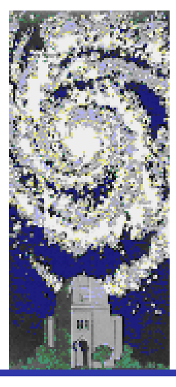
Evidence for Co-Spatial Optical and Radio Polarization in Active Galactic Nuclei



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Abstract

In a comparison of simultaneous optical and 5 GHz VLBI polarisation observations for a small sample of Active Galactic Nuclei, the optical and VLBI core polarisation position angles were virtually always either aligned or perpendicular to each other. This can be understood if the radio cores with their polarisation aligned with the optical polarisation were predominantly optically thin, while the radio cores whose polarisation was perpendicular to the optical polarisation were predominantly optically thick. We present the results of coordinated optical and high-frequency (43+22+15 GHz) VLBA polarisation observations of 14 AGN designed to test this hypothesis. The distribution of the differences between the optical and VLBI core-region polarisation corrected for the core Faraday rotation shows a clear peak near zero degrees (optical and radio polarisation aligned). This indicates that the magnetic field directions in the regions in which the optical and compact radio polarisations arise are the same, suggesting that a substantial fraction of the optical and radio polarisations are, in fact, emitted by the same regions.

Introduction

The continua of radio-loud active galactic nuclei (AGN) are dominated by nonthermal (synchrotron) emission, which is clearly associated with the relativistic jets in these objects, although the details of the jet structure and physics remain uncertain. BL Lac objects and optically violently variable quasars are sometimes collectively referred to as "blazars".

Although it is believed that synchrotron radiation dominates over essentially the entire observed spectrum of blazars, it has usually been expected that there should be little correlation between observed properties in widely spaced wavebands, even if genuinely simultaneous measurements are compared. This is due in part to early attempts to search for optical—radio correlations that were unsuccessful or yielded ambiguous results (e.g. Kinman et al. 1974; Pomphrey et al. 1976; Rudnick et al. 1978). In addition, it seemed natural to suppose that the higher-energy optical emission was generated in more compact regions than the radio emission, closer to the base of the jet.

For these reasons, few studies of possible correlations between different wavebands were carried out until the middle 1990s. Gabuzda, Sitko & Smith (1996) analyzed simultaneous optical and 6cm VLBI polarization measurements for eight blazars, primarily BL Lac objects. The 6cm polarization angles were corrected for the integrated rotation measures, presumed to be Galactic. Although those results were not conclusive due to the small number of objects considered, there were clear suggestions of a possible correlation between the optical polarization position angle χ_{opt} and the polarization position angle in the VLBI core χ_{core}. An analysis of these results together with simultaneous optical and 6cm VLBI polarization data for additional blazars (bringing the total number of objects for which such data are available to 15; see Gabuzda 2003) shows clear evidence for a correlation between χ_{opt} and χ_{core}, with χ_{core} nearly always being aligned with or perpendicular to χ_{opt}.

This bimodal behavior in the distribution of $|\chi_{opt} - \chi_{core}|$ can easily be understood if **(1)** the optical and radio polarization are roughly ***co-spatial***, and **(2)** the VLBI cores for which χ_{core} is aligned with and perpendicular to χ_{opt} are dominated by optically ***thin*** and optically ***thick*** emission regions, respectively. Placing constraints on co-spatiality of the optical and radio emission can provide useful input to jet models; for example, in their analysis of inhomogeneous synchrotron-self-Compton models, Ghisellini et al. (1985) found that the radio and ultraviolet-optical-infrared emission can come from the same region of the jet, but only for certain combinations of jet geometry and particle flow acceleration.

Observations & Reduction

We obtained optical and 7mm+1.3cm+2cm VLBA polarization observations of 14 AGN simultaneous to within about one day on August 7, 2002 (5 sources) and March 5, 2003 (9 sources) in order to test the hypothesis described above. The optical polarization observations were obtained on August 8 on the 60" telescope and on March 4 and 7 on the 90" telescope of the Steward Observatory.

