood in the now, $Λ$ 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 [27]. In fact, current observations show about $68\%-73\%$ percentage composition of the total energy density of the universe is dark energy; while the rest is composed of baryonic matter density, dark matter density, and electromagnetic radiation energy density [1-4]. Fig. 1 shows a pie chart for the total energy density of the universe. Blue sector represents dark energy density $\left(72\%\right)$, Brick-red represents dark matter $\left(23\%\right)$, and green sector represents baryonic matter/atoms $\left(4.6\%\right)$; while the remaining $\left(0.4\%\right)$ represents the density contribution by other entities not mentioned in the pie chart.

Moreover, it has been found that dark energy density remains constant while others decrease in value due to the accelerated expansion of the universe over time (see Fig. 2).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 by dark energy automatically increases. Of course, the implication is that the universe will continue to undergo accelerated expansion indefinitely, since dark energy which causes the expansion will continue to overcome possible dilution effects that may originate from matter-dominated energy densities.

**Fig. 2:**Schematics (not to scale) comparing dark energy density and other densities (e.g. baryonic matter, dark matter, and energy). Dashed horizontal line represents dark energy; while dotted curved line represents total density contributed by other entities.

Energy density of the universe

Time

Quintessence, on the other hand, is a theoretical framework in which some dynamic field is believed to drive the observed accelerated expansion of the universe. It varies in space and time, and must be light [1-4].The prominent difference between quintessence and cosmological constant is that while the former is dynamic, the latter remains constant.

**1.2 Extragalactic Radio Sources and Quasars**

Extragalactic radio sources (EGRS) emitample amount of radio waves. These sources exhibit high percentage of radio to optical emission. The ratio is generallydefined by${S\_{5 GHz}}/{S\_{6×10^{5}GHz}}>1$; where$S\_{5 GHz}$ and $S\_{6×10^{5}GHz}$ are flux densities at radio and optical wavelengths respectively [5–9]. They are sitedoutside the boundaries of the Milky Way, our galaxy. Based on their morphologies, the main sub-classes of these objects include: radio galaxies and radio-loud quasars[8–9]. Also based on their observed linear sizes, we have the large extended sources whose linear sizes, $D>30kpc$; and their miniaturized counterparts whose linear sizes are mostly well below $30kpc$. The latter are referred to as the compact steep spectrum (CSS) sources. While the sizes of the extended sources are intergalactic, those of the CSS sources are sub-galactic. This simply implies that the CSS sources suffer more drag than their large extended counterparts. 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 two 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 core) of the host galaxy [8, 11–12] (see figure 3). In some sources, the lobes contain hotspots believed to be the termination points of the jets [8, 12–14].

**Hotspot**

**Hotspot**

Figure 3: The structure of a typical EGRS.

Source: Authors

**core**

**Lobe**

**Lobe**

**Jet**

**Jet**

The more extended sources 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 jut into intergalactic media. It has been observed that their radio luminosity is in excess of$10^{26} W$at$ 5 GHz$ frequency; while, values of their overall luminosities range from $10^{37}W$ which are in common with the more compact versions [8–16].

Itis well noted by authors that a significance of jet presence in radio sources is simply anindication of tenuous ambient media [13-18]. Hence, a number of hydrodynamic computer simulations of jet propagations have been performed for theirphenomenology [17–25]. Results of these simulations indicate that the jet materials have smaller masses than those of thesurrounding media. In addition, Ezeugo and Ubachukwu[15] created a mathematical model for evolution of the CSS sources and used the result to estimate their ambient densities.

In this work, we use both analytical methods and statistical methods to find possible effects of observed space-time expansion on some extragalactic sources; namely, the radio-loudquasars.These samples are of two groups – the extended quasars (170 in number) selected from Nilsson 1998 [26], and 27 smaller sources (i.e. the CSS quasars) obtained for O’Dea 1998 [16].

**2.1.LUMINOSITY/REDSHIFT RELATIONFOR THE MORE EXTENDED QUASARS**

We carry out linear regression analysis of observed source luminosity, $P,$ of the more extended quasars and their corresponding observed redshifts, $z,$ (Figures 4) in our sample. Result shows that

$$Log P=0.039Log \left(1+z\right)+1.637 (1)$$

The correlation coefficient, $r=0.8 $is good. Transforming the equation, we obtain

$$P\~z^{0.04} (2)$$

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

Hubble’s law states that velocity of recession, $v$, linearly relates with source distance, $r$, as

$$v=Hr (3)$$

$H$ is Hubble parameter. Also, the redshift relation with source velocity of recession is written by

$$z=\frac{v}{c} (4)$$

where$ c$ is speed of light and $z$, redshift. Combining equations (3) and (4) gives

$$z=\frac{Hr}{c} (5)$$

Therefore, equation (2) becomes

$$P\~\left(\frac{Hr}{c}\right)^{0.04} (6)$$

In terms of $r$, the last equation becomes

$$P\~r^{0.04} (7)$$

That is the observed linear size scales as $r^{0.04}$; where we have already define $r$ as distance to the source.

