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Asymmetric depolarization in double low-luminosity radio galaxies

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Abstract. To investigate the presence of the Laing-Garrington effect (i.e. the lobe containing the jet more depolarized than that containing the counter-jet), we analyse polarization data at 6 and 20 cm for a sample of double low-luminosity radio galaxies. The effect is well visible, although not very strong. We therefore confirm what was inferred in a previous paper based on data at one frequency (20 cm) only. Furthermore, we find that radio galaxies with strong radio cores show a more pronounced asymmetry in depolarization. We conclude that the presence of the Laing-Garrington effect in our sample is a indication that relativistic motions do occur on the kpc scale of low-luminosity radio galaxies as recently suggested by theoretical arguments and observational evidence.

Key words: radio continuum: galaxies – galaxies: active – polarization – galaxies: jets

1. Introduction

Laing (1988) and Garrington et al. (1988, 1991) have shown that a remarkable depolarization asymmetry exists in powerful radio sources (hereafter called the Laing-Garrington effect, LG): the lobe containing the main radio jet is much less depolarized than that containing the counter jet. The LG effect (that is commonly observed in radio loud quasars and is weaker in radio galaxies) has been interpreted as a strong confirmation that the brightness asymmetry, commonly observed in the jets of radio galaxies, is caused by Doppler beaming. The depolarization is assumed to be external, produced in a halo surrounding the radio lobes, and the jets are supposed to have relativistic speeds. The counter-jet side, which would point away from the observer, would be seen through a larger portion of the halo, and therefore would appear more depolarized than the jet side.

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Is the LG effect present also in low-luminosity radio galaxies? In these sources it has been suspected for some time that jet velocities are quite low, of the order of $10^3 - 10^4$ km s^{-1} (Bicknell 1984; Bicknell et al., 1990). However, more recently, theoretical arguments and observational evidence have been presented which indicate that in these radio sources jets are relativistic on scale of a few kpc and then are slowed down to much lower velocities at larger distances (Laing 1993; Parma et al., 1994, 1996; Bicknell 1994). Furthermore, the unification scheme for radio-loud active galactic nuclei (see e.g. Urry & Padovani 1995) identifies low-luminosity radio galaxies as the parent population of BL Lacs, for which relativistic motions on parsec scales are well established. The presence or absence of the LG effect could represent an important confirmation of relativistic velocities in these jets on kpc scales.

In a previous paper (Parma et al., 1993) we reported searching for the LG effect in the B2 low-luminosity radio galaxy sample (see Fanti et al., 1987 and references therein for the characteristics of the sample). Since at that time we had polarization data at one frequency only (20 cm), we examined the polarization asymmetry at this frequency and argued that it is an indicator of depolarization asymmetry. We found that the "jetted" lobe shows, in general, a larger fractional polarization at 20 cm. We concluded that the LG effect is present also in low-luminosity radio galaxies, although weaker than in high-luminosity galaxies.

In the present paper we discuss again the LG effect in the B2 radio galaxies sample by means of new VLA observations at 6 cm (Morganti et al., 1996), which allow us to determine the actual depolarization between 20 and 6 cm.

2. The new 6 cm VLA data and the depolarization analysis

The sample discussed in Parma et al. (1993) has been observed at 6 cm with the VLA, and images have been obtained at the same resolution as the 20 cm data previously presented in Capetti et al. (1993). The details of the new observations, the description of the data reduction and the final data are presented in a companion paper (Morganti et al., 1996).

For the purpose of the present paper we discuss the double sources only and do not consider head-tail sources or more complex morphologies. Furthermore, we consider only sources for which polarization could be measured for both lobes at both frequencies. This leaves us with a sample of 47 objects.

These sources have been divided into three subsets: sources with a one-sided jet, two-sided jets or no jets. The classification into one- or two-sided was done according to a parameter, A_j, defined as the main-to-counter jet brightness ratio within the first 5 kpc from the core. A source is considered one-sided if $A_j \geq 3$. This classification is slightly different from the one given in Parma et al. (1993). Moreover, the main jet is defined on the basis of the whole set of observations, at several resolutions, at our disposal, including unpublished high-resolution VLA data. In general the main jet is quite clear, although there are some slightly uncertain cases.

