THE ANGULAR DIAMETER-REDSHIFT TEST FOR LARGE REDSHIFT QUASARS

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Complete samples of quasars in the 3CR and 4C catalogues have been observed with a resolution of 2" arc in RA and 2" cosec δ in dec with the Cambridge 5-km telescope at 5 GHz (Riley & Pooley 1975; Jenkins et al 1977), from which it has been possible to determine the overall angular sizes of their radio structures (LAS). The angular diameter-redshift test for quasars has been reexamined using these data; details are described fully elsewhere (Hooley et al 1977).

The samples of quasars used were selected as follows:
a) the 40 quasars in the complete sample of 166 3CR sources which have flux densities $S_{178} \geqslant 10$ Jy using the values given by Kellermann et al (1969), $\delta \geqslant 10^o$ and $|b| \geqslant 10^o$.
b) the 19 quasars with $z > 1.5$ and flux densities $S_{178} \geqslant 2.5$ Jy in the complete samples of 4C quasars of Lynds & Wills (1972) and Schmidt (1975).

1. THE ANGULAR DIAMETER-REDSHIFT DIAGRAM

The angular diameter-redshift (θ - z) plot is shown in Fig. 1. It includes all the radio galaxies and quasars with measured redshifts in the sample of 166 3CR sources and the 19 4C quasars with $z > 1.5$. It can be seen from this plot that the well-defined upper bound noted by Miley (1971) still remains. Comparison of this plot with the expectations of homogeneous world models, and its interpretation, depend on whether the quasars and radio galaxies are treated separately or not. If they are considered together, the upper bound is best described by the line corresponding to $\Omega = 0$, though the line $\theta \propto z^{-1}$ is also a reasonable fit. For the quasars alone, however, the upper bound is more or less independent of z and a large value of Ω would fit the data well; this result is similar to that of Hewish et al (1974) which is based on the distribution of the angular diameters of the compact structure within radio components as determined by the scintillation technique, a sample which is also dominated by quasars.

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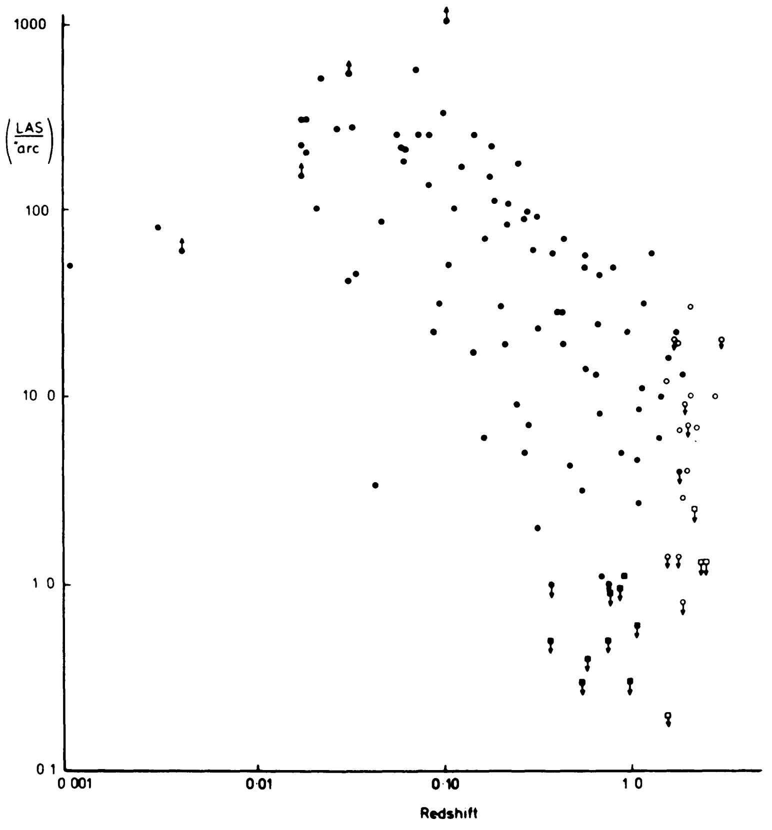

Fig. 1. The angular diameter-redshift diagram for all the radio galaxies and quasars with redshifts in the 166 sample of 3CR sources (filled circles and squares) and the 19 4C quasars with z > 1.5 (open circles and squares).

