Transverse magnetic field structures in BL Lacertae Objects

By ALEXANDER B. PUSHKAREV[1]
AND DENISE C. GABUZDA[2,1]

[1] Astro Space Center of Lebedev Physical Institute, 53 Leninsky pr., Moscow, Russia

[2] Joint Institute for VLBI in Europe, Postbus 2, 7990 AA Dwingeloo, the Netherlands

We are currently analyzing multi-frequency (2+4+6 cm) VLBA polarization observations of all sources from a complete sample of northern 1-Jy BL Lacertae objects. In a number of cases, the polarization position angles of the jet components are aligned with the local jet direction, even when the jet has a very bent structure. This behaviour supports the idea that transverse magnetic fields are present throughout the VLBI jets of these sources. The nature of the transverse magnatic fields is still unclear. One possible explanation of this phenomenon is the presence of shock waves which are associated with the VLBI components. Alternatively, it may be that the transverse jet magnetic fields represent the toroidal component of a helical magnetic field associated with the VLBI jet.

1. Introduction

BL Lacertae objects are active galactic nuclei with weak or undetectable line emission and strong variability in total intensity and linear polarization over a wide wavelength range from optical to radio. They usually have pointlike optical images and compact radio structure, with flat or inverted radio spectra. The radio emission and much of the optical emission is believed to be synchrotron radiation. Sources in the complete sample of BL Lac objects defined by Kühr and Schmidt (1990) have: 5 GHz fluxes of at least 1 Jy, radio spectral index $\alpha \geq -0.5$ ($S_\nu \sim \nu^{+\alpha}$), rest frame equivalent width of the strongest emission lines less than 5 Å, and optical counterparts on the Sky Survey plates with brightness greater than 20^m.

Previous VLBI polarization observations of radio-bright BL Lac objects have showed certain characteristic properties on parsec scales: one-sided core-jet structure with jet superluminal motions with typical speeds on average lower than those in quasars, jet electric vector χ parallel to the local jet axis, and a tendency for the core χ's to lie either parallel or perpendicular to the jet axis (Gabuzda et al. 2000 and refs therein). Jet components are typically optically thin (their degree of polarization can range up to ∼60%). Therefore the tendency for the jet χ vectors to align with the jet direction implies that the associated magnetic field is transverse. This may indicate the presence of relativistic shocks (Hughes et al. 1989; Laing 1980), which we observe as distinct jet knots. Alternatively, it may reflect the presence of spiral magnetic fields associated with the jets (Gabuzda 1999, 2000). We discuss here new evidence from our multi-wavelength VLBA data in support of this latter picture.

2. Observations

Observations of most sources presented here were made in February 1997 at 5, 8 and 15 GHz ($0954+658$ was observed in April 1997 at these three frequencies plus 22 GHz) using the VLBA array of ten antennas: St.Croix, Hancock, North Liberty, Fort Davis, Los

Alamos, Pie Town, Kitt Peak, Owens Valley, Brewster, and Mauna Kea (the diameter of all antennas is 25m). The data were correlated on the VLBA correlator in Socorro, and were calibrated and imaged in the AIPS package (NRAO) using standard techniques.

3. Results

Most sources from the complete sample have shown the magnetic field configuration in their jets to be perpendicular to the local jet direction. Here we present results for four BL Lac objects with different types of the jet, from roughly straight to highly bent, in each of which the magnetic field is transverse everywhere along the jet.

In each map presented, the contours increase in multiples of two, and the peak fluxes, bottom contours, and observing frequencies are given in the captions; the superposed sticks represent the electric vectors of the polarization.

3.1. $0820+225$

The optical spectrum of this faint, unresolved BL Lac object shows only a weak broad emission feature, which is most likely attributed to Mg II $\lambda 2798$ at a redshift of $z = 0.951$ (Stickel et al. 1993). $0820+225$ has a non-uniform rotation measure distribution on parsec scales, with sharp gradients (see Gabuzda, Garnich, & Pushkarev, these proceedings). Our map at 15 GHz (Fig. 1, left) shows that the inferred magnetic field is transverse in the two polarized features detected at 3 and 6 mas from the core (at this frequency the influence of the measured parsec scale Faraday rotation is negligible for the inner knot and only about 8° for the outer knot).

