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Optical polarimetry of the southern compact radio source PKS 1934 − 63

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ABSTRACT

We present *B*-band polarimetry measurements which show significant optical polarization in the nucleus of the galaxy associated with the southern compact radio source PKS 1934 − 63. The polarization *E*-vector is within 10° of the perpendicular to the VLBI radio axis. The observations are consistent with dichroic absorption in a dust band perpendicular to the radio axis, with scattered AGN light, or with non-thermal emission associated with the compact double radio structure. In the former two cases, the observations support the idea that the optical emission from compact radio sources is anisotropic, and that the 'unified schemes' may apply to compact as well as extended radio sources. Spectropolarimetric observations are required to identify the polarization mechanism.

Key words: polarization – dust, extinction – galaxies: active – galaxies: individual: PKS 1934 − 63 – galaxies: nuclei – radio continuum: galaxies.

1 INTRODUCTION

PKS 1934 − 63 ($z = 0.183$) was the first radio source to be discovered with a spectral turnover in the GHz radio regime (Bolton, Gardner & Mackey 1963). In common with most GHz-peaked (GPS) radio galaxies discovered since, VLBI maps show that the double radio structure is extremely compact, with a measured diameter of only 0.042 arcsec or 0.17 kpc[1] (Gubbay et al. 1971; Preston et al. 1984).

The detailed analysis of the optical emission-line spectrum reveals several interesting features, including relatively high electron densities and reddening for the narrow-line gas (Penston & Fosbury 1978; Fosbury et al. 1987), hints of broad wings to the narrow emission lines (Tadhunter 1987), and a clear dilution of the stellar absorption features which implies the presence of a featureless continuum component (Penston & Fosbury 1978; Tadhunter 1987).

Despite certain similarities (e.g. double radio structure, strong emission lines) between compact radio sources like PKS 1934 − 63 and their more extended ($D > 15$ kpc) counterparts, the relationship between the two types is uncertain. In particular, it is not clear whether the anisotropy-based unified schemes, originally proposed to explain the relationship between *extended* radio galaxies and quasars (e.g. Barthel 1989), can also be applied to the *compact* sources. The statistics appear to rule out the idea that compact sources are simply extended radio sources projected at small angles to the line of sight (Fanti et al. 1990). However, it remains a possibility that a parallel unified scheme might exist which links the compact radio quasars and the compact radio galaxies.

As one of the few bright, nearby GPS radio galaxies, PKS 1934 − 63 is an ideal candidate to test whether the unified schemes apply to the compact sources. In this paper we present new optical polarization measurements which provide strong evidence for optical anisotropy in the galaxy associated with this source.

2 OBSERVATIONS AND RESULTS

PKS 1934 − 63 was observed on the night of 1993 July 12 using the ESO 3.6-m telescope at La Silla with the ESO Faint Object Spectrograph and Camera (EFOSC) in polarimetric mode (di Serego Alighieri 1989). The observations consisted of four 900-s exposures in the *B* band with the telescope rotator at position angles (PAs) of 135°, 180°, 225° and 270°. The measured seeing for these observations was 1.4 arcsec (FWHM), and the *B* band covers the rest-wavelength range 3300–4300 Å at the redshift of PKS 1934 − 63.

Following bias subtraction and the correction for non-uniformities using flat-fields, the mean background level was determined for the 'o'- and 'e'-ray images separately, using several apertures placed evenly around the source. The

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[1] $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.0$ assumed throughout.

degree and angle of the polarization were then derived from the background-subtracted source counts using the prescription by Tinbergen & Rutten (1992), with the absolute angle calibration facilitated by observations of the polarimetric standard star HD 126593. Finally, in order to rule out a spurious polarization induced by, for example, a cosmic ray at one of the PAs, we checked that the 'o'- and 'e'-ray intensities at the four rotator positions followed the pattern expected for a linearly polarized source.

