# Superluminal Accelerations Along a Helically Twisted Jet

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ABSTRACT. The relativistic dispersion relation describing the spatial growth of a helical perturbation to a relativistic supersonic jet is applied to observations of the nonlinear superluminal acceleration of component C4 along the inner jet in 3C345.

## A HELICALLY TWISTED JET

The radio source 3C345 has a curved, inner-jet structure. Component C4 appeared at a position angle $\simeq -135$ deg and has exhibited nonlinear motion and apparent acceleration from $\beta \simeq 4$ to 12 ($H_o = 55$ Km/s/Mpc, $q_o = 0.05$) over a three year period with motion from 0.3 to 0.8 mas separation from the central component along a mean direction $\lesssim -75$ deg and expansion indicating an opening angle of $\simeq 27$ deg. (Biretta et al. 1983 - BCU ; Moore et al. 1983 - MRB; Biretta et al. 1986 - BMC ). It can be shown that (Hardee 1987) the fastest growing helical wavelength along a constantly expanding jet in static pressure balance with an isothermal external medium can be written in the form

$$\lambda(z) = \lambda_1(R/R_1)^c, \qquad (1)$$

where $\lambda_1 = \lambda(z_1)$, $R_1 = R(z_1)$ and $1 \leq c \leq 1.5$ with the lower limit set by isothermal jet expansion and the upper limit set by adiabatic expansion of a light jet, i.e., $\gamma\sqrt{\eta} \ll 1$ where $\eta \equiv n_j/n_{ex}$, and that following rapid initial growth in amplitude that the amplitude $A \simeq \alpha R$. Figure 1 shows the positions of C4 from 1981 to 1984, and an isothermal and adiabatic helical trajectory with wavelength varying according to equation (1) and helical amplitude $A = \alpha R$. The axis of the trajectories is at an angle of 2 deg with respect to the line of sight. At $z_1 = 10^{19}$ cm (0.0143 mas projected on the plane of the sky) $R_1 = 1.04 \times 10^{17}$cm and the intrinsic opening angle is $\simeq 0.6$ deg, $1.6 \times 10^{20}\text{cm} > \lambda_1 > 2.5 \times 10^{19}$cm, $12.3 > M_1 > 1.9$, $3.8 > \alpha > 3.2$, and the upper and lower limits are given by the isothermal and adiabatic trajectories, respectively. The most likely case is initial adiabatic expansion with $\eta \ll 0.004$ so that $\gamma\sqrt{\eta} \ll 1$ at $z_1$, and with jet heating becoming important by 0.5 mas so that $1.7 < M < 12$ between 0.01 and 0.8 mas. C4 must be traveling with $\beta_o = 0.9980$, and $\gamma = 15.8$. A minimum apparent velocity occurs at position p*. Subsequently, we find an

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apparent motion $<\beta>\simeq 5$ during 1981, followed by acceleration to $<\beta> \simeq 10$ during 1982, and $<\beta> \simeq 11.5$ during 1983. Values of the length of time that a feature takes to reach a position, of the angle $\varepsilon$ that the velocity vector makes with the line of sight, of the angle $\theta$ that a shock normal would appear to make with respect to the line of sight, of the apparent velocity, $\beta$, and of the Doppler factor, $\delta \equiv 1/[\gamma(1 - \beta_o \cos \varepsilon)]$, are given in Table I.

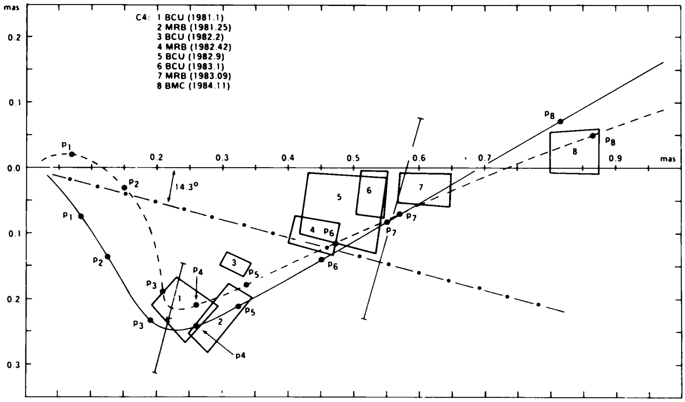

Figure 1 - Positions (error boxes) of component C4 observed by BCU, MRB, and BMC, and the adiabatic (dashed line), and isothermal (solid line) trajectories around the helical axis (dashed and dotted line). The jet's apparent cross section is indicated by the bars perpendicular to the helical axis.

Table I

Timescale, orientations, apparent speed and Doppler factor along the (a)Isothermal Trajectory ($\lambda \propto R$); (b)Adiabatic Trajectory ($\lambda \propto R^{1.5}$)

| | a: t(yr) | $\varepsilon^o$ | $\theta^o$ | $\beta$ | $\delta$ | b: t(yr) | $\varepsilon^o$ | $\theta^o$ | $\beta$ | $\delta$ |
|---|---|---|---|---|---|---|---|---|---|---|
| p1 | 0.25 | 2.08 | 59.9 | 13.7 | 23.7 | 0.25 | 5.13 | 109.4 | 14.9 | 10.5 |
| p2 | 0.50 | 1.36 | 41.1 | 10.5 | 22.7 | 0.50 | 3.95 | 95.1 | 15.7 | 14.5 |
| p3 | 1.08 | 0.59 | 18.4 | 5.1 | 30.8 | 1.00 | 0.92 | 28.5 | 7.7 | 29.7 |
| p* | 1.25 | 0.56 | 17.6 | 4.8 | 30.9 | 1.29 | 0.40 | 12.7 | 3.4 | 31.2 |
| p4 | 1.62 | 0.69 | 21.7 | 5.7 | 30.5 | 1.60 | 0.73 | 22.8 | 6.0 | 30.4 |
| p5 | 2.03 | 0.91 | 28.1 | 7.3 | 29.7 | 2.00 | 1.06 | 32.7 | 8.3 | 29.1 |
| p6 | 2.86 | 1.21 | 36.8 | 9.3 | 28.5 | 2.63 | 1.35 | 40.9 | 10.3 | 27.7 |
| p7 | 3.15 | 1.38 | 41.8 | 10.4 | 27.6 | 3.04 | 1.47 | 44.2 | 10.9 | 27.1 |
| p8 | 4.24 | 1.69 | 50.0 | 12.0 | 26.0 | 4.14 | 1.66 | 49.3 | 11.9 | 26.1 |

## REFERENCES

Biretta, J.A., Cohen, M.H., Unwin, S.C., and Pauliny-Toth, I.I.K. 1983, *Nature*, 306, 42.

Biretta, J.A., Moore, R.L., and Cohen, M.H. 1986, *Ap.J.*, 308, 93.

Hardee, P.E. 1987, *Ap.J.*, 318, 78.

Moore, R.L., Readhead, A.C.S., and Baath, L. 1983, *Nature*, 306, 44.