2. VARIATIONS IN THE OVERALL PHYSICAL SIZES OF QUASARS WITH REDSHIFT

The present data may be used to test whether the overall physical sizes of radio sources of given luminosity are smaller at large redshifts. A plot of the radio luminosity at 178 MHz emitted frequency, P, against overall physical size, D, for all the quasars in the present samples is shown in Fig. 2; it is assumed that $\Omega = 0$ and $H_0 = 50$ km s^{-1} Mpc^{-1}. The test can be made by inspection of Fig. 2 in the region in which there is a mixture of sources of large and small redshifts in the same range of intrinsic luminosity i.e. $6 \times 10^{27} \lesssim P \lesssim 3 \times 10^{28}$ W Hz^{-1} sr^{-1}. In this region, the 4C quasars with z > 1.5 span the same range of physical sizes as the 3CR quasars with z < 1.5 and, in particular, the source 4C 28.40 with z = 1.989, is almost as large as the most extended sources at small redshifts. The significance of this result is not great in view of the very small sample. It is interesting to note from Fig.2

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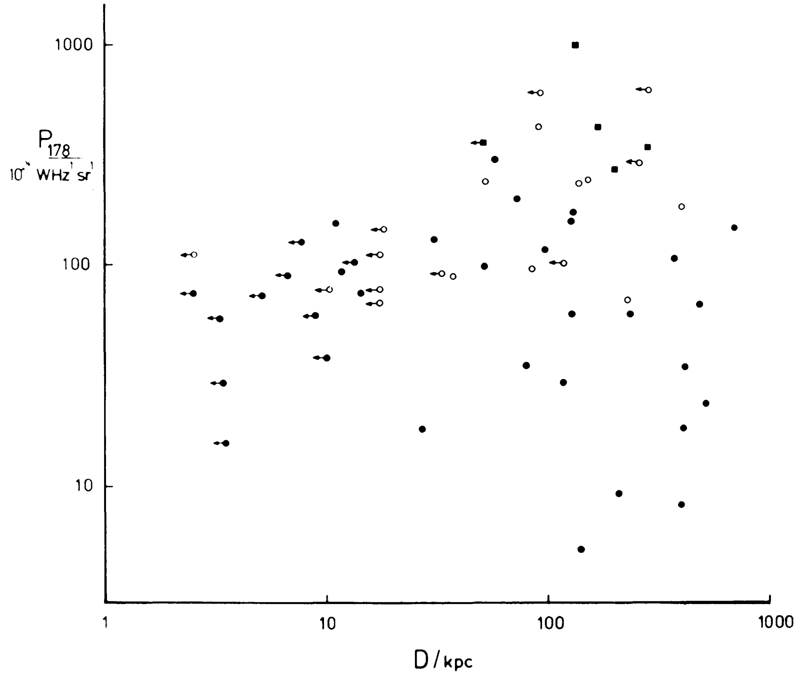

Fig. 2. The luminosity-linear size plot for the 40 quasars in the 3CR 166 sample and the 19 4C quasars with z > 1.5 for $\Omega = 0$. The symbols used are : ● 3CR quasars with z < 1.5, ■ 3CR quasars with z > 1.5, ○ 4C quasars.

that the most luminous sources in the samples are not the most compact.

3. THE STATISTICS OF QUASARS IN THE 3CR AND 4C SAMPLES

Because the 4C quasars are drawn from complete samples it is possible to compare the actual numbers of quasars in different angular size and redshift ranges with the numbers predicted from the 3CR sample of quasars. In this way the overall distributions of physical size in the samples can be used rather than just the upper bound in the θ - z plot or the crude distribution in the P - D diagram.

In order to predict from the 3CR sample the numbers expected in the 4C samples, it is necessary to take account of the effects of cosmological evolution on the comoving space density of quasars at large redshifts. The evolution laws derived by Jackson (1974) from the combined 3CR sample and the 4C sample of Lynds & Wills (1972) were adopted. It was then assumed that the 3CR quasar sample is complete down to 10 Jy, and hence the space density of quasars, with physical properties similar to those of a given 3CR quasar, can be derived directly from the limiting redshift at which that 3CR quasar could be observed and still remain in

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the 3CR sample. The angular size distributions expected for quasars in the 4C samples similar to each 3CR quasar were calculated taking account of the optical ($m_v \leqslant 19.5$) and radio limits ($S_{178} \geqslant 2.5$ Jy) of the 4C samples. The predicted distributions for $\Omega = 0$ and $\Omega = 1$ were very similar.

There is excellent agreement between the predicted and observed angular size distributions for 4C quasars with $z > 1.5$ for both the $\Omega = 0$ and $\Omega = 1$ cases. This indicates that at least down to a flux density level of 2.5 Jy at 178 MHz the observations are consistent with the hypothesis that the physical sizes of the most powerful quasars do not change with cosmological epoch. It is important to note that this method of using each 3CR quasar individually means that any correlations between the radio luminosity and overall linear size of quasars are automatically incorporated in the predictions.