Fig. 1 shows the percentage polarization and angle for various apertures centred on the source. The error bars have been derived by combining the uncertainty in the background (from the standard deviation of the separate background measurements) with the Poisson error in the source + background intensities for each separate 'o'- and 'e'-ray measurement, and then propagating the errors using standard formulae. We find that the correction for the positive bias which can affect polarization measurements at low P/σ_p-values (Simmons & Stewart 1985) is negligible for all the apertures [−0.1 per cent in P(per cent) or less], and we have not made this correction. The emission-line contamination of our measurements is also small. The data in Fosbury et al. (1987) show that emission lines contribute of the order of 15 per cent of the total flux in the B band. Correction for this contamination under the assumption that the emission lines are unpolarized would raise the measured polarization in the smallest aperture to 4.1 ± 0.5 per cent. However, since the emission-line polarization properties are unknown, and the apertures used for the spectroscopy and polarimetry may be different, we have not corrected the values plotted in Fig. 1 for emission-line dilution.

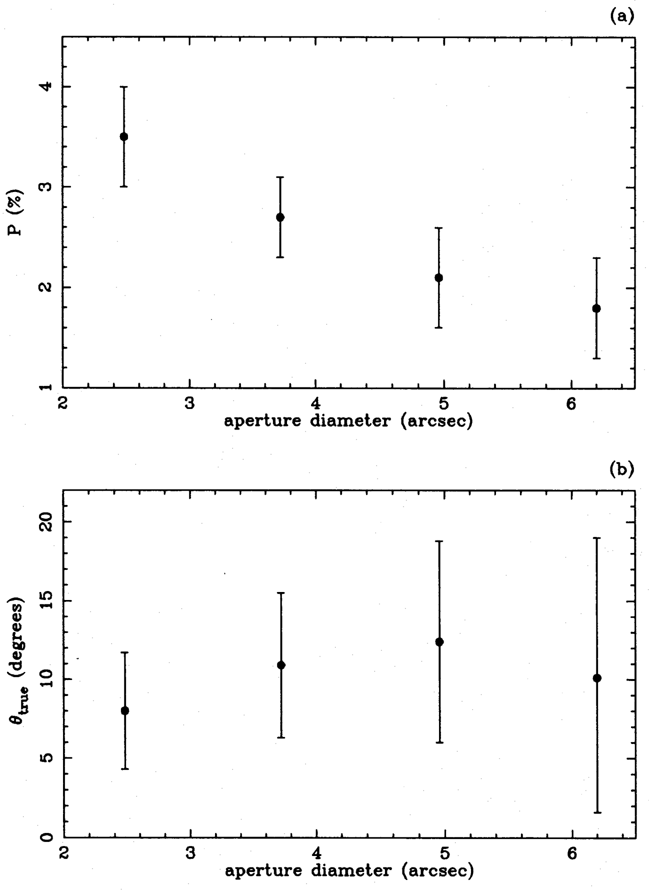

Figure 1. B-band polarization measurements for the compact radio source PKS 1934 − 63: (a) the percentage polarization versus aperture diameter; (b) the polarization E-vector position angle versus aperture diameter.

It is clear that significant polarization is detected for all the apertures, with the polarization increasing from a minimum of 1.8 ± 0.5 per cent for the largest (6.2-arcsec diameter) aperture to a maximum of 3.5 ± 0.5 per cent for the smallest (2.4-arcsec diameter) aperture (Fig. 1a). The orientation of the E-vector remains constant, within the errors, over these apertures (Fig. 1b), and is aligned close to the perpendicular to the VLBI radio axis [PA(radio) = 90° ± 1° (Gubbay et al. 1971); PA(radio–optical) = 82° ± 4° for the smallest aperture]. The aperture dependence suggests that the polarized component is concentrated in the nucleus (radii < 1.2 arcsec), with unpolarized light from the stars in the galactic halo diluting the polarization in the larger apertures. Thus it is likely that, in common with the radio and narrow-emission-line regions in this galaxy, the polarized continuum source is relatively compact.

