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Orientations of extended radio sources in the Third Bologna (B3) catalogue

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Summary. We have mapped all 157 B3 radio sources within 3° of RA $14^h\,15^m$, Dec +39° at 1.3 arcsec resolution at 21 cm, using the VLA in its 'A' configuration. We find that the 83 extended sources in this sample are randomly oriented. This contrasts with the tendency towards parallelism on these angular scales that was previously reported by Willson and by Sanders.

1 Introduction

Willson (1972) and Sanders (1984) have reported that extended extragalactic radio sources tend to be parallel to one another if separated by less than a few degrees on the sky. Willson's Sample comprised 74 extragalactic radio sources that had been mapped by the Cambridge One-Mile radio telescope. He found that the mean angle between pairs of sources that are separated by less than 10° (as measured along the great circle connecting the sources) is about 35°. If sources are randomly oriented with respect to each other, this angle should be 45°. For the number of source pairs considered by Willson, the tendency towards alignment represented a 2σ fluctuation with a formal significance of about 10 per cent.

Sanders used the same technique to analyse two larger samples, each of about 300 sources. The first sample consisted of published maps of radio sources, mostly from the 3C and 4C catalogues, that had been observed with several different radio instruments. He found significant alignments when the sample was restricted to sources identified with objects at redshifts greater than 0.4; with this restriction, the mean angle between radio sources separated by less than 5° was about 36°, representing a 3.4σ deviation with a formal significance of about 3 per cent. He therefore

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inferred that the effect was present primarily in distant radio sources. His second sample consisted of unpublished VLA maps of sources from the Third Bologna (B3) catalogue (Ficarra, Grueff & Tomassetti 1985; R. Perley, B. Clark, A. Bridle & G. Grueff, in preparation). Significant (4.3σ) alignment was detected in pairs of sources separated by less than 10° when this sample was restricted to sources with angular sizes <42 arcsec. Since these B3 sources are mainly small doubles with no optical counterparts on the Palomar Sky Survey, they are probably distant radio galaxies or quasars beyond the Sky Survey. The angular size restriction applied to the B3 sample should therefore be roughly equivalent to the distance restriction applied to the 3C and 4C samples. Sanders therefore concluded that both samples provided evidence for alignment of distant radio sources.

Kapahi, Subrahmanyan & Singal (1985) have since examined the orientation statistics of three other large samples of radio sources: sources mapped by lunar occultation techniques (Joshi & Singal 1980), sources from the GB and GB2 radio surveys (Machalski & Condon 1983), and a sample consisting of sources with published maps which should be comparable to the first sample considered by Sanders. They found no significant tendency for alignment in the first two samples. In the third sample, the tendency towards alignment was only marginal (2σ). Kapahi *et al.* therefore questioned the reality of the alignment effect. We have since verified that the algorithms used by Kapahi *et al.* and by Sanders to analyse the position-angle data are identical, so the difference between their results reflects different properties of their samples, rather than different methods of analysis.

If distant extended radio sources were indeed aligned over scales of several degrees, the cosmological implications would be profound, for either of two possible interpretations. The first interpretation (Oort 1984) is that radio sources form in large-(100 Mpc) scale structure which is already present at early cosmological epochs ($z>1$) and then reflect that structure in their orientations. The second interpretation is that images of distant sources are gravitationally distorted by intervening massive ($\sim 10^{14}\, M_\odot\, \mathrm{Mpc}^{-1}$), thin (~1 Mpc), and long (~50 Mpc) filaments or strings along the line-of-sight (Sanders, van Albada & Oosterloo 1984). It is therefore important to obtain further evidence bearing on the alignments of distant radio sources.

2 A new source sample

A good test for the effect (Sanders 1984) is to map all radio sources down to a low flux density limit in a region of the sky that is a few degrees across. If sources are everywhere aligned on scales of degrees, this alignment should appear as a non-uniform distribution of source position angles in such a sample.

We have made such an observation with the VLA in its 'A' configuration at 21 cm. We made 'snapshot' maps of all 157 B3 sources within 3° of RA $14^{\mathrm{h}}\, 15^{\mathrm{m}}$, Dec +39°. We observed the quoted position for each B3 source for about 90 s, using two 50-MHz bandwidths, centred on 1415 and 1465 MHz. The data from both bandwidths were combined to map each field with a resolution of 1.3 arcsec and an rms noise (after 'CLEAN'ing) that was typically 0.2 mJy per 'CLEAN' beam area. The maps were made and 'CLEAN'ed using the ungridded subtraction algorithm 'MX' in the NRAO Astronomical Image Processing System ('AIPS').

Eighty-three of the detected sources were resolved into structures which were simple enough (usually a 'classical' double or triple) to define unambiguous orientations on the sky. Most of the sources are near the B3 flux density limit of 100 mJy at 408 MHz; judging from the optical identifications of previously mapped B3 sources (G. Grueff, private communication), most such sources cannot be optically identified to the limit of the Palomar Sky Survey. We therefore expect that this sample is dominated by distant radio galaxies at redshifts $z\sim 1$ and would therefore meet the distance criterion for alignments suggested by Sanders (1984).

3 Orientations of sources in the new sample

Fig. 1 shows the observed distribution of the position angles of the 83 extended structures in the new sample. It is clearly random, showing immediately that there is no evidence in this part of the sky for alignments on the scale of 3 to 5°.

