Are Luminosities of Radio Galaxies affected by Dark Energy?

**Abstract**

Dark energy is an intrinsic property of the space-time. At astronomical distances, it is the energy strongly believed to be driving the observed accelerated expansion of the space-time or the universe as whole. Analytical and statistical methods have been used in this work to find possible effect(s) (if any) of this observed space-time expansion on radio galaxies. This is done by carrying out simple linear regression analyses on some larger (or the more extended radio galaxies), and on some smaller (or the more compact radio galaxies).The two plots show good correlations. The result of the more compact sources shows a direct power-law function, while that of the more extended sources indicates an inverse power-law function. We noted that this disagreement must have originated from the ambient environments in which the two subclasses of objects are domiciled. Since they have been shown to be situated in different ambient media, their observable physical processes should not be expected to be exactly the same. Therefore, since the more compact radio galaxies are generally sub-galactic in dimensions, they are affected more by their denser ambient gases and interstellar gravitational pull. In contrast to this, the components of larger radio galaxies are located in the intergalactic media where there is insufficient gravitational pull and little amounts of dust particles. Hence, space expansion should naturally be expected to affect the luminosities of the larger radio galaxies. This is shown in the obtained relation, $L\~-\dot{R}^{-0.9}$; where $\dot{R}$ is source velocity of recession, and $L$ is source luminosity. The result simply shows that the observed universal space-time expansion may affect the luminosities of the more extended radio galaxies. Moreover, comparing the two results obtained ($L\~-\dot{R}^{-0.9}$ for the larger radio galaxies, and $L\~-\dot{R}^{0.096}$ for the more compact radio galaxies), we find that if we assume little or no effect of the observed space-time expansion on CSS galaxies, the effect is much more appreciable on the larger radio galaxies. Using the two results, the effect is estimated to be about 10 times more on the luminosities of the larger sources than on those of the smaller sources.

(Keywords: Dark energy, space-time, linear size, luminosity, radio galaxies, extragalactic, expansion)

**1. Introduction**

**1.1 Dark Energy**

Universe expansion was first pointed out by Edwin Hubble in 1929. He discovered that when he found a direct linear relationship between velocities of the galaxies and distances to the galaxies. The equation is as follows:

$$\dot{R}=HR (1)$$

Here, $\dot{R}$ represents velocity of a galaxy; which is generally referred to as velocity of recession of the galaxy. $H$ is Hubble’s parameter, and $R$ is the distance to the galaxy. The physical significance of this equation may be seen from what follows:

Equation (1) suggests that if the velocity of a galaxy at distance, $R\_{1}$, is $\dot{R}\_{1}$ at the time, $T\_{1}$; then at distance, $R\_{2}$ (where $R\_{2}$ is greater than $R\_{1}$), and time, $T\_{2}$ (where $T\_{2}$ is greater than $T\_{1}$), the new velocity, $\dot{R}\_{2}$ will be greater than $\dot{R}\_{1}$. Therefore, we obtain

$$\frac{\dot{R}\_{2}-\dot{R}\_{1}}{T\_{2}-T\_{1}}=\ddot{R} (2)$$

where $\ddot{R}$ is recognized as acceleration. This implies that Hubble’s law predicts accelerating expansion of the universe.

Moreover, by observation of type 1A supernovae, it was observed that the galaxies are receding with acceleration from each other; which shows that the universe is suffering from rapid expansion. Observation of the cosmic microwave background anisotropy has supported this phenomenon. Another independent method which supports this expansion entails the use of voids and super-voids as standard rulers for measuring cosmic distances [1-4].

Many authors have suggested, with some observational supports, that recession of galaxies is not brought about by the individual galactic kinematics/dynamics; rather, the recession is the result of creation of more spaces in the fabric of the space-time [27]. This means that when the volume of space increases, the distances between the galaxies embedded in the space increases too. The name ‘Dark Energy’, has been introduced to account for the energy in the space-time which generates more spaces thereby triggering off the observed accelerated expansion. The energy is believed to be an intrinsic characteristic of the space-time. Since, its effect is seen only at astronomical distances, only little is known about it. [1-4].

Some authors have suggested models for explaining dark energy. The most important models are ‘The Cosmological Constant $\left(Λ\right)$’, and ‘The Quintessence’. The former was introduced by Albert Einstein in 1917, when he attached a constant, $Λ$, without any mathematical proof, to his mathematical model for a static universe. Although he has regretted ever doing that, scientists found later that the constant was needed to account for the observed accelerating expansion of the universe. Since dark energy density is found to be constant everywhere, the cosmological constant is used by many authors to explain it.

