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Research Paper

Compact Steep Spectrum Source Size and Cosmological Implication

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ABSTRACT: *In this paper, we use analytical methods to develop mathematical relation that expresses relationship between the linear size* ($\mathcal{D}_0$) *of compact steep spectrum (CSS) sources and their redshift* (z)*. Result shows that* $\mathcal{D}_0 \sim (1+z)^{\mathcal{L}}$*, where* $\mathcal{L} = -4.5$*. For the purpose of obtaining an empirical relation, we carry out simple linear regression analyses on the observed linear sizes of the CSS sources in our sample against their respective observed redshifts. We obtain a relation of the form,* $\mathcal{D}_0 \sim (1+z)^{\xi}$*, where* $\xi \approx -2.2$ *and* 2.9 *for CSS quasars and galaxies respectively, and correlation coefficients given by,* $r \approx 0.33$ *and* 0.4 *respectively. These coefficients are marginal. In comparison with the theoretical relation, we notice that for the CSS quasars,* $\mathcal{D}_0 - z$ *data show an inverse correlation. This is in consonance with the theoretical relation. So, this suggests that the source linear sizes may have some cosmological implication. However, the converse is the case for the CSS galaxies – the correlation is direct. The possible explanation for this difference is that quasars are observed at higher redshifts than their galaxy counterparts. Hence, the cosmological effects are expected to be more visible on the quasars.*

KEYWORDS: *Radio sources, Redshift, Steep Spectrum, Compact, Evolution, Cosmology*

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I. INTRODUCTION

The building blocks of the Universe are the galaxies. In terms of their luminosities, galaxies can be classified into normal galaxies and active galaxies. Active galaxies are those galaxies that radiate in excess of $10^{36} W$ [1,2,3,4,5]. Unlike the normal galaxy whose radiation comes from the constituent stars, the active galaxy radiate copious amount of radiation from its three major components, namely, central core (believed to harbor a suppermassive blackhole), two-sided jets emanating from the core, and two-sided lobes fed by the jets [1,2,3,4,5] (Figures 1 and 2).

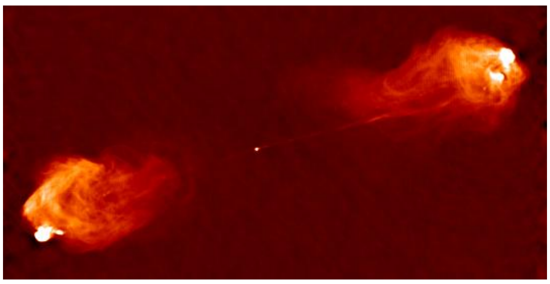

Figure 1: Cygnus A – an EGRS.
Source: Wikipedia

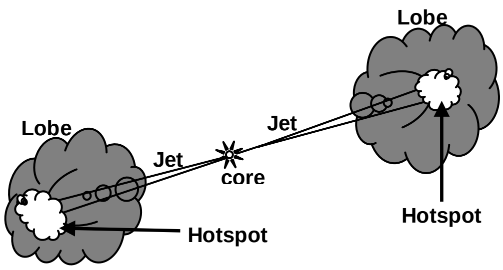

Figure 2: The structure of a typical EGRS.
Source: the author

Compact steep spectrum sources (CSSs), on the other hand, belong to a class of active galaxies known as extragalactic radio sources (EGRSs) that radiate more in the radio wavelengths [6]. The major difference between the CSSs and the normal EGRSs (or extended radio sources) is their smallness but yet powerful in radiation [6,7]. They constitute a remarkable class of radio sources accounting for a substantial fraction of the extra-galactic 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 [6]. 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.

The CSS sources are a mixture of radio galaxies and radio loud quasars with radio power, $P_{5GHz} > 10^{25.5}$ WHz^{-1} and show double, triple and core-jet morphologies on the radio maps. Their projected linear sizes range from less than 1 kpc to 20 kpc assuming Hubble's constant, $H_0 = 75\ Kms^{-1}Mpc^{-1}$, and deceleration parameter, $q = 0$, [6]. They have steep high frequency spectrum of spectral index, $\alpha < 0.5, S_\nu \propto \nu^{-\alpha}$. Sometimes, the spectrum remains straight up to 100 GHz, proving that no dominant flat spectrum core exists. Generally, they have their radio spectral turnovers at frequencies, sometimes > 5GHz; and have very low polarization at both radio and optical bands, usually less than one percent [6,7,8]. Their proportion is high; about 15 – 30%, depending on the selection frequency, among distant ($z > 0.2$) radio sources of high power [6,7,8].