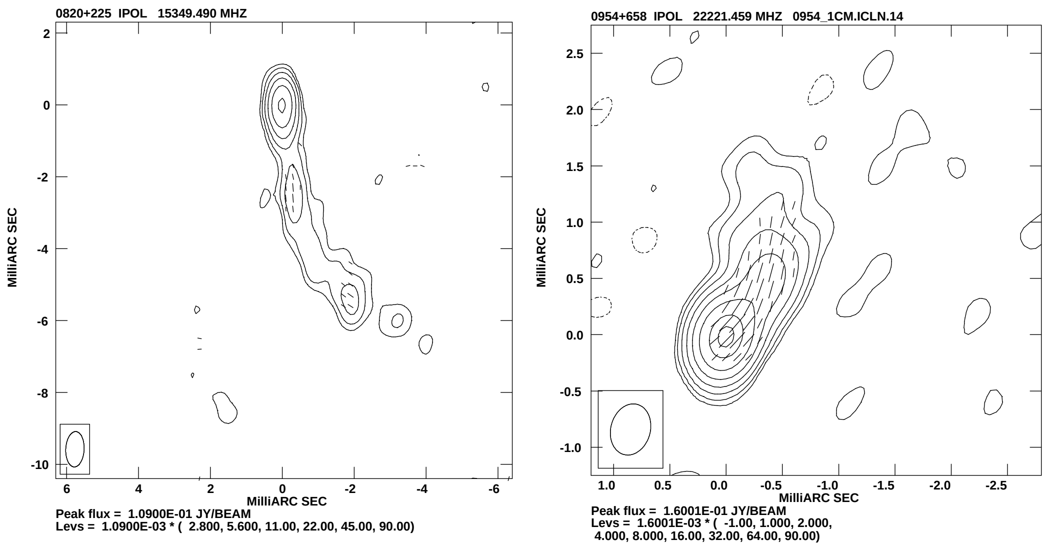

FIGURE 1. The total intensity map with polarization vectors superposed of the sources 0820+225 (left) and $0954 + 568$ (right). The observing frequencies are 15 and 22 GHz, total peak fluxes are 109 mJy and 160 mJy, and bottom contours are 2.8% and 1% of the peaks, respectively.

3.2. 0954 + 568

Lawrence et al. (1986) have suggested a redshift of this BL Lac object $z = 0.368$, based on galactic absorption lines O III $\lambda\lambda$ 4959, 5007. The source has a jet that propagates toward the north (Fig. 1, right) and then turns to the west about 1.5 mas from the core (visible at lower frequencies). The 22 GHz map in Fig. 1 clearly demontrates that the polarization position angles of the jet components align nicely with the local jet direction, which means that the magnetic field is transverse along the jet.

3.3. 1749 + 701

The redshift of this object is $z = 0.77$, based on identification of a line observed at 6600 Å with [O II] λ3727 (Stickel et al. 1989). In this case, the jet is quite bent, and the linear polarization vectors closely follow the local jet direction at every location where polarized emission has been detected (Fig. 2, left), so that the inferred jet magnetic field is transverse, and remains so as the jet bends.

3.4. 2254 + 074

The redshift for this BL Lac is $z = 0.19$, based on a spectrum taken by Stickel et al. (1988). The 15 GHz map (Fig. 2, right) shows relatively simple structure, with a straight jet and a transverse magnetic field in it.

