THE RADIO STRUCTURE OF QUASARS

G. K. MILEY and G. H. MACDONALD*
*National Radio Astronomy Observatory,*** *Green Bank, West Va., U.S.A.*

Abstract. The statistics on the angular structures of quasars have been more than doubled. Quasars are discussed from both morphological and statistical viewpoints and the angular diameter-redshift relation has been confirmed.

1. Introduction

Measurements of the radio structures of quasars are important for several reasons. Firstly, any understanding of the astrophysical processes in quasars must take into account both the morphology and the physical dimensions of the radio emitting regions. Secondly, if established, a relation between angular size and redshift would place constraints on the nature of the redshifts. Thirdly, if the redshifts are cosmological in origin, the statistics of quasar angular sizes might be a valuable new tool for investigating the geometry of the Universe.

Recently we investigated the structures of seventy-nine quasars using the 2695 MHz three-element interferometer at Green Bank with resolutions of up to 3″. All of these quasars had measured redshifts but structures that were previously unknown. Combining our data with those of other workers gives structural information on 128 quasars at the same observing frequency and with similar resolution.

2. The Morphology

A summary of the results is displayed in Table I. At 2695 MHz about half of all quasars have structures >5″, more than 20% are larger than 30″, and some are as large as 150″. We hope that this will dispel the widely prevalent illusion that the radio dimensions of all quasars are very small.

TABLE I
Interferometer observations of 128 quasars

	Number
Unresolved (< 2″ near PA 70°, < 7″ in any PA)	55
Slightly resolved (3″–10″)	10
Well resolved (> 5″)	63

* Present address: University of Kent, Canterbury, England.
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D. S. Evans (ed.), External Galaxies and Quasi Stellar Objects, 216–221.

The structures of the well resolved sources can be classified as follows:

'D1': Two well-separated emitting regions, neither of which coincides with the optical QSO (7 sources).

'D2': Two well-separated emitting regions, one of which coincides with the optical QSO (2 sources).

'C': Triple or more complex (7 sources).

Most of the remaining sources appeared double but were not sufficiently resolved to establish whether the two emitting regions were separated or whether there was a bridge or third component between them.

D1 quasars (like 3C 47) and C quasars have quite similar radio components and relatively steep radio spectra which do not vary with time. On the other hand, a D2 quasar (like 3C 273) has one small active component coincident with the optical QSO, having an anomalous radio spectrum and a second larger component with a much steeper radio spectrum. It is likely that some of the sources which we find to be unresolved at 2695 MHz will be found to be D2 quasars when observed at lower frequencies, where the steep spectrum components contribute significantly to the total flux density of the source.

3. The Angular Size-Redshift Relation

We have now enough measurements of quasar angular structures to start playing

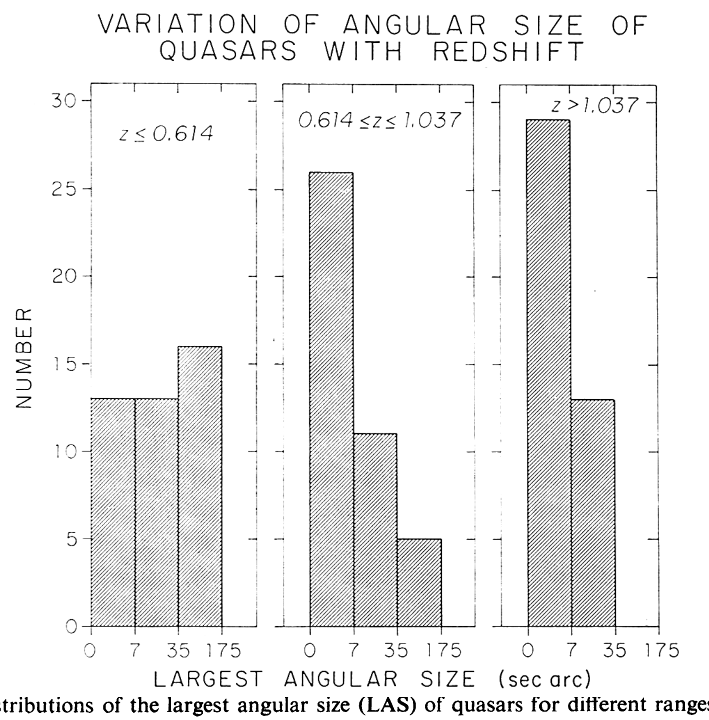

Fig. 1. Distributions of the largest angular size (LAS) of quasars for different ranges of redshifts.