II. MODELS OF FORMATION AND EVOLUTION

The nature of CSSs has been discussed for many years. Immediately after their discovery, it was suggested that they might be very young radio sources; that is, the progenitors of the extended doubles [6,7,8,9,10]. However, it has been proposed that CSSs are, instead, old 'frustrated sources which have been kept small by a dense confining medium [6,7,8,9,10,11]. Moreover, it has been suggested that CSSs might be 'smothered' sources in which a large deposition of gas had recently confined an existing radio-loud AGN to a small volume; though this does not have any footing for want of data [6,7,8,9,10,11]. Other models include: Relativistic Beaming and Orientation Effects [12,13]; and Hybrid Model – in which Youth, Frustration scenarios and Relativistic Beaming & Orientation Effects are combined.

Furthermore, from simulation and statistical approach, it has been concluded that if CSSs were randomly oriented in space, only a minority ($\leq 30\%$) of them were larger sources of the same intrinsic radio luminosity foreshortened by projection effects. This simply implies that hybrid model could be of great importance in the proper explanation of the phenomenal occurrences in the CSSs.

In this paper, we use analytical methods to obtain a theoretical expression that may show a relationship between the linear size of a radio source and its redshift. After which, we find an empirical relation between the two observable parameters using 59 CSS sources in our sample. These sources are from [6] and they are made up of 31 CSS quasars and 28 CSS galaxies.

III. COSMOLOGICAL EVOLUTION OF RADIO SOURCE SIZE

The synchrotron aged spectrum model for CSS sources can be expressed as [6,8]

$$\mathcal{T}_{syn} = 1610\frac{\mathcal{B}^{\frac{1}{2}}}{\mathcal{B}^2 + \mathcal{B}_{CMB}^2}\left((1+z)v_{br}\right)^{-\frac{1}{2}} \qquad \rightarrow 1$$

where $\mathcal{B}$ is magnetic field intensity, $\mathcal{B}_{CMB} = 3.25(1+z)^2$ in μG is the magnetic field equivalent to the microwave background, $\mathcal{T}_{syn}$ in Myr is elapsed time since the source formation, v_{br} in GHz is the breaking frequency. Substituting for $\mathcal{B}_{CMB}$, we obtain

$$\mathcal{T}_{syn} = 1610\frac{\mathcal{B}^{\frac{1}{2}}}{\mathcal{B}^2 + 10.56(1+z)^4\left((1+z)v_{br}\right)^{\frac{1}{2}}} \qquad \rightarrow 2$$

Simplifying, we have

$$\mathcal{T}_{syn} = \frac{1610\mathcal{B}^{\frac{1}{2}}}{(1+z)^{\frac{9}{2}}[\mathcal{B}^2(1+z)^{-4} + 10.56]v_{br}^{\frac{1}{2}}} \qquad \rightarrow 3$$

Since $(1+z)^{\frac{9}{2}} \gg (1+z)^{-4}$, we ignore the smaller term to obtain

$$\mathcal{T}_{syn} \approx \frac{1610\mathcal{B}^{\frac{1}{2}}}{10.56v_{br}^{\frac{1}{2}}(1+z)^{\frac{9}{2}}} \qquad \rightarrow 4$$

Moreover, kinematic age, $\mathcal{T}$, of a radio source can be expressed simply as a function of the source linear size, $\mathcal{D}_0$, as [13]

$$\mathcal{T} = \int_{\mathcal{D}_m}^{\mathcal{D}_0}\frac{d\mathcal{D}_0}{\mathcal{V}_\ell} \qquad \rightarrow 5$$

where $\mathcal{D}_m$ is the lower limit of the linear size, $\mathcal{V}_\ell$ is lobe velocity. Assuming radiation age has similar value with the kinematic age, we combine the last two equations to obtain

$$\mathcal{D}_0 \approx \frac{1610B^{\frac{1}{2}}\mathcal{V}_\ell}{10.56\nu_{br}^{\frac{1}{2}}(1+z)^{\frac{9}{2}}} \qquad \to 6$$

Hence, we have

$$\mathcal{D}_0 \sim (1+z)^{-4.5} \qquad \to 7$$

which can be referred to as theoretical relation. It can be interpreted to mean that the linear size of an EGRS possibly may be affected by cosmological evolution.

