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

Denise C. Gabuzda,[1] Elizaveta Rastorgueva,[2] Shane O'Sullivan[1], Paul Smith[3]

[1] Department of Physics, University College Cork, Cork, Ireland; gabuzda@phys.ucc.ie
[2] Tuorla Observatory, University of Turku, Turku, Finland; eliras@utu.fi
[3]Steward Observatory, the University of Arizona, Tucson, AZ, USA; psmith@as.arizona.edu

Abstract

In a comparison of simultaneous optical and 5 GHz VLBI polarization observations for a small sample of Active Galactic Nuclei (AGN), the optical and VLBI core polarization positions were virtually always either aligned or perpendicular to each other. This can be understood if the radio cores with their polarization aligned with the optical polarization were predominantly optically thin, while the radio cores whose polarization was perpendicular to the optical polarization were predominantly optically thick. We present the results of coordinated optical and high-frequency (43+22+15 GHz) VLBA polarization observations of 15 AGN (12 in final analysis) designed to test this hypothesis. The distribution of the differences between the optical and the VLBI core polarization shows a clear peak near zero degrees (polarization in the optical and radio is aligned). This indicates that the magnetic field directions in the regions in which the optical and compact radio polarization arise are the same, suggesting that a substantial fraction of the optical and radio polarization is, in fact, emitted by the same region. **These results are published in Gabuzda, D.C., Rastorgueva, E.A., Smith, P.S., O'Sullivan, S.P. 2006, MNRAS, 369,1596, and work on the extended sample of sources is in progress.**

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 polarization 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 (Pushkarev, 2001).

Although these results were not conclusive due to the small number of objects considered, there were clear indications of a correlation between the optical polarization position angle χ_{opt} and the polarization position angle in the VLBI core χ_{core}. Gabuzda, Garnich & Smith (2004) analyzed 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).

These collected data show clear evidence for a correlation between χ_{opt} and χ_{core} , with χ_{core} nearly always being aligned with or perpendicular to χ_{opt}.

The 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, 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 (outer) region of the jet, but only for certain combinations of jet geometry and particle flow acceleration.

Observations & Reduction

We obtained optical and 7mm+1cm+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. In all the cases of August 2002 session we used optical polarization angle χ_{opt} obtained without any correction, in the March 2003 session we interpolated between two values to estimate χ_{opt} to the moment of VLBA observations assuming linear change. In all cases, the optical polarization angles measured on these two nights agreed to within 25^{o}, suggesting the optical polarization was not wildly variable near the time of the VLBA observations; in four cases, the two measurements agreed to within about 5^{o} or less.

Core radio polarization angles χ_{core} were estimated using AIPS task IMSTAT, obtained values were used to estimate core rotation measures for all sources and

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

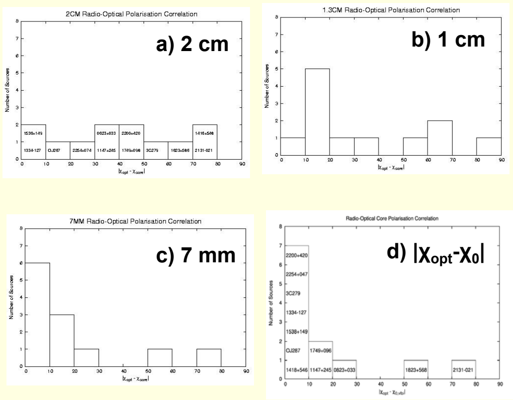
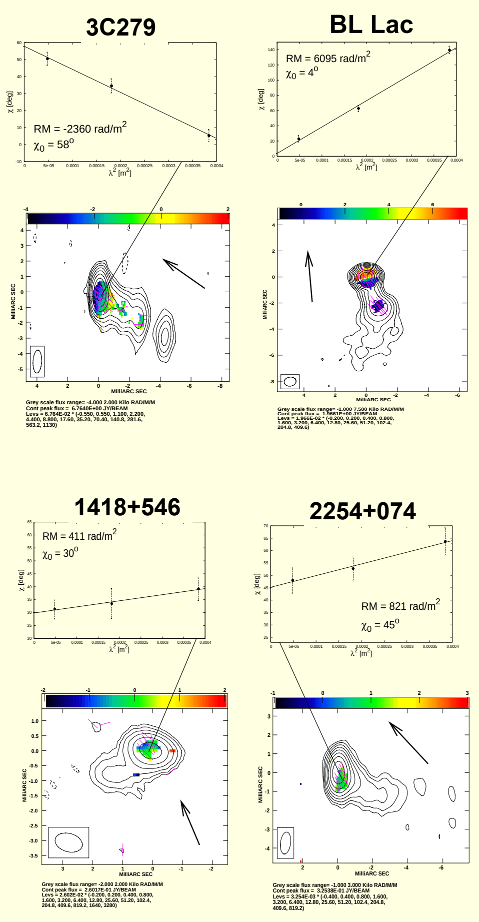


Fig.2 RM distribution maps



Observations & Reduction (cont.)

to plot the $|\chi_{opt}-\chi_{core}|$ and $|\chi_0-\chi_{core}|$ distribution histograms (χ_0 is the radio polarization 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, Garnich & Smith (2004) that optical polarization and that in the VLBI core are either aligned or perpendicular.

When χ_{opt} was compared with the 6cm VLBI core polarization, 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 polarized radiation was emitted by optically thin and optically thick regions, we should expect higher fraction of sources to show χ_{opt} parallel to χ_{core} as we consider VLBI data at shorter wavelengths.

The results presented here clearly support this idea. Histograms in the Fig.1 show the distribution of $|\chi_{opt}-\chi_{core}|$ at 7 mm, 1.3 and 2 cm. For the sources in the left side of the plot χ_{opt} and χ_{core} are nearly parallel, for those which tend to the right side – nearly perpendicular. It is clearly seen that the number of sources grouped near the zero difference 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 polarization angles is proportional to the square of the observing wavelength, $\Delta\chi \sim \lambda^2$. 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 polarization angle corrected for the internal Faraday rotation. Histogram d) on the Fig.1 presents the distribution of $|\chi_{opt}-\chi_0|$, which strikingly shows that essentially all the sources have their optical and zero-wavelength polarization are parallel within **10-20º**.

As an example, Fig.2 presents maps of the rotation measure (RM) distributions for the sources 3C279, 2200+420 (BL Lac), 1418+546, and 2254+074. The contours maps show the radio flux at 2 cm with χ_0 sticks superposed, while the color map represents RM distributions. The accompanying graphs show the linear fits for χ_{core} vs. λ^2 for the regions of the RM maps indicated by arrows. The black arrow near the source on the each map shows orientation of the optical polarization vector.

Later studies of the correlated radio and optical polarization variability in both angle and percentage supported the idea that optical and radio (high frequency) polarization may arise from the same spatial region (D'Arcangelo et al., 2007). We continue our studies by extending the number of observed sources. Work is in progress.

Conclusions

These results demonstrate that, once corrected for the measured core Faraday rotation, the observed VLBI core polarization angles display a striking correlation with the nearly simultaneously measured optical polarization 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 cospatial, or because the jet bends only slightly between the locations of the optical and radio emission.

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