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The Large-scale Distribution of Quasars Identified with Strong Radio Sources at 5 GHz

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Abstract. The large-scale angular distribution of quasars from a complete sample of extragalactic radio sources is examined at different redshifts. The sample contains 264 quasars which have been found so far among the complete sample of 518 radio sources stronger than. 1 Jy at 5 GHz. Of these, 19 quasars have redshift $z > 2$. Dividing the entire sky into three separate declination zones of equal area, the counts of quasars seem to indicate a deficit of high redshift quasars in the northernmost declination zone. On the other hand, the Iow-redshift quasars ($z \lesssim 1$) appear fairly uniformly distributed. We discuss some possible selection effects that might have led to the apparent anomaly at high redshifts and estimate the expected number of high-redshift quasars amongst the radio sources in the sample for which redshifts are presently not available.

Key words: quasars, radio-bright – quasars, distribution of

1. Introduction

While clustering of quasars on a scale of ~ 1° has been suggested by Oort, Arp & de Ruiter (1981), there is no evidence for extragalactic radio sources in general being clustered on such scales, or for their being distributed anisotropically on a larger scale (Webster 1977; Fanti, Lari & Olori 1978). In the present paper we examine the large-scale angular distribution of radioselected quasars located at different redshift ranges. Such an analysis has become feasible due to the availability of an almost complete sample of extragalactic radio sources, which covers practically the entire sky away from the galactic plane (Kühr *et al.* 1981).

2. The sample

The sample of quasars used in the present investigation has been derived from the catalogue of strong extragalactic radio sources at 5000 MHz published by Kühr *et al*. (1981). The catalogue contains 518 sources and is believed to be 99 per cent complete above a flux density limit of $S_{5000} = 1$ Jy. It covers a sky area of 9.8 steradian away

Table 1. Distribution of the radio sources from the sample in the three decimation zones.

	Northern zone $+90°$ to $+19.5°$	Central zone $+19°.5$ to $-19°.5$	Southern zone $-19°.5$ to $-90°$	Total
1. Sky coverage	3.2 sr (77 per cent)	3.4 sr (83 per cent)	3.2 sr (76 per cent)	9.8 sr (78 per cent)
2. All radio sources	164	188	166	518
3. Optical identification not available	3	6	35	44
4. Empty fields	11	16	4	31
5. Galaxies	66	55	58	179
6. Quasars	84	110	70	264
7. Quasars with z known				
total	47	75	37	159
$0 < z \leqq 1$	30	45	16	91
$1 < z \leqq 2$	16	21	12	49
$z > 2$	1	9	9	19
8. $f_Q(z>2)$ (per cent)	2 ± 2	12 ± 4	24 ± 7	12 ± 3

Note:

In response to this paper, Dr H. Kuhr has recently communicated to us an updated version of Table 1, based on the redshift measurements of quasars in the present sample that are now available to him. According to him, redshifts are now known for a total of 188 quasars distributed as 57, 84 and 47 quasars in the northern, central and southern declination zones, respectively; the corresponding numbers for high-redshift quasars ($z > 2$) are 5, 9 and 14, respectively. This gives f_Q ($z > 2$) values of 9 ± 4,11 ± 4 and 30 ± 8 per cent, for the three zones respectively. According to Dr Kühr, at most one or two high-redshift quasars might still be missing from the numbers given for the northern and central zones together (as indicated by a preliminary analysis of his spectroscopic data for the 15 flat spectrum quasars of still unknown redshift). He too, therefore, feels that there may exist an anomaly in the distribution of high-redshift quasars, albeit at a reduced level of significance compared to our original indication in the paper.