The sample contains 12 one-sided (subset A), and 25 two-sided (subset B) sources. For ten sources no jets are visible in our data. Table 1 summarizes the relevant information we have for all these sources. We give in column 2 the arm-length ratio ($r_\theta = \theta_{\rm j}/\theta_{\rm cj}$), i.e. the ratio of the separations from the core of the jet to the counter-jet sides. For the sources without a jet, the ratio has been computed as $\theta_{\rm north}/\theta_{\rm south}$ or $\theta_{\rm east}/\theta_{\rm west}$. Column 3 lists the normalized core power ($P_{\rm cn}$) defined as the ratio of the core flux to the extended flux, normalized to the average value for sources of the same total radio power (de Ruiter et al., 1990). We expect the sources strongly beamed (asymmetric) to have $P_{\rm cn} > 1$, and weakly beamed sources (symmetric) to have $P_{\rm cn} < 1$.

As discussed in Morganti et al. (1996), we have determined for each source the mean scalar polarization (at 6 cm), m'_6, defined as the integrated polarization flux over the total intensity. For the radio lobes, the typical values of m'_6 range from 10% to 30%, with a median value 15.5 ± 1%. The m'_6 values for the two lobes of a source are rather similar, contrary to what was found at 20 cm. (Parma et al., 1993), where the lobe containing the brighter jet was found to be more polarized than the other.

The old maps at 20 cm and the new at 6 cm have been analysed to determine the depolarization, DP_6^{20}, between these two frequencies (Morganti et al., 1996). The depolarization is defined as the ratio of the mean scalar fractional polarization, m', at 20 cm over that at 6 cm: $DP_6^{20} = m'_{20}/m'_6$. The depolarization values are peaked around 0.7 and extend down to $\approx$ 0.25. Only about 25% of objects show little or no depolarization ($DP > 0.9$). The values of the depolarization in the jet and counter-jet sides are given in columns 4 and 5 of Table 1. For the sources without a jet, DP_j actually referes to the north or to east jet. The typical errors for the DP measurements are $\sim$0.1 as estimated in Morganti et al. (1996). In the last two columns of Table 1 we indicate for each source the main jet and the morphological type according to the Fanaroff & Riley (1974) classification.

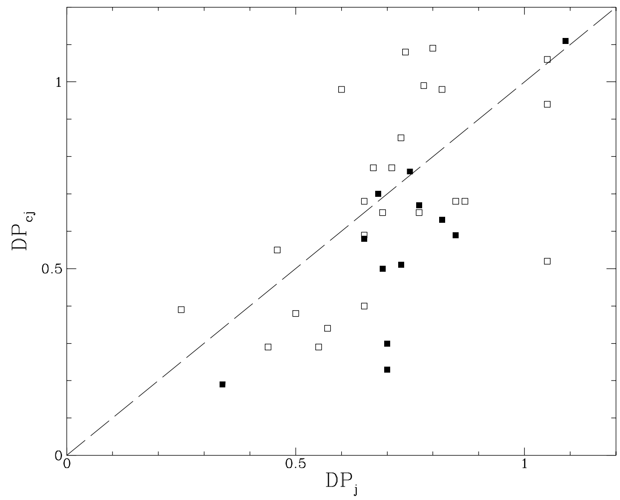

Fig. 1. Plot of the depolarization of the counter-jet versus the depolarization of the jet. Filled squares represent the one-sided jet and open squares represent two-sided jets

3. Discussion

The new data are ideal to investigate the possible presence of the LG effect in low-luminosity radio galaxies, and here we compare the depolarization of the "jetted" lobes ($DP_{\rm j}$) with the depolarization of the counter-jet lobes ($DP_{\rm cj}$).

