# Identification of the Superluminal Motion in Faint Parsec-Scale Jet of 3C390.3

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**Abstract**. New VLBI observation of the radio galaxy 3C390.3 made at 6 cm in 1989 and a multi-method image processing tried in successive years support previously reported evidence for superluminal motion in the faint jet of the N galaxy. We see some evidence for a counter-jet which may be identified with the component previously observed by LINFIELD (1981) at 2.8 cm.

## 1. Introduction

The N galaxy 3C390.3 (1845 + 797) is one of the classical powerful double radio galaxies and closest ($z = 0.0569$) sources with reported superluminal motion (ALEF *et al.*, 1988). VLBI observations made in 1976 and 1978 showed a jet-like structure about 8 parsecs long extending toward the NW lobe (PREUSS *et al.*, 1980), the same direction as that in arcsec map. ALEF *et al.* (1988) reported further VLBI observations made during the period 1978 to 1985 which showed evidence for the ejections of radio components at a rate of about every four years with an apparent transverse velocity of 0.74 mas/yr ($\beta_{\rm app} = 3.8$). However, they noted that at each epoch, there is a bright, possibly stationary, component located about 4 mas from the core. A 6 cm image at 1982.25 obtained by PEARSON and READHEAD (1988) is also consistent with an interpretation consisting of stationary components, without any net motion.

The existence of superluminal motion has also been reported in at least two other lobe dominated radio galaxies, 3C111, 3C120, as well as a number of lobe dominated quasars, e.g. 3C47, 3C179, 3C263 and 3C334. As the distribution of component velocities in the presumably randomly oriented lobe dominated sources has an important impact on the relativistic beaming model and unified theories, we have made additional VLBI observations of 3C390.3 at 6 cm in Nov. 1986, Oct. 1987, and Apr. 1989 in an attempt to verify the reality of the reported superluminal motion and to more accurately determine the apparent component velocities. A preliminary report of these observations has been given by PREUSS *et al.* (1990). A multi-package image processing has been tried in final experiment to define as

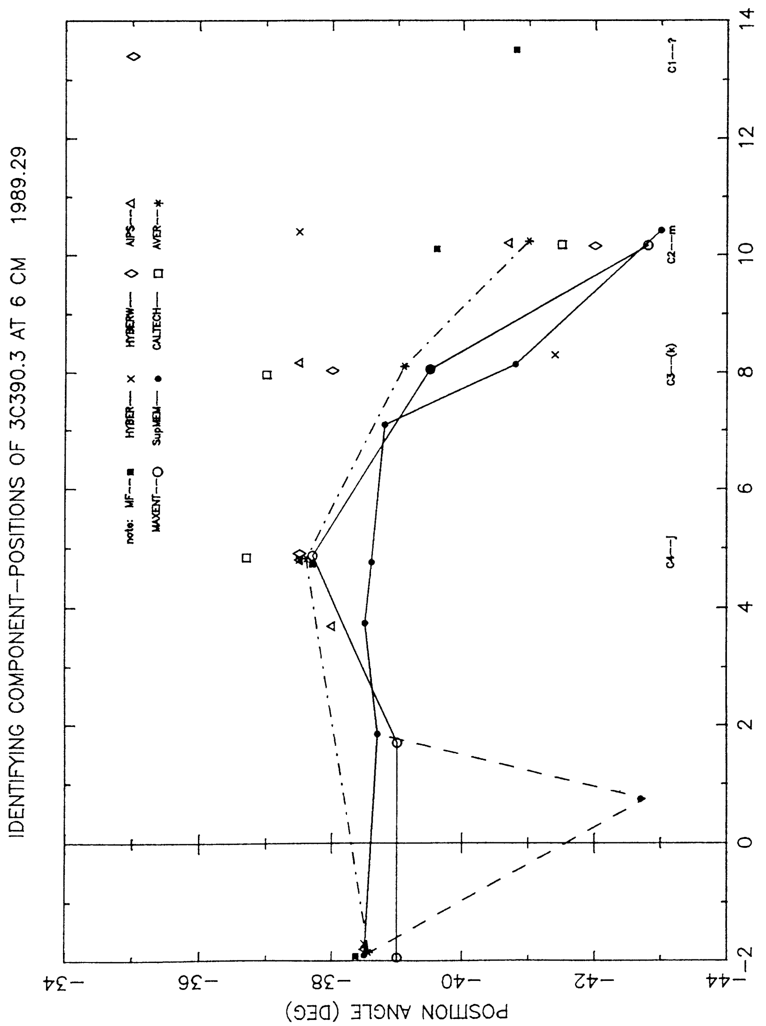


Fig. 1. The separations and position angles of the components with respect to the core of 3C390.3 at 1989.29 from various package (seven maps together).

clearly as possible the discernible components in the faint parsec-scale radio jet of the source, which has been introduced by WU and CAI (1993).