The VLBA total intensity and linear polarization calibration and imaging were done in AIPS using standard techniques.

It was not possible to obtain the optical observations on the nights during the VLBA session due to bad weather. For sources observed in the August 2002 session, we used optical polarisation angles χ_{opt} obtained the night after the VLBA observations for sources observed in the March 2003 session, we linearly interpolated between two (similar) values observed the nights before and after the VLBA observations. In all cases, the optical polarization angles measured on these two nights agreed to within 25°, suggesting the optical

Fig.1 Histograms of distribution of $|\chi_{opt} - \chi_{core}|$

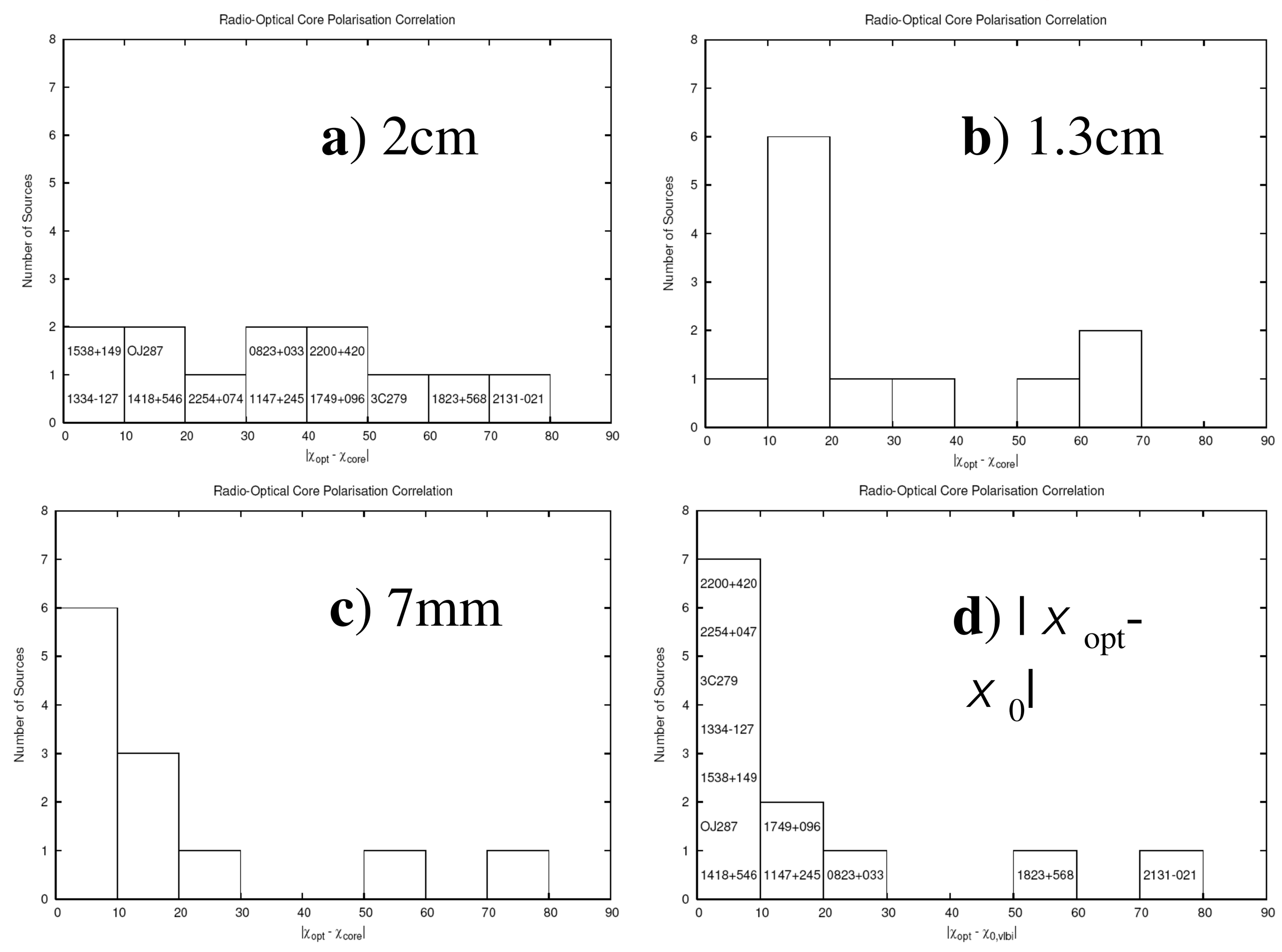
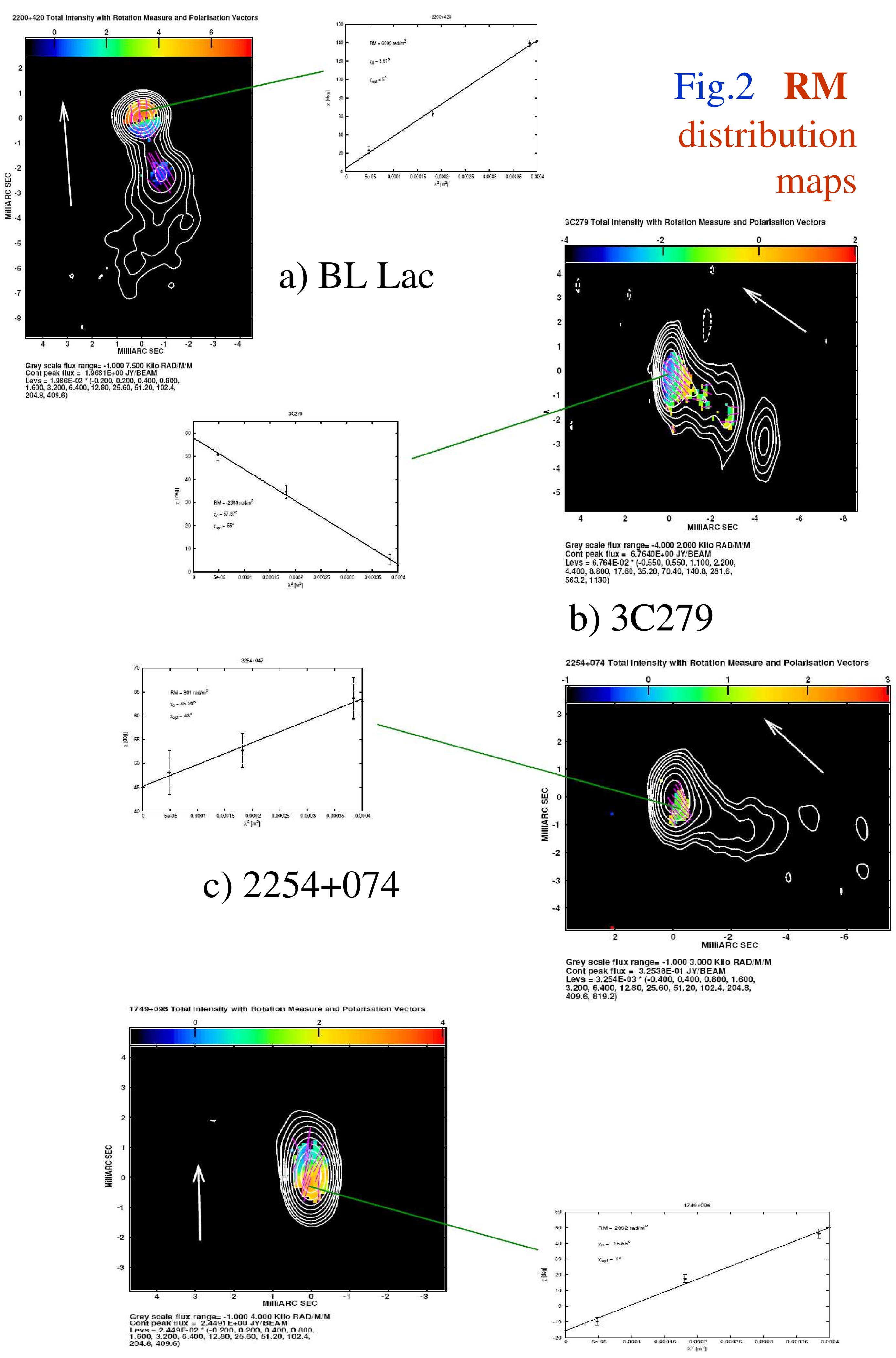


Fig.2 RM distribution maps



a) BL Lac

b) 3C279

c) 2254+074

d) 1749+096

Observations & Reduction (cont.)

polarization was not wildly variable near the time of the VLBA observations; in four of nine sources, the two measurements agreed to within 5° or less.