Summarizing the current data for the radio source sample, the number of high-redshift quasars found in the southern zone exceeds the corresponding number for the northern zone by a factor of ~ 3, which is probably a conservative estimate as redshift information is still missing for many quasars and optically-unidentified sources in the southern zone.

from the galactic plane. Reliable optical identification data are also provided in the catalogue, as the accuracy of most of the radio positions is a few seconds of arc or better. Of the 474 sources for which information on the optical field is given, 264 are identified with quasars, 179 with galaxies and 31 with, empty fields. Values of emission-line redshifts are given in the catalogue for 150 of the quasars. Subsequently, redshifts have become available for an additional nine of the quasars (Peacock & Wall 1981; Hewitt & Burbidge 1980; Peterson *et al.* 1982). Thus, redshifts are known for a total of 159 quasars in the sample.

To examine the large-scale angular distribution of the quasars in the sample, the celestial sphere has been divided into 3 declination zones of equal area as defined in Table 1. For each zone, the fractional area actually covered by the catalogue and the counts of sources belonging to different optical types are given in the table, together with the redshift distributions for the quasars with known redshifts. The fractions of

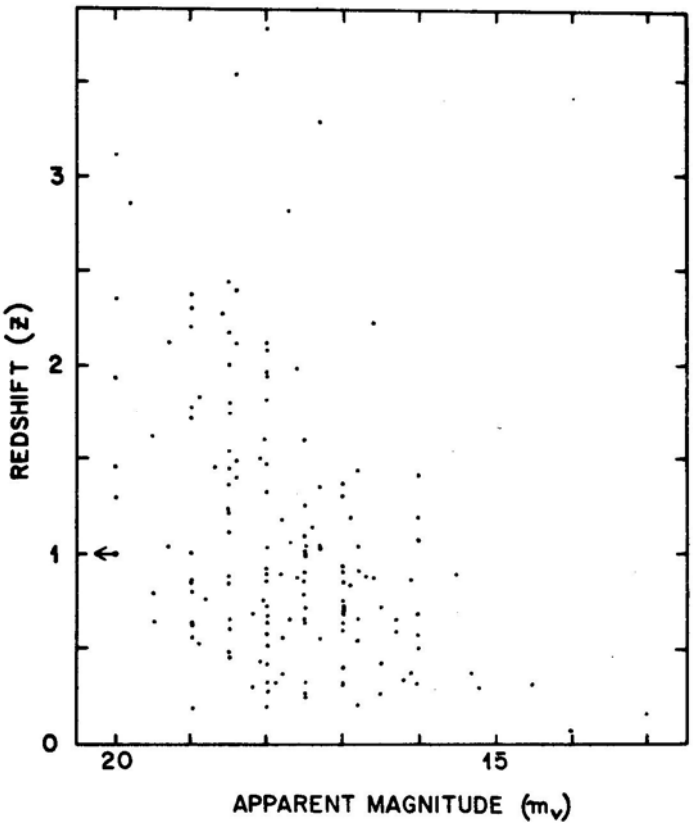

Figure 1. Redshift – apparent visual magnitude ($z - m_v$) diagram for the 159 quasars of known redshifts in our sample. References to the values of redshift are given in the text. The values of m_v are given by Kühr *et al.* (1981) for all sources except 0834-20 (see Shimmins & Bolton 1981) and 1611 + 34 (see Hewitt & Burbidge 1980).

such quasars having $z \geq 2$ are given in the last row, denoted by $f_Q(z > 2)$.

3. Results and discussion

From Table 1 it is seen that among the quasars with known redshifts, which constitute ~ 60 per cent of all known quasars in the sample, a deficit of high-redshift quasars ($z >$ is apparent for the northern declination zone. While in the northern zone 2 ± 2 per cent of all quasars with known redshifts have $z > 2$, the corresponding fraction is f_Q ($z > 2$) = 12 ± 4 per cent for the central zone and f_Q ($z > 2$) = 24 ± *7* for the southern zone. The difference between the extreme values of f_Q ($z > 2$) is formally significant at a level of about 3 sigma. This apparent anisotropy is seen even at somewhat lower redshifts, the values of f_Q ($z > 1.5$) being about 9 ± 4, 20 ± 5 and 41 ± 8 per cent for the northern, central and southern declination zones, respectively. No significant difference of this kind is apparent, however, for lower redshifts ($z < 1$, see Table l).