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the 'correlation game'. Just over two years ago Miley measured single fringe visibility points for seventy-six quasars. Despite the limited data he showed that for quasars with steep spectra the mean visibility increased with redshift, implying that the angular sizes of their radio components probably decreased with increasing redshift. Subsequently, Legg, and independently Miley and Macdonald, showed that the separation of known double quasars also appeared to decrease with increasing redshift. We have now more than doubled the available data and are therefore in a position to re-examine this correlation.

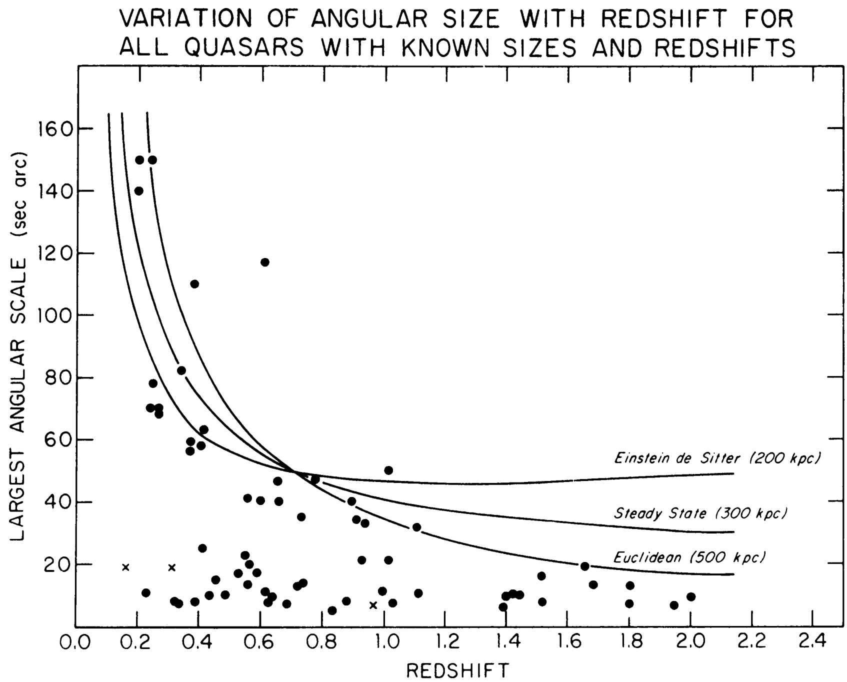

Fig. 2. Variations of LAS with redshift, z, for all quasars with known redshift and with angular size $\lesssim 7''$.

We have first divided our sample into three different redshift ranges with equal numbers in each and have drawn histograms of the three angular size distributions. These are shown in Figure 1 from which the decrease of largest angular size (LAS) with redshift is strikingly evident. Figure 2 is a plot of LAS against redshift for all quasars with known redshift and angular size. The curves show the expected behaviour for sources of constant physical size in different model Universes. The observed angular size will always lie below these envelopes because of projection effects. In Figure 2 we have been arbitrary in excluding the unresolved quasars. We can do this in a more satisfactory way by using the radio spectrum of the source as a suitable criterion. Figure 3 shows the same result for all quasars (including the unresolved ones) which have spectral indices steeper than -0.5 and which definitely have no low frequency cutoff in radio emission between 20 and 100 MHz. As you can see, not many unresolved sources remain here from our original fifty-five.

Although more statistics are needed, there is an indication in Figures 2 and 3 that the angular size falls off with redshift faster than one might expect for most cosmological models and in fact the best agreement occurs for a Euclidean universe. However, Rees and Sciama, van der Laan and Christiansen have all pointed out that inverse Compton losses due to the background radiation should increase as $(1+z)^4$ and would therefore 'snuff-out' physically large quasars at high redshifts.

