Mon. Not. R. astr. Soc. (1987) **224**, 379–391

Polarization properties of radio cores in active galaxies

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Accepted 1986 July 29. Received 1986 July 29; in original form 1985 July 23

Summary. To investigate the polarization properties of cores in both lobe- and core-dominated radio sources associated with active galaxies, we present VLA A-array observations of core polarization at 6 cm of 10 lobe-dominated quasars, and new optical identification data for 33 compact radio sources observed by Perley with the VLA. We then use the entire Perley sample of ~400 sources to examine the distributions of the two-point core spectral index between 20 and 6 cm, of the degree of polarization at these two frequencies, and of the depolarization parameter between these frequencies for both flat-spectrum cores (FSCs) and compact steep-spectrum sources (CSSs) associated with different kinds of optical objects. The FSCs in galaxies are significantly less polarized at both 6 and 20 cm than those in quasars. This is also true for the CSSs, although at 20 cm the difference in the median values is reduced. The CSSs in quasars exhibit significant evidence of depolarization towards longer wavelengths. The median degree of core polarization at 6 cm for the 10 lobe-dominated quasars is similar to that of the core-dominated quasars observed by Perley, suggesting that the cores in the two groups are not intrinsically different. The degree of polarization does not appear to be correlated with the core radio luminosity, contrary to a recent suggestion by Rudnick, Jones & Fiedler.

1 Introduction

Compact radio sources found in the nuclei of active galaxies are thought to be closely related to the central nuclear powerhouses which generate relativistic particles and magnetic fields. These radio cores have been the subject of intense investigation for many years. Although the vast majority have flat spectra (and will be referred to as FSCs) and are often strongly variable, a small but significant fraction, which also remain unresolved in aperture synthesis observations with resolutions of a few arcsec, have steep (α>0.5 where $S \propto \nu^{-\alpha}$) high-frequency spectra (Kapahi 1981; Peacock & Wall 1982). These compact steep-spectrum sources or CSSs reveal a wide variety of structures when observed with sub- or milli-arcsec resolution, perhaps reflecting different processes responsible for their observed morphology (van Breugel, Miley & Heckman 1984; Pearson, Perley & Readhead 1985; Fanti *et al.* 1985). It is possible, as suggested by a number of authors, that at least some of them are distorted and confined to sub-galactic dimensions by a dense interstellar medium (*cf* references in van Breugel *et al.* 1984).

Polarization observations of cores can, in principle, provide valuable insights into the physical conditions in the central regions. In this paper, we present the results of our observations of core polarization of 10 lobe-dominated quasars with the VLA at 6 cm; and new optical identification data for 33 compact radio sources observed by Perley (1982, hereinafter referred to as P82) with the VLA. We then use the entire sample of ~400 sources observed by Perley, which is still the largest, reasonably homogeneous set of high-resolution observations of core flux density and polarization at 20 and 6 cm, to investigate differences in the distributions of core spectral-index, α_c, polarization at 6 and 20 cm, p_6 and p_{20} respectively and the degree of depolarization, $DP=p_{20}/p_6$, between the above two frequencies for both the FSCs and CSSs associated with different kinds of optical objects. The distributions of core polarization at 6 cm are updated versions of those published by Saikia, Swarup & Kodali (1985) where they reported that at 6 cm both types of cores in galaxies tend to be significantly less polarized than those in quasars. To examine whether the cores in lobe-and core-dominated sources exhibit any difference in polarization we investigate whether the p_6 distributions for the lobe-dominated sources we observed differ from the core-dominated ones observed by P82, but find no significant difference. Further, we find no evidence for a significant correlation between the degree of polarization and the core radio luminosity, contrary to a recent suggestion by Rudnick *et al.* (1986).

2 VLA observations of core polarization for a sample of lobe-dominated quasars

In this section, we present the results of our observations of core polarization at 6 cm for 10 largely lobe-dominated quasars. The maps of the large-scale structure will be given elsewhere. In Section 4.4 we investigate whether their distribution of p_6 differs significantly from the core-dominated sources observed by P82. The 10 sources were observed on 1983 November 25 at 4885 MHz with a

Table 1. Observational parameters and polarization properties of 10 lobe-dominated quasars.

Source	Alt name	Redshift	HPBW maj ″	HPBW min ″	HPBW PA °	σ mJy/b	S_{core} mJy	P_{core} W Hz^{-1} sr^{-1}	Polarization percent	Polarization PA
0919+218	4C 21.25	1.421	0.41	0.40	11	0.10	18	24.88	<1	
1012+232	4C 23.24	0.565	0.41	0.39	3	0.40	1083	25.97	0.5	179
1040+123	3C 245	1.029	0.41	0.39	9	0.36	1149	26.45	10.4	24
1132+303	4C 30.22	0.614	0.42	0.42		0.17	72	24.86	6.1	88
1136-135	PKS	0.554	0.56	0.38	10	0.24	444	25.57	1.8	13
1203+109	4C 10.34	1.088	0.45	0.41	175	0.10	54	25.17	0.9	130
1222+216	4C 21.35	0.435	0.42	0.40	179	0.31	650	25.54	2.6	88
1433+177	4C 17.59	1.203	0.41	0.41		0.22	228	25.86	3.3	46
1509+158	4C 15.45	0.828	0.42	0.42		0.23	80	25.13	2.2	165
1741+279	4C 27.38	0.372	0.58	0.40	102	0.25	178	24.85	6.4	71

bandwidth of 50 MHz in the VLA A-configuration. Each source was observed in one scan lasting ~5–10 min, with 3C 286 as the primary flux density and polarization calibrator. The data reduction including self-calibration was done using the AIPS package. The results of our observations are presented in Table 1. The core flux density and the degree of polarization and PA are at the pixel of maximum intensity near the nucleus. The core radio luminosity has been calculated in an Einstein–de Sitter universe with H_0=50 km s^{-1} Mpc^{-1}.

3 Optical identifications

We have looked for optical identifications for 33 radio sources observed by P82 for which no optical information was available in the literature. They are listed in Table 2. Using transparent

Table 2. The optical identification data.