Since, at present, both the identification and redshift data for our sample are incomplete, we investigate possible selection effects that might have led to the signify-

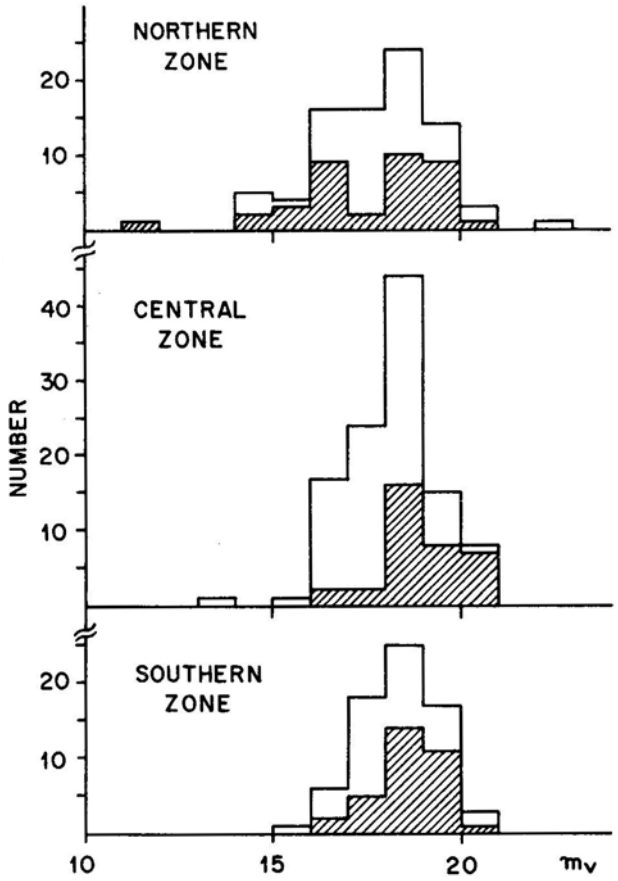

Figure 2. Distribution of m_v for all quasars in each of the 3 declination zones. Among these, the quasars with unknown redshift are shown with hatched areas.

cantly lower value of f_Q ($z > 2$) for the northern zone. It is conceivable that optical obscuration could be higher over this zone. Then, as quasars of higher redshifts tend to apppear fainter on an average (Fig. 1), in the northern zone, a higher fraction of them would be dimmed beyond the limits of optical plates or spectroscopic measurements. However, the distributions of apparent visual magnitudes of all quasars in our sample look similar for the three zones (Fig. 2) and suggest no evidence for differential obscuration. Another possibility is that redshifts of the quasars in the southern zone might have been taken in appreciable numbers from optical surveys of quasars which have been carried out largely in that zone and which are known to favour detection of high-redshift quasars (Woltjer & Setti, 1982; Smith 1982). A check with the literature reveals, however, that none of the high redshift quasars in our sample was observed in the optical surveys of quasars.

An important selection effect that may have affected the values of f_Q ($z > 2$) in the declination zones (Table l) is related to the correlation between flatness of radio spectrum and redshift, apparent for the quasars in our sample. The spectral index–redshift diagram shown in Fig. 3 indicates that, on an average, quasars with flatter

