Searching for Helical Magnetic Fields In Several BL Lac Objects

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Abstract

A multi-wavelength polarization study by Gabuzda, Murray and Cronin (2004), showed systematic Faraday-Rotation gradients across the parsec-scale jets of several BL Lac Objects, interpreted as evidence for helical magnetic fields – the gradients were taken to be due to the systematic variation of the line-of-sight magnetic field across the jet. We present initial results for new analyses of the parsec-scale Faraday-Rotation distributions for several BL Lac objects, based on VLBA polarization data obtained at wavelengths near 2cm, 4cm and 6cm in December 1999 and August 2003.

Introduction

BL Lac objects are a Active Galactic Nuclei (AGNs) that are observationally similar to radio-loud quasars in many respects, but display systematically weaker optical line emission, whose origin is not clear. It has long been known that some radio-loud Active Galactic Nuclei (AGN) show a tendency for the magnetic (B) fields in their parsec-scale jets to be orthogonal to the local jet direction. Although this was initially interpreted as reflecting the presence of transverse shocks in the jets, it now appears more likely that many of these transverse B fields represent a toroidal dominant ordered component of the intrinsic B fields of the jets themselves.

The most recent evidence supporting this hypothesis is the observation of systematic gradients in the Faraday rotation across the parsec-scale jets of a number of AGN, which have been interpreted as reflecting the systematic change in the line-of-sight component of a toroidal or helical jet B field across the jet (Blandford 1993; Asada et al. 2002; Gabuzda, Murray & Cronin 2004; Zavala & Taylor 2005). Such fields would come about in a natural way as a result of the "winding up" of an initial "seed" field by the rotation of the central accreting object (e.g. Nakamura, Uchida, & Hirose 2001; Lovelace et al. 2002; Hujeirat et al. 2003; Lynden-Bell 2003; Tsinganos & Bogovalov 2002).

We report here first results of an observational search for Faraday rotation measure (RM) gradients transverse to the VLBI jet direction among sources in two samples of BL Lac objects. This study is aimed at both verifying the previously reported RM gradients and identifying new sources in which such gradients are observed. Since the detection of toroidal or helical jet B fields is a result of cardinal importance for our understanding of the jets of AGN, it is important to determine how widespread this phenomenon is.

Observations & Reduction I

We are currently using with two sets of multi-frequency VLBA polarisation observations of BL Lacs in our search for transverse jet RM gradients.

1) We have recently obtained VLBA polarisation observations for all 34 objects in the sample of 1-Jy Northern radio-loud BL Lac objects defined by Kühr & Schmidt (1990) at two wavelengths in each of the VLBA 2cm, 3.6cm and 6cm bands (in other words, a total of six wavelengths). We present here preliminary results for the first such set of observations, obtained in August 2003.

2) VLBA polarisation observations of 21 BL Lac objects in the University of Michigan sample (6cm fluxes greater than 0.4 Jy; Aller et al. 1999) were observed at 6cm, 3.6cm and 2cm in December 1999.

In both cases, the data were calibrated and imaged in the NRAO AIPS package following standard techniques.

