Polarimetric VLBI observations of 0735+178

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We present a new centimeter polarimetric VLBI image of the BL Lac object 0735+178. This source exhibits one of the most pronounced curvatures observed in jets of AGNs, with two sharp apparent bends of 90 degrees within the inner 2 milliarcseconds from the core. Through the analysis of the data gathered over the past decades we study whether this curvature is produced by precession of the jet with ejection of ballistic components, or a precession in such a way that components' velocity vector are always parallel to the jet axis. These possibilities are also studied by comparison with 3D hydrodynamic relativistic simulations of precessing jets.

1. Introduction

Multi-epoch VLBI observations of BL Lac object 0735+178 ($z = 0.424$, Carswell et al. 1974) by Bääth & Zhang (1991), Bääth et al. (1991), Zhang & Bääth (1991), Gabuzda et al. (1994) and Gómez et al. (1999, 2001) have shown the existence of superluminal motions with apparent velocities in the range of $\sim$ 6.5 to 12.2 h_{65}^{-1} c ($H_{\circ}$= 65 h_{65} km s^{-1} Mpc^{-1}, $q_{\circ}$= 0.5). First indications of a strongly twisted curvature in 0735+178 were presented by Kellermann et al. (1998) as part of a VLBI survey at 15 GHz.

First polarimetric VLBI observations of this source were obtained by Gabuzda, Wardle & Roberts (1989), showing a magnetic field predominantly perpendicular to the jet axis. Polarimetric VLBI observations at 22 and 43 GHz by Gómez et al. (1999) revealed a twisted jet with two sharp apparent bends of 90° within two milliarcseconds of the core. The magnetic field appears to smoothly follow one of the bends in the jet, interpreted as perhaps produced by a precessing nozzle in the jet of 0735+178.

2. The twisted jet structure of 0735+178

Figure 1 shows a 15 GHz image obtained on 27 February 1999, as part of a monitoring of 0735+178 consisting of 8, 15, 22 and 43 GHz VLBI observations covering a total of 12 epochs, from March 1996 to February 2000. In agreement with previous observations (Gómez et al. 1999), both total and polarized intensity images show two bends of 90 degrees in the inner jet structure, with a magnetic field vector that follows the projected jet axis along the bends.

To explain the sharp apparent structure in 0735+178 we need to assume a very small viewing angle for 0735+178, which would enhance the intrinsic curvature by projection effects. Figure 2 summarizes the detected modelfit components in 0735+178 from 1996 to 1998 (from Gómez et al. 2001), restricted to the inner 5 milliarcseconds from the

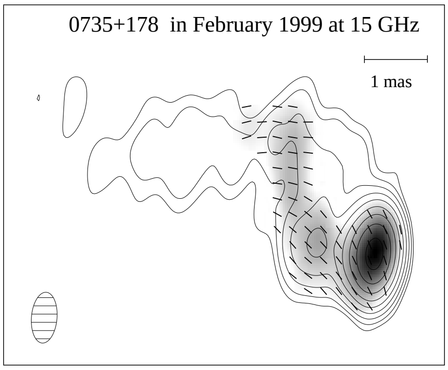

FIGURE 1. 15 GHz VLBI image of 0735+178 for epoch 27 February 1999. Contour levels represent total intensity for 0.3, 0.6, 1.2, 2.4, 4.8, 8.6, 19.2,38.4,and 76.8% of the peak intensity of 0.438 Jy/beam. Grey scale represents the polarized flux (peak at 5 mJy/beam with the noise at the level of 1 mJy/beam) and bars indicate the direction of the projected magnetic field vector. Convolving beam (shown as an ellipse) is 0.80x0.40 mas with position angle of -5°.

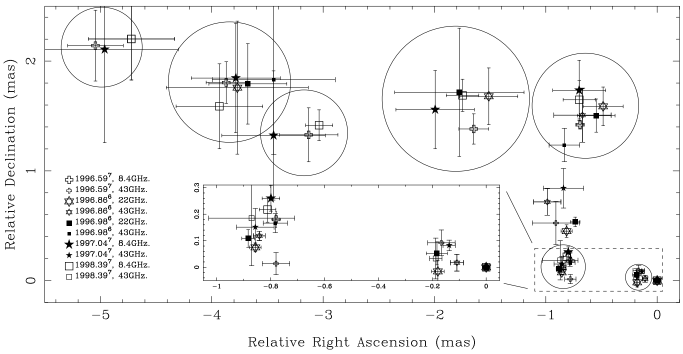

FIGURE 2. Components position, relative to the core, in the jet of 0735+178 detected between 1996.59 and 1998.39. Epoch, frequency, reference, and symbol for each epoch are as labeled. Estimated errors are indicated by bars. References correspond to: *6* Gómez et al. (1999) and *7* Gómez et al. (2001.)

core. After 1996.59 all the observed components lie in a well defined twisted structure coincident with our map presented in Fig. 1. We could interpret the bending as produced either by a true change in the direction of ejection (e.g., jet precession) or by gradients in the external pressure not aligned with the initial direction of the jet flow. Precession of the jet allows, a priori, for motions in which the flow velocity vectors follow the jet bending (non-ballistic motion), or ballistic motions. In the next subsections we discuss these two different interpretations.

2.1. *Non Ballistic Superluminal Motion Model*

The observed magnetic vector parallel to the curved jet axis of 0735+178 (Fig. 1) supports the idea of non-ballistic fluid motions. Further evidence of non-ballistic motions is obtained by analyzing the trajectories followed by the different components, shown in Fig. 3, in which we observe that components K5 and K6 seem to move following a non-ballistic trajectory with superluminal motions of 10 ± 3.5 and 4.6 ± 0.1 h_{65}^{-1} c, respectively. However, we should note that this is based on uncertain identification of components through epochs, in some cases more than 4 years apart.