Figure 1: 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; while dotted curved line represents total energy density contributed by other entities.

Energy density of the universe

Time

Figure1 is a schematic diagram that shows how dark energy density compares with the energy densities contributed by baryonic matter, dark matter, and electromagnetic radiation as cosmic time increases. It can be seen that dark energy density remains constant while the total energy density from other sources decays exponentially. At earlier time, dark energy density was overwhelmed by the other energy densities; while at later time dark energy density is more prevalent and overshadows the other energy densities. This shows that dark energy will continue to increase even beyond $99.999999\%$ as time goes on; while the other energy densities will continue to decrease below $0.000001\%$. For the present epoch, observations have shown that dark energy density lies between $68\%$ and $73\%$ of the total energy density; while the other energy density lies between $27\%$ and $32\%$. This simply implies that at infinite time, the universe will be ‘completely empty’ (i.e. with infinitesimal amount of matter or electromagnetic radiation) [1-4]. Figure 2 is a column chart for total energy density of the universe. Blue column represents dark energy density $\left(72\%\right)$, Brick-red represents dark matter $\left(23\%\right)$, and green column 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 column chart.

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. It was first introduced in 1998, and has been proposed by some authors to be a fifth fundamental force. It is not constant but it dynamically changes with time [1-5].

**1.2 Radio Galaxies – A subclass of Extragalactic Radio Sources**

Extragalactic radio sources are found beyond the confines of our galaxy – The Milky Way. They are generally known to emit much more radiation in the radio region than in the optical region [6-9]. Their radio morphologies on the radio maps show two main subclasses. They are radio galaxies and radio-loud quasars [8–9]. Quasars have been identified to have redshift distribution up to 10.1; while radio galaxies have a redshift distribution well below that. Radio galaxies always show three components; namely, central core, two-sided jets, and lobes. All these emit copious amounts of radio radiation. The quasars, on the other hand, may not immediately show all the three components [6,10]. Their central cores outshine those of the radio galaxies.

Moreover, classification based on linear sizes shows only two subclasses which are (i) the large (more extended) sources, and (ii) the compact (miniaturized) sources. The latter may be seen as scaled-down versions of the former, and are generally called compact steep spectrum (CSS) sources. These compact sources are sub-galactic in dimensions; meaning that they are hidden inside their host galaxies. The larger ones are inter-galactic, and means that their components, such as, the jets and lobes are domiciled outside the galactic boundaries. Usually, a galaxy has a diameter of about $30kpc$, implying that the compact sources have their linear sizes below $30kpc$; while the larger sources have theirs beyond $30kpc$. The implication of this is that the jets and lobes of the CSS sources are expected to be affected by the interstellar dusts and gravity; while the components of the larger sources are expected to be free from the interstellar factors [8–16].

It is worth noting that these subclasses of extragalactic radio sources (no matter the mode of classification) has a structure that typifies them. This enables them be recognized on the radio map. So, on their radio maps, typical structure of these classes of objects usually takes the form of two bi-focal relativistic jets that connect the base of the accretion disk to two radio-emitting lobes straddling 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 (I and II)). In some sources, the lobes contain hotspots, which are believed to be the termination points of the jets [8, 12–14].



**Hotspot**

**Hotspot**

*Figure 3 (I and II): The structure of a typical EGRS.*

**core**

**Lobe**

**Lobe**

**Jet**

**Jet**

**(I)**

**(II)**

It has been well established that presence of a jet is a characteristic signature of a tenuous medium [13-18]. For description of their physical processes, some authors have performed a number of hydrodynamic computer simulations of jet propagations in rarefied media of different densities with jet speeds of different march numbers [17–25]. Results suggest that jet materials have smaller masses than those of the surrounding media. More so, Ezeugo and Ubachukwu (2010) [15] created a mathematical model for evolution of the CSS sources and used the result to estimate their ambient densities. It is now known that dynamical evolutions of CSS sources with time are influenced by their dense ambient media; while those of the more extended sources are not since they are located in a more rarefied medium. This medium is intergalactic, and incidentally, that is where the space-time expands.

Therefore, we want to find out whether the larger sources – namely the more extended radio galaxies – are affected by the dark energy which drives the cosmic accelerated expansion. We apply both analytical methods and statistical methods to find effects (if there is any).The samples are of two groups – the extended radio galaxies (109 in number) selected from Nilsson 1998 [26], and 28 smaller sources (i.e. the CSS galaxies) obtained for O’Dea 1998 [16].