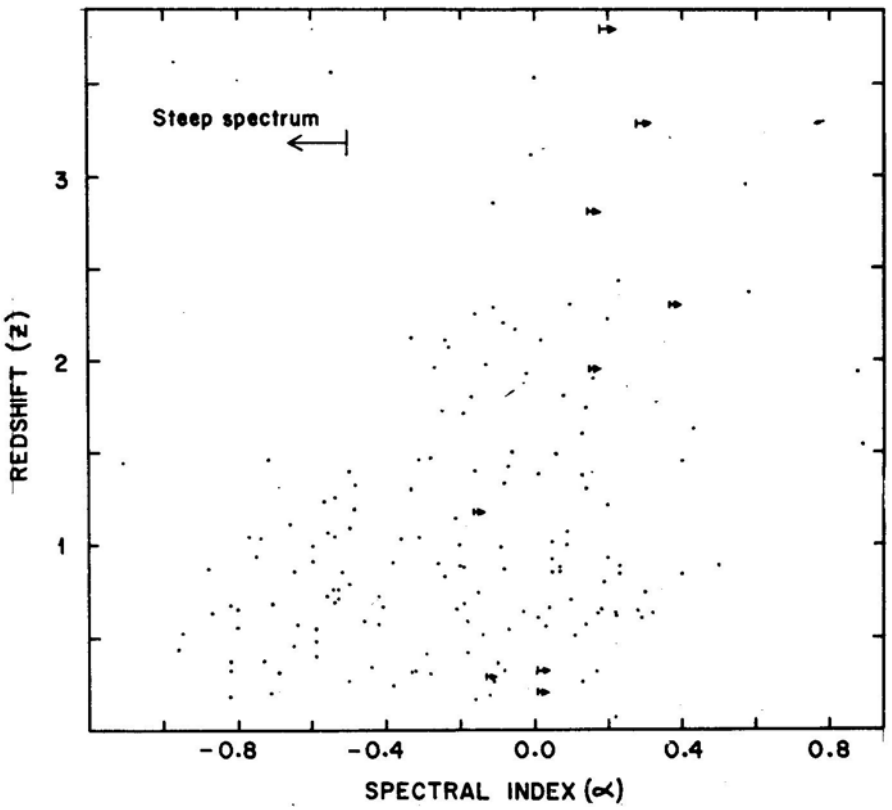

Figure 3. Redshift-spectral index ($z - \alpha$ diagram for the quasars of known redshift in our sample. For each source, the value of α was computed between a low and a high frequency selected in the following order of preference depending upon the availability of published flux densities:
(a) High frequency: 2700 MHz, 5000 MHz (Kühr *et al.* 1981)
(b) Low frequency: 408 MHz (Large *et al.* 198l);408 MHz (Fanti *et al.* 1974 and references therein); 81.5 MHz (Branson 1967); 178 MHz (Pilkington & Scott 1965; Gower, Scott & Wills 1967); 327 MHz, 750 MHz, 635 MHz and 966 MHz all from Kühr *et al.* (1981).

radio spectra are seen to higher redshifts. This is not unexpected, in view of the sample having been defined above a certain flux density limit at a high radio frequency. The relatively low value of f_Q ($z > 2$) for the northern zone could then arise if the quasars with measured redshifts in this zone had steeper spectra, on an average, compared to the quasars in the other two zones. This could possibly occur if the radio sources selected for redshift measurement in the northern and southern zones have been derived largely from surveys made at low and high radio frequencies, respectively. To examine this question, we have plotted in Fig.4 the distributions of radio spectral index α (defined as $S_\nu \sim \nu^\alpha$) for the quasars in our sample whose redshifts are known. Although such quasars in the northern zone do seem to have somewhat steeper spectra, on an average, it is clearly important to complete both optical identifications and redshift measurements for the sample before any definite conclusion can be drawn.

In what follows, we shall attempt to make rough estimates of the numbers of high redshift quasars expected in our sample from among (i) the sources for which identification