Alignments between closer pairs can be investigated using the algorithm described by Willson (1972). Fig. 2 shows the result as a plot of the mean angle between two radio sources in a pair as a function of angular separation of the two sources, binned in separation intervals of 0°.5. The expectation value for randomly oriented radio sources is 45°, with an rms fluctuation of $45/\sqrt{3n}$ where n is the number of pairs in the separation bin. The error bars show this $\pm 1\sigma$ variation. There is clearly no tendency for pairs in this sample to be aligned, down to separations of 0°.5. The

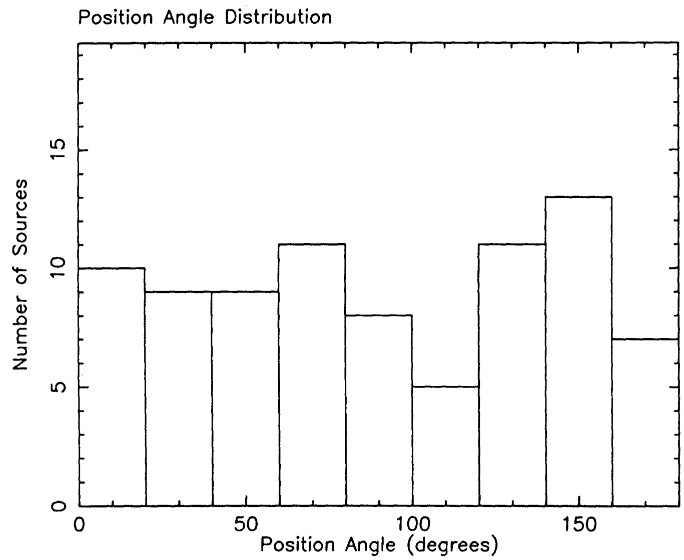

Figure 1. The distribution of the position angles of the major axes of the 83 clearly resolved sources in the present sample.

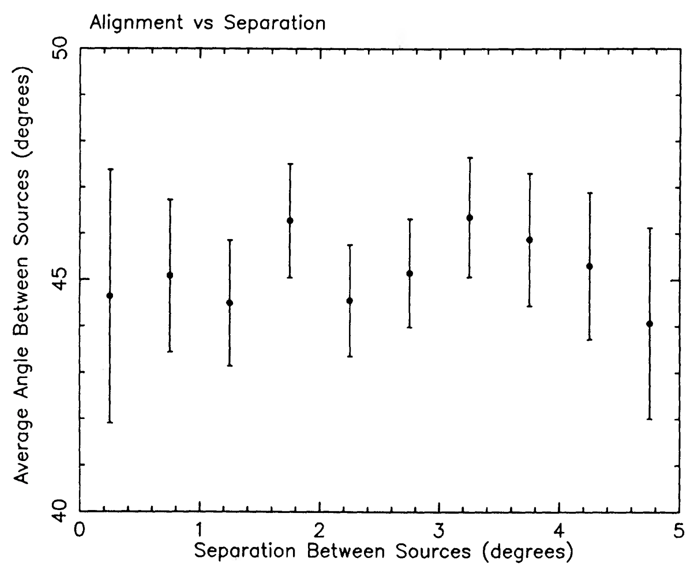

Figure 2. The mean angle between radio sources as a function of their angular separation, for the 83 clearly resolved sources in the present sample. The average is taken over an 0°.5 interval and the error bar indicates the standard deviation.

numbers of pairs at these separations in the new sample exceed those in the two samples analysed by Sanders (1984); the new results are therefore in clear conflict with the earlier results.

Our conclusion is unchanged if we restrict the present sample to the 74 sources smaller than 42 arcsec in diameter, or to the 63 clear doubles or triples. Both of these restrictions would weight the sample more heavily towards more distant sources. We also compared the alignment statistics for the 41 smallest and 42 largest extended sources in the sample; both groups appear to be randomly oriented.

4 Discussion

These new observations do not support the suggestion that distant radio sources are generally aligned on scales smaller than 5°. Indeed, the random character of the orientations found here casts some doubt on the astronomical reality of the previously reported alignments. Possibly the significance of the previously reported effect results from alignments that are restricted to certain special regions of the sky, and the region we have observed here is not one of these special regions. The region was, however, selected because it included a small group of parallel B3 sources that contributed to the effect seen by Sanders. The parallel pairs which contribute to the effect in the published sample of radio sources discussed by Sanders (1984) also appear to be uniformly distributed over the sky. Thus, while we cannot rule out the 'special region' hypothesis, the present data do not encourage it.

We are unable to explain why an apparently significant tendency to alignment was found by Sanders in the unpublished VLA snapshot maps of B3 sources by Perley *et al.* Possibly some of these snapshots are corrupted by side-lobe artefacts at preferred position angles, especially in crowded fields of view. Further processing of the Perley *et al.* data set is planned to check this possibility.

Definitive statements about the alignments or non-alignments of distant radio sources should await observation and publication of more high-resolution maps of such objects. We believe, however, that there is now no compelling evidence that their orientations are correlated on any scale.

References

Ficarra, A., Grueff, G. & Tomassetti, G., 1985. *Astr. Astrophys. Suppl.*, **59**, 255.

Joshi, M. N. & Singal, A. K., 1980. *Mem. astr. Soc. Ind.* **1**, 49.

Kapahi, V. K., Subrahmanyan, R. & Singal, A. K., 1985. *Nature*, **313**, 463.

Machalski, J. & Condon, J. J., 1983. *Astr. J.*, **88**, 143.

Oort, J. H., 1984. In: *Large Scale Structure of the Universe, Cosmology, and Fundamental Physics*, p. 209, eds Setti, G. & van Hove, L., ESO/CERN, Geneva.

Sanders, R. H., 1984. *Nature*, **309**, 35.

Sanders, R. H., van Albada, T. S. & Oosterloo, T., 1984. *Astrophys. J.*, **278**, L91.

Willson, M. A. G., 1972. *Mon. Not. R. astr. Soc.*, **155**, 275.