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Polarization study of BL Lacertae objects on pc-scales

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Abstract. We present results of the VLBA[3] polarization observations of "X-ray selected" BL Lac objects from the *HEAO*-1 survey and also a few from the *ROSAT*-Green Bank (RGB) sample. These primarily high energy peaked BL Lacs (HBLs) have "core-jet" morphologies with modestly polarized pc-scale cores and jet components, similar to their radio-selected counterparts (primarily low energy peaked BL Lacs, LBLs). However, we find that the jets in HBLs show preferentially longitudinal magnetic fields, as opposed to the jets in LBLs, which tend to have transverse magnetic fields.

Keywords : BL Lacertae objects – galaxies: active – radio galaxies

1. Introduction

BL Lacertae objects comprise a rare subclass of active galactic nuclei (AGN) characterised by a highly variable predominantly non-thermal continuum ranging from the radio to γ-rays; high and variable polarization; and weak or no emission lines (equivalent width ≤ 5 Å, *e.g.*, Urry & Padovani, 1995). These extreme properties are attributed to a relativistic jet oriented close to the line of sight (*e.g.*, Blandford & Königl, 1979), thus leading to "unified schemes" which propose that radio galaxies of the Fanaroff–Riley type I are the plane-of-sky counterparts of BL Lacs (*e.g.*, Browne, 1983). BL Lacs have traditionally been identified from radio and X-ray surveys. The majority of BL Lacs discovered in radio surveys have their Spectral Energy Distributions (SEDs) peaking in the IR/optical band – these have been classified as the Low–energy peaked BL Lacs

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(**LBLs**). The majority of those discovered in X-ray surveys have their SEDs peaking in the UV/soft X-ray band – the High-energy peaked BL Lacs (**HBLs**).
LBLs are typically more core-dominated on arcsec-scales than HBLs, show higher average optical polarization and more variability and have more powerful radio lobes than HBLs (*e.g.*, Laurent-Muehleisen *et al.*, 1993). In order to explain these differences, two main scenarios have been proposed.
Orientation-based scenario : If LBLs have their jets pointed closer to the line of sight than HBLs, the more extreme properties of LBLs would be explained (Stocke *et al.*, 1985). However, this scenario alone cannot explain the different peaks in the SEDs.
Intrinsically differing SED or differing jet scenario : If HBLs have higher electron Lorentz factors and/or magnetic fields than LBLs, this would result in synchrotron peaks at a higher frequency than in the LBLs (Sambruna *et al.*, 1996). This scenario explains the more extreme properties of LBLs as being due to selection effects (Giommi & Padovani, 1994).
We attempt to attack the question as to whether the jets in HBLs and LBLs are intrinsically different or not. The pc-scale total intensity shows "core-jet" morphology in both HBLs and LBLs. In analogy with the case of the radio-loud quasars versus BL Lacs, which show different magnetic field structures in their jets, we aimed to look for such differences in HBLs versus LBLs. We therefore undertook pc-scale polarimetric imaging of HBLs. We were able to then contrast the magnetic field geometry of their jets with that of LBLs, already studied by Gabuzda *et al.* (2000).

2. Our Sample and Observations

Very Long Baseline Polarimetry (VLBP) at 5 GHz with the VLBA was done for a sample of 21 northern hemisphere BL Lacs detected in hard X-rays by the *HEAO*–1 survey (Wood *et al.*, 1984) and six BL Lacs from the *ROSAT*-Green Bank (RGB) sample (Laurent-Muehleisen *et al.*, 1997), in order to measure their pc-scale nuclear polarization.

3. Results and Conclusions

The VLBP observations of LBLs (primarily the 1–Jy sample, *e.g.*, Gabuzda *et al.*, 2000) and HBLs (our work) reveal that both LBLs and HBLs have compact "core-jet" morphologies. Though the orientation of the pc-scale *core* polarizations of HBLs and LBLs relative to the local VLBI jet direction do not show any systematic differences, the *jet* polarizations of the two types of object do, as seen below. The inferred magnetic field (**B**) direction is perpendicular to the observed polarization angle if the emission region is predominantly optically thin, as is the case for jet emission. Taking this into account, the LBLs show predominantly *transverse* jet magnetic fields, while the HBLs show predominantly *longitudinal* fields.

