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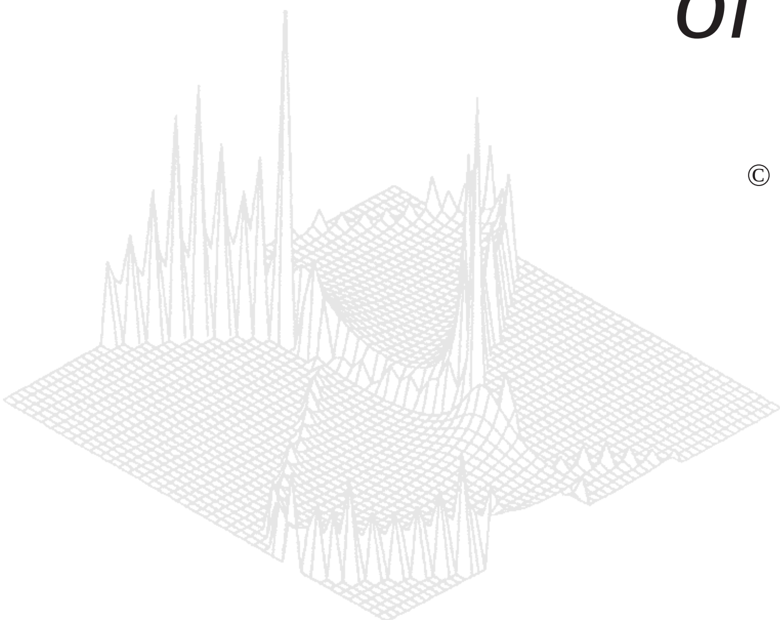

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Linear Size Evolution and Luminosity Selection Effects in Quasars

A. A. Ubachukwu

Hartebeesthoek Radio Astronomy Observatory, Box 443,
Krugersdorp 1740, South Africa.
Permanent address: Department of Physics and Astronomy,
University of Nigeria, Nsukka, Nigeria.

Abstract

We have quantitatively estimated the amount of luminosity selection effects present in the observed linear size–redshift data for a large sample of extended steep spectrum quasars. We show that ~90% of the observed dependence of sizes of quasars on redshift can be interpreted in terms of luminosity selection effects alone. This gives quantitative support to earlier results which show that little or no intrinsic linear size evolution appears to be occurring among quasars.

1. Introduction

The first indication that the physical sizes of extended extragalactic radio sources may depend on cosmological epoch comes from the work by Miley (1968) who showed that the angular sizes of quasars decrease with increasing redshift faster than would be expected in any uniform world models. Later works (e.g. Miley 1971; Legg 1970; Wardle and Miley 1974) have confirmed this result for both quasars and radio galaxies. The discrepancy between the observed angular size–redshift (θ–z) data and theoretical uniform world models can be reconciled by assuming a linear size evolution in which radio sources were, on the average, smaller at earlier epochs. However, due to the strong correlation between radio luminosity and redshift in flux density limited source samples, the observed (θ–z) data can be equally explained in terms of an inverse correlation between linear size and redshift (see e.g. Masson 1980) or in terms of temporal evolution in both the sizes and luminosities of extragalactic double radio sources (e.g. Gopal-Krishna *et al*. 1996).

Recent observational as well as theoretical results (e.g. Oort *et al*. 1987; Gopal-Krishna and Wiita 1987, 1991; Kapahi 1989; Ubachukwu *et al*. 1991; Singal 1993) have shown that linear sizes of radio galaxies appear to correlate directly with luminosity and to evolve steeper with redshift than was earlier inferred. However, whether quasar sizes undergo similar evolution is now an on-going debate (see Singl 1996 for a brief summary).

One of the major difficulties in interpreting radio source data has remained how to disentangle the effects of luminosity from those of redshift. Recently,

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Ubachukwu (1995) and Ubachukwu *et al*. (1996) have developed a simple mathematical formalism for factoring out the effects of luminosity from those of redshift. We use this method in the present paper to show quantitatively that the observed linear size evolution for quasars often found in the literature is an artefact of the strong luminosity selection effects present in most well-studied flux-density-limited samples.