## 2. Outlines of Observations and Imagings

A total of twelve stations including Effelsberg, Medicina, WSRT, Onsala, Crimea, Haystack, Green Bank, Fort Davis, VLA27, Pie Town, OVRO and Shanghai

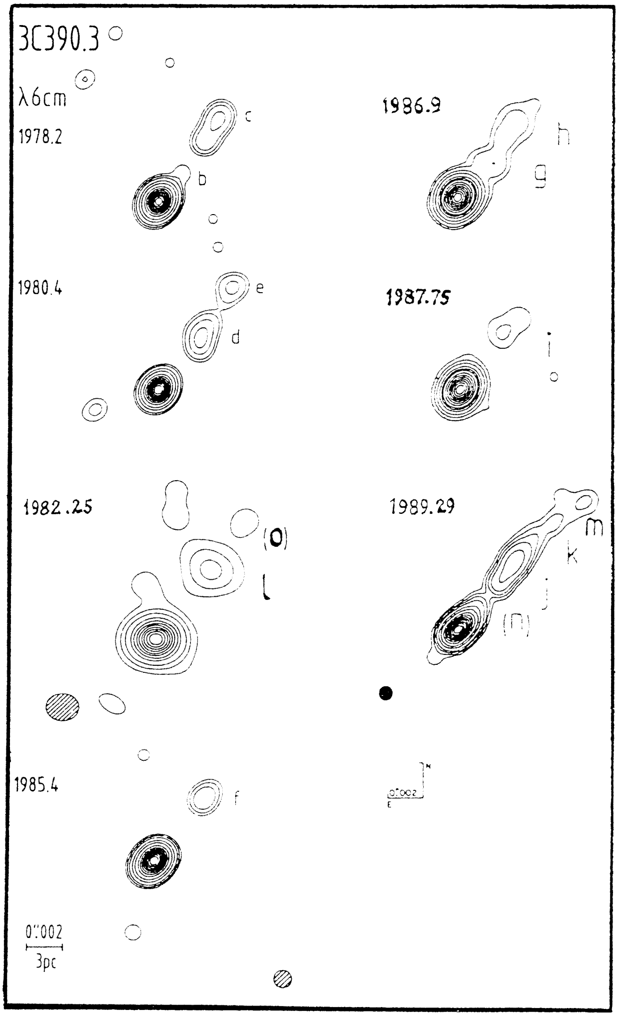


Fig. 2. The AIPS map at 1986.9 and 1987.75, the maximum entropy map (1989.29) of 3C390.3 with the contour levels of 0.2, 0.5, 1, 2, 5, 10, 20, ..., 80, and 90% of the maximum, combining with the maps at other epochs reported.

have been involved in the final experiment to achieve particularly good U-V coverage. The inclusion of the 100 m Effelsberg antenna, Westerbork, and the full 27 element VLA tied arrays gave unusually good sensitivity and correspondingly high dynamic range in the final map.

The data were analyzed using a combination of the MPI, AIPS and Caltech reduction programs in the final experiment. Both conventional CLEAN, HYBRID as well as maximum entropy (VLBMEM) images were constructed, and the model fitting was applied and gave consistent results as shown in Fig. 1. The identification of all maxima in both P.A. and separation as discernible components with the accuracy of separation within 5% or the population standard deviation less than 0.12 mas and the population standard deviation of P.A. less than 1.8°. The average separations of the major maxima with respect to the core are 1.9 (counter-jet), 4.8, 8.1, 10.2 and (13.5) mas. The position angles are 141.4°, –37.6°, –39.1°, –41.0° and (–37.9°) respectively. The consistence enable us to confirm the extended feature and components under the 5% level of the contours, to compare that with the precedents and draw some definite kinematic scene of 3C390.3. The identified components and the whole core-jet morphology of 3C390.3 can be represented by the MAXENT map convolved with a circle beam of 0.8 mas considerably well. Figure 2 shows the 5-GHz hybrid maps at 1986.9 and 1987.75, the MAXENT map at 1989.29 together with the scaled 5-GHz hybrid maps at other epochs reported (ALEF *et al.*, 1988; PEARSON and READHEAD 1988).

## 3. Superluminal Motion in the Jet

Figure 3 shows the relative position of each maximum seen along the jet at each epoch using and extending the alphabetic designation used by ALEF *et al.* (1988). Positions are measured relative to the unresolved core. We also indicate in Fig. 3 a proposed association of each of these maxima with moving components designated Cl through C4 and solid/dashed lines. The plot is just an extension of similar plot in ALEF *et al.* (1988). The data are all fit by assuming a series of ejecta at intervals of about 4 years each with proper motion and an apparent velocity:

$$\mu = 0.72 \ \ \text{mas / yr}, \quad \text{and} \quad \beta_{\text{app}} = 3.8. \tag{1}$$

Under the frame of relativistic beaming model, the apparent transverse velocity is

$$\beta_{\text{app}} = \frac{\beta \sin\theta}{1-\beta\cos\theta}. \tag{2}$$

The maximum ejecting angle of the jet with respect to the line of sight and the minimum Lorentz factor can be deduced from Eqs. (1) and (2) as $\theta_{\text{max}} = 29.5°$ and $\gamma_{\text{min}} = 3.93$ respectively. An interpretation in terms of stationary components appears unlikely from the fitting, but cannot be completely excluded on the basis of these data.