**2. OBSERVED LUMINOSITIES AND REDSHIFTS FOR LARGER RADIO GALAXIES**

In this section, we have applied statistical methods of analysis on the luminosity and redshift data for the larger radio galaxies. This is done by plotting luminosity, $L$, against redshift, $z$, as shown in Figure 4. Result of the linear regression states that

$$Log L=-0.89Log \left(1+z\right)+1.26 (3)$$

with a good correlation whose coefficient is $0.71$. Making $L$ subject, yields

$$L\~z^{-0.9} (4)$$

showing an inverse power-law relationship between luminosity and redshift.

Moreover, redshift relates with source velocity of recession according to the expression,

$$z=\frac{\dot{R}}{c} (5)$$

Of course, $c$ is speed of light, and combining equations (1) and (5) gives

$$z=\frac{HR}{c} (6)$$

Thus, equation (4) yields

$$L\~\left(\frac{HR}{c}\right)^{-0.9} (7)$$

Ignoring the constants and rewriting the last equation for $R$, we have

$$L\~R^{-0.9} (8)$$

Equation (8) implies that source luminosity scales as $R^{-0.9}$ (where $R$ remains the distance to the source).

Now, we want to obtain an expression for the time, $T$. From equation (1), $H$ becomes

$$H=\frac{\dot{R}}{R} (9)$$

From the dimension analysis,

$$\frac{\dot{R}}{R}=T^{-1} (10)$$

Therefore, time may be written as

$$T=\frac{R}{\dot{R}} (11)$$

From equations (8) and (11), we obtain

$$L\~\left(T\dot{R}\right)^{-0.9} (12)$$

Notably, these radio galaxies are receding from us. This implies that the velocity of recession is a negative quantity; hence, we attach a minus sign to $\dot{R}$, and obtain

$$L\~-\dot{R}^{-0.9} (13)$$

We remember that $\dot{R}$ is triggered off by expansion of the space-time in the intergalactic media, and is neither caused by any galactic dynamics nor any other force. Therefore, the last equation suggests that the source luminosity, $L$, of the large extended radio galaxies are affected by the accelerated expansion of the space-time. This should be expected because the source components (i.e. jets and lobes; see Figure3 (I and II)) are intergalactic; and the space-time expansion is actually brought about by dark energy. Because the intergalactic medium is very much less dense than the interstellar medium, and it has little or no gravitational attraction between the components, we expect dark energy to appreciably hold sway on the components – that is what equation (13) suggests.

3. OBSERVED LUMINOSITIES AND REDSHIFTS FOR CSS RADIO GALAXIES

Furthermore, we plot a graph of luminosity against redshift for the compact (CSS) radio galaxies. The graphical plot is as shown in Figure 5.

Result of the plot shows that

$$Log L=0.096Log \left(1+z\right)+1.412 (14)$$

with good correlation coefficient, $0.90$. Transforming the equation, we obtain

$$ L\~z^{0.096} \left(15\right)$$

We find that this is in dissonance with the result obtained for the more extended galaxies (see equation (4)). The result of the more extended radio galaxies shows inverse relationship; while that of the CSS radio galaxies indicates a direct relationship.

We ponder over what must have caused this disagreement. Earlier, we made mention that these two classes of objects are domiciled in different ambient media. CSS radio galaxies are situated in the interstellar media, implying that they are expected to be significantly affected by both interstellar gravity and dusts; while the larger radio galaxies are not, instead, they are located in the intergalactic media, where dark energy is mostly prevalent. As a result of these, dark energy is expected to affect more substantially luminosities of larger radio galaxies than those of their more compact counterparts.

Writing $L$ in terms of time and space expansion velocity just as we did in the previous section, we obtain

$$L\~\left(T\dot{R}\right)^{0.096} (16)$$

Since we are only interested in the relationship between source luminosity and rate of expansion of the space-time, equation (16) becomes

$$L\~-\dot{R}^{0.096} (17)$$

The last equation tells us suggestively how space expansion rate affects source luminosity. Note that we have negative velocity because the source is receding from us. Comparison with equation (13) shows that if we assume little or no effect of the observed space-time expansion on CSS galaxies, the effect is much more appreciable on the larger radio galaxies. From the two results (i.e. comparing the indices), the effect is estimated to be roughly 10 times higher on the luminosities of the larger sources than on the those of the smaller sources.