2. Linear Size Evolution and Luminosity Selection Effects

Following the method outlined in Ubachukwu *et al*. (1996), we write the variation of linear size D with redshift z and radio luminosity P in simple power-law functions of the form

$$\log D(z) = a_0 - n\log(1+z)\,, \tag{1}$$

$$\log D(z) = b_0 - q\log P. \tag{2}$$

Basically, equations (1) and (2) assume that the exponents n and q are the same for all redshift and luminosity ranges, and also that there is no significant correlation between radio luminosity and redshift so that the two equations are mutally independent. Although the first assumption is approximately true for quasars, the second is not. In flux-density-limited source samples, there is a strong correlation between redshift and luminosity due to the ubiquitous Malmquist bias. This P–z relation can also be approximated to a power-law function as (see Onuora and Okoye 1982)

$$\log P(z) = P_0 + \log(1+z)\,. \tag{3}$$

We can use equation (3) in (2) to obtain an expression for the variation of linear size with redshift independent of luminosity. Thus, we have

$$\log D[P(z)] = a_1 + q\beta\log(1+z)\,, \tag{4}$$

where $a_1 = b_0 + q\log P_0$. It follows immediately from equations (4) and (1) that, if the observed D–z correlation is due to luminosity selection effects alone, then

$$n = q\beta\,. \tag{5}$$

Otherwise, we have

$$x = n - q\beta\,, \tag{6}$$

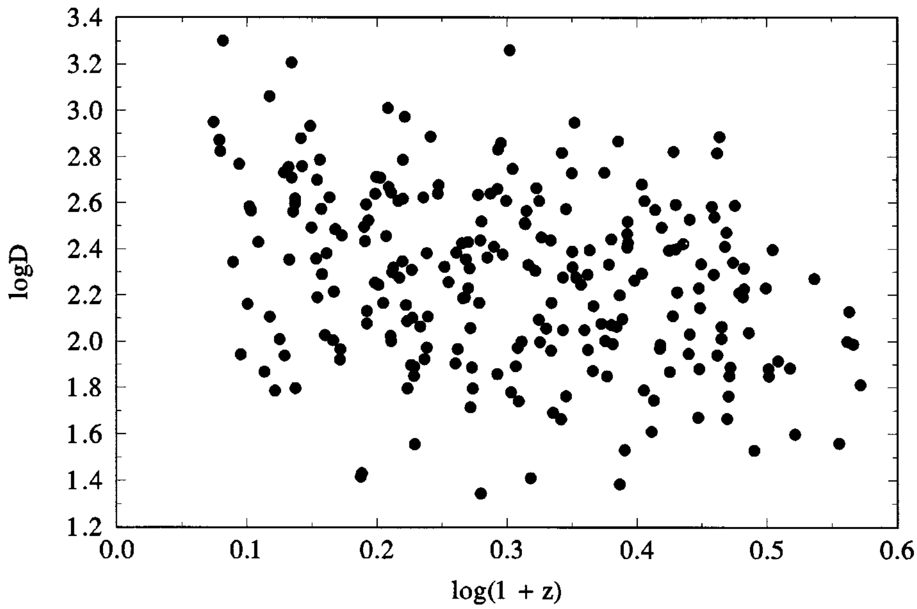

Fig. 1. Plot of linear size against redshift.

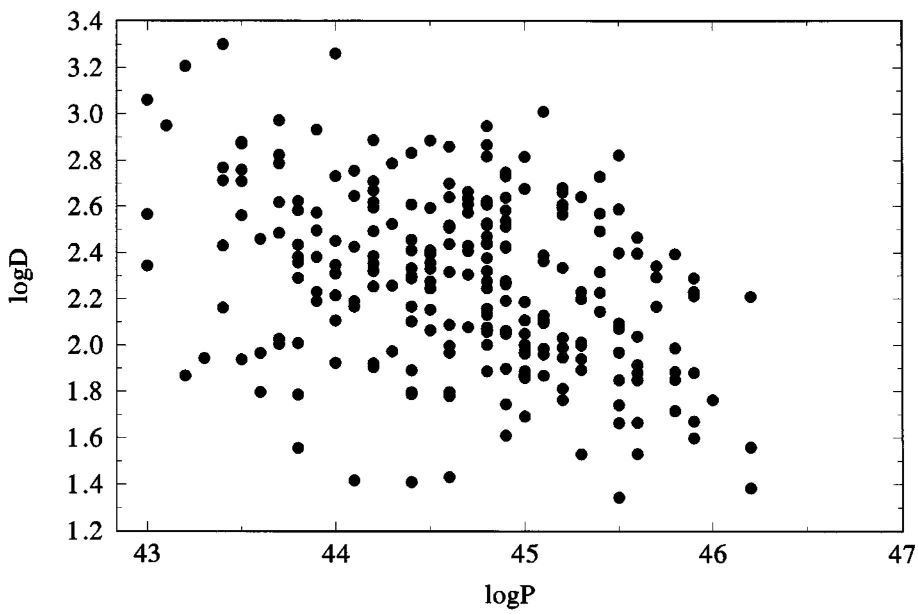

Fig. 2. Plot of linear size against luminosity.

where x is the residual redshift dependence after correcting for that which results from the luminosity selection effects.

