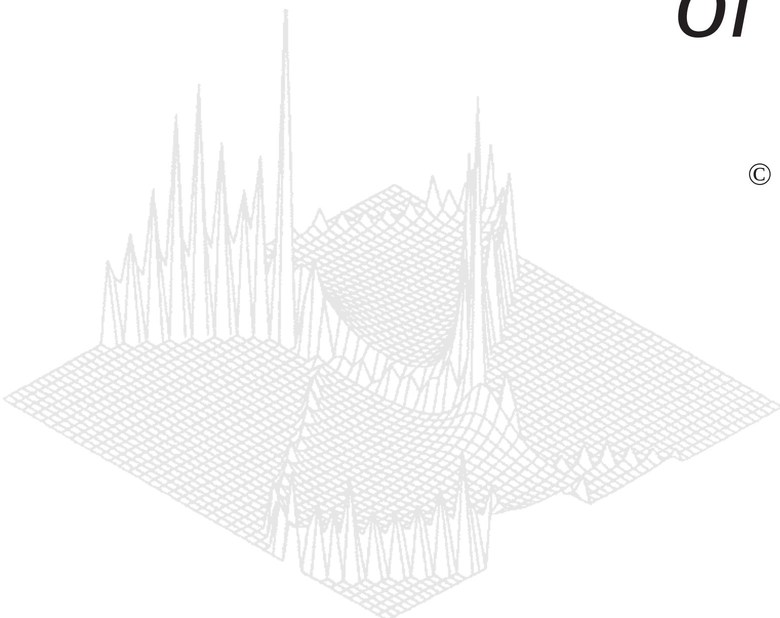
CSIRO PUBLISHING

Australian Journal of Physics

Volume 52, 1999



A journal for the publication of
original research in all branches of physics

www.publish.csiro.au/journals/ajp

All enquiries and manuscripts should be directed to
Australian Journal of Physics
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood
Vic. 3066
Australia
Telephone: 61 3 9662 7626
Facsimile: 61 3 9662 7611
Email: peter.robertson@publish.csiro.au

Published by **CSIRO** PUBLISHING
for CSIRO Australia and
the Australian Academy of Science

Aust. J. Phys., 1999, **52**, 141–6

Redshift and Luminosity Dependence of Linear Sizes of Compact Steep Spectrum Sources and the Quasar/Galaxy Unification Scheme

A. A. Ubachukwu[A,B] *and J. N. Ogwo*[A,C]

[A]Department of Physics and Astronomy, University of Nigeria, Nsukka, Nigeria.
[B]Hartebeesthoek Radio Astronomy Observatory, Box 443, Krugersdorp, 1740 South Africa.
[C]Abia State University, Uturu, Abia State.

Abstract

We present and analyse plots of linear size–luminosity and linear size–redshift data for a sample of compact steep-spectrum sources (CSSs) and use them to investigate the currently popular but controversial orientation-based unification hypothesis for high-luminosity radio sources. This is based on the assumption that CSSs belong to a separate class of object. Our results show that the observed distributions of linear size (D) as a function of redshift (z) and radio luminosity (P) are in accord with the unified scheme in which CSS radio galaxies and CSS quasars are expected to be indistinguishable in their D–P/z correlations. This is particularly true when the two classes of object are properly matched in redshift. In the unification paradigm, both radio galaxies and quasars are expected to differ only in their orientation-dependent properties; all other properties should appear similar.

1. Introduction

The phenomenology of compact steep-spectrum sources (CSSs) appears hard to explain. Although Fanti *et al.* (1990*a*, 1990*b*) have used statistical arguments to show that only a small fraction of CSSs could have been larger sources seen at smaller angles to the line of sight, it is not, however, clear whether these sources are small because they are embedded in a high-density environment or because they are young sources in their early stages of evolution (Mutel *et al.* 1995; Fanti *et al.* 1990*a*, 1990*b*; Dallacasa *et al.* 1995). CSSs are generally characterised by small linear dimensions ($D < 25$ kpc), steep spectra with spectral index $\alpha > 0.5$ ($S_\nu \sim\nu^{-\alpha}$) and high radio power $P_{2.7} > 10^{25.5}$ W Hz^{-1}, and are usually located at high redshifts ($z > 0.2$).