Source	Radio Position RA (1950.0) h m s	Radio Position DEC (1950.0) ° ' "	Optical Position RA (1950.0) h m s	Optical Position DEC (1950.0) ° ' "	Opt obj	m_b	Notes
0023-263	00 23 18.914	-26 18 49.25	*00 23 18.87	-26 18 51.4	G	21.0	
0039+230	00 39 25.70	+23 03 34.9	*00 39 25.82	+23 03 32.7	NO?	21.0	1
0107+562	01 07 53.796	+56 16 20.70			EF		
0400-319	04 00 23.609	-31 55 41.90			EF		
0435+487	04 35 14.085	+48 42 52.10			EF		
0519+011	05 19 42.346	+01 10 41.40			EF		
0537+531	05 37 13.520	+53 10 54.25	05 37 13.62	+53 10 54.2	G	19.0	2
0646-306	06 46 19.2	-30 40 55.1	*06 46 19.20	-30 40 54.6	BO	21.0	3
0646+692	06 46 29.261	+69 14 46.20			EF		
0648-165	06 48 10.296	-16 34 05.85			EF		
0727-115	07 27 58.100	-11 34 52.62			EF		
0733-174	07 33 31.417	-17 29 06.23			EF		
0738+272	07 38 20.906	+27 13 48.45	*07 38 20.89	+27 13 49.0	BO	20.5	
0741-063	07 41 54.700	-06 22 20.00			EF		
1144+402	11 44 21.024	+40 15 14.15	11 44 21.06	+40 15 13.5	G	19.5	4
1213-172	12 13 11.674	-17 15 05.25					5
1323+799	13 23 30.986	+79 58 27.60			EF		
1339+696	13 39 29.919	+69 38 30.30	*13 39 30.35	+69 38 28.3	BO	20.0	
1459+480	14 59 07.240	+48 03 04.00	14 59 07.32	+48 03 03.8	BSO	19.5	
1547+507	15 47 52.276	+50 47 09.23	15 47 52.32	+50 47 08.6	BSO	19.0	
1622-253	16 22 44.110	-25 20 51.50					6
1622-297	16 22 57.246	-29 44 41.15	16 22 57.23	-29 44 42.0	NO	20.5	
1648+015	16 48 31.579	+01 34 25.65			EF		
1654+866	16 54 31.382	+86 37 07.21			EF		
1657-261	16 57 47.720	-26 06 29.25					7
1741-312	17 41 09.340	-31 15 20.70			EF		
1748-253	17 48 45.789	-25 23 17.43					8
1848+283	18 48 29.070	+28 21 38.45	18 48 29.12	+28 21 38.2	BSO	17.5	
1908-201	19 08 12.465	-20 11 55.10	19 08 12.52	-20 11 54.6	BO	20.0	
1923+210	19 23 49.788	+21 00 23.20					9
1937-101	19 37 12.646	-10 09 39.50	19 37 12.65	-10 09 39.8	G	19.5	10
2008-068	20 08 33.699	-06 53 01.75			EF		
2135-209	21 35 01.323	-20 56 03.70			EF		

1 0039+230: Very faint optical object at the plate limit in both the blue and red prints.
2 0537+531: Appears to be slightly brighter in the red.
3 0646−306: Optical object not seen in the red print.
4 1144+402: Object is brighter in the blue and also appears slightly elongated in this print.
5 1213−172: Broad image of a bright star covers the field of view near the radio position in both the red and blue prints.
6 1622−253: Obscured field (l=352°.1, b=16°.3).
7 1657−261: Crowded field (l=356°.7, b=9°.7).
8 1748−253: Obscured region (l=3°.7, b=0°.6).
9 1923+210: Obscured field (l=55°.6, b=2°.2).
10 1937−101: The galaxy is brighter in the red print.

plastic overlays, a 2×2 arcmin^2 field centred on the radio position was examined on both the red (E) and blue (O) prints of the Palomar Sky Survey (PSS). The positions of a few optical objects lying close to the radio position were then measured from negative contact prints using an X–Y coordinate measuring machine. Their right ascensions and declinations were determined from similar X–Y measurements of ~six reference SAO stars evenly distributed about the radio position.

The optical positions of the brightest objects are generally believed to be accurate to ±0.5 arcsec in both right ascension and declination. In the case of some very faint optical objects, whose direct images were not visible on the negative contact prints, a secondary set of three or more nearby optical objects was used to calculate the position of the faint object. In these cases the rms error in each coordinate may be as large as ±2 arcsec. The optical positions of the objects with larger errors are preceded by an asterisk in Table 2. The optical nature of the identified objects was determined based on their appearance on PSS prints. Objects entered as galaxy (G) in Table 2 are those for which a diffuse optical image (as distinct from the stellar appearance) was noted on at least one of the two (E or O) prints. The following abbreviations have been used in Table 2 to describe the nature of the optical objects. G: galaxy; EF: empty field; NO: neutral object; BO: blue object; BSO: blue stellar object. A question mark indicates an uncertainty in the above classification. The tabulated magnitude estimates are from the blue PSS prints using the scale given by King & Raff (1977). These estimates are believed to be accurate to ±1 mag. The relevant finding charts for the 13 new identifications are presented in Plate 1.

3.1 BACKGROUND NUMBER DENSITY COUNTS AND THE RELIABILITY OF IDENTIFICATIONS

As the radio positions given in Perley's list are generally much more accurate than the optical positions (he quotes an rms error of ~0.05 arcsec for the radio positions), we regard the optical position-measurement errors mentioned earlier as the only source of error in the radio–optical position difference.

To ascertain the reliability of each individual identification we have employed the likelihood ratio criterion of de Ruiter, Willis & Arp (1977). The likelihood ratio compares the *a priori* probability that the optical object closest to the radio position is the correct identification with the probability that it is a confusing background object lying within this particular distance. The assumption is made that the radio source and its optical identification are intrinsically located at the same position and that the radio–optical position difference can arise only due to the measurement errors. We also discount the unlikely possibility that a confusing background optical object, rather than the true identification, may lie closer to the radio source, since such a possibility is negligible because of the low background density on Palomar prints and the small extent of the radio–optical error ellipse.

If σ_α and σ_δ are the combined radio–optical position errors in both coordinates and $\Delta\alpha$ and $\Delta\delta$ denote the distance of the closest optical object from the radio position, then we first define a normalized radio–optical distance parameter as

$$r=\left\{\left(\frac{\Delta\alpha}{\sigma_\alpha}\right)^2+\left(\frac{\Delta\delta}{\sigma_\delta}\right)^2\right\}^{1/2}.$$

Now if ϱ is the number density of background optical objects then the average number of these in the radio–optical error ellipse is given by $\lambda=\pi\sigma_\alpha\sigma_\delta\varrho$. Then the likelihood ratio, LR, of the two probabilities, governed by the Rayleigh and Poisson distributions respectively, is given by

