Magnetic Field Structure in Relativistic Jets

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We present work in progress aimed to study the configuration and importance of the magnetic field in the emission and dynamics of relativistic jets through direct comparison between polarimetric VLBI images and numerical simulations.

We present monthly polarimetric VLBA observations of the jet in the radio galaxy 3C120 at 15, 22 and 43 GHz. A variable rotation measure (RM) is observed in the same jet location as that reported for the maximum interaction between the jet and the external medium (Gómez et al. 2000). A high RM is also detected in a recently ejected superluminal component, which could arise at the location where the underlying helical magnetic field mapped by the component is oriented along the line of sight.

The simulations explore the role played by the magnetic field making use of our recently developed relativistic magnetohydrodynamic (RMHD) code (Leismann et al. 2005). Computation of the synchrotron emission using the RMHD results as inputs allows the generation of synthetic total and polarized intensity maps that can be directly compared with observations.

We present preliminary simulations that explore jet asymmetries in the emission across the jet as produced by an underlying helical magnetic field.

Observations

We intend to study the role played by the magnetic field in the emission and dynamics of relativistic jets in Active Galactic Nuclei.

One of the best sources for such a study is the radio galaxy 3C120. Previous VLBA observations, performed at a frequency of 22 and 43 GHz and in polarization , monitored the inner jet structure on a monthly basis from Novembre 1997 to March 1999.They revealed a very rich emission structure with multiple superluminal components, from which an upper limit for the viewing angle of $\sim 20^\circ$ and a minimum Lorentz factor for the pattern speed of ~ 6 were estimated (e.g. Gómez et al. 2000). Some of the components were observed to appear in the wake of strong jet perturbations and to share similar properties as those of the *trailing* components analyzed with numerical simulations. (Agudo et al. 2001; Gómez et al. 2001)

This intensive monitoring program revealed a jet region in which superluminal components present varations in the total and polarized flux densities with time scales of months, accompanied by a progressive rotation of the magnetic polarization vector. This was interpreted as due to the interaction of the jet with the external medium or a cloud with properties intermediate of those of the broad and narrow emission-line regions (Gómez et al. 2000). The rotation of the electic vector was interpreted as produced by Faraday rotation of the ionized cloud, the level of which was estimated from the different polarization angles observed at 22 and 43 GHz.

In order to follow up the interaction of the jet with the cloud we continued our monthly VLBA monitoring in 2001, adding also observations at 15 GHz to confirm the existence of Faraday rotation.