Estimates of the VLBI core polarisation angles χ_{core} were obtained using the AIPS task IMSTAT, and the obtained values were used to estimate the core Faraday rotation measures for all the sources and to plot histograms of the distributions of $|\chi_{opt} - \chi_{core}|$ and $|\chi_0 - \chi_{core}|$, where χ_0 is the radio polarisation angle for zero wavelength (i.e. corrected for Faraday rotation).

Results & Discussion

These results support the earlier findings of Gabuzda, Sitko & Smith (1996) and Gabuzda (2003) that χ_{opt} and χ_{core} are very often either aligned or perpendicular.

When χ_{opt} was compared with the 6cm VLBI core polarization angle, about half of the cores displayed χ_{opt} aligned with χ_{core} and half displayed χ_{opt} perpendicular to χ_{core}. If these two groups of sources are those in which the core polarization was emitted by optically thin and optically thick regions, we should expect a higher fraction of sources to show χ_{opt} parallel to χ_{core} as we consider VLBI data at shorter wavelengths. Results for 2 and 1.3 cm were presented by Rastorgueva (2003). Seven out of 14 sources showed χ_{opt} aligned with χ_{core} within 25° for 1.3 cm, while one had χ_{opt} perpendicular to χ_{core}. At 2 cm, only 3 out of 14 sources had their core and optical polarisation angles aligned within 25°, while 2 were perpendicular.

Histograms a, b and c in Fig. 1 show the distributions of $|\chi_{opt} - \chi_{core}|$ for 7 mm, 1.3 and 2 cm, respectively. For the sources near the left side of the histogram, χ_{opt} and χ_{core} are nearly parallel, while for those located near the right side are nearly perpendicular. It is clearly seen that the number of sources grouped near a difference of zero is larger at the shorter wavelengths.

Not only does the optical depth of the radio emission regions affect the observed χ_{core} values. In some cases, local core Faraday rotation was significant. In the case of Faraday rotation, the change in the observed polarisation angles is proportional to the square of the observing wavelength, $\Delta\chi \propto \lambda^2$. Plots of χ_{core} vs. λ^2 for each source showed a linear dependence within the estimated errors in virtually all cases. Linear fits to these dependences yielded the angle $\chi_0 = \chi_{core}$ ($\lambda = 0$), which is the point of intersection of the fitted line with the χ axis. This angle is the estimation of the core polarisation angle corrected for the internal Faraday rotation. Histogram d of Fig. 1 presents the distribution of $|\chi_{opt} - \chi_0|$, which strikingly demonstrates that essentially all the sources have their χ_{opt} and χ_0 parallel within 10-20°.

As examples, Fig. 2 presents maps of the rotation measure (**RM**) distributions for 3C279, 2200+420 (BL Lac), 1749+096, and 2254+074. The contours show the radio flux at 2 cm with χ_0 sticks superposed, while the colour plots the **RM** distributions. The accompanying graphs show the linear fits of χ_{core} vs. λ^2 for the regions of the RM maps indicated by the arrows. The bold white arrows depict the orientation of χ_{opt}.

Conclusions

These results demonstrate that, once corrected for the measured core Faraday rotation, the observed VLBI core polarisation angles display a striking correlation with the nearly simultaneously measured optical polarisation angles.

This provides convincing evidence that the magnetic field orientation in the optical and radio emission regions is the same – either because the optical and radio emission is co-spatial, or because the jet bends only slightly between the locations of the optical and radio emission.

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