$$LR=\frac{1}{2\lambda}\exp\left[\frac{r^2(2\lambda-1)}{2}\right].$$

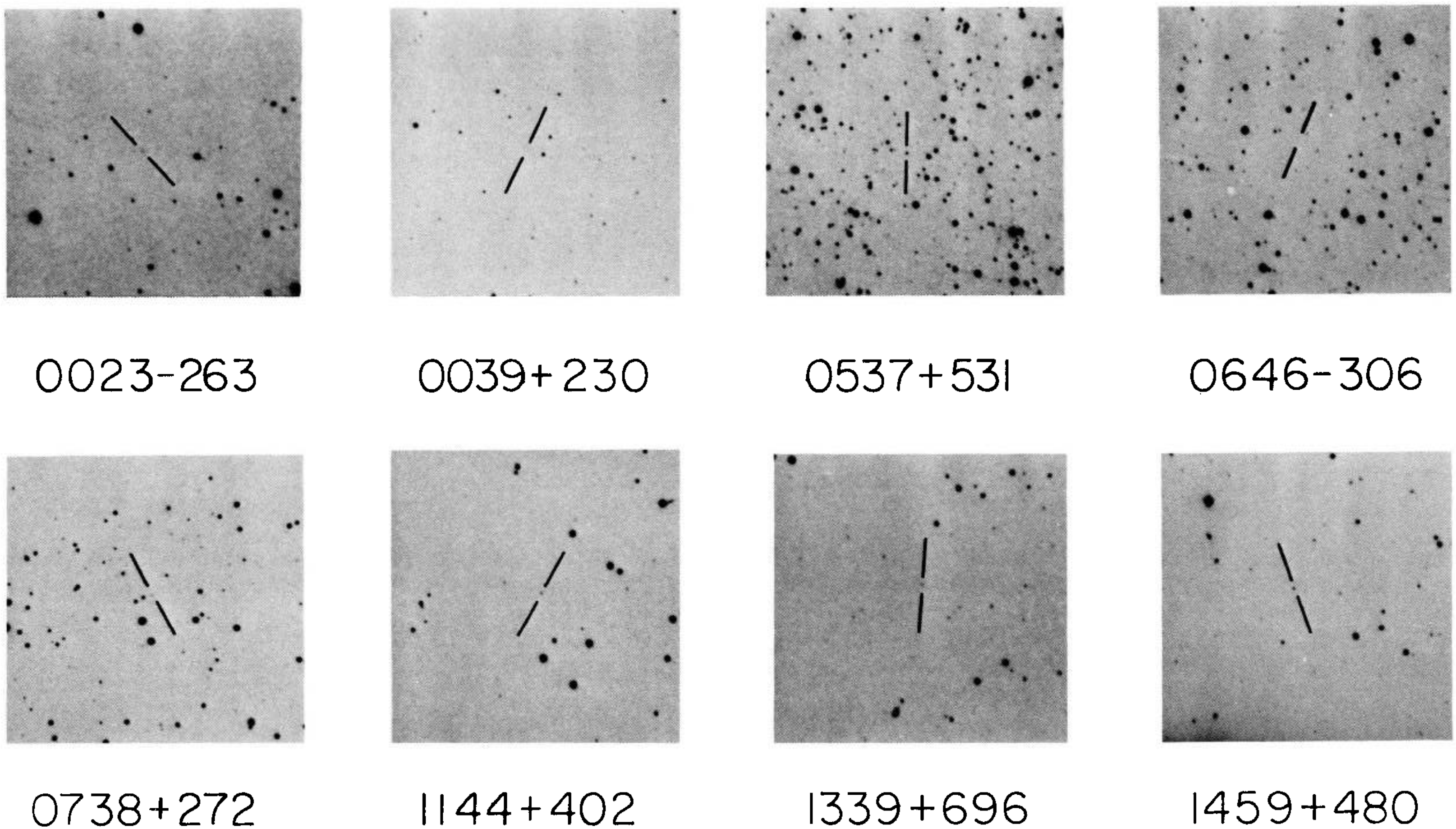

Plate 1. Finding charts for 13 radio sources. North is at the top and east is to the left. The field shown covers ~9 arcmin on each side. These are reproduced from the National Geographic Society Palomar Sky Survey prints by permission of the California Institute of Technology

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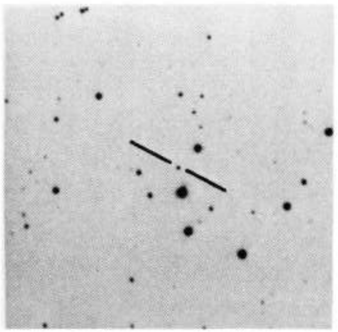
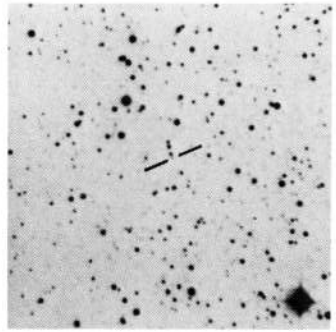
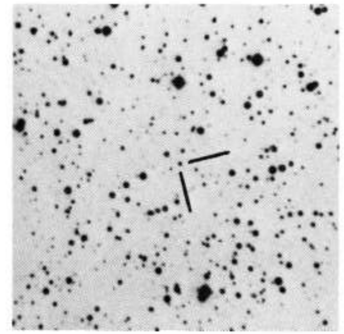


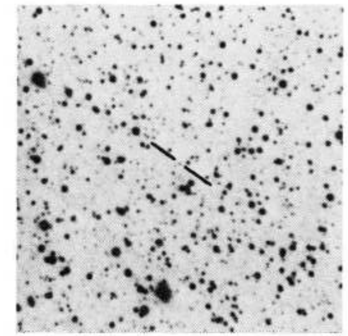
1547+507



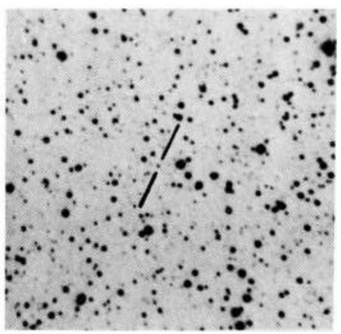
1622 −297



1848+283



1908−201



1937−101

Plate 1 – *continued*

Obviously $LR>1$ implies that the considered optical object has a higher probability of being the true identification, while $LR<1$ implies that it is more likely to be a background confusing object. de Ruiter *et al.* (1977) and Windhorst, Kron & Koo (1984) have suggested a lower cut-off value for $LR \approx 2$, above which an object should be accepted as a true identification. This is a compromise between missing too many real identifications in the tail of the Rayleigh distribution and including too many spurious objects due to chance encounters of confusing background objects in the near vicinity of radio positions.

The average background number density ϱ varies considerably with galactic latitude (see e.g. de Ruiter *et al.* 1977). We have determined ϱ at various galactic latitudes for both the red (E) and blue (O) PSS prints. For this purpose at each galactic latitude a PSS print was selected randomly and on both the red and blue prints the number of all discernible objects in 20 different fields, each of 4π square arcmin area, were counted. An average for the 20 fields determined ϱ at that galactic latitude. The rms variation around the average was also computed. Due to the large background number density at low galactic latitudes ($b<10°$), objects in 40 fields, each of area π arcmin^2, were counted in each of the E and O prints. As the number density may also be strongly dependent on galactic longitude (l), especially at low galactic latitudes (see e.g. Willis & de Ruiter 1977), we generally chose areas near the anticentre regions ($l \sim 180°$). The background number density counts are summarized in Table 3. As seen from Table 3 the O prints have a significantly lower ϱ, although the ratio on E and O prints at different galactic latitudes is quite stable (1.46 ± 0.16). de Ruiter *et al.* (1977) found that a function of the form $\varrho = \varrho_1 + \varrho_2 \operatorname{cosec} |b|$ was a good fit to the number density. Albeit at a different magnitude limit, this gave an extremely poor fit to our counts. However, a good fit was obtained (Fig. 1) with a gaussian expression of the form

$$\varrho(b) = [\varrho_1 + \varrho_2 \exp(-b^2/b^2_0)] \times 10^{-4} \text{ arcsec}^{-2},$$

where $\varrho_1 = 2.0$, $\varrho_2 = 14.0$ and $b_0 = 20°$.

We also show in Fig. 1 the background density at different galactic latitudes (with longitude chosen near the anticentre region) from the plotted data of Bergamini *et al.* (1973). Their values are consistent with our counts. The above expression for $\varrho(b)$ has been used here to calculate LR for each case. Ideally, one might also like to consider the longitude dependence of ϱ, but the values of LR in all our cases are either $\gg 1$ (identified cases) or are $\ll 1$ (empty fields), leaving very little doubt about the identification status. In no case would an uncertainty by a factor of a few in ϱ change the value of LR sufficiently to bring it near to 1. These 33 sources do not compromise any statistically homogeneous sample and are merely those cases in Perley's list for which no optical identification was attempted earlier.