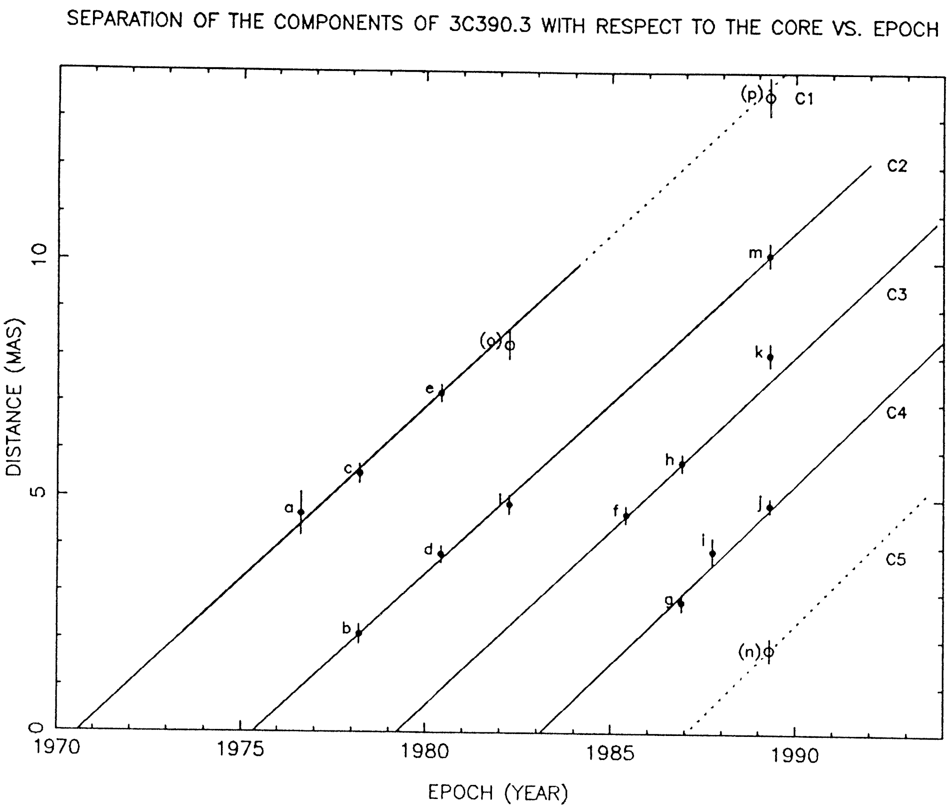


Fig. 3. The separation of the components with respect to the core vs. observational epoch by which the superluminal motion is indicated.

## 4. The Jet and Counter-jet

The 1989 image, which has an apparent dynamic range better than 500 to 1, shows at least three apparent maxima (designated as ***j***, ***k***, ***m***) along the jet which extends 13.5 mas (20 pc) toward the northwest (P.A. = –38°). A fourth component (***n***) located only about 2 mas from the core may be visible in the MEM super-resolution reconstruction. A probably reappeared faint feature of ***C1*** labeled as (***p***) has been identified in the model fitting and MPI hyber map and shown in the plot.

There is evidence for a weak counter-jet located 1.9 mas in position angle 141.5°. The existence of the counter-jet is supported by the 2.8 cm observations made by LINFIELD (1981), which showed a single extension oriented in P.A. = 140°, opposite to that of the 6 cm jet.

It is not clear if 3C390.3 is one of a small number of radio sources with a two-sided jet such as 3C147, and if so how this may be interpreted in terms of the canonical twin beam model. In the standard picture, each source contains a pair of symmetric jets which may appear one-sided due to differential Doppler boosting. In this case, the ratio of apparent intensity of the approaching and receding components is given by the familiar expression:

$$R = \left( \frac{1 + \beta \cos\theta}{1 - \beta \cos\theta} \right)^{2-\alpha}, \tag{3}$$

where $\alpha$ is the spectral index with $S \propto \nu^{\alpha}$, $\theta$ is ejecting angle of the jet with respect to the line of sight, and

$$\beta = \sqrt{\gamma^2 - 1} / \gamma. \tag{4}$$

Equation (3) requires that the ratio of jet to counter-jet be independent of the frequency of observation. However, the 10.7 GHz observations of LINFIELD (1981) suggests that the spectrum of the northwestern and southeastern components are quite different. The inverted spectrum of the southeastern component suggests that it, rather than the strong 6 cm component, may be the true core. High dynamic range observations over a range of wavelength, especially at shorter wavelengths will be needed to determine if there is really a two-sided jet in 3C390.3, and to unambigously identify the core component.

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