3. Application to Lobe-dominated Quasars

We show in Figs 1 and 2 the observed dependence of D on $(1+z)$ and P using the 242 extended ($D > 20$ kpc) steep spectrum ($\alpha \geq 0 \cdot 5$) quasars from the Nilsson *et al*. (1993) sample. We have adopted $H_0 = 50$ kms/s/Mpc and $\Omega_0 = 0$. We have decided to exclude the compact steep and flat spectrum sources since they are likely to belong to different classes of objects with different cosmic evolution. Their inclusion in the present analysis will obviously bias our result.

Although there is a large scatter in each of Figs 1 and 2, there is, however, an indication of a general decrease of linear size towards higher redshifts and luminosities. This supports our earlier assumption of constant exponents for the variation of linear size with redshift and radio luminosity given by equations (1) and (2) respectively.

To investigate the relative strengths of the D–$(1+z)$ and D–P dependence more quatitatively, we fitted the observed median value data in four different redshift bins: $z \leq 0 \cdot 5$; $0 \cdot 5 < z \leq 1 \cdot 0$; $1 \cdot 0 < z \leq 1 \cdot 5$; and $z > 1 \cdot 5$ and luminosity bins: $\log P \leq 44 \cdot 0$; $44 \cdot 0 < \log P \leq 44 \cdot 5$; $44 \cdot 5 < \log P < 45 \cdot 0$; $\log P \leq 45 \cdot 0$ respectively to equations (1) and (2) independent of each other. The following results were obtained (see also Figs 3 and 4):

$$\log D_{\text{med}}(z) = 2 \cdot 60 \pm 0 \cdot 05 - (1 \cdot 04 \pm 0 \cdot 16) \log(1+z)\,, \tag{7}$$

$$\log D_{\text{med}}(P) = 12 \cdot 40 \pm 2 \cdot 87 - (0 \cdot 23 \pm 0 \cdot 06) \log P\,. \tag{8}$$

The correlations are highly significant in each case (correlation coefficient $r \sim 0 \cdot 9$). The last two equations show a steeper slope for the redshift dependence than for the case of luminosity. However, some workers have argued that the observed D–$(1+z)$ correlation is an artefact of the luminosity selection effects in the sample (e.g. Masson 1980; Singal 1993, 1996; Nilsson *et al*. 1995), while othere believe that there is a genuine cosmological evolution in the physical size of quasars (e.g. Barthel and Miley 1988; Chyzy and Zieba 1995; Neeser *et al*. 1995).

We show in Fig. 5, the observed $\log P$–$\log(1+z)$ plot for the present sample. In order to derive the cosmological linear size evolution of quasars independent of luminosity effects, we fitted the observed $\log P$–$\log(1+z)$ data to equation (3) and used the result in equation (4). A linear regression analysis of Fig. 5 gives

$$\log P(z) = 43 \cdot 44 \pm 0 \cdot 53 + 4 \cdot 00 \pm 0 \cdot 23 \log(1+z)\,, \tag{9}$$

with correlation coefficient $r \sim 0 \cdot 9$. Substituting equation (9) into (8) gives