Table 3. Average background number density on PSS prints at different galactic latitudes.

$\lvert b \rvert$ deg	PSS print (o h m)	ρ(arcsec^{-2}) x 10^4 Red Print E	Blue print O
2.3	+24 05 38	15.0 ± 4.5	11.2 ± 3.1
10.5	+30 06 30	13.7 ± 3.3	8.8 ± 2.3
19.5	+06 08 00	7.2 ± 1.7	4.7 ± 0.7
32	+30 08 14	2.9 ± 0.7	2.1 ± 0.6
49	+00 02 48	2.0 ± 0.5	1.3 ± 0.4
62	+00 12 48	1.9 ± 0.4	1.2 ± 0.4
87	+30 12 34	1.9 ± 0.8	1.5 ± 0.3

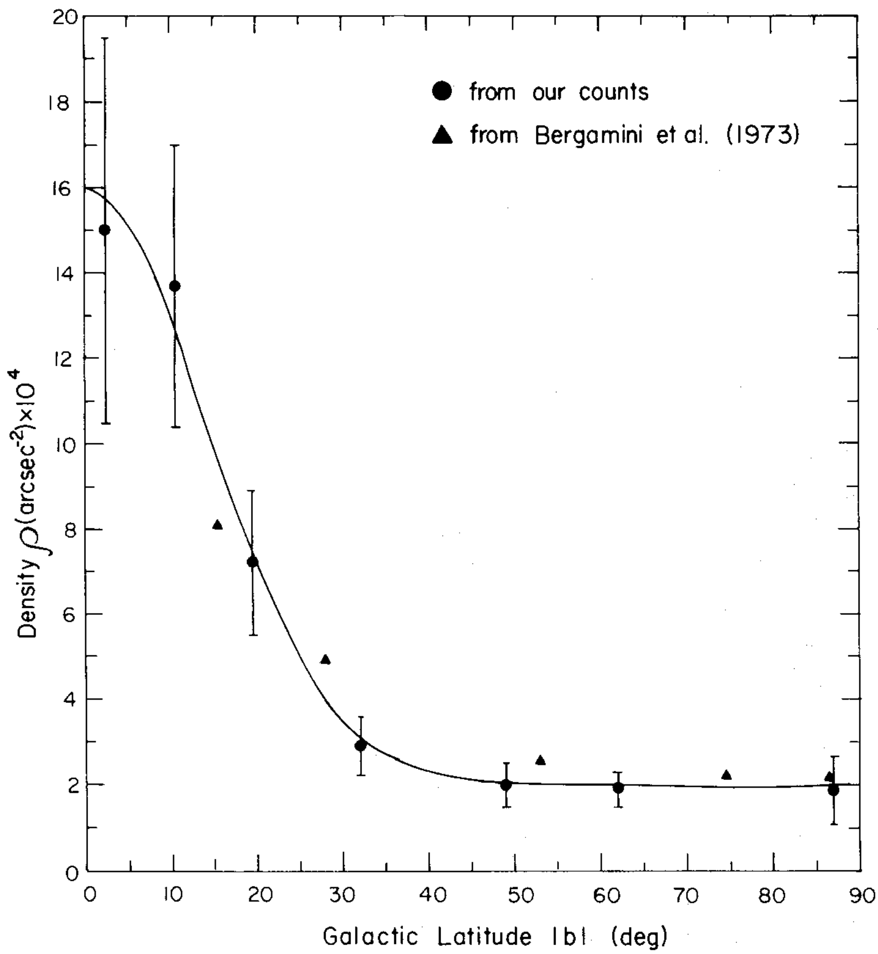


Figure 1. The mean density of all objects on the red (E) Palomar Sky Survey prints as a function of galactic latitude $|b|$. The solid line represents a Gaussian fit to the data of the form $\varrho=[\varrho_1+\varrho \exp(-b^2/b^2_0)]\times10^{-4}$ arcsec^{-2} where $\varrho_1=2$, $\varrho_2=14$ and $b_0=20°$.

4 Radio spectra and polarization of cores

The results in most of this section are based on observations of a large sample of ~400 radio cores by P82 with the VLA A-configuration at 20 and 6 cm. This unique data base is the largest set of reasonably homogeneous, high-resolution observations of cores with the VLA in both total intensity and linear polarization.

Following Saikia *et al.* (1985, hereinafter referred top as SSK), we have checked the identifications of all the sources in P82 using a recent compilation of optical identifications by Véron-Cetty & Véron (1983), and also the catalogues Hewitt & Burbidge (1980), Kühr *et al.* (1981) and the recent quasar catalogue by Véron-Cetty & Véron (1985). After incorporating the results of our optical identifications (Section 3) we have separated the sources into quasars, BL Lac objects, galaxies and empty fields. The total numbers are 275, 19, 43 and 39 respectively. The degree of polarization is not available for one source at 6 cm and 12 sources at 20 cm. Sources where the optical nature of the identified object is unclear have been eliminated.

4.1 CORE SPECTRAL INDEX DISTRIBUTIONS

In Fig. 2 we show the distributions of the two-point spectral-index of the cores, α_c, between 20 and 6 cm for different classes of optical objects. The median values of α_c are ~0 for quasars and

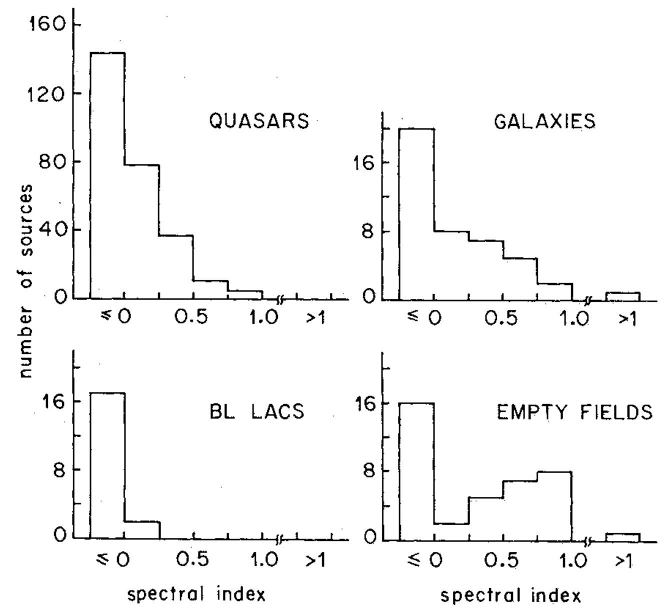


Figure 2. The distributions of the two-point core spectral between 20 and 6 cm.

galaxies, and ~0.3 for EFs. Almost all the BL Lacs appear to have flat or inverted spectra ($\alpha_c<0$), the median value being ~−0.1. A comparison of this distribution with that presented by Weiler & Johnston (1980) from VLA observations at 6 and 2 cm suggests that BL Lac spectra flatten towards higher frequencies. The distribution of α_c for the highly polarized quasars or HPQs (Moore & Stockman 1984) observed by P82 shows a median value close to about −0.1, with $\alpha>0$