Morphological differences appear to exist between CSS radio galaxies and quasars: radio galaxies appear to have a double structure with weak jets and cores, while quasars in general have more complex structures with stronger cores and jets (e.g. Wilkinson *et al.* 1984; Spencer *et al.* 1989; Fanti *et al.* 1990*a*; Akujor *et al.* 1991). These differences are in good agreement with the Barthel (1989) unification scheme, in which quasars are at closer angles to the line of sight than radio galaxies. Recently, Saikia *et al.* (1995) have observed that while the symmetry parameters and the degree of core prominence for these sources appear broadly consistent with the unified scheme, there is a strong indication of interaction

 10.1071/PH97011 0004-9506/99/010141$05.00

with a dense asymmetric ambient medium. In the orientation-based unification schemes, both radio galaxies and quasars are believed to be indistinguishable except in their aspect-dependent properties. In the absence of any correlation between the viewing angle and redshift, quasars and radio galaxies are expected to have similar linear size distributions with redshift. Also, unless the lobe emission is boosted, the linear size–radio luminosity relation will be similar in both classes of object. We investigate these expectations in more detail in the present paper.

2. Analysis and Results

The data used in the present investigation were obtained from three recent related works: Sanghera *et al.* (1995), Dallacasa *et al.* (1995) and Fanti *et al.* (1995). The final compilation consists of 46 sources: 23 radio galaxies and 23 quasars belonging to the 3CRR source sample of Laing *et al.* (1983) and/or the Peacock and Wall (1982) catalogue. These two catalogues have been well studied (e.g. Fanti *et al.* 1990*a*; Spencer *et al.* 1991; Dallacasa *et al.* 1995) and are best suited for the present studies because they have reliable structural and spectroscopic redshift information. Linear sizes and luminosities were estimated using $\Omega_0 = 1$ and $H_0 = 100$ km s^{-1} Mpc^{-1}.

Fig. 1 shows the relation between luminosity P and redshift z; different symbols have been used for radio galaxies (circles) and quasars (squares). It can be seen that there is a strong correlation between radio luminosity and redshift. Linear regression analyses of Fig. 1 (assuming a simple power-law function) show that $P \sim (1 + z)\beta$, with $\beta = 4.3 \pm 0.2$ and $\beta = 2.5 \pm 0.2$ for radio galaxies and quasars respectively. The correlations are highly significant, with correlation coefficients $r \sim 0.8$ for radio galaxies and $r \sim 0.6$ for quasars. The slightly steeper slope for the radio galaxy subsample as compared to that for quasars could be traced to the three high-redshift ($z \leq 2$) quasars: 0319+121, 1225+368 and 1442+101 (see Fig. 1). The similarity in the behaviour of quasars and radio galaxies in the P–z

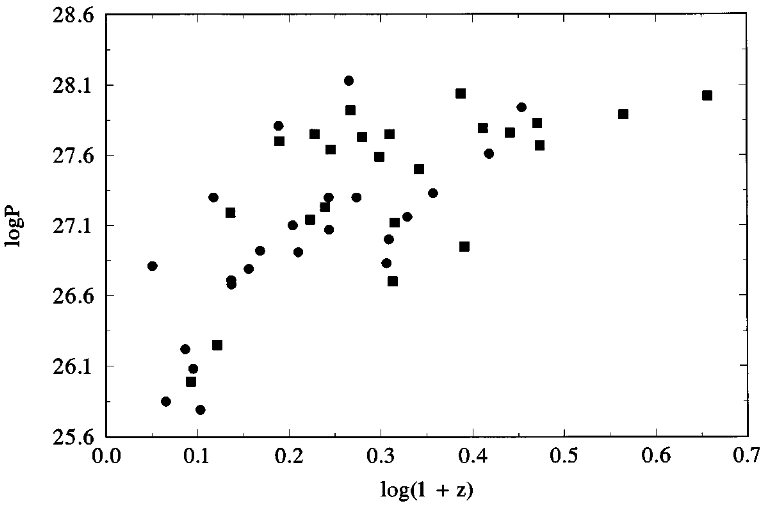


Fig. 1. Plot of luminosity versus redshift for CSS radio galaxies (circles) and quasars (squares).

plane is probably a reflection of the strong luminosity selection effects usually reminiscent of bright, flux-density-limited samples. Similar correlations are known to exist among their more extended counterparts, and are usually attributed to the well-known Malmquist bias (e.g. Onuora and Okoye 1983; Ubachukwu 1997).