$$\log D_{\text{med}}[P(z)] = 2 \cdot 41 + 0 \cdot 92 \log(1+z)\,. \tag{10}$$

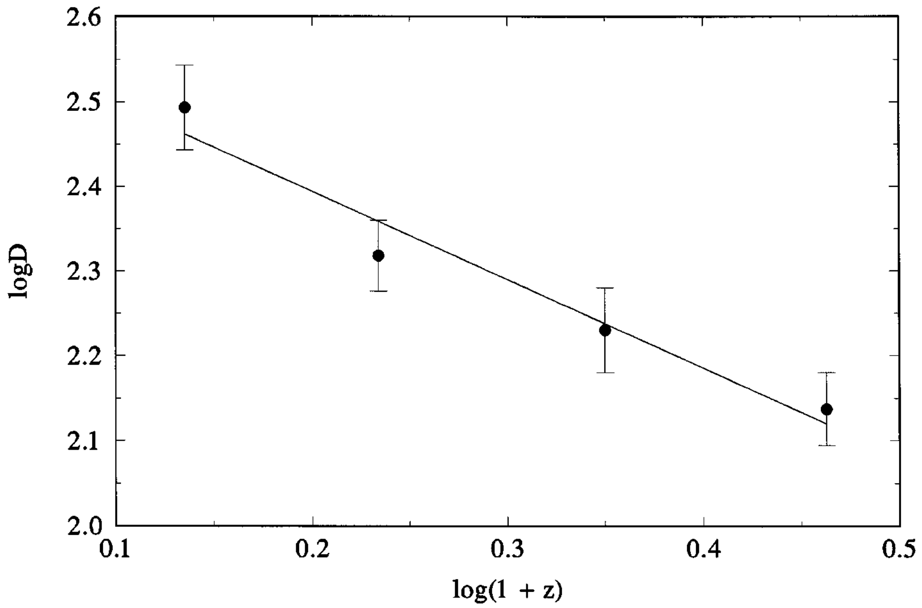

Fig. 3. Plot of median linear size against redshift data.

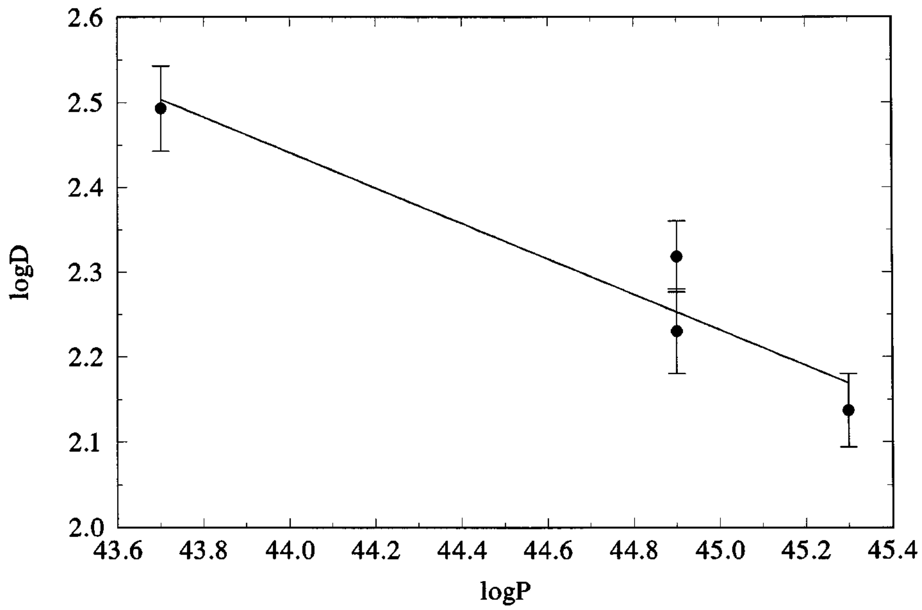

Fig. 4. Plot of median linear size against luminosity data.

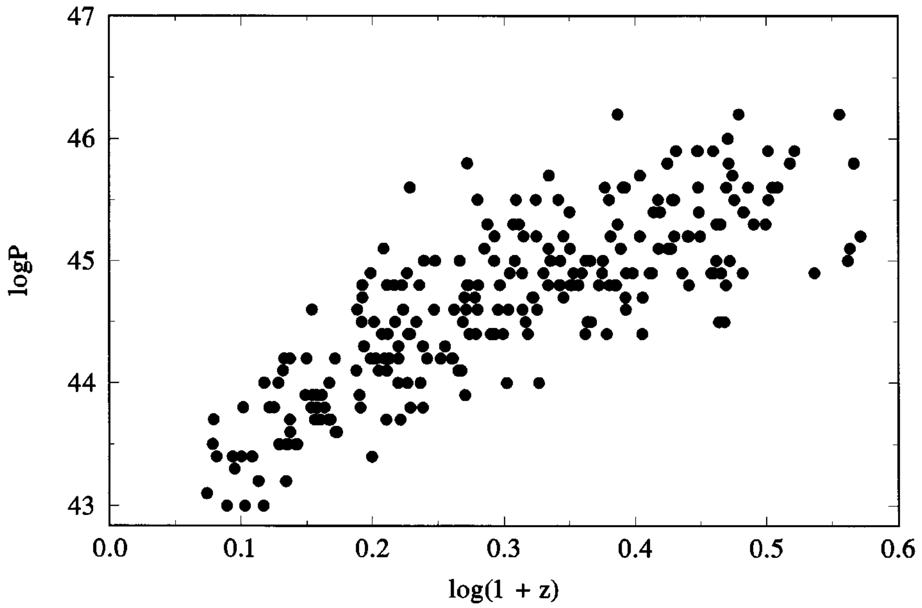

Fig. 5. Plot of luminosity against redshift.