We have also investigated the fainter companion source, situated some 2.8 arcsec to the north-west of the main galaxy along PA = 284° (Fosbury et al. 1987), but in this case fail to measure significant polarization (P = 1.0 ± 0.8 per cent).

3 DISCUSSION

3.1 Origin of the polarization

Large optical polarization, with the E-vector oriented close to perpendicular to the radio axis, has recently been detected in the near-UV continua of several high-redshift extended radio galaxies (e.g. Tadhunter et al. 1992; Cimatti et al. 1993). These observations are generally interpreted in terms of a beaming/scattering model in which much of the UV continuum represents light scattered out of the radiation cone of a hidden quasar (Tadhunter, Fosbury & di Serego Alighieri 1988; Fabian 1989).

Given the similarities between the polarization properties of PKS 1934 − 63 and those of the high-redshift radio galaxies, it is important to consider a scattering origin for the polarization in this compact source, and also to investigate the possible relationship between any scattered component and the featureless optical continuum deduced from the optical spectroscopic observations (Penston & Fosbury 1978; Tadhunter 1987).

The fractional contribution of the featureless component can be estimated from the dilution of the stellar spectral features, under the assumption that the old stellar population is typical of nearby elliptical galaxies. First, we can compare the average of the equivalent widths of the Na I (5890) and Mg I (5190) features, measured by Tadhunter (1987) for PKS 1934 − 63 (EW = 2.2 Å), with the similar average measured by Tonry (1981) for a sample of normal ellipticals (EW = 4.31 ± 0.82 Å). This comparison yields a fractional contribution of the featureless component of f = 0.49 ± 0.13 for rest wavelengths between 5190 and 5890 Å, although this is likely to be an upper limit because of the possible contamination of the absorption features by adjacent emission lines.

A second estimate can be obtained from the depth of the 4000-Å break B_{4000}, defined as the ratio of the continuum fluxes in line-free continuum windows centred at 4022 and 3804 Å (Shaw & Tadhunter 1994). We find that $B_{4000} = 1.39$ and 1.47 from the spectra in Penston & Fosbury (1978) and Fosbury et al. (1987) respectively. Comparing these with the break depth for normal elliptical galaxies ($B_{4000} \eqsim 1.86 \pm 0.18$: Shaw & Tadhunter 1994), we obtain $f = 0.45 \pm 0.12$ (Fosbury et al. 1987 data) and $f = 0.54 \pm 0.1$ (Penston & Fosbury 1978 data), where in this case the fractional contribution is estimated shortward of the break (3804-Å window). Both sets of estimates suggest that the featureless component contributes of the order of 50 per cent of the light at optical/UV wavelengths. This is larger than the featureless contribution in most other low-redshift radio galaxies, with the possible exception of Cygnus A (Shaw & Tadhunter 1994).

If we assume that *all* of the polarization is associated with the featureless component, then the degree of polarization in this component is of the order of $P \sim 7$ per cent (for the smallest polarization aperture, consistent with the slit used for the spectroscopic measurements). At such a level, a large fraction, perhaps all, of the featureless component might be scattered light, the exact fraction depending on the geometry and the nature of the scattering medium.

However, scattering is not the only explanation. The observed level and orientation of polarization can also be explained in terms of dichroic absorption by dust grains aligned in the toroidal magnetic field of a disc oriented perpendicular to the radio axis. The presence of such 'polarization discs' has already been inferred from polarimetric measurements of the dust-lane radio galaxies Centaurus A and Cygnus A (Berry 1985; Hough et al. 1987; Jackson & Tadhunter 1993), and it is possible that such an absorbing band lies hidden within the unresolved core of PKS 1934 − 63. Since 1 mag of visual extinction can result in up to 3 per cent polarization by the dichroic mechanism (Serkowski, Mathewson & Ford 1975), the observed level of polarization is consistent with the extinction deduced from the narrow emission lines ($A_V \sim 2$ mag: Penston & Fosbury 1978).