Fig. 1 shows the plot of $DP_{\rm j}$ versus $DP_{\rm cj}$ for the sources of both subsets A and B (indicated with different symbols). The LG effect is clear. Among the one-sided, nine sources show a stronger depolarization in the counter-jet side, i.e. $DP_{\rm j} > DP_{\rm cj}$ (7 of them with $DP_{\rm j} - DP_{\rm cj} > 2\sigma$), and only three have $DP_{\rm j} \leq DP_{\rm cj}$. Also the two-sided sources show a preference for $DP_{\rm j} > DP_{\rm cj}$, although at a lower extent. Out of 25 objects, there are 13 sources with $DP_{\rm j} > DP_{\rm cj}$ (6 of them with $DP_{\rm j} - DP_{\rm cj} > 2\sigma$, although the depolarization of the southern lobe of 1243+26 could be uncertain due to the possible confusion with an other radio galaxy, see Morganti et al. 1996), and of the remaining objects, i.e. with $DP_{\rm j} < DP_{\rm cj}$, only three have $DP_{\rm cj} - DP_{\rm j} > 2\sigma$.

It is worth noticing that, as expected, the "one-sided jet" sources tend to be more powerful than the "two sided" ones by half an order of magnitude. The latter are mostly FRI type ($\sim$70%, either "fat doubles" or "3C31 type"), while the former contain $\sim$50% of objects which are of morphology intermediate between FRI and FRII. It is therefore clear that the depolarization asymmetry does appear to be stronger, as expected, in the sources which have FRII or intermediate morphology.

The ten sources without jets show depolarization values distributed roughly like the sources with jets, and the distribution of their ratios $DP_{\rm min}/DP_{\rm max}$ is similar to the distribution of $DP_{\rm cj}/DP_{\rm j}$.

The above result confirms the conclusion reached by Parma et al., (1993) and the preliminary results, based on a smaller sample, presented in Garrington, Holmes & Saikia (1996). In Parma et al. (1993) the polarization asymmetry found at 20 cm

Table 1.

Object	r_θ	P_{cn}	DP_j	DP_{cj}	Main Jet	FR-type
Subset A: One-sided						
0206+35	1.02	1.9	0.77	0.67	NW	I
0755+37	1.00	5.5	0.73	0.51	E	I
0836+29	1.65	10.0	0.69	0.50	N	I-II
0844+31	1.00	1.8	0.85	0.59	N	I-II
0908+37	1.06	3.2	0.34	0.19	N	I-II
1113+29	0.76	1.2	0.82	0.63	W	I-II
1521+28	1.78	4.5	0.70	0.23	S	I
1553+24	1.70	6.6	1.09	1.11	NW	Naked jet
1643+27	0.95	1.2	0.70	0.30	N	I-II
1658+30	0.81	2.7	0.65	0.58	SW	I-II
1827+32	1.88	2.8	0.68	0.70	NE	I
1833+32	1.03	5.0	0.75	0.76	NE	II
Subset B: Two-sided						
0034+25	0.84	0.45	0.74	1.08	E	I
0149+35	0.97	0.54	0.50	0.38	W	I
0722+30	1.00	1.10	0.73	0.85	E	I
0828+32	1.06	0.10	1.05	0.94	SW	II
0913+38	0.71	0.30	1.05	1.06	W	I
0915+32	0.66	1.20	0.60	0.98	N	I
1005+28	1.25	0.60	0.69	0.65	S	I-II
1102+30	0.93	1.10	0.77	0.65	E	I
1116+28	1.23	1.10	0.67	0.77	W	I
1122+39	1.00	0.10	0.80	1.09	NW	Naked jet
1243+26	1.12	1.30	1.05	0.52	N	I
1254+27	1.11	0.16	0.57	0.34	N	I
1316+29	1.21	2.80	0.71	0.77	E	I
1322+36	1.00	1.30	0.85	0.68	S	I
1347+28	1.00	0.50	0.65	0.68	SW	I-II
1357+28	1.00	0.77	0.55	0.29	N	I
1422+26	1.09	0.50	0.65	0.40	W	I
1450+28	0.50	2.30	0.65	0.59	E	I
1525+29	0.77	0.40	0.82	0.98	S	I
1528+29	0.98	0.46	0.46	0.55	NE	I-II
1613+27	0.82	1.40	0.87	0.68	SE	I
1615+32	1.20	1.20	0.25	0.39	S	II
1626+39	1.06	2.10	0.44	0.29	W	I
1752+32	1.00	0.60	1.86	1.12	SW	I
2236+35	0.90	0.27	0.78	0.99	NE	I
Double sources without jet						
0708+32	1.19	$\lesssim$4.50	0.25	0.31		?
0922+36	0.62	1.20	0.12	0.33		I-II
1141+37	1.00	0.37	0.71	0.68		II
1317+33	0.96	1.20	0.58	0.91		I
1441+26	1.29	0.20	0.68	0.31		I-II
1455+28	0.90	0.90	0.57	0.63		II
1457+29	1.11	0.30	0.78	0.74		I
1512+30	1.00	1.10	0.84	0.92		?
1609+31	1.15	0.15	0.81	0.90		I-II
1726+31	1.04	0.86	0.35	0.37		II