Also, in our diagrams we have used structures obtained at the same *observing* wavelength (11.1 cm). A more useful comparison would be between structures measured

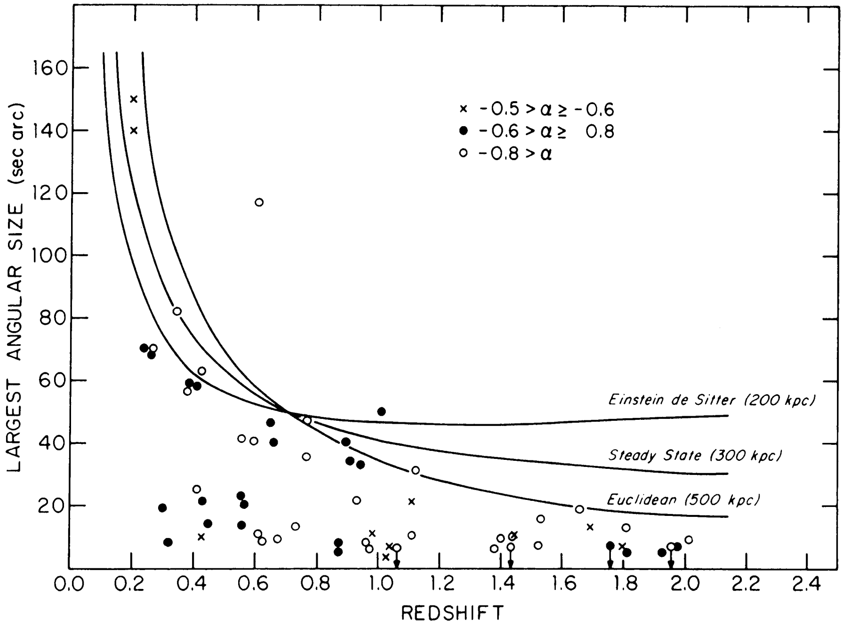

Fig. 3. Variations of LAS with redshift, z, for quasars with known redshift and angular size which have their spectral indices steeper than -0.5 and have no low-frequency cutoff.

at the same *emitted* wavelength. For the high redshift quasars the corresponding emitted wavelength is as short as 3 cm. As yet we have no knowledge of the structures of the small redshift quasars at 3 cm, but there is little evidence to expect that at this wavelength they should have very different structures from those observed at 11 cm.

Figure 4 is a combination of data from quasars and radio galaxies plotted logarithmically. It shows very clearly the continuity in overall angular size. Since this continuity must be explained by any theory of quasar redshifts, it is improbable that the origin of the redshift of quasars differs appreciably from that of the redshift of radio galaxies.

Finally we would like to mention briefly an apparent anisotropy which we observed when we plotted our angular size data on the sky. The small sources tended to cluster

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in the southern galactic hemisphere and there was a difference in the angular size distributions between the two hemispheres which is statistically significant at better than the 1% level. This can be explained because firstly, we have seen that angular size decreases with redshift and secondly in our complete sample there are relatively more high redshift quasars in the southern galactic hemisphere. The explanation for

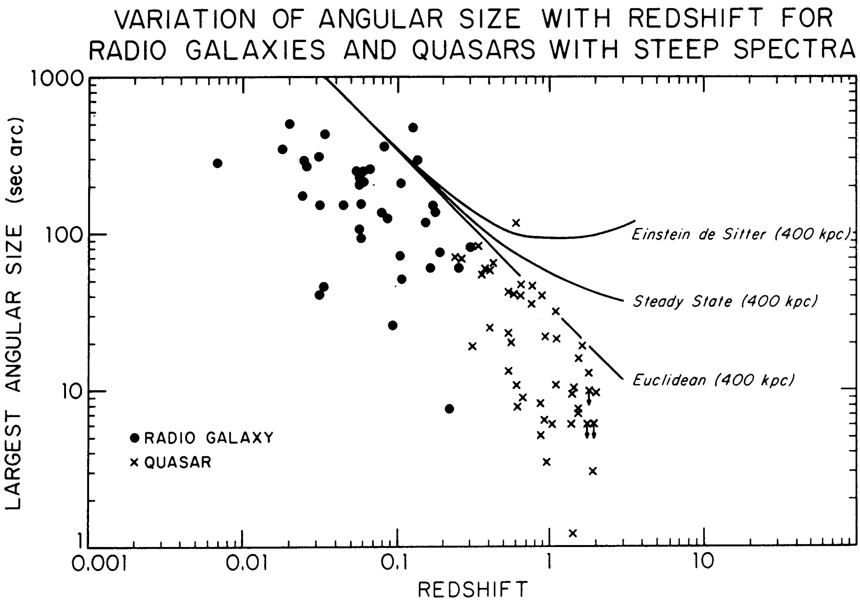

Fig. 4. Variation of LAS with redshift for quasars and galaxies with steep spectra and no low frequency cutoff.