In terms of time, we have from equation (3),

$$H=\frac{v}{r} (8)$$

which becomes

$$t=\frac{r}{v} (9)$$

$t $is time. Solving equations (7) and (9) simultaneously, we obtain

$$P\~\left(tv\right)^{0.04} (10)$$

Since the object recedes from us, we attach a minus sign to the velocity of recession, $v$, to obtain

$$P\~-v^{0.04} (11)$$

We remember that $v$ is not an intrinsic velocity of the source, rather it is the rate of expansion of the space-time in the intergalactic media. Therefore, the last equation suggests thatthe source luminosity, $P$, of the large extended quasarsareattenuated by the accelerated 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. Effects of dark energy is expected to manifest more in the intergalactic media. So, equation (11) tells us that as long as the source components; namely, the jets and the lobes are not held by gravity, the source luminosities are weakened as more spaces are created in the intergalactic media.

2.2. LUMINOSITY/REDSHIFT RELATION FOR CSS QUASARS

We also obtain $P-z$ data (Figure 5) for the CSS quasars in our sample.

In addition to the foregoing, we carry out linear regression of $P/z$ data for the CSS quasars (Figure 5). We obtain a relation given by

$$Log P=4.328Log \left(1+z\right)+26.46 (12)$$

(with good correlation coefficient given by $r=0.8$). Transforming the equation, we obtain

$$P\~z^{4.33}\left(13\right)$$

We notice that this is inconsonance with the result obtained for the more extended quasars (see equation (2)); except thatthe result of the CSS quasars shows steeper slope$\left(4.33\right)$, while the result of the more extended quasars indicates a flatter slope $\left(0.04\right)$.

We ask ourselves what must have caused this disagreement. We 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.Also, 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 source luminosity for a source located within a galactic perimeter.

Solving for $P$ in terms of time and space expansion velocity just as we did in the previous section, we obtain

$$P\~\left(tv\right)^{4.33} (14)$$

which shows that

$$P\~-v^{4.33} (15)$$

This suggestively shows that the effects of the observed space-time expansion on CSS quasars are smaller than the effects on the larger quasars.This may be the reason why CSS sources tend to show higher luminosities than their more extended counterparts.

**3. DISCUSSION AND CONCLUSION**

The sources used in this work are two sub-classes of extragalactic objects; 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) radio-loud quasars are sub-galactic in dimensions.In this work, we have carried out linear regression analyses of observed source linear sizes, $D,$and their corresponding observed redshifts, $z,$(Figure 4)of the more extended radio-loudquasars; as well as, those of the CSS radio-loud quasars (Figure 5).

For the larger quasars, correlation coefficient, $r,$shows$r≈0.8$, and is very good. Therefore, we have the relation, $P\~z^{0.04}$ (i.e. equation 2). Combining this result and Hubble’s law yields$P\~-\left(\frac{Hr}{c}\right)^{0.04}$ (i.e. equation 6). This shows that observed source luminosity scales with source distance $\left(r\right)$as $-r^{0.04}$. Also, in terms of velocity of recession, we obtain$P\~-v^{0.04}$ (i.e. equation 11). We have attached a minus sign to the expressions to indicate that the object is receding from us.

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 space-time. Therefore, equation (11) states that the luminosities of the larger quasars are decreased 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; and (ii) are not gravitating about each other and about the central engine. An implication of these is that since these components are not held by gravity and are located in the intergalactic medium, the source luminosity are expected to be attenuated by the creation of more spaces in the same intergalactic media which drives the observed accelerated expansion of the universe.

Dark energy is the culprit driving accelerated expansion of the space. Effects of dark energy are expected to manifest mostly in the intergalactic media because they are the most rarefied environments in the universe. So, equation (11) tells us that as long as the source components; namely, the jets and the lobes are not held by gravity, the source luminosities are diminished as more spaces are created in the intergalactic media.

We also obtain $D-z$ data (Figures 5) for the more compact (CSS) radio-loudquasars in our sample.Result of the linear regression showsgood correlation with coefficient given as$ 0.8$. Result indicates that luminosity $\left(P\right)$ and redshift$\left(z\right)$ relates according to the equation,$P\~z^{4.33}$(i.e. equation 13). We notice that this result is in harmony with result obtained for the more extended quasars (see equation 2); except that the result for the CSS quasars shows steeper slope $\left(4.33\right)$, while that forthe more extended quasars shows a flatter slope $\left(0.04\right)$. This indicates that CSS quasars tend to shine as much as (or sometimes may outshine) the larger quasars.

This disagreement must have originated from the ambient environments in which they are located, 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 sources are generally sub-galactic in dimensions (i.e. linear sizes are below $30kpc$), they are affected more by their denser ambient gases; as well as the gravitational pull within the galaxies they are residing. This is not the case with the intergalactic media. In this medium, ambient density is very much smaller than that of the interstellar medium; and the components (jets and lobes) are not held by gravitational pull,so, space expansion should unsurprisingly attenuate the luminosities of the larger quasars. This is shown in the relation, $P\~-v^{4.33}$ (i.e. equation 15). Theresults establishes that the observed universal space-time expansion may posea threat to the luminosities of the more extended radio-loud quasars.A plausible implication is that photons in the intergalactic media suffer delay in their propagation as ‘elements of space-time’pop in between the photons as they propagate.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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