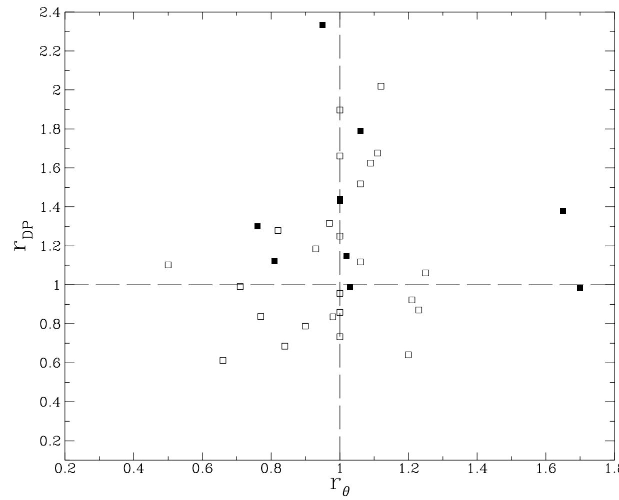

Fig. 2. Ratio of the depolarization versus arm-length ratio (see text for details). Filled squares represent one-sided jet, open squares represent two-sided jets

was used as a qualitative indicator of depolarization asymmetry. This assumption allowed the authors to infer that the LG effect is also present in low-luminosity radio galaxies. This is now confirmed by the analysis of the actual depolarization.

Parma et al. (1993) also found a correlation between the 1.4 GHz fractional polarization (assumed to related to depolarization) of the lobe and the gap length of the corresponding jet (the gap length is defined as the distance from the core to the point where the jet brightens). Using the new data, this correlation (not shown) persists with the same significance level as before.

In their work on quasars and powerful radio galaxies, Garrington & Conway (1991) concluded that the major contribution to depolarization arises from a halo of hot gas surrounding the radio source. It is worth noticing that the parameters of such a halo derived in Morganti et al. (1996) from the distributions of the depolarization and Faraday dispersion in the lobes agree well with what Garrington & Conway (1991) found for the low red-shift ($z < 1$) radio galaxies.

Apart from the LG effect, other asymmetries have been found in the last few years for powerful radio galaxies. With the data available for the B2 sample, we can investigate if these asymmetries are also present in our sample.

Liu & Pooley (1989) have found (for a sample of powerful radio galaxies) that the most depolarized lobe also has the steeper radio spectrum. We have searched for this effect in our sample, but we did not find it. If this effect is caused by a larger contribution of the jet and hot-spot (which tend to have radio spectra less steep than the lobes) on the jet side, its absence in our sample would be expected because of the relatively low prominence of hot-spots and of the symmetry of the jets on scales larger than a few kpc.

Pedelty et al. (1989) have shown a correlation between the arm length and depolarization in a sample of high red-shift

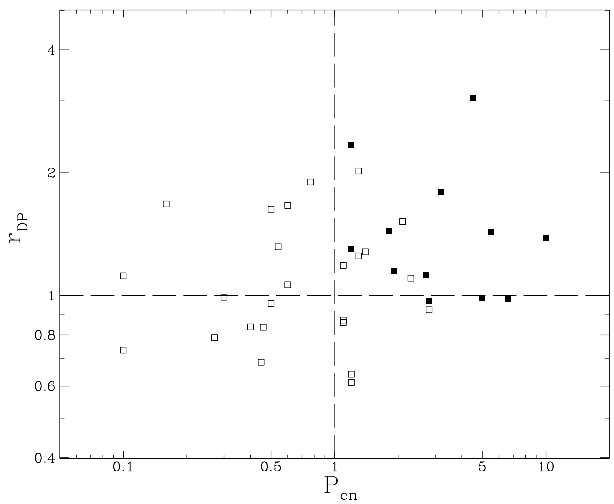

Fig. 3. Ratio of the depolarization versus P_{cn} (see text for details). Filled squares represent a one-sided jet, open squares represent two-sided jets

galaxies without jets. The lobe closer to the nucleus is the one that is more depolarized. A similar effect was also found by Liu & Pooley (1989).