We show in Fig. 2 the plots of the observed linear size–luminosity (D–P) relation for both radio galaxies and quasars in the present sample. Although the plots show a large scatter, there appears to be a general indication of a decrease in linear size with increasing radio luminosity. Quantitative analysis using a power-law variation of linear size with luminosity of the form $D \sim P^{-q}$ gives $q \sim 0{\cdot}6 \pm 0{\cdot}1$ ($r \sim 0{\cdot}4$) for quasars and $q \sim 0{\cdot}2 \pm 0{\cdot}1$ ($r \sim -0{\cdot}2$) for radio galaxies. The two results appear statistically different and therefore contrary to the expectations of the orientation-based unification scheme. Ubachukwu and Ogwo (1998) have shown that one of the major considerations when investigating the quasar/galaxy unification scheme is to ensure that the two classes of object are properly matched in redshift and/or luminosity. (As shown above, both P and z are strongly correlated with each other in flux-density-limited samples.) Excluding the three high redshift ($z \leq 0.2$) quasars from the analysis gives $q \sim -0.09$ (with $r \sim -0.1$), which agrees closely with the value obtained for the radio galaxy subsample. This result is in good agreement with the Barthel (1989) unification scheme.

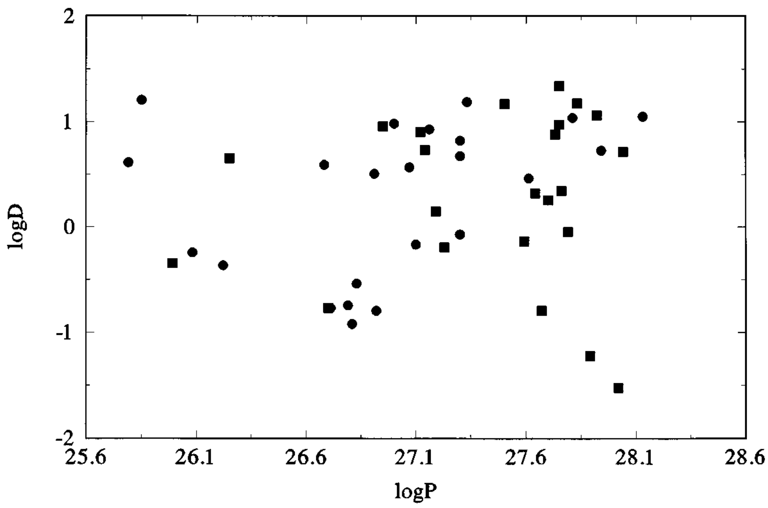


Fig. 2. Plot of linear size versus luminosity (symbols as in Fig. 1).

Finally, we show in Fig. 3 the observed dependence of linear size on redshift for the two subsamples. Taken together, the plots show a wide scatter in which it is difficult to discern any obvious trend. However, the sizes of radio galaxies appear to increase with redshift while the reverse seems to be the case for quasars. One-dimensional linear regression analysis of log$D$ against $\log(1+z)$ for each subsample shows $D \sim (1+z)^{-n}$, with $n \sim -1{\cdot}4 \pm 0{\cdot}3$ ($r \sim -0{\cdot}5$) for radio galaxies and $n \sim 2{\cdot}9 \pm 0{\cdot}4$ ($r \sim 0{\cdot}3$) for quasars. Apparently, these results suggest an intrinsic difference in the behaviour of the two classes of object in the

D–z plane. Repeating the quasar analyses after excluding the three high redshift sources now yields $n = -1{\cdot}4 \pm 0{\cdot}3$ with $r \sim -0{\cdot}3$. This result is now similar to that obtained for the radio galaxy subsample. Apparently, the D–z results seem to mimic those obtained from the D–P analyses and suggest that any intrinsic difference in the observed D–P/z relationship between radio galaxies and quasars could be attributed to the differences in their redshift distributions. The present results are thus consistent with the orientation-based unification hypothesis in which radio galaxies and quasars are expected to be statistically similar in all their orientation-invariant parameters. This is particularly true when the two classes of object are properly matched in their redshifts.