Finally, given that the spatial relationship between the radio and optical continuum-emitting regions is uncertain, we must also consider the possibility that the polarization has a non-thermal origin, i.e. that the optical featureless continuum represents a high-frequency 'tail' to the radio continuum emission. Although PKS 1934 − 63 has a low measured radio polarization ($P < 2$ per cent at 8.4 GHz: N. Killeen, private communication), it remains possible that the radio continuum is *intrinsically* polarized at a level similar to that of the optical: it is likely that the compact radio source is strongly depolarized by the interstellar medium in the core of the galaxy. From the latest high-frequency flux measurements for this source (J. Reynolds, private communication), we derive a spectral index of 1.15 ± 0.05 between 4.9 and 8.4 GHz. Assuming that this spectral index also applies at optical wavelengths, the extrapolated flux at 4730 Å (corresponding to the 4000-Å break in the rest frame) is $F_{4730} = 1.0^{+2.5}_{-0.4} \times 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1}. For comparison, the featureless continuum level, estimated from the optical spectra in Penston & Fosbury (1978) and Fosbury et al. (1987), is $F_{4730} = (1.2 \pm 0.5) \times 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1} – well within the uncertainty of the radio extrapolation. Thus we cannot rule out a non-thermal origin purely on the basis of the radio extrapolation. However, given the curvature in the radio spectrum of PKS 1934 − 63 and other GPS galaxies at high frequencies, it seems unlikely that the spectral index would in fact remain constant between the radio and optical, and we regard non-thermal synchrotron emission as the least likely of the three possible polarization mechanisms.

3.2 Anisotropy and unification in compact radio sources

The scattering and dichroic mechanisms both imply some optical anisotropy associated with the radio axis in this compact radio source. Since anisotropy lies at the heart of the unified schemes which link extended radio galaxies and radio-loud quasars, it is important to explore the possibility that there exists a similar, parallel unified scheme for the compact radio sources.

Based on the radio observations alone, the application of the unified schemes to the GPS and related compact steep-spectrum (CSS) objects is controversial (Fanti & Fanti 1990; O'Dea, Baum & Stanghellini 1991). Two main observational results have been cited as evidence against the unification: first, the different redshift distributions of the GPS quasars and radio galaxies; secondly, the lack of evidence for superluminal motions and beaming in the GPS quasars. Neither of these arguments is conclusive, however: the redshift distributions are affected by a variety of unquantified selection effects, and the superluminal motions may be difficult to measure in the compact cores of the GPS/CSS objects if the scales of the core and more extended radio structures are correlated. Moreover, even if repeated observations failed to provide evidence for relativistic motions and beaming in the cores of the compact sources, this would not rule out an anisotropy-based unified scheme, since the anisotropy could be produced by obscuration, rather than by the relativistic beaming.

The ultimate confirmation of the unification idea for the compact radio sources would be provided by the detection of broad lines in the polarized light, revealing the presence of hidden quasars in the cores of the galaxies.

4 CONCLUSIONS

Our measurements show that the southern GPS radio galaxy PKS 1934 − 63 is significantly polarized at blue optical wavelengths, with the polarization oriented close to the perpendicular to the VLBI radio axis.

Scattered nuclear light, dichroic absorption and non-thermal emission are all viable polarization mechanisms, and we cannot distinguish between them using our *B*-band polarization measurement alone. The former two mechanisms would both imply a degree of anisotropy in the optical radiation associated with the radio axis, consistent with the idea that the unified schemes apply to compact as well as extended radio sources. The non-thermal possibility is also interesting, because it would imply the presence of a population of energetic electrons, which would have consequences for our understanding of the nature of compact radio sources.

PKS 1934 − 63 is a prime candidate for future spectropolarimetric measurements, which would allow us both to distinguish the polarization mechanism, and to search for the polarized broad-line signature of a hidden quasar.

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