A comparision of equation (10) with (7) shows from (6) that $x = 0{\cdot}12$, so that we can say from equation (5) that $n \sim q\beta$. This clearly suggests that the observed D–$(1 + z)$ correlation is an artefact of the luminosity selection effects present in the sample.

4. Discussion

We have carried out a quantitative analysis of the influence of luminosity selection effects in the interpretation of the observed correlation between linear size and redshift using a source sample that is flux density limited. Our result shows that ~90% of the correlation can be attributed to the luminosity selection effects present in the sample. More specifically, we showed that the residual redshift dependence is only given by $D \sim (1 + z)^{-0{\cdot}12}$ which agrees qualitatively with the result obtained by Singal (1993). This result is qualitatively in good agreement with that obtained by Nilsson *et al.* (1993) for $\Omega_0 = 0$.

Although the present result is not new, the method we used is different from those of other workers. We have been able to provide a quantitative estimate for the luminosity selection effects in the observed D–$(1+z)$ relation. Similar analysis for radio galaxy samples (Ubachukwu 1995) was able to yield D–$(1 + z)^{-2{\cdot}8}$, consistent with both theoretical and observational results.

Barthel and Miley (1988) have used a large sample of quasars to show that quasar sizes evolve as $(1 + z)^{-1{\cdot}5}$. Similar results were also obtained recently by Neeser *et al.* (1995) who showed that $D \sim (1+z)^{-1{\cdot}2}$. However, the method used by Barthel and Miley (1988) in their analysis shows that the effects of luminosity were only partially corrected for. Also, taking into account the large statistical errors for the value of n in the Neeser *et al.* (1995) result, coupled with the fact that their sample contains some compact steep spectrum sources whose evolution appears to be steeper than those of their more extended counterparts (see Onuora and Ubachukwu 1995), we believe that their result does not significantly differ from ours.

In conclusion, we have shown that $<20\%$ of the observed correlation of linear sizes of extended steep spectrum quasars appears intrinsic, while the rest is an artefact of the strong luminosity selection effects in the sample. Evidence in the literature for any significant cosmic evolution of quasar sizes stems from either partial compensation for the influence of luminosity selection effects or due to the presence of compact steep spectrum sources whose evolution appears steeper.

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References

Barthel, P. D., and Miley, G. K. (1988). *Nature* **333**, 319.
Chyzy, K. T., and Zieba, S. (1995). *Astron. Astrophys.* **303**, 420.
Gopal-Krishna, and Wiita, P. J. (1987). *Mon. Not. R. Astron. Soc.* **226**, 531.
Gopal-Krishna, and Witta, P. J. (1991). *Astrophys. J.* **373**, 325.
Gopal-Krishna, Kulkarni, V. K., and Wiita, P. J. (1996). *Astrophys. J. Lett.* **463**, L1.
Kapahi, V. K. (1980). *Astron. J.* **97**, 1.
Legg, T. H. (1970). *Nature* **226**, 65.
Masson, C. R. (1980). *Astrophys. J.* **242**, 8.
Miley, G. K. (1968). *Nature* **218**, 933.
Miley, G. K. (1971). *Mon. Not. R. Astron. Soc.* **152**, 477.
Neeser, M. J., Eales, S. A., Law-Green, J. D., Leahy, J. P., and Ralwings, S. (1995). *Astrophys. J.* **451**, 76.
Nilsson, K., Valtonen, M. J., Kotilainen, J., and Jaakkola, T. (1993). *Astrophys. J.* **413**, 453.
Onuora, L. I., and Okoye, S. E. (1983). *Astrophys. J.* **270**, 370.
Onuora, L. I., and Ubachukwu, A. A. (1995). *Astrophys. Sp. Sci.* **226**, 370.
Oort, M. J. A., Katgert, P., and Windhorst, R. A. (1987). *Nature* **328**, 500.
Singal, A. K. (1993). *Mon. Not. R. Astron. Soc.* **263**, 139.
Singal, A. K. (1996). *In* 'Extagalactic Radio Sources' (Eds R. Ekers *et al*). p. 563.
Ubachukwu, A. A. (1995). *Astrophys. Sp. Sci.* **232**, 23.
Ubachukwu, A. A., Okoye, S. E., and Onuora, L. I. (1991). *Astrophys. J.* **383**, 56.
Ubachukwu, A. A., Ugwoke, A. C., and Ogwo, J. N. (1996). *Astrophys. Sp. Sci.* **238**, 151.
Wardle, J. F. C., and Miley, G. K. (1974). *Astron. Astrophys.* **30**, 305.

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