We have searched for such correlation in our sample, by plotting the depolarization ratio $r_{DP} = DP_{\rm j}/DP_{\rm cj}$ versus the arm-length ratio, $r_\theta = \theta_{\rm j}/\theta_{\rm cj}$. We found no effect for the one-sided sources. On the contrary, there may be a slight effect for the two-sided sources (Fig. 2). Note that the sources of our sample tend to have arm-length ratios not very different from unity, unlike the sources in the Pedelty et al. (1989) sample.

We conclude that the effect found by Pedelty et al (1989) if present is not very strong. In the one-sided sources it could be masked by the stronger LG effect, but it could be present in the two-sided ones, although at low level. On the other hand a correlation between depolarization and arm length could make the LG asymmetry less clear for the two-sided sources. In fact, the two-sided sources well below the symmetry line in Fig. 1 tend to have arm-length ratio larger than 1, while those well above the line tend to have arm-length ratios less than one, thus broadening the overall distribution across the symmetry line.

We have also searched for a correlation between the r_{DP} parameter and the core prominence (P_{cn}) parameter. This would be, naively, expected if the LG effect is the result of orientation effects in sources with relativistic jets. Garrington & Conway (1991) failed to find this effect in their sample, and concluded that the r_{DP} parameter depends more strongly on the depolarizing halo properties and source sizes than on the orientation angle. In our sample, we find that for the objects with $P_{cn} > 1$ the depolarization ratio r_{DP} is predominantly > 1 (15 objects against 8), while for the sources with $P_{\rm cn} < 1$ the depolarization ratio is equally distributed above and below one (Fig. 3).

We consider this a further argument in favour of the interpretation that the LG effect is caused by a combination of orientation and Doppler boosting effects.

4. Conclusions

We have confirmed the presence of the LG effect in a sample of low-luminosity radio galaxies. The effect appears to be stronger in those sources which show a FRII or intermediate morphology while is less prominent in FRI. An associated effect between depolarization ratio and core prominence, measured by the P_{cn} parameter, was also found. These two effects together support the interpretation that the jets are relativistic on the kpc scale and that the asymmetry in depolarization is caused by a combination of Doppler favouritism and the presence of an external depolarizing halo.

Parma et al. (1993), in their discussion of the polarization asymmetry at 1.4 GHz for the present sample, pointed out the contradiction between the interpretation of their result in terms of Doppler favouritism and current, at that time, ideas that jets in low luminosity radio galaxies were not relativistic (Bicknell, 1984; Bicknell et al., 1990). Since then new theoretical arguments (Bicknell, 1994; Laing 1993) and the new observational evidence for a clear correlation between core prominence and jet brightness asymmetry (Parma et al., 1994) have indicated that these jets are likely to be relativistic close to the core, on scales of a few kpc, and then are slowed down to non-relativistic velocities on larger scales, removing the previous contradiction.

Also the correlation between depolarization and jet gap can be understood if the gap represents the base of the jet where the Lorentz factor is higher. In jets at large angles to the line of sight their radiation would be beamed away from the line of sight, producing the observed gap.

Based on the existence of relativistic motion on kpc scale, there should be a fraction of these sources which are beamed when aligned close to the line of sight, and the question is which is the associated population. BL Lacs have been suggested by several authors as such a beamed population (see, e.g., Urry and Padovani, 1995). However, as Parma et al. (1996) have pointed out, some doubts remain as to the Lorentz factors required. In the unification scenario, values of $\gamma \sim 5$ are required (Urry and Padovani, 1995), whereas both the jet asymmetry and the distribution of core strength (Parma et al., 1996; Morganti et al., 1995) suggest $\gamma \sim 2$.

We found also some hints for a correlation between the arm-length ratio and the depolarization ratio, in the sense that the more distant lobe tends to be less depolarized.

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