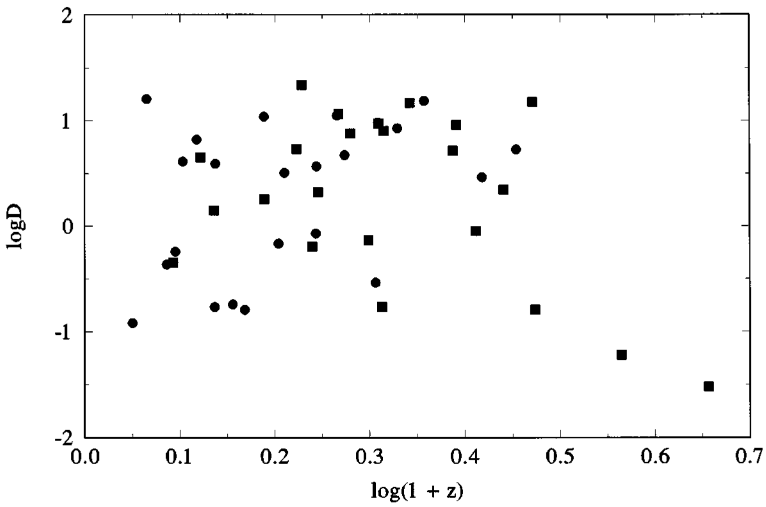


Fig. 3. Plot of linear size versus redshift (symbols as in Fig. 1).

3. Discussion

Here we discuss the conclusions that can be drawn from the results of the analysis presented in the preceding section. Although the statistics are rather poor, there appear to be some similarities in the correlations of intrinsic properties of CSS radio galaxies and quasars, which fundamentally argue in favour of the unification hypothesis in which the two classes of object are expected to differ only in their aspect-dependent properties. In particular, the distribution of linear sizes (D) of both quasars and radio galaxies in the luminosity–redshift (P–z) plane are expected to be indistinguishable. This is confirmed in the present study, especially when the two subsamples are properly matched in redshift.

Spencer *et al.* (1989) have pointed out that the observed differences in the radio morphologies of CSS quasars and CSS radio galaxies could not be explained simply in terms of interaction of jets with a dense interstellar medium in quasars. They concluded that projection effects, with the jet axis of quasars pointing at closer angle to the line of sight, could explain the observed structures. They conceded, however, that there were some other features relating to relativistic beaming that were not observed.

More recently, Saikia *et al*. (1995) have examined the consistency of CSSs with the Barthel (1989) unification scheme, using their core-to-lobe emission ratios f_c as an orientation indicator. They found a difference in the values of f_c between radio galaxies and quasars, which is consistent with the unified scheme in which quasars are expected to be oriented within some cone angle to the line of sight, while radio galaxies are expected to lie outside this angle. Moreover, they found from the correlations between f_c and other aspect-dependent parameters that, while the effects of relativistic beaming are more pronounced in quasars, the galaxy subsample appears to be consistent with a scenario in which the jets are interacting with an asymmetric environment. It should be noted, however, that it is not possible to unambiguously discriminate between the relativistic beaming and interaction scenarios (e.g. Hough and Readhead 1989).

One major argument against the quasar/galaxy unification scheme, especially for the more extended sources, is the suggestion that the size distributions of radio galaxies in the P–z plane differ significantly from those of quasars (e.g. Kapahi 1990; Singal 1993, 1996; Gopal-Krishna and Wiita 1996; Gopal-Krishna *et al*. 1996*a*, 1996*b*). However, Ubachukwu and Ogwo (1998) have argued that the difficulties in reconciling the quasar/galaxy sizes with the unified scheme could be due to the differences in their redshift distributions. Similar conclusions are again arrived at in the present analyses based on compact steep-spectrum sources. Also, Gopal-Krishna *et al*. (1996*b*) have observed that these inconsistencies can be removed by making allowance for the temporal evolution of radio sources in both linear size and luminosity.

In summary, it has been shown that CSS radio galaxies and quasars have similar size distributions in the luminosity–redshift plane, provided that the two classes of object are properly matched in their redshifts. This result is consistent with a pure orientation-based unification hypothesis in which radio galaxies and quasars are expected to be indistinguishable in all their orientation-invariant properties. Since the statistics are currently very poor, we need a larger, complete sample to confirm these conclusions.