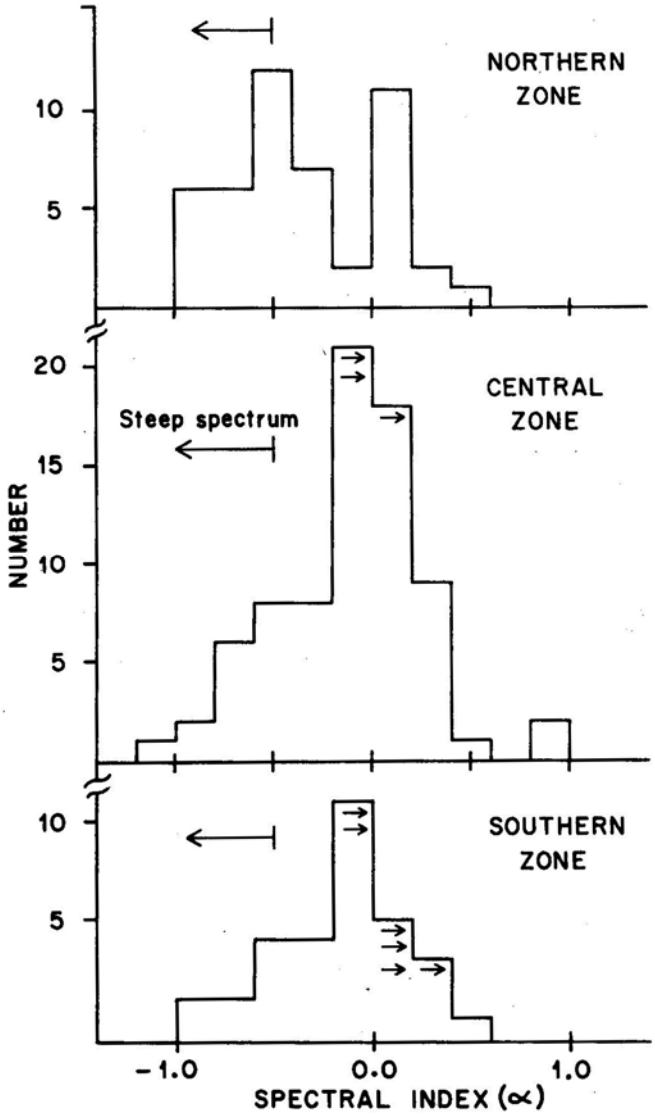

Figure 4: The distributions of α for the quasars of known redshift in our sample, in the 3 declination zones. The definition of α is given in the caption to Fig. 3. Each arrow inside the histogram represents a lower limit to. *a* of one source.

data are not available (44 sources), (ii) the empty-field sources (31) and (iii) the quasars of unknown redshift (105) (see Table l).Since ~ 60 per cent of strong extragalactic radio sources having flat spectra ($\alpha > -0.5$) are expected to be quasars (Pauliny-Toth *et al.* 1978), the first category of quasar candidates mentioned above should yield approximately 1,2 and 14 possible (flat spectrum) quasars in the northern,central and southern zones, respectively. For the empty-field sources, we have used the 2.7 GHz sample of strong sources (Peacock & Wall 1981) and this indicates that the fraction of flat-spectrum quasars likely to be identified with empty fields on POSS prints is at

most ~ 0.4; this suggests that the empty-field sources in our sample should yield ~ 1 possible flat-spectrum quasars in the southern zone and ~ 4 flat-spectrum quasars in each of the other two zones. These estimates when added to those expected for the sources in category (i) and finally to the numbers of flat spectrum quasars with unknown redshift in the three declination zones (category iii) bring the total to ~ 41 possible flat-spectrum quasars in each zone. Of these ~ 16 per cent are expected to lie at high redshifts ($z > 2$), as indicated by the α - z diagram for the quasars in our sample (Fig.3). Adding this estimated number of ~ 7 high-redshift quasars still to be found in each zone (from our sample) to the numbers of such quasars already catalogued in the three zones (Table l) brings the total to 8, 16 and. 16 of high-redshift quasars in the northern central and southern declination zones, respectively. The significance of the deficit of high-redshift quasars in the northern zone would thus be diminished. But, on the other hand, the expected number of ~ 7 high-redshift quasars in the northern zone could well be an overstimate, in view of the fact that the quasars of unknown redshift in that zone seem to be, on an average, optically brighter compared to their counterparts in the other two zones (see Fig.2). Completion of optical identification work and of the quasar redshift measurements for the sample (Kühr *et al.* 1981) would enable a definitive assessment of the question of any large-scale effects in the distribution of radio-bright quasars at high redshifts.

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