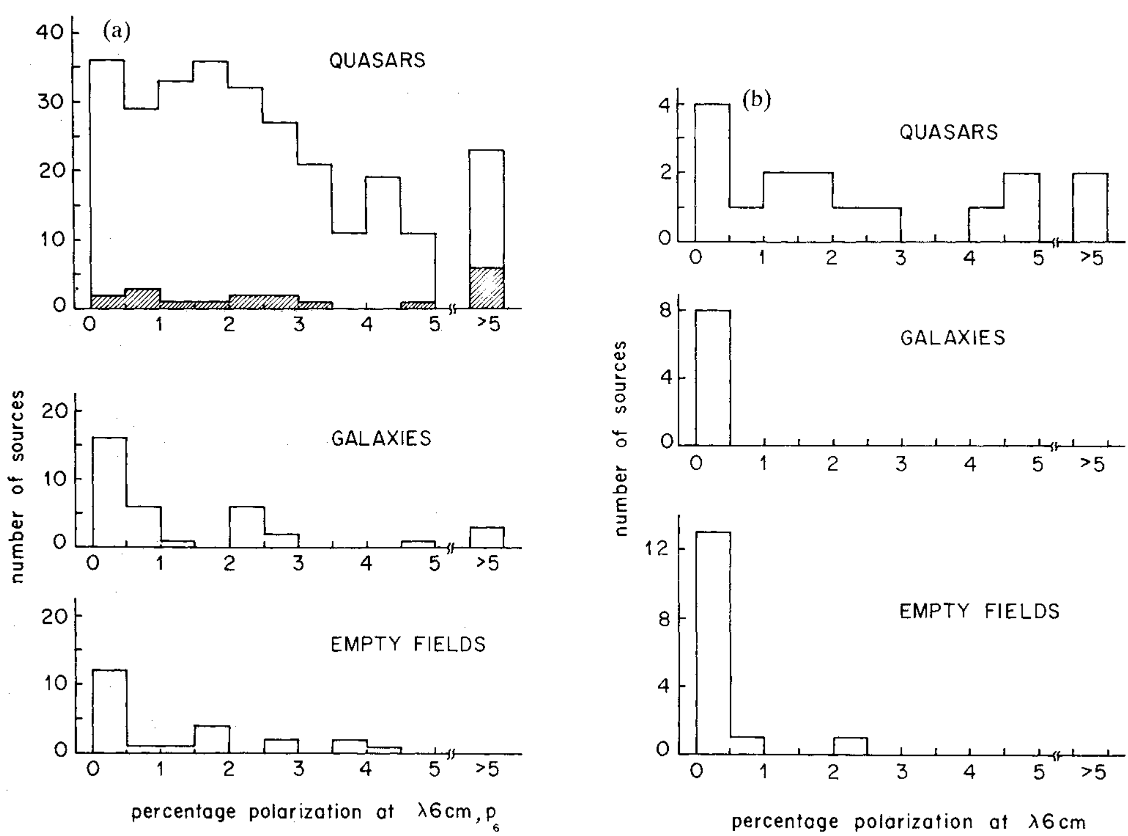


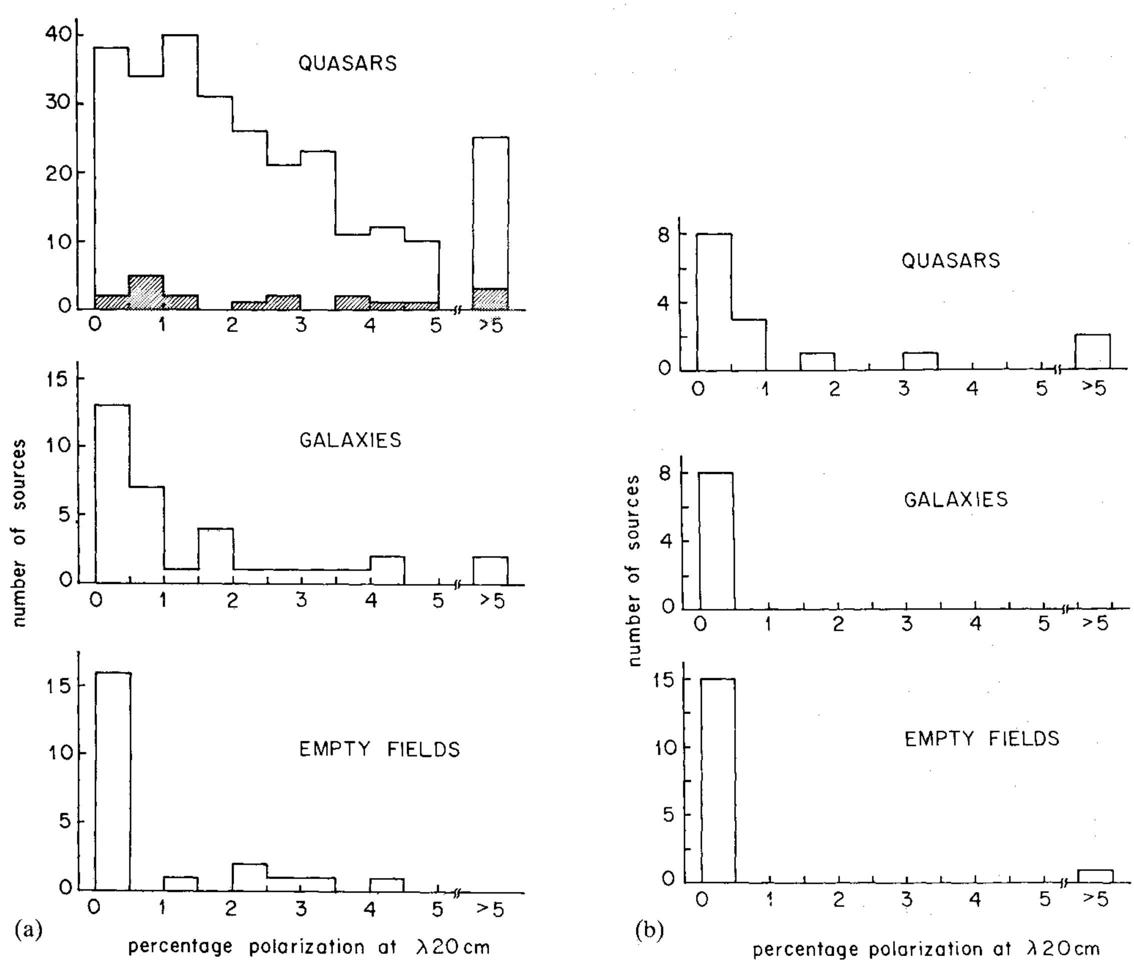
Figure 3. (a) The distributions of p_6 for FSCs; the hatched area denotes BL Lacs. (b) The distributions of p_6 for CSSs.

for five of the 15 objects. The HPQs along with the BL Lac objects are often referred to as blazars (*cf.* Angel & Stockman 1980). The fraction of CSSs in quasars, galaxies and EFs observed by P82 are ~5, 20 and 40 per cent respectively.