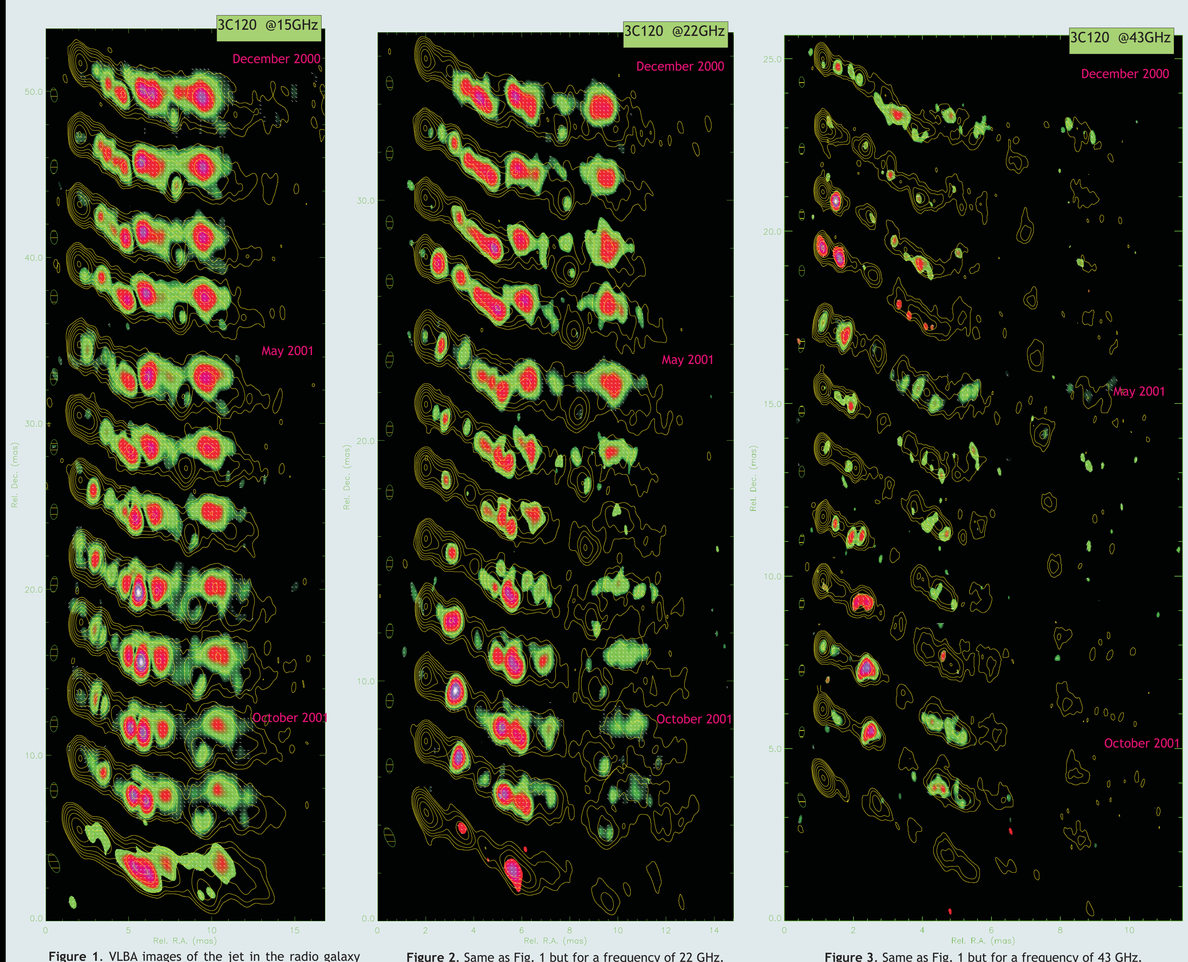


Figure 1. VLBA images of the jet in the radio galaxy 3C120 at 15 GHz. Contours give the total intensity, colors show the polarized intensity, and bars (of unit length) indicate the direction of the magnetic vector.

Figure 2. Same as Fig. 1 but for a frequency of 22 GHz.

Figure 3. Same as Fig. 1 but for a frequency of 43 GHz.

Computing the rotation measure.

Combining the previous images we have computed the following *rotation measure* (RM) maps for three of the epochs.

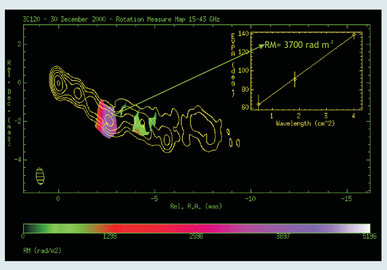


Figure 4. Rotation measure map (in colors) for epoch 30 December 2000 obtained by combining the images of Figures 1 to 3. Contours show the total intensity image at 22 GHz.

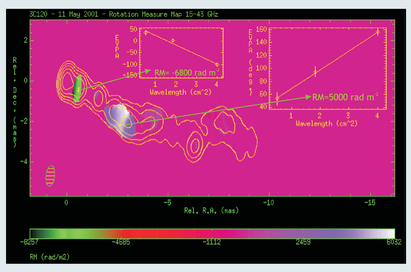


Figure 5. Same as Fig. 4 but for epoch 11 May 2001.

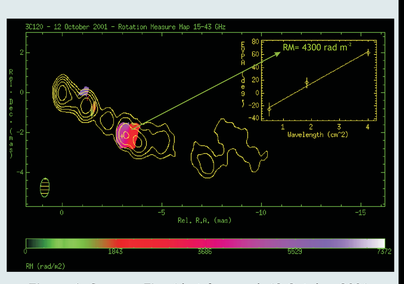


Figure 6. Same as Fig. 4 but for epoch 12 October 2001.

The RM maps confirm the presence of a relatively high rotation measure region at the same location as that reported by Gomez et al. (2000), coincident with the expected location of the maximum interaction between the jet and the cloud,as traced by the jet opacity (see Figure 7, reproduced from Gómez et al. 2000).