Figure 3 also reveals quasi-stationary components (K1, K8 and K9), as well as some

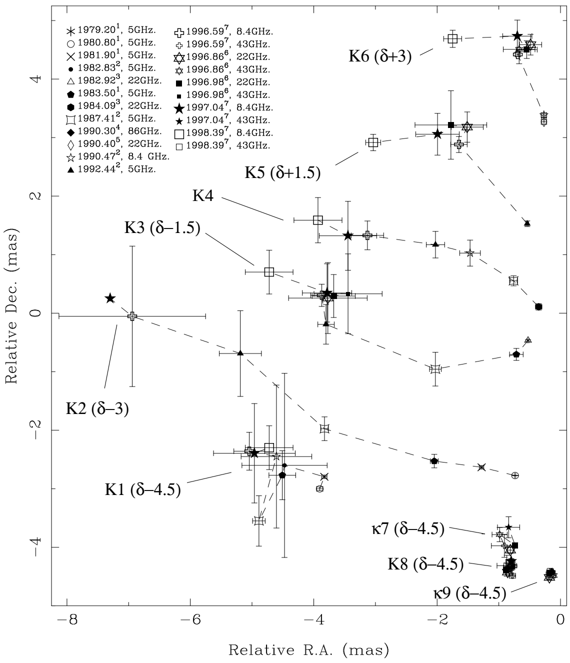

FIGURE 3. Apparent trajectories of components in 0735+178. Components positions have been shifted in declination by the amount (in milliarcseconds) expressed in parenthesis. Epoch, frequency, reference, and symbol for each epoch are as labeled. Estimated errors are indicated by bars. References correspond to: *1* Bääth & Zhang (1991); *2* Gabuzda et al. (1994); *3* Zhang & Bääth (1991); *4* Rantakyrö et al. (1998); *5* Bääth, Zhang, & Chu (1991); *6* Gómez et al. (1999) and *7* Gómez et al. (2001).

other components that seem to move following rectilinear (ballistic) trajectories. That is the case for components K2, K3 and K4, moving at apparent superluminal speeds of 11.6 ± 0.6, 8 ± 1.5, and 5 ± 1 h_{65}^{-1} c, respectively. There is some evidence for a possible change in the jet structure of 0735+178 (Gómez et al. 2001) suggesting that perhaps this rectilinear trajectory was actually present when these components were detected. Therefore the apparent ballistic motions of these components may just be due to this initial rectilinear structure of the jet.

The existence of standing and moving features is in agreement with non-ballistic components, where the stationary components would be associated with bends in the jet trajectory. Our observations support this scenario, where component K8 is observed to remain quasi-stationary, and is located at the first sharp bend of 90°. A region of higher emission is also observed in the second bent of 90°, in which the jet turns back to its initial east direction. Therefore, all the evidence suggests that the components in 0735+178 are not ballistic but follow the local jet flow direction, but this is not conclusive.

2.2. *Low Velocity "Ballistic" Motion Model*

As pointed out in Fig. 2, components show a tendency to be clustered near the same position (indicated by circles), within the errors. Therefore, the actual structure of 0735+178 is also consistent with a quasi stationary situation in which all components would have remained at similar locations.

To test this model we have performed three dimensional hydrodynamic relativistic simulations of a precessing jet, using the numerical code developed by Aloy et al. (2000, and references therein). Radio emission from these HD results can be obtained by solving

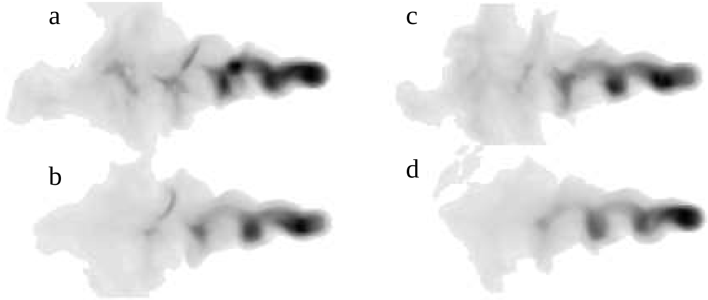

FIGURE 4. Synthetic synchrotron emission, for a viewing angle of 10°, of a 3D hydrodynamical relativistic simulation for a jet with a helical perturbation in velocity. The four epochs, separated by the same amount of time, are labeled accordingly to the time-evolution.

the transfer equations for synchrotron radiation (Gómez et al. 1997). Figure 4 shows the resulting simulated total intensity maps for a viewing angle of 10° and at different time steps. A twisted jet structure, similar to the observed in 0735+178, can easily be distinguished. Differential Doppler boosting results in the appearance of emission components in the jet regions that are better oriented with the observer. Because of the precession of the helix, these components seem to move following ballistic trajectories, even though the jet fluid moves along the jet axis, that is, with non-ballistic trajectories. It is possible that some of the components that we observe moving ballistically may be associated with the components produced by the differential Doppler boosting. On the other hand, the components observed to follow bent trajectories may be associated with moving shocks, that should follow a non-ballistic motion along the jet. In this scenario, ballistic components should move with a smaller velocity than the non-ballistic ones.

3. Conclusions

Our new map of 0735+178 in 1999 shows a twisted geometry in the inner jet regions as seen previously (Gómez et al 1999), but the observational evidence is not conclusive as to whether the twisted geometry of 0735+178 is produced by ballistic or non-ballistic motions of components. Further observations, and their comparison with numerical simulations, should provide the necessary information to understand this unussual bent structure observed in 0735+178.

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