Moreover, for the purpose of obtaining an empirical relation of similar form, we carry out simple linear regression analysis on the observable source linear sizes against their respective observed redshifts (Figures 3 and 4). Figure 3 is for the CSS quasars while Figure 4 is for the CSS galaxies. Results of the regression show,

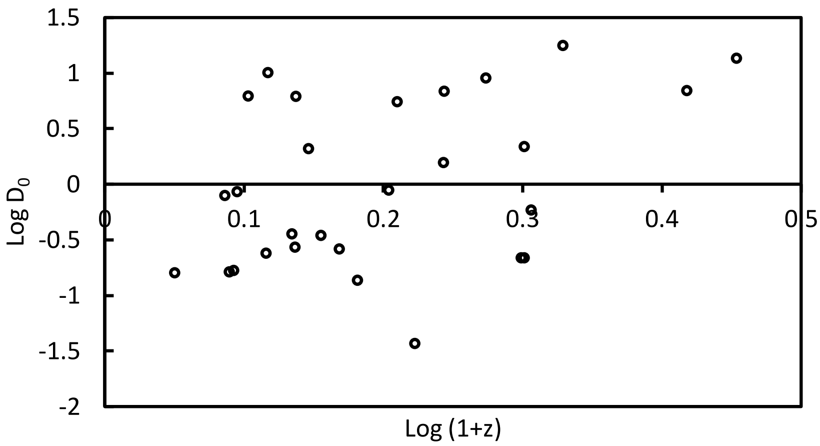

Figure 3: The scatter plot of linear size against redshift for the CSS galaxies

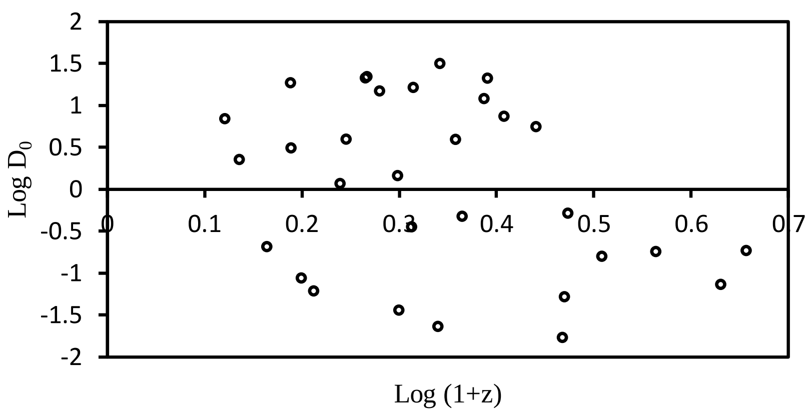

Figure 4: The scatter plot of linear size against redshift for the CSS quasars

$$\mathrm{Log}\mathcal{D}_0 = -2.49\mathrm{Log}(1+z) + 0.89 \qquad \to 8$$

and

$$\mathrm{Log}\mathcal{D}_0 = 2.92\mathrm{Log}(1+z) - 0.58 \qquad \to 9$$

for quasars and galaxies respectively. Their correlation coefficients are given respectively as 0.33 and 0.40. These show marginal correlation. Rewriting equations (8) and (9) yields respectively

$$\mathcal{D}_0 \sim (1+z)^{-2.5} \qquad \to 10$$

and

$$\mathcal{D}_0 \sim (1+z)^{2.9} \qquad \to 11$$

These last two relations can be referred to as empirical relations. In comparison with the theoretical relation (equation (7)), we notice that for the CSS quasars, $\mathcal{D}_0 - z$ data show an inverse correlation. This is in consonance with the theoretical relation. So, this suggests that there may be effects caused by cosmological evolution on the source linear sizes.

However, the converse is the case for the CSS galaxies – the correlation is direct. The possible explanation for this difference is that quasars are observed at higher redshifts than their galaxy counterparts. Hence, the cosmological effects are expected to be more visible on the quasars.

IV. DISCUSSION AND CONCLUSION

We have used analytical methods with some plausible assumptions to find a relation (equation (7)) which plausibly may indicate a source size dependence on cosmological evolution. However, for the purpose of obtaining an empirical relation of similar form, we carry out linear regression analyses of observed linear sizes against their respective observed redshifts for CSS quasars (Figure 3) and CSS galaxies (Figure 4). The power-law relations obtained are of the form, $\mathcal{D}_0 \sim (1+z)^{\xi}$; where the index, ξ, is -2.5 and 2.9 for quasars and galaxies respectively. Correlation coefficients are generally marginal with 0.33 for quasars and 0.40 for galaxies.

In comparison with the theoretical relation (i.e. equation (7)), it can be seen that for the CSS quasars, the linear size $(\mathcal{D}_0)$ shows an inverse relationship with redshift (z). This is similar to the theoretical relation. Hence, this similarity simply suggests that cosmological evolution may have some consequences on the source linear sizes.

However, the converse is found to be the case for the CSS galaxies. In this case the correlation is direct. One plausible explanation for this difference is that quasars are observed at higher redshifts than the galaxies. Therefore, cosmological effects are expected to be more prominent on the quasars.

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