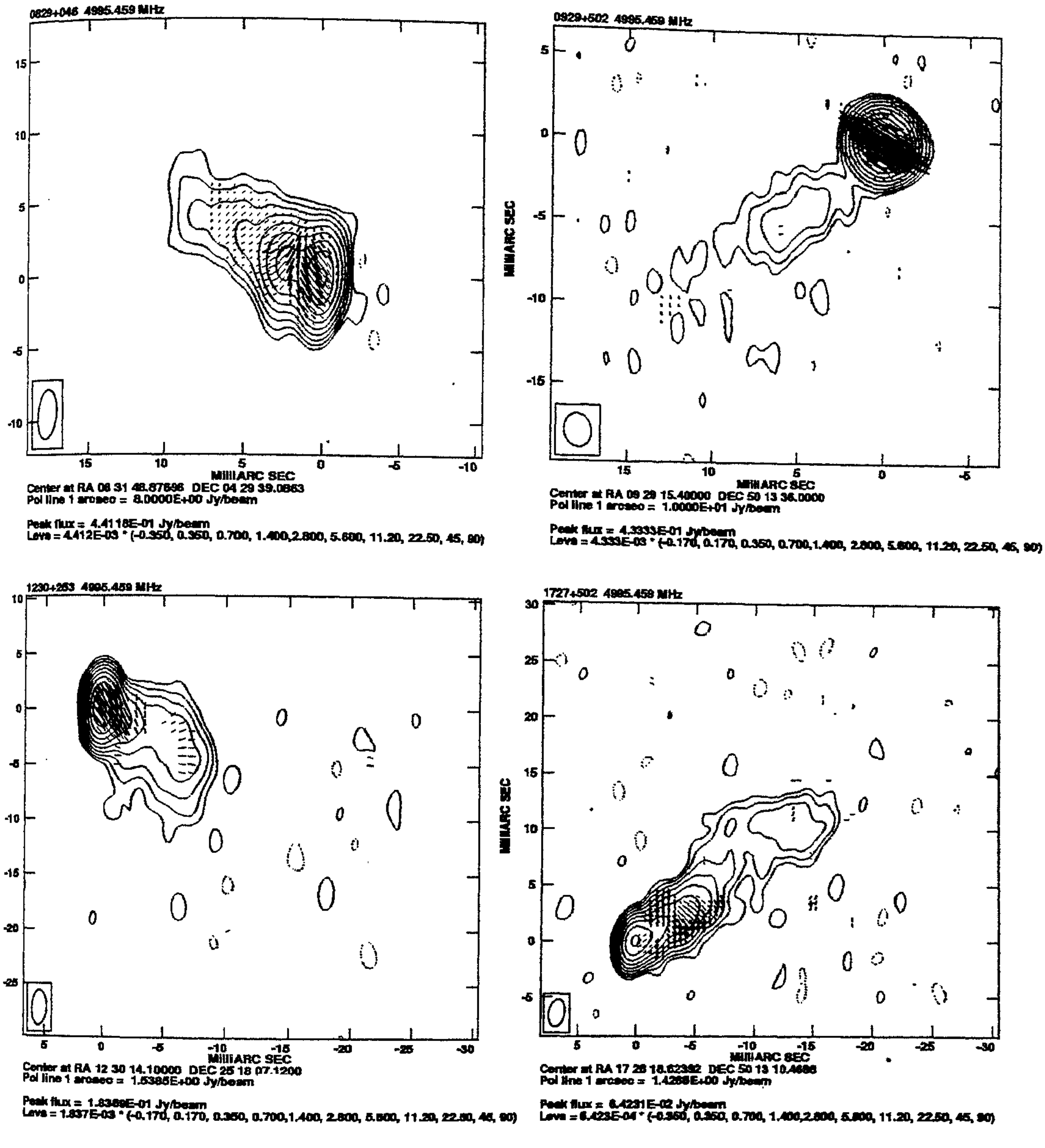

Figure 1. Total intensity contours with polarization electric vectors superimposed as ticks for four BL Lacs from the HEAO-1 and RGB samples. The direction and length of the ticks denote the direction and strength of the polarized intensity. Longitudinal jet magnetic field structures (electric vectors transverse to the jet direction) are especially clearly visible in the images of 0829+046 (top right) and 1727+502 (bottom left). The beam size is shown in the bottom left corner of the images.

Magnetic field structure in the VLBI jet	LBL	HBL
$B_\perp$: ie., inferred direction of **B** is transverse to the local jet direction	65 %	35 %
$B_\parallel$: ie., inferred direction of **B** is parallel to the local jet direction	35 %	55 %
Unclear: cannot infer direction of the local jet due to resolution effects	–	10 %

The dominant longitudinal fields that we observe in HBLs may be due to greater shear as the jet propagates from the core through the surrounding medium and interacts with it, consistent with the possibility that the jet flows of HBLs have larger bulk kinetic energy than those of LBLs. The dominant transverse field in the LBLs may indicate the presence of relativistic shocks that compress the jet magnetic field perpendicular to the direction of propagation, or alternatively the dominance of the toroidal component of helical jet magnetic fields (Gabuzda *et al.*, 2000). This appears to indicate that there might be intrinsic differences between the jets in LBLs and HBLs; *e.g.* differences in the characteristic jet flow speeds.

However, we cannot completely rule out the possibility that the different magnetic field structures are associated with different characteristic orientations of the jets to the line of sight; for example, if the jets are comprised of an inner fast-moving "spine" dominated by $B_\perp$ and a slower-moving "sheath" dominated by $B_\parallel$, we might expect the spine to dominate in jets oriented at smaller angles to the line of sight, since it will be more strongly beamed.

One possible way to distinguish between these pictures is by comparing the superluminal speeds observed for the two types of sources. If the jets of HBLs have intrinsically larger bulk kinetic energy than those of LBLs, we expect the superluminal motions to have, on average, higher speeds. On the other hand, if the HBL and LBL jets are intrinsically similar but the jets of HBLs are, on average, oriented further from the line of sight, we expect the opposite trend, *viz.*, lower superluminal speeds in HBLs. Analysis of VLBI polarization data at additional epochs is underway, and should help determine which of these two scenarios is more realistic. The relationship between the different jet magnetic field structures and different SEDs in HBLs and LBLs also remains to be seen.

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