As expected for the case of an evolving interaction, the RM varies with time, from the estimated value of ~ 600 rad m^{-2} during 1998, to values of 3700, 5000 and 4300 rad m^{-2} for December 2000, May and October 2001, respectively. For epoch May 2001 we measured a RM of -6800 rad m^{-2} for a newly ejected superluminal component. As observed previously, new superluminal components show a rapid rotation of the electric vector within the inner milliarcsecond from the core, interpreted as mapping a twisted (helical) underlying magnetic field (Gómez et al. 2001). The high RM detected in May 2001 could arise at the location where the helical magnetic field is aligned with the line of sight.

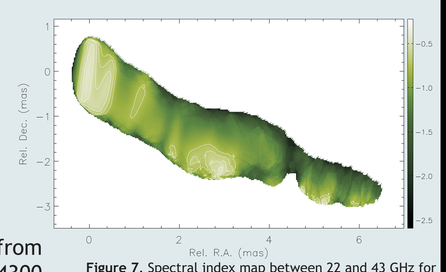


Figure 7. Spectral index map between 22 and 43 GHz for data obtained in 1998.
Reproduced from Gómez et al. (2000).

Simulations

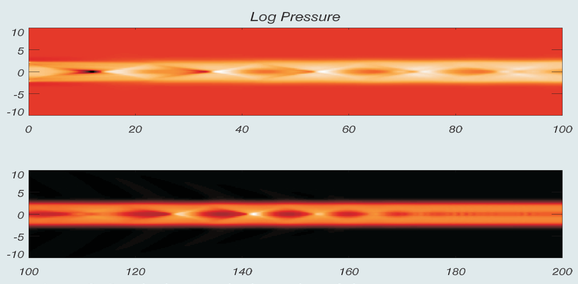


Figure 8. Panels showing the logarithm of the pressure.

Relativistic magnetohydrodynamic simulations

The relativistic magnetohydrodinamical (RMHD) simulations have been performed using a numerical code that solves the RMHD equations in conservation form and cylindrical coordinates with axial symmetry. Details of the numerical code can be found in Leismann et al (2005). Numerical fluxes between contiguous zones are computed using HLL approximate Riemann solver. Spatial second order accuracy is accomplished by means of piecewise linear, monotonic reconstruction of the rest mass density, gas pressure, spatial components of the fluid four=velocity and of magnetic field. Averaged values of the conserved variables are then advanced in time by means of a Runge·Kutta algorithm of third order. The magnetic field configuration is kept divergence·free thanks to the implementation of a

Simulating a relativistic jet with a helical magnetic field

We have modelled a jet with a beam speed of $v_j = 0.99c$, local Mach number $M_j = 1.75$, and overpressured with respect to the ambient medium by a factor of 2. The grid used is 3200 x 160 cells, with a resolution of 16 cells per beam radii.

The magnetic field energy is set to be equal to that of the fluid thermal pressure. For the configuration of the magnetic field we have chosen a helical geometry, with a pitch angle of 20°.

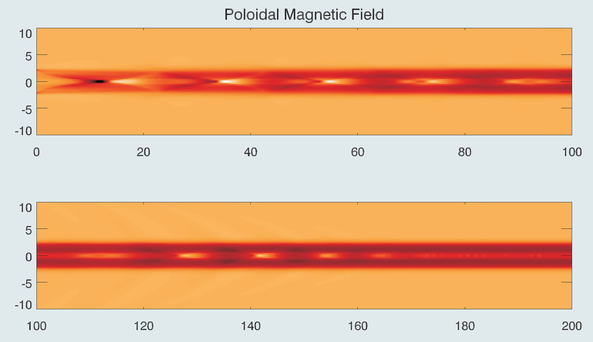


Figure 9. Panels showing the distribution of the poloidal magnetic field.

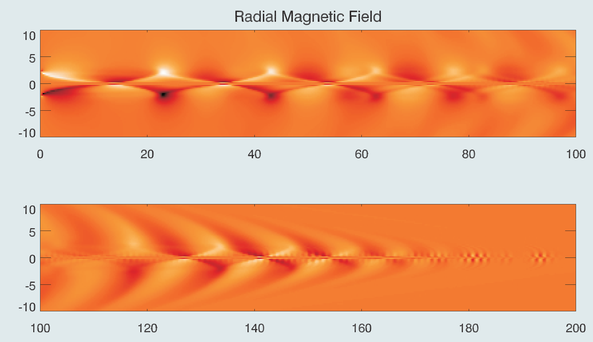


Figure 10. Panels showing the distribution of the radial magnetic field.