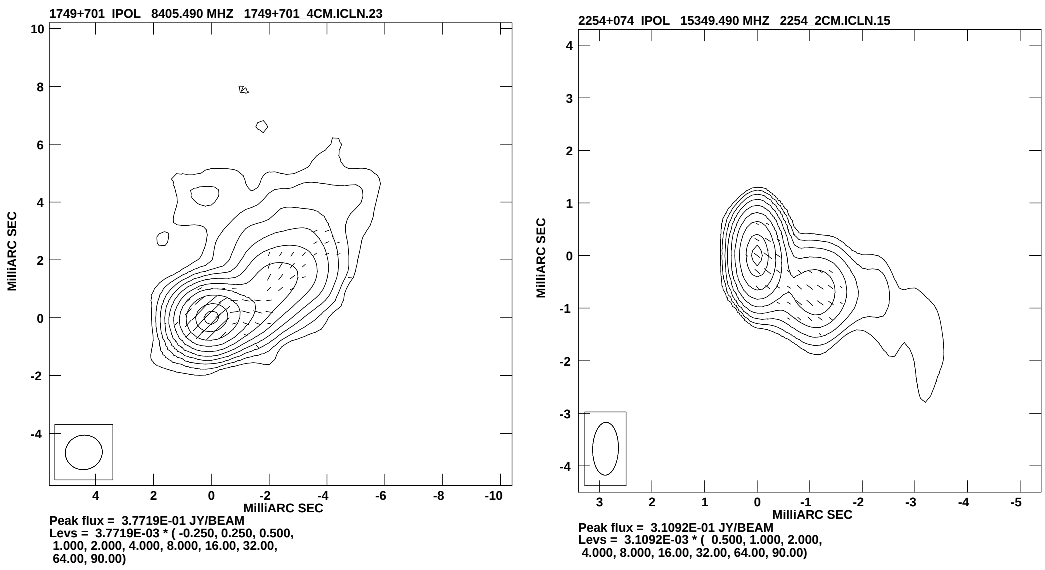

FIGURE 2. The total intensity map with polarization vectors superposed of the sources 1749+701 (left) and 2254 + 074 (right). The observing frequencies are 8 and 15 GHz, total peak fluxes are 377 mJy and 311 mJy, and bottom contours are 0.25% and 0.5% of the peaks, respectively.

4. Conclusions

In all these sources, the observed jet polarization vectors χ are aligned with the local jet direction, in some cases, remaining aligned in the presence of substantial bends (e.g. 1749+701). We suggest that we have detected the dominant toroidal component of a helical magnetic field associated with the jets. This could easily explain the good alignment of the χ vectors with the local jet direction, no matter how strong the curvataure of the jet. Shock models encounter some difficulties in the case of very twisted jets, and seem to be contrived as a way to explain extended regions of transverse fields in both bent and straight jets. Of course, it is likely that certain individual compact features are associated with transverse shocks. However, the presence of intrinsic helical fields associated with the jets themselves seems to provide a much more natural explanation for the overall transverse field structures. Further studies are needed to determine if such helical fields are characteristic of BL Lacertae objects as a class.

5. Acknowledgments

We thank the workshop organizers for financial support for ABP, and the NRAO for their allocation of observing time. The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under a cooperative agreement by Associated Universities, Inc.

REFERENCES

Gabuzda, D. C. 2000, *Plasma Turbulence and Energetic Particles in Astrophysics*, Krakow: Obserwatorium Astronomiczne, Uniwersytet Jagiellonski, 301–310.

Gabuzda, D. C. 1999, *New Astronomy Reviews*, **43**, 691–694.

Gabuzda, D. C., Pushkarev, A. B., and Cawthorne, T. V. 2000, *MNRAS*, in press.

Kühr, H. & Schmidt, G. D. 1990 *AJ*, **90**, 1–6.

Hughes, P. A., Aller, H. D., Aller, M. F. 1989 *ApJ*, **341**, 68–79.

Laing, R. A. 1980, *M.N.R.A.S.*, **193**, 439–450.

Lawrence, C. R., Pearson, T. J., Readhead, A. C. S., and Unwin, S. C. 1986, *AJ*, **91**, 494–495.

Stickel, M., Fried, J. W., and Kühr, H. 1988, *A&A*, **191**, 16–18.

Stickel, M., Fried, J. W., and Kühr, H. 1989, *A&AS*, **80**, 103–114.

Stickel, M., Fried, j. W., and Kühr, H. 1993, *A&AS*, **98**, 393–409.