the apparent anisotropy of angular sizes therefore lies with the unequal distribution in the observed redshifts. Complex selection effects occur when comparing optical spectra taken for different redshifts and the reality of this redshift anisotropy is a question for the optical astronomers.

4. Conclusion

We have shown that the largest angular size of quasars with steep spectra decreases with increasing redshift. This is the strongest observed correlation between the radio and optical properties of quasars and indicates that in future the linear diameter may be a more useful 'standard candle' in cosmology than is the luminosity.

Discussion of Papers Read by Palmer and Miley

Longair: Two comments. Firstly, Pooley and I have performed a redshift-angular diameter test for radio sources of large angular size by comparing the numbers of such sources in the 3C and 5C catalogues. We find that there is an excess of such sources in the 5C catalogue. This is, of course, not inconsistent with the present results since our test probably refers to intrinsically weaker radio galaxies.

Secondly, there are difficulties with the hypothesis that inverse Compton scattering of the relict radiation by the relativistic electrons originating in extragalactic radio sources can snuff out radio sources at large redshifts. Normally, this effect will be accompanied by an increase in the radio spectral indices of distant sources at the observing frequency and should be apparent in the spectral index distribution of QSOs at large redshifts. The absence of these changes in mean spectral index suggests that inverse Compton scattering does not affect the properties of distant QSOs. (M. S. Longair: 1970, *Monthly Notices Roy. Astron. Soc.*, in press).

Shakeshaft: Could Dr Palmer please clarify his plot of axial ratio of double sources against flux density? There are dangers in plotting together data from surveys with different resolving power.

Mackay: In connection with the plot of flux density against axial ratio (overall angular size divided by component size) shown by Dr Palmer, I think it unlikely that the lack of bright sources of large axial ratio is a real effect. The majority of sources in the Cambridge work from which Dr Palmer has taken the axial ratios for the bright sources have only lower limits to their axial ratios and so are not shown on his plot. Some of these limits are already very large, and as the Cambridge telescope is very different from that used by Dr Palmer, it seems probable that any effect may be attributed to differences in instrumental limitations.

Palmer: Almost all the comparison group of sources from the 3CR catalogue have also been observed with interferometers of baselines $\geqslant 20000\ \lambda$. I therefore believe that any double sources with separation $\geqslant 30$ arc sec and axial ratios in excess of 20, if present, are already known.

Miley: Because Cygnus A is the strongest known extragalactic radio source, it is possible to investigate its structure in more detail than that of any other such source. As Dr Palmer has mentioned Cygnus A in his talk, I would like to report some recent unpublished observations on the microstructure of this source by myself and Dr Wade. On a large scale Cygnus A has long been known to consist of two very similar components separated by about 2 arc min and located asymmetrically about the optical galaxy. Each component is extended by ~ 30 arc sec and has a small bright core near its outer edge. We have resolved both of these cores with the 2695 MHz radio link interferometer at Green Bank using baselines of up to 35 km or 3×10^5 wavelengths.

The data for the westerly core can be explained by a double model with components extended by ~ 1 arc sec and separated by 4.6 arc sec in a position angle of 130° (inclined by 20° to the main axis of the source). The data for the easterly core, although more difficult to interpret, show that it consists of at least two components (and not many more) with sizes ~ 0.5 arc sec.

These compact regions that we have found must all have brightness temperatures in excess of 3 million deg, a factor of about ten greater than the background source. Each of them subtends an angle of less than one degree at the parent galaxy. The double nature of at least one of them is of considerable interest since in this respect it would appear that the microstructure of extragalactic sources resembles the large scale structure.