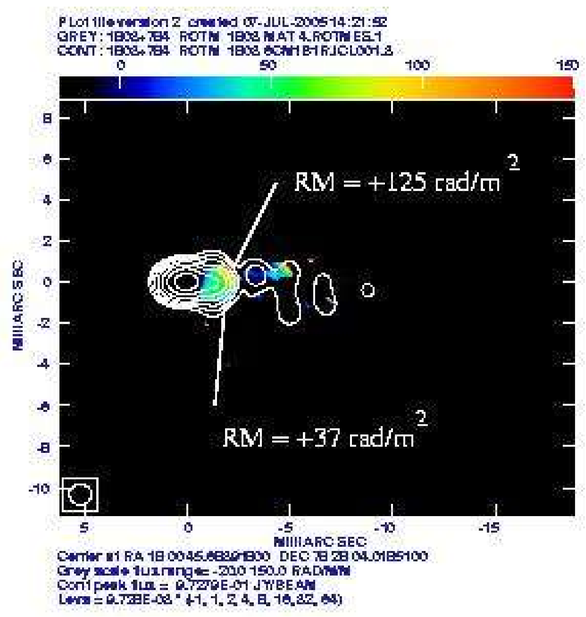


Fig. 1. Tentative new detection of a transverse RM gradient in the VLBI jet of 1803+784 from the Kühr & Schmidt (1990) 1 Jy BL Lac sample.

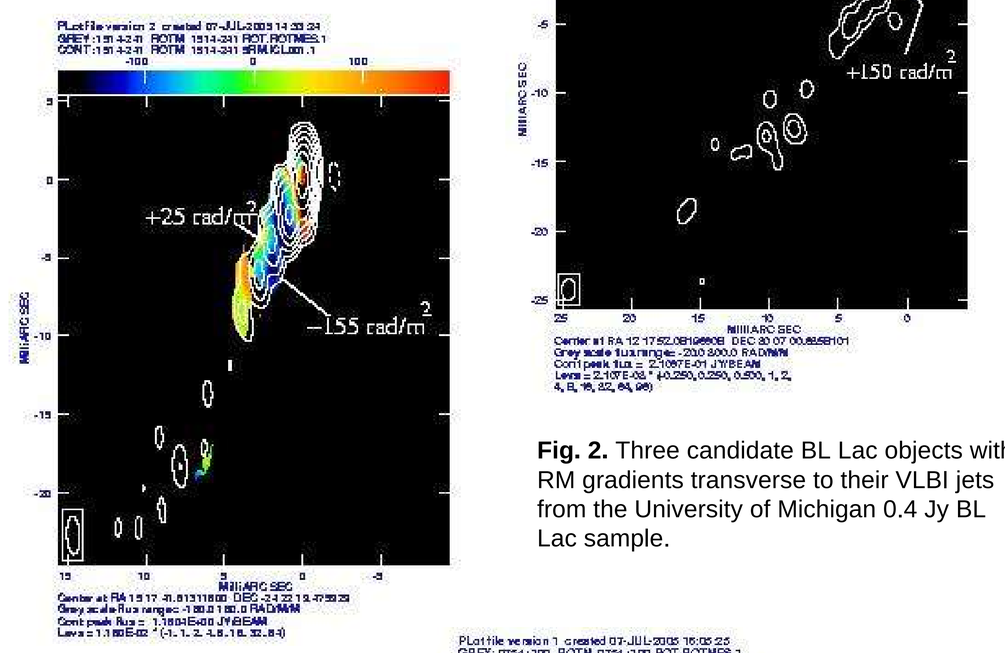
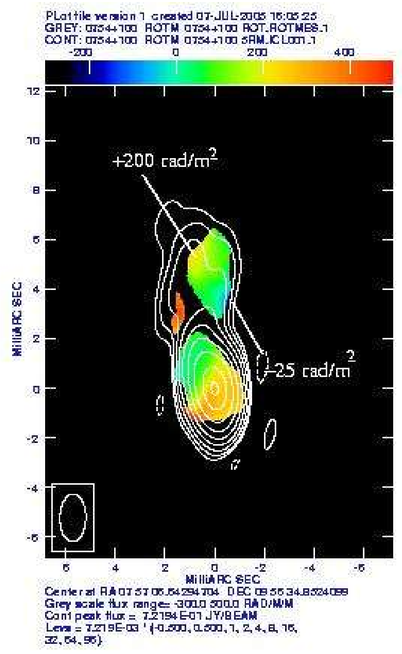


Fig. 2. Three candidate BL Lac objects with RM gradients transverse to their VLBI jets from the University of Michigan 0.4 Jy BL Lac sample.