4.2 POLARIZATION OF CORES AT 6 AND 20 CM

The distribution of polarization at 6 cm for FSCs and CSSs are shown in Fig. 3(a) & (b) respectively. Fig. 3 represents updated versions of the figures presented by SSK, and the results are essentially similar to those reported earlier. The cores in quasars appear more highly polarized than the cores in galaxies and EFs. The median values of p_6 are similar for FSCs and CSSs in quasars (~2 per cent), while the FSCs in galaxies and EFs with a median value of ~0.5 per cent appear slightly more polarized than the CSSs which are, almost always, <0.5 per cent polarized. Although the error in p_6 for these weakly polarized sources is often large, the data suggest that the median is close to ~0.2 per cent. The median p_6 for both BL Lacs and HPQs is ~2.7 per cent, marginally higher than that for quasars. It is interesting to note that only one of the 15 HPQs observed by P82 is <1 per cent polarized, while for both quasars and BL Lacs ~25 per cent of the sources have p_6 <1 per cent.

In Fig. 4(a) & (b) we show the distributions of the degree of polarization at 20 cm for FSCs and CSSs. The FSCs in quasars and BL Lacs still appear significantly more polarized than those in



(a) (b)

Figure 4. (a) The distributions of p_{20} for FSCs; the hatched area denotes BL Lacs. (b) The distributions of p_{20} for CSSs.

galaxies and EFs, the median values for the different optical objects being ~1.7, 2.0, 0.6 and 0.3 per cent respectively. The median values of p_{20} for CSSs in quasars, galaxies and EFs are ~0.5, 0.2 and 0.2 per cent respectively. Values below ~0.5 per cent are subject to larger uncertainties because many are very weakly polarized with large errors in the listed polarized flux density. The CSSs in quasars are significantly less polarized than the FSCs. The data for galaxies are suggestive of a similar trend.

Since the polarized flux density, m_6, listed by P82 is sometimes close to the errors, we have re-examined the above results using the larger of the following two values for the degree of polarization: p_6 or p_{20} listed by P82 or 3 $(\Delta m/S)\times 100$ per cent where Δm is the error in the polarized flux density and S is the total core flux density. Our basic conclusions remain unaffected.

As shown by SSK, the tendency for quasar cores to be more highly polarized than those in galaxies is neither due to any difference in the degree of core prominence, which appears to be a reasonable statistical indicator of source orientation in the beaming models (cf. Saikia 1985), nor to a difference in the emitted wavelength in its rest frame arising from the different cosmological redshifts. Considering only the FSCs in quasars, we find that the median values of p_6 and p_{20} for a subsample with $z<0.5$ are similar to those with $z>0.5$. The $z<0.5$ quasars show the same difference in core polarization between quasars and galaxies, although the average emitted wavelengths of 4.6 and 5.4 cm respectively are only marginally different. It should, however, be

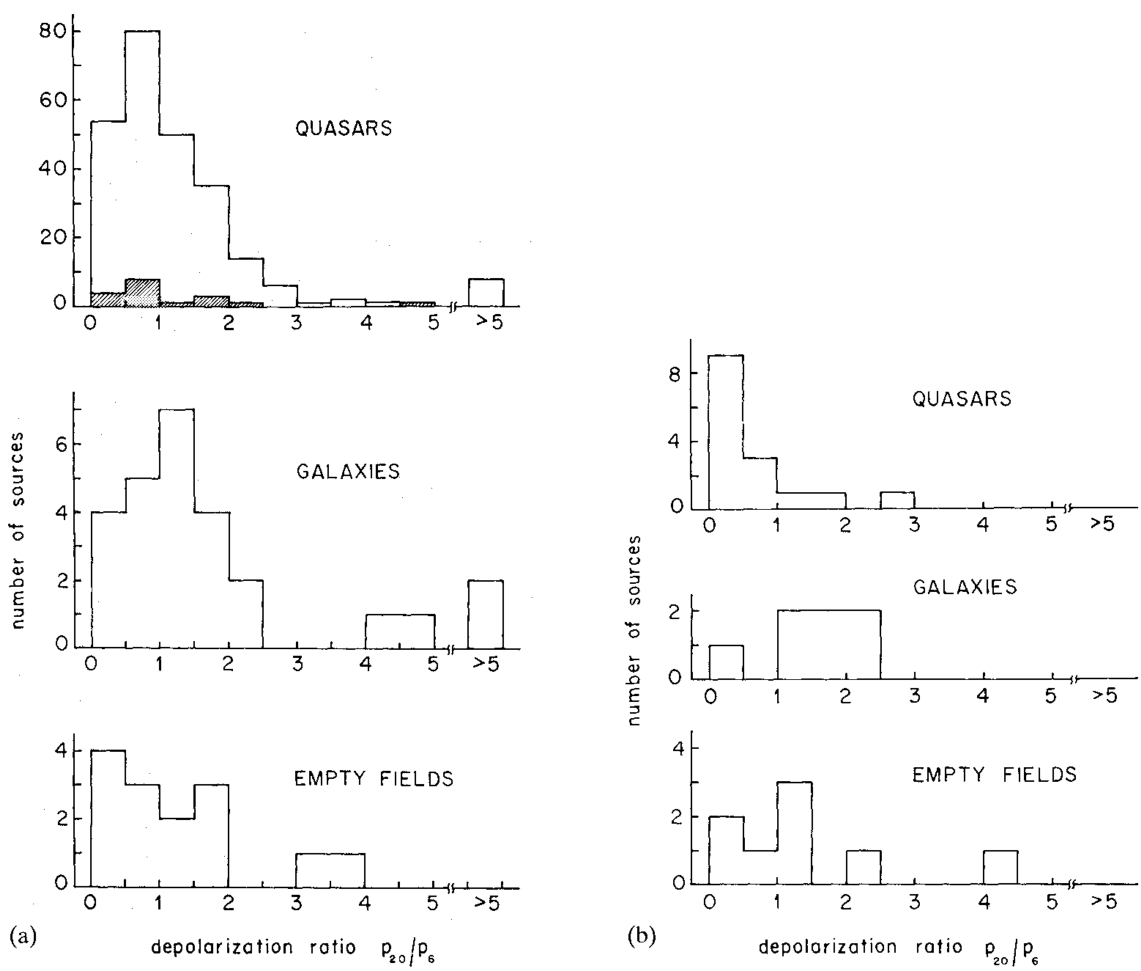


Figure 5. (a) The distributions of $DP=p_{20}/p_6$ for FSCs; the hatched area denotes BL Lacs. (b) The distributions of $DP=p_{20}/p_6$ for CSSs.

noted that if the radiation is strongly beamed, a significant difference in the bulk Lorentz factor of the beams in quasars and galaxies could also cause the emitted wavelengths to differ, in addition to the effects of cosmological redshift. It is also relevant to note that to compare the polarization over similar linear scales, it is necessary to observe the cores in a sample of galaxies and quasars with very similar redshift distributions.

4.3 DISTRIBUTIONS OF THE DEPOLARIZATION PARAMETER $DP=p_{20}/p_6$

Fig. 5(a) & (b) presents the distributions of $DP=p_{20}/p_6$ for the FSCs and CSSs respectively, after excluding sources for which both $\Delta m_6/m_6$ and $\Delta m_{20}/m_{20}$ are >0.5. Here m is the polarized flux density and Δm is the error given by $[4+(0.4S)^2]^{1/2}$ mJy where S is the flux density of the core (P82). This restriction avoids spurious values of DP, due to sources whose listed values of polarized flux density at both 6 and 20 cm are $<2\sigma$. Increasing this threshold to $\sim3\sigma$ does not alter the results. The median value of DP is usually close to ~1, except for the CSSs in quasars which appear significantly less polarized at 20 than 6 cm. Although it is tempting to speculate that this depolarization is due to a dense inhomogeneous medium which interacts actively with the radio plasma, it is relevant to note that the extended (>100 kpc) 3CR quasars with $>2\sigma$ integrated polarized flux density at 6 and 20 cm as listed by Tabara & Inoue (1980) also have a similar median value of DP and a similar median redshift. Higher resolution multifrequency polarization observations should be useful for understanding the depolarizing mechanisms in these two groups of sources.