This result is in marked contrast to that of Swarup (1975) and Kapahi (1975) who find that evolution in physical size is required to explain their angular size-flux density relation. However, as the fraction of quasars in their samples is small, exclusion of known quasars from their samples has little effect on the degree of physical size evolution required to explain their data, and there is little evidence from their data alone for physical size evolution in quasars. The apparent contradiction between the two results could therefore be reconciled by a difference between the overall physical size evolution in radio galaxies and quasars.

4. CONCLUSIONS

The results of this investigation are consistent with the hypothesis that the overall physical sizes of the radio structures of quasars of the highest radio luminosity do not change with cosmological epoch.

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DISCUSSION

THE LARGEST ANGULAR SIZE-REDSHIFT DIAGRAM FOR A COMPLETE SAMPLE OF QUASARS

J.F.C. Wardle and R. Potash

The complete sample of quasars from the 3C and 4C catalogues, recently published by M. Schmidt, has been mapped using the NRAO three element interferometer, and a new LAS-z diagram has been constructed. There is an apparent lack of large redshift large linear size quasars. In a $q_o = 0$ cosmology, which minimises this effect, it is still significant at a level of about 2%. The distribution in redshift and luminosity of the quasars has been analysed using Lynden Bell's C^m method, for three groups of linear size. There is no evidence of a difference in their spatial distribution between the largest and the smaller quasars. However, the optical luminosity junctions appear to be significantly different, in the sense that the luminosity function of the largest sources cuts off at a lower maximum luminosity than that of the smaller sources. The average optical luminosity, F(2500 Å $_{emitted}$) is a factor of 2 less for sources larger than 200 kpc. The distributions of the ratio of radio to optical luminosity show no significant dependence on linear size, implying that on the average the radio luminosities are also smaller for the largest sources.

We suggest that as a source reaches large linear sizes and becomes older, its optical and radio luminosities both decline, leading to an under representation of large sources in any sample which is limited in flux density and apparent magnitude. There is no evidence that the space density of large sources evolves differently from the smaller ones at large redshifts.

Wardle: Several speakers have suggested that the linear size distribution of quasars changes with redshift. I want to stress that our results are in complete agreement with those presented by Mrs. Riley, and we both find no evidence that the linear size distribution is different at high redshifts.

Readhead: Julia Riley has shown that in the complete sample of 3CR and 4C quasars the upper envelope of the LAS distribution does not show the decrease with redshift which is found in the complete sample of 3CR quasars and radio galaxies. As she mentioned, the scintillation results show an apparent lack of component angular size with redshift. I wish to point out that if one looks at the scintillating radio galaxies in the complete 3CR sample, there is good continuity of their LAS with those of the quasars, and that for these galaxies too there is no variation with redshift in the upper envelope to the LAS distribution.

Condon: I would like to point out an important selection effect on the QSO angular diameter-redshift test. This test for QSO's is affected by any incompleteness which depends on source diameter. The spectra of sources identified in samples found at 11cm (Condon, Balonek and

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Jauncey, Astrophys. J. 79, 1220, 1975) and 6cm (Condon, Balonek and Jauncey, Astrophys. J. 80, 887, 1976) indicate that the larger diameter QSO's have relatively low optical-to-radio luminosity ratios. All radio selected QSO's belong to optically incomplete samples (in the sense that empty fields remain), and the high redshift large diameter QSO's are the most likely to be missed. The result of this selection is to make it appear that we are in a static Euclidean universe (Miley, Mon. Not. Roy. Astron. Soc., 152, 477, 1971, Wardle and Miley, Astron. & Astrophys., 30, 305, 1974).

A closely related selection effect explains the apparent excess of QSO's larger than 7 arc sec in the northern galactic hemisphere relative to the southern galactic hemisphere (Miley 1974). The radio surveys which found the sources in the two hemispheres were made at different frequencies; the southern sources being found at the higher frequency. A chi-squared test shows that the division of sources into the steep and flat spectrum groups in the northern (50 steep, 23 flat) and southern (25 steep, 24 flat) galactic hemispheres is nearly as significand as the anisotropy in angular sizes. Thus statistical QSO diameter-redshift tests should not be used to determine either the geometry of the universe or the evolution of QSO's unless the QSO sample is both optically complete and taken from a single, homogeneous radio survey.

Ekers: I wish to emphasise that the effects of optical selection on the $\theta(z)$ relation do not apply to the $\theta(s)$ relation. Perhaps the fact that the linear size evolution effects required to explain the $\theta(s)$ relation are weaker than those apparently required to explain the $\theta(z)$ results from this optical solution effect in the $\theta(z)$ data.