Computing the radio emission

Using the magnetohydrodynamic results as inputs we compute synthetic radio continuum emission (total and polarized) maps that can be directly compared with observations. For this we integrate the transfer equations for the synchrotron radiation (for an optically thin frequency, and in arbitrary units) taking into account all the appropriate relativistic effects (see Gómez 2001, 2002; and references therein, for a complete description).

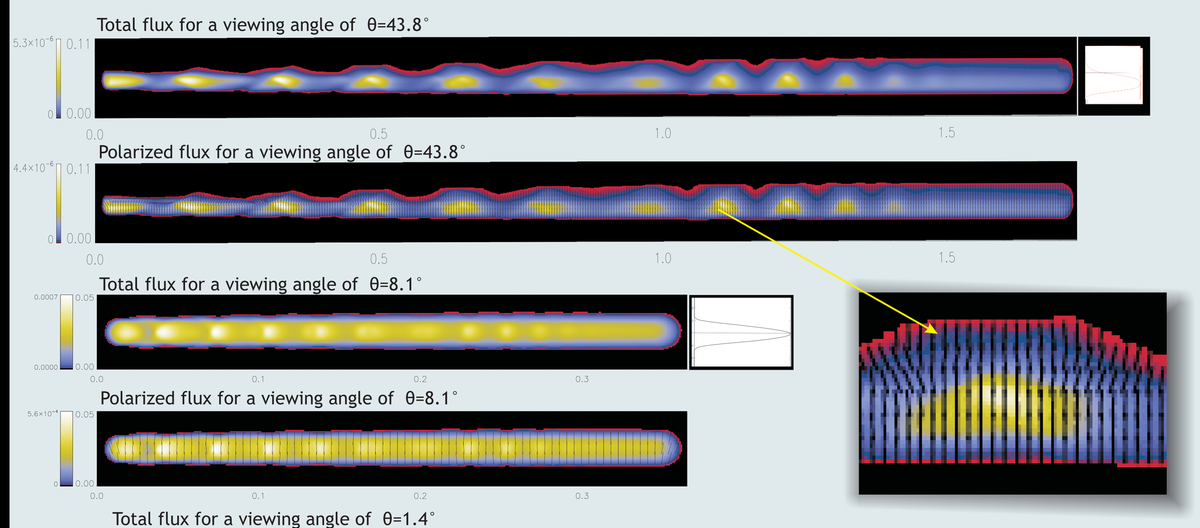


Figure 10. From top to bottom, panels show total and polarized intensities (plotted on a square root scale) for different viewing angles. The bars in the polarized intensity panels show the direction of the electric vector.
The three plots at the right of the total flux panels show the integrated emission along the jet.

Jet asymmetries as produced by a helical magnetic field

Because of the helical magnetic field structure introduced in our RMHD simulations, an asymmetry in the emission appears across the jet. This is produced by the sine of the angle between the magnetic field and the line of sight, measured in the *fluid's frame*, that appears as a multiplicative factor in the synchrotron radiation coefficients (see e.g., Aloy et al. 2000). The maximum asymmetry will be obtained for a viewing angle in the fluid frame (θ') equal to the helical pitch angle (Φ) and for $\theta'=\pi-\Phi$. The predominance of the emission between the top and bottom of the jet will reverse at $\theta'=\pi/2$, which corresponds to a viewing angle in the observer's frame of $\cos\theta=\beta$ (where β is the fluid velocity in units of c).

We have computed the synthetic emission maps for the viewing angles that maximize the asymmetry effect across the jet. Those correspond to $\theta=1.4^\circ$ ($\theta'=\Phi$), where the top side of the jet dominates the emission; $\theta=8.1^\circ$ ($\theta'=\pi/2$), where there is no asymmetry; and $\theta=43.8^\circ$ ($\theta'=\pi-\Phi$), where the bottom side of the jet dominates.

References

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