References

Asada K. et al. 2002, PASJ, 54, L39
Blandford, R. 1993, in *Astrophysical Jets* (Cambridge: Cambridge University Press), 26
Gabuzda D., Murray E. & Cronin P. 2004, MNRAS, 351, L89
Hujeirat A., Livio M., Camenzind M. & Burkert A. 2003, A&A, 408, 415
Kühr H. & Schmidt G. 1990, AJ, 99, 1
Lovelace R.V.E., Li H., Koldoga A. V., Ustyugova G.V. & Romanova M. M. 2002, ApJ, 572, 445
Lynden-Bell D. 2003, MNRAS, 341, 1360
Pushkarev A. 2001, Astron. Rep., 45, 667
Rusk R. 1988, PhD Thesis, University of Toronto
Tsinganos D. & Bogovalov S. 2002, MNRAS, 337, 553
Zavala R. & Taylor G. 2005, ApJ, 626, L73

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Observations & Reduction II

Faraday rotation of the plane of linear polarisation occurs during the passage of an electromagnetic wave through a region with free electrons and a magnetic field with a non-zero component along the line of sight, and is essentially due to the difference in the propogation velocities of the right- and left-circularly polarised components of the wave.

The amount of rotation is proportional the integral of the density of free electrons n_e multiplied by the line-of-sight magnetic field **B** • **dl**, the square of the observing wavelength, and various physical constants; the coefficient of λ^2 is called the rotation measure, RM:

$$\Delta\chi \propto \lambda^2 \int n_e \, \mathbf{B}\cdot\mathbf{dl} \equiv \mathbf{RM}\,\lambda^2$$

After matching the imaging parameters and beam sizes of the final images at all the wavelengths, we constructed maps of the rotation measure using the task RM in AIPS, after first subtracting the effect of the integrated rotation measures (presumed to be Galactic) from the observed polarisation angles (Pushkarev 2001; Rusk 1988).

Results to Date

Six-wavelength data for August 2003

We are still in the process of analysing these data, which is the first of five datasets providing six-wavelength VLBA polarisation observation for the Kühr & Schmidt (1990) BL Lac sample. Thus far, we have found one new tentative detection of a systematic transverse RM gradient, in the jet of 1803+784 (Fig. 1; the scale is such that the core RM does not appear). There are hints that this gradient may persist at appreciable distances from the core, but this must be verified.

Three-wavelength data for December 1999

VLBA rotation-measure maps have been made for all 21 BL Lac objects observed (see the poster by O'Dowd, Gabuzda & Aller). Although the main goals of that work are to study the characteristic core and jet RMs, and to more accurately determine the intrinsic orientation of the polarisation electric vectors (and hence of the underlying magnetic field), these data provide us with the opportunity searching for evidence of helical/toroidal B fields among this slightly weaker sample of BL Lac objects as well. Thus far, this has yielded three new candidates for jets displaying transverse RM gradients (Fig. 2): 0754+100, 1215+303 and 1514-241.

There may be two regions with transverse RM gradients oriented in opposite directions in 1514-241; if confirmed, this could represent a change in the helicity of a helical B field associated with this jet, providing valuable information for input to theoretical models for such B-field structures.

Summary

Firm evidence for transverse jet Faraday-rotation gradients has now been reported for the quasar 3C273 (first reported by Asada et al. 2002, later confirmed by Zavala & Taylor 2005) and several BL Lac objects (Gabuzda, Murray & Cronin 2004). The BL Lac objects considered here provide four new candidates for AGN displaying this phenomenon.

Our future work includes the construction of six-wavelength parsec-scale RM maps for all remaining sources in the Kühr & Schmidt (1990) BL Lac sample, as well as a more detailed search for jets with transverse RM gradients among the University of Michigan BL Lac objects. Verification of this phenomenon and determination of how common it occurs can provide crucial information for our understanding of the formation and launching of AGN jets.