IAU Colloquium 164: Radio Emission from Galactic and Extragalactic Compact Sources
ASP Conference Series, Vol. 144, 1998
J. A. Zensus, G. B. Taylor, & J. M. Wrobel (eds.)

Sub-arcsecond Radio Imaging of Jets in Low-luminosity Radio Galaxies

M. Bondi, P. Parma
Istituto di Radioastronomia, CNR, Bologna, Italy

R. Fanti
Dipartimento di Fisica, Università di Bologna, Bologna, Italy

H. de Ruiter
Osservatorio Astronomico, Bologna, Italy

R.A. Laing
Royal Greenwich Observatory, Cambridge, UK

Abstract. We used VLA and MERLIN observations of 4 FR I radio galaxies to study the radio jet properties in the inner kiloparsecs from the core. We present evidence for relativistic motion in the inner regions.

1. Introduction

Jets in weak FR I radio galaxies are predominantly two sided and therefore cannot be significantly affected by Doppler boosting. However, often the bases of two sided jets (few kpc scale) are asymmetric and the hypothesis that they are relativistic has been mentioned by a number of authors. Recent additional evidence for this idea are: 1) the discovery of proper motions, corresponding to apparent transverse velocities of 0.1–1.0c, on kpc scales in the jet of M87 (Biretta 1993); 2) polarization asymmetry found in the lobes of FR I radio galaxies (Parma et al. 1991), in the same way as the Laing-Garrington effect, which is considered evidence of relativistic jet velocities; 3) the idea that the FR I radio galaxies are the unbeamed parent population of BL Lac objects (see, e. g., Urry, Padovani, & Stickel, 1991). The deduction is that in FR I radio galaxies the flow is relativistic on sub-kpc and kpc scales (where the jets are one sided) and that it must decelerate further outwards, producing the symmetrical structure seen on larger scale.

2. Observations and Analysis

We used MERLIN and VLA observations at 20 cm of four objects in order to study the jet and counter-jet properties over 3 orders of magnitude. We took slices across the jets from the MERLIN and VLA images. Gaussian functions were then fitted to each slice to obtain the peak surface brightness and the deconvolved Gaussian half-width. The surface brightness was deconvolved as well (Killeen, Bicknell, & Ekers 1986).

From the jet counter-jet brightness ratio (R) we calculated beta vs. distance from the core for various angles to the line of sight:

$$\beta \cos(\theta) = \frac{R^a - 1}{R^a + 1}$$

Table 1. Source properties

(1) Name	(2) z	(3) log $P_{\rm tot}$ [W/Hz]	(4) log $P_{\rm core}$ [W/Hz]	(5) $P_{\rm cN}$	(6) $B_{\rm j}/B_{\rm cj}$	(7) $\rm r_f$ [kpc]	(8) $\rm r_s$ [kpc]	(9) $\beta_{\rm in.}$ [c]	(10) θ [deg.]
0755+37	0.043	24.49	23.59	5.5	90	0.63	>5		
0206+35	0.037	24.50	23.07	1.9	16	0.55	>2	0.6	45
1116+28	0.067	24.39	22.85	1.3	4	1.37	>3	0.8	65
1752+32	0.049	23.47	22.33	1.0	3	0.52	>0.6	0.3	50

Notes: (1) name; (2) redshift; (3) log of total radio power at 20 cm; (4) log of core radio power at 20 cm; (5) normalized core power ($P_{\rm cN}$): ratio between the observed core radio power and the expected core radio power for a source at 60 degrees; (6) brightness ratio at the flaring point; (7) distance of the flaring point, (8) distance corresponding to a jet counter-jet brightness ratio < 2; (9)-(10) modeled initial velocity and angle to the line of sight.

where $a = 1/(2+\alpha)$ in the case $B_\perp$ and $a = 1/(3+2\alpha)$ in the case $B_\parallel$. Finally, we used the relativistic formulae for an adiabatic jet (Baum et al. 1997) to model an independent profile of β vs. distance:

$$I_v \propto (\Gamma_j v_j)^{-2(\alpha+3)/3} r_j^{-(10\alpha+9)/3} D^{2+\alpha} \quad \text{predominantly} \quad \mathrm{B}_\parallel$$

$$I_v \propto (\Gamma_j v_j)^{-(5\alpha+6)/3} r_j^{-(7\alpha+6)/3} D^{2+\alpha} \quad \text{predominantly} \quad \mathrm{B}_\perp$$

3. Results

For 3 sources (0206+35, 1116+28, 1752+32) we obtained a good agreement between the velocity profiles calculated from the jet-counterjet brightness ratio and from the modeling of the brightness and FWHM width in the adiabatic jet scenario. The derived initial velocity and angle to the line of sight are listed in Table 1 together with other relevant characteristics of the sources. The remaining source (0755+37) clearly shows a much more complex behavior and intrinsic differences in the jet and counterjet must be considered.

Acknowledgments. The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under a cooperative agreement by Associated Universities, Inc.

References

Baum, S. A., et al. 1997, *ApJ*, **483**, 178–193.

Biretta, J. A. 1993. in *Astrophysical Jets*, eds. D. Burgarella, M. Livio & C. P. O'Dea, 263–304.

Killeen, N. E. B., Bicknell, G. V., & Ekers, R. D. 1986, *ApJ*, **302**, 306–336.

Parma, P., et al. 1993, *A&A*, **267**, 31–38.

Urry, C. M., Padovani, P., & Stickel, M. 1991, *ApJ*, **382**, 501–507.