Acknowledgment

AAU wishes to acknowledge the IAU Commission 38 Travel Grant to South Africa where this work was done. It is a pleasure to thank the Director and staff of Hartebeesthoek Radio Astronomy Observatory for hospitality and encouragement. The authors acknowledge useful criticisms by an unknown referee.

References

Akujor, C. E., Spencer, R. E., Zang, F. J., Davis, R. J., Browne, I. W. A., and Fanti, C. (1991). *Mon. Not. R. Astron. Soc.* **250**, 2151.

Barthel, P. D. (1989). *Astrophys. J.* **336**, 606.

Dallacasa, D., Fanti, C., Fanti, R., Schilizzi, R. T., and Spencer, R. E. (1995). *Astron. Astrophys.* **295**, 27.

Fanti, C., Fanti, R., Dallacasa, D., Schilizzi, R. T., Spencer, R. E., and Stangellini, C. (1995). *Astron. Astrophys.* **302**, 317.

Fanti, R., Fanti, C., Schilizzi, R. T., Spencer, R. E., Nan Rendong, Parma, P., Van Breugel, W. J. M., and Venturi, T. (1990*a*). *Astron. Astrophys.* **231**, 333.

Fanti, C., Fanti, R., Schilizzi, R. T., Spencer, R. E., Van Breugel, W., Parma, P., Venturi, T., and Nan Rendong (1990*b*). *In* 'Compact Steep Spectrum and GHz Peaked Radio Sources' (Eds C. Fanti *et al*.), p. 48 (Instituto di Astronomia: Bologna).

Gopal-Krishna, Kulkarni, V. K., and Hooda, J. S. (1996*a*). *Astron. Astrophys.* **316**, L13.
Gopal-Krishna, Kulkarni, V. K., and Wiita, P. J. (1996*b*). *Astrophys. Lett.* **463**, L1.
Gopal-Krishna and Wiita, P. J. (1996). *Astrophys. J.* **467**, 191.
Hough, D. H., and Readhead, A. C. S. (1989). *Astron. J.* **98**, 1208.
Kapahi, V. K. (1990). *In* 'Parsec Scale Jets' (Eds J. A. Zensus and T. J. Pearson), p. 304 (Cambridge Univ. Press).
Laing, R. A., Riley, J. M., and Longair, M. S. (1983). *Mon. Not. R. Astron. Soc.* **183**, 204.
Mutel, R. L., Hodges, M. W., and Phillips, R. B. (1985). *Astrophys. J.* **290**, 86.
Onuora, L. I., and Okoye, S. E. (1983). *Astrophys. J.* **270**, 360.
Peacock, J. A., and Wall, J. V. (1982). *Mon. Not. R. Astron. Soc.* **198**, 843.
Saikia, D. J., JeyaKumar, S., Wiita, P. J., Sanghera, H. S., and Spencer, R. E. (1995). *Mon. Not. R. Astron. Soc.* **276**, 1215.
Sanghera, H. S., Saikia, D. J., Ludke, E., Spencer, R. E., Foulsham, P. A., Akujor, C. E., and Tzioumis, A. K. (1995). *Astron. Astrophys.* **295**, 629.
Singal, A. K. (1993). *Mon. Not. R. Astron. Soc.* **263**, 139.
Singal, A. K. (1996). *In* 'Extragalactic Radio Sources', IAU Symp. 175 (Eds R. Ekers *et al.*) p. 563 (Kluwer: Dordrecht).
Spencer, R., McDowell, J. C., Charlesworth, M., Fanti, C., Parma, P., and Peacock, J. A. (1989). *Mon. Not. R. Astron. Soc.* **240**, 657.
Spencer, R., *et al.* (1991). *Mon. Not. R. Astron. Soc.* **250**, 225.
Ubachukwu, A. A., and Ogwo, J. N. (1998). *Aust. J. Phys.* **51**, 143.
Wilkinson, P. N., Spencer, R. E., Readhead, A. C. S., Pearson, T. J., and Simon, R. S. (1984). *In* 'VLBI and Compact Radio Sources', IAU Symp. 110 (Eds R. Fanti *et al.*), p. 25 (Reidel: Dordrecht).

Manuscript received 12 February 1997, accepted 24 September 1998