From broad-band monitoring of a sample of 20 active, compact sources between 1.4 and 90 GHz, Jones *et al.* (1985) found that the median value of p_λ/p_6 is close to unity although there is clearly a great deal of scatter in p_λ/p_6, even for adjacent wavebands. The DP distributions for the FSCs in our sample are consistent with this result.

4.4 POLARIZATION OF CORES IN LOBE-DOMINATED SOURCES

In this section we compare the degree of polarization of cores in lobe- and core-dominated sources to investigate whether they show any difference. In the unified schemes (Orr & Browne

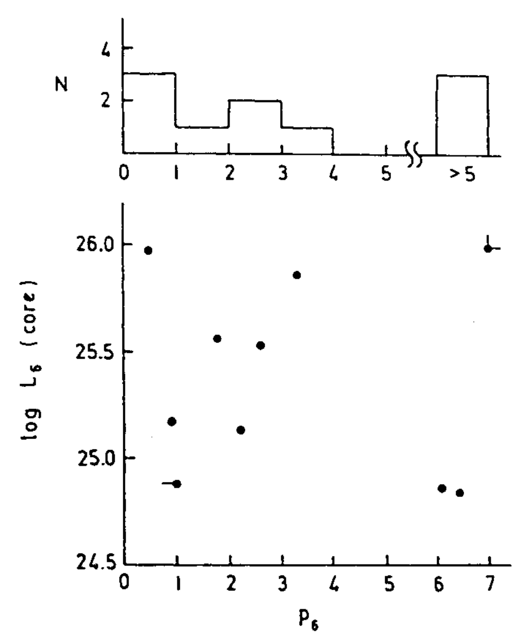


Figure 6. The distribution of p_6 for the 10 lobe-dominated quasars and the p_6-core radio luminosity diagram for this sample.

1982; Kapahi & Saikia 1982) the cores in these two types of sources are assumed to be intrinsically similar.

In Fig. 6(a), we present the distribution of p_6 for the 10 lobe-dominated quasars observed with the VLA A-array (Section 2). The median value of p_6 is 2.5, which as shown earlier (SSK and Section 4.2) is similar to that of the sample of core-dominated quasars observed by P82.

Three of the quasars we observed, 1040+123, 1203+109 and 1222+216, were also observed by Rudnick *et al.* (1986) with 14 antennae of the VLA on 1980 October 25–28. They detected polarized flux density from the core of only 1040+123. This they found to be 13 per cent polarized along PA 23°, compared to our value of 10.4 per cent along 24°. Their upper limit of 0.6 per cent for 1203+109 is close to our measured value of 0.9 per cent. However, in the case of 1222+216,

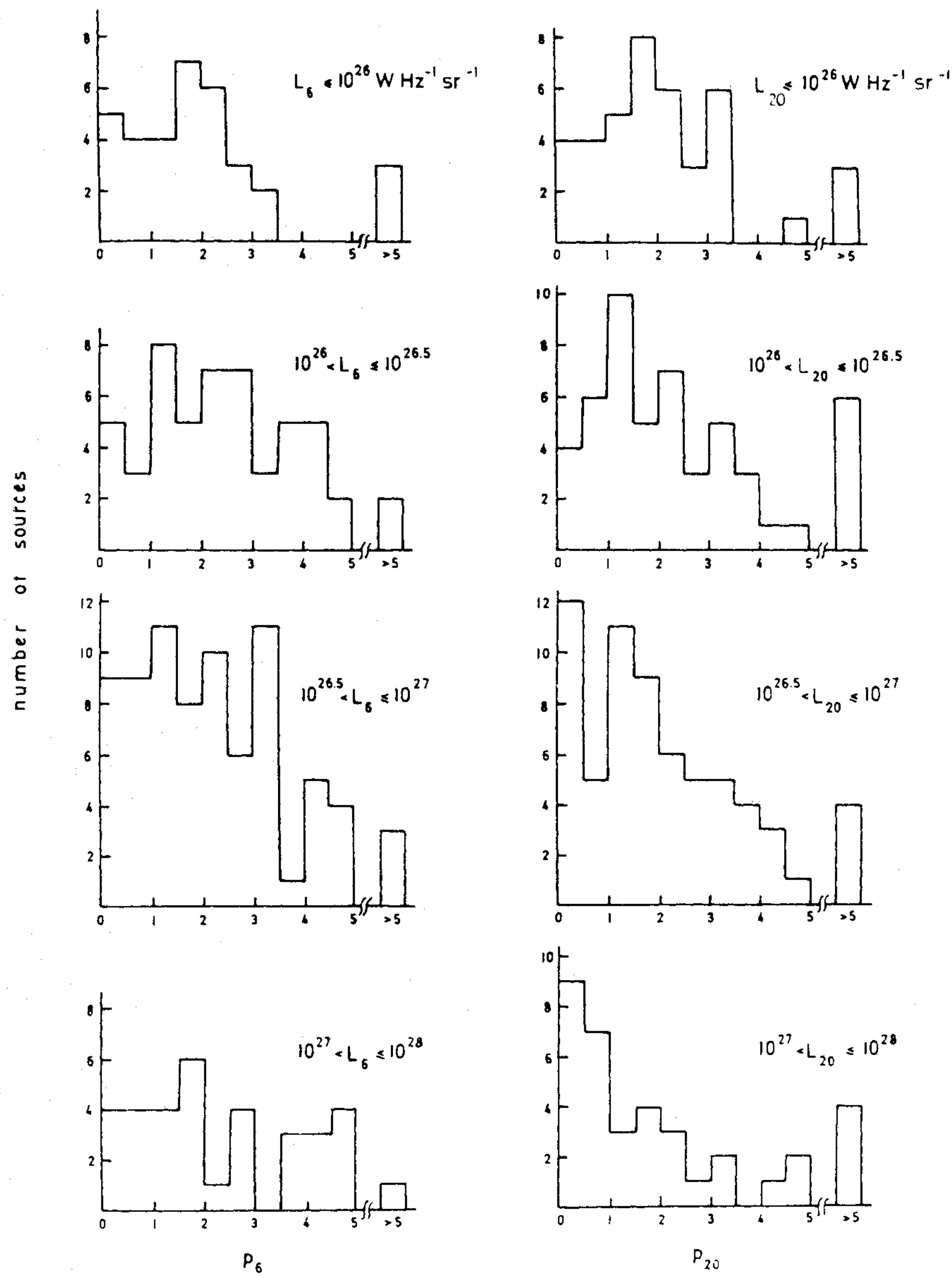


Figure 7. The distributions of p_6 and p_{20} for quasars in different ranges of core radio luminosity.

we find the core to be ~2.6 per cent polarized along PA 88°, while Rudnick *et al.* quote an upper limit of 0.2 per cent.