**4. DISCUSSION AND CONCLUSION**

It has been observed that the universe is expanding with acceleration; and dark energy has been seen as the energy behind the driving force. Dark energy is the intrinsic property of the empty space. In earlier epochs, total energy density of the universe has largely been contributed by baryonic matter, dark matter, and electromagnetic radiation densities. However, in the present epoch and subsequent epochs, contribution to the total energy density by dark energy has been predicted plausibly to increase indefinitely. So, in this work, we seek to find if there is any effect posed by this dark energy on the luminosity of the radio galaxy.

We have used two data sets in this work. They are two subclasses of radio galaxies; and usually they show similar properties as mentioned earlier on the radio maps, except on their observed linear sizes. The more extended radio galaxies are intergalactic while the more compact (CSS) radio galaxies are sub-galactic in dimensions. So, we have carried out linear regression analyses of observed source luminosities, $L,$ and their corresponding observed redshifts, $z,$ (Figure 4) of the more extended radio galaxies; as well as those of the CSS radio galaxies (Figure 5).

In Section 2, we have applied statistical methods of analysis on the luminosity and redshift data for the larger radio galaxies. We have done this by plotting luminosity, $L$, against redshift, $z$, as shown in Figure 4. Result of the linear regression (with a good correlation whose coefficient, $0.71$) states that $L\~z^{-0.9}$ which indicates an inverse power-law relationship between luminosity and redshift.

Moreover, merging this with Hubble’s law gives $L\~\left(\frac{HR}{c}\right)^{-0.9}$. Since we are interested in the $L/R$ relationship, we now have $L\~R^{-0.9}$. This shows that source luminosity for the larger radio galaxy scales as $R^{-0.9}$. To obtain an expression for time, we combine equations (8) and (11), and have $L\~\left(T\dot{R}\right)^{-0.9}$. We attach a minus sign because the radio galaxies are receding from us. This implies that the velocity of recession is a negative quantity; hence, we get$ L\~-\dot{R}^{-0.9}$.

As was mentioned earlier, the velocity $\dot{R}$ is brought about by expansion of the space-time in the intergalactic media, and is neither caused by any galactic dynamics nor any other force. Therefore, the last equation advocates that the source luminosity, $L$, of the large extended radio galaxies are constrained by the accelerated expansion of the space-time. This should be expected because the source components, such as, jets and lobes are intergalactic; and the space-time expansion is actually brought about by dark energy. Because the intergalactic medium is very much less dense than the interstellar medium, and it has little or no gravitational attraction between the components, we expect dark energy to considerably exert influence on the components; and this is the suggestion of equation (13).

In addition to the foregoing, we carry out linear regression on the luminosity data against redshift data for the compact (CSS) radio galaxies (see Figure 5). With a good correlation coefficient, $0.90$, result of the plot shows that $L\~z^{0.096}$. Comparing this result with equation (4), we find that the two results are incoherent. The result of the more extended radio galaxies shows an inverse function; while that of the CSS radio galaxies indicates a direct function.

Pondering over possible causes of the disparity, we remember that earlier, we made mention that these two subclasses of objects are embedded in different ambient media. CSS radio galaxies are resident in the interstellar media, implying that they are expected to be significantly affected by both interstellar gravity and dusts; while the larger radio galaxies are not, instead, they are located in the intergalactic media, where dark energy is mostly prevalent. As a result of these, dark energy is expected to affect more significantly larger radio galaxies than their more compact counterparts.

We write luminosity, $L$, in terms of time and space expansion velocity just as we did earlier, to obtain $L\~\left(T\dot{R}\right)^{0.096}$. We are only interested in the relationship between source luminosity and rate of expansion of the space-time; hence, we obtain the expression, $L\~-\dot{R}^{0.096}$. This equation plausibly indicates the effect space expansion rate (or expansion velocity) poses on source luminosity. Note that we have negative velocity because the source is receding from us. Comparison with equation (13) shows that if we assume little or no effect of the observed space-time expansion on CSS galaxies, the effect is much more pronounced on the larger radio galaxies. Comparing the indices of the two results ($L\~-\dot{R}^{-0.9}$ for the larger radio galaxies, and $L\~-\dot{R}^{0.096}$ for the more compact radio galaxies), we estimate the effect to be $≈10$ times higher on the luminosities of the larger sources than on those of the smaller sources.

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