5 Dependence of core polarization on luminosity

Rudnick *et al.* (1986) have recently claimed a positive correlation between core radio luminosity, L_{core}, and the degree of polarization, and have also suggested that the difference in core polarization between galaxies and quasars, first reported by SSK, could be due to such a correlation.

In this section, we use the results of our observations, as well as those of P82, to examine whether p_6 correlations with L_{core}. We first consider the quasars. The degree of polarization versus core radio luminosity diagram for the quasars we observed (Fig. 6b) as well as the large quasar sample observed by P82 (Fig. 7) show no evidence of a correlation. A similar result is also found for the galaxies observed by P82. A closer examination of the correlation reported by Rudnick *et al.* (1986) showed that all of their sources below a core luminosity of $10^{25.8}$ W Hz^{-1} at 6 cm are galaxies while those above this luminosity are quasars. This could easily give rise to a spurious correlation between $p_{6,20}$ and L_{core} if the galaxies and quasars are not considered separately.

It is also relevant to note that the EFs are expected to be at larger cosmological distances than the galaxies, and hence also have more luminous cores since their flux densities are similar. If p correlates with L_{core}, the cores in EFs ought to appear more strongly polarized than those in galaxies, but, we find no evidence of such a trend. Also, considering the galaxies and quasars in P82 whose core luminosities overlap, we find the same difference in core polarization as for the whole sample. This all strongly suggests that the tendency for cores in quasars to be more strongly polarized than the cores in galaxies is not due to any p–L_{core} correlation as suggested by Rudnick *et al.* (1986).

6 Conclusions

We now summarize the principal conclusions of the paper.

(i) To examine whether the degree of polarization in core- and lobe-dominated quasars differ, we have presented VLA A-array observations of core polarization at 6 cm for a sample of 10 lobe-dominated quasars and investigated whether their degree of polarization, p_6, differs from that of the core-dominated quasars observed by Perley (1982). The median value of p_6 for the 10 lobe-dominated quasars is ~2.5 per cent, which is not significantly different from the value for the core-dominated ones.

(ii) We have presented new optical identification data for 33 compact radio sources observed by Perley (1982) with the VLA. There are 13 new identifications, five of which are very faint and could have position errors ±2 arcsec. We have determined the surface density of objects from $|b|$ ~90° to almost the galactic plane in both the E and O prints of the Palomar Sky Survey to estimate the reliability of the faint identifications with larger errors in their positions. We find that all our proposed identifications should be reliable.

(iii) Using the large sample of ~400 compact radio sources observed by Perley (1982), Saikia *et al.* (1985) found that the cores in quasars tend to be more strongly polarized than those in galaxies and empty fields. They also showed that at 6 cm, the compact steep-spectrum sources or CSSs are not significantly less polarized than the flat-spectrum ones or FSCs, contrary to an earlier suggestion by van Breugel *et al.* (1984).

In this paper, we have used the same sample to present updated versions of the distributions of p_6, as well as to investigate the distributions of p_{20} and of the depolarization parameter $DP = p_{20}/p_6$

for both FSCs and CSSs associated with different kinds of optical objects. At 20 cm too, the cores in quasars appear more highly polarized than the cores in galaxies for both FSCs and CSSs, although the latter do tend to be less polarized than the FSCs. The CSSs in quasars exhibit the most convincing evidence of depolarization towards longer wavelengths, while the data for galaxies are suggestive of a similar trend. The median value of DP for the FSCs is ~1 for the different types of optical objects.

(iv) We have investigated a possible correlation between the degree of core polarization and core radio lumninosity suggested by Rudnick *et al.* (1986), but find no evidence in support of such a relation.

Acknowledgments

It is a pleasure to thank Professor F. G. Smith and Drs Ian Browne, Chris Salter and Ralph Spencer for their valuable comments.

We thank the Director of Palomar Observatory for his permission to reproduce the finding charts from the Palomar Sky Survey prints. One of us (DJS) thanks IAU Commission 38 for travel support.

The National Radio Astronomy Observatory is operated by Associated Universities Inc. under contract with the National Science Foundation.

References

Angel, J. R. P. & Stockman, H. S., 1980. *Ann. Rev. Astr. Astrophys.* **18,** 321.
Bergamini, R. *et al.*, 1973. *Astr. Astrophys.*, **23,** 195.
de Ruiter, H. R., Willis, A. G. & Arp, H. C., 1977. *Astr. Astrophys. Suppl.*, **28,** 211.
Fanti, C., Fanti, R., Parma, P., Schilizzi, R. T. & van Breugel, W. J. M., 1985. *Astr. Astrophys.*, **143,** 292.
Hewitt, A. & Burbidge, G., 1980. *Astrophys. J. Suppl.*, **43,** 57.
Jones, T. W., Rudnick, L., Aller, H. D., Aller, M. F., Hodge, P. E. & Fiedler, R. L., 1985. *Astrophys. J.*, **290,** 627.
Kapahi, V. K., 1981. *Astr. Astrophys. Suppl.*, **43,** 381.
Kapahi, V. K. & Saikia, D. J., 1982. *J. Astrophys. Astr.*, **3,** 465.
King, I. R. & Raff, M. I., 1977. *Publs. astr. Soc. Pacif.*, **89,** 120.
Kühr, H., Witzel, A., Pauliny-Toth, I. I. K. & Nauber, U., 1981. *Astr. Astrophys. Suppl.*, **45,** 367.
Moore, R. L. & Stockman, H. S., 1984. *Astrophys. J.*, **279,** 465.
Orr, M. J. L. & Browne, I. W. A., 1982. *Mon. Not. R. astr. Soc.*, **200,** 1067.
Peacock, J. A. & Wall, J. V., 1982. *Mon. Not. R. astr. Soc.*, **198,** 843.
Pearson, T. J., Perley, R. A. & Readhead, A. C. S., 1985. *Astr. J.*, **90,** 738.
Perley, R. A., 1982. *Astr. J.*, **87,** 859.
Rudnick, L., Jones, T. W. & Fiedler, R., 1986. *Astr. J.*, **91,** 1011.
Saikia, D. J., 1985. *Extragalactic Energetic Sources,* ed. Kapahi, V. K., Indian Academy of Sciences.
Saikia, D. J., Swarup, G. & Kodali, P. D., 1985. *Mon. Not. R. astr. Soc.*, **216,** 385.
Tabara, H. & Inoue, M., 1980. *Astr. Astrophys. Suppl.*, **39,** 379.
van Breugel, W., Miley, G. & Heckman, T., 1984. *Astr. J.*, **89,** 5.
Véron-Cetty, M. P. & Véron, P., 1983. *Astr. Astrophys. Suppl.*, **53,** 219.
Véron-Cetty, M. P. & Véron, P., 1985. *A catalogue of quasars and active nuclei, ESO Scientific Report No. 4.*
Weiler, K. W. & Johnston, K. J., 1980. *Mon. Not. R. astr. Soc.*, **190,** 269.
Willis, A. G. & de Ruiter, H. R., 1977. *Astr. Astrophys. Suppl.*, **29,** 103.
Windhorst, R. A., Kron, R. G. & Koo, D. C., 1984. *Astr. Astrophys. Suppl.*, **58,** 39.