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OBSERVATIONS OF 3C 273 WITH HIGH NORTH-SOUTH RESOLUTION

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ABSTRACT

We present the first VLBI maps of 3C 273 with high north-south resolution. A strong, nonmonotonic curvature is found in the jet at projected radii $\leq$ 5 pc. Measurements of the core size show that bulk relativistic motion in the core is not required for consistency with the observed X-ray flux.

Subject headings: quasars — radio sources: galaxies

I. INTRODUCTION

The compact radio source in the quasar 3C 273 ($z = 0.158$; Schmidt 1963) shows superluminal motion with $v/c \approx 6$ (Pearson *et al.* 1981; Unwin *et al.* 1985, hereafter U85). Since it lies at a declination of $+2°$, the northern hemisphere VLBI networks give a north-south resolution nearly an order of magnitude worse than the east-west resolution. The compact source is elongated at position angle (P.A.) $\approx -115°$, and motions along this direction are seen. However, it has not been possible to show that the compact source is narrow and jetlike, as is the case for other superluminal sources like 3C 345. It is also known that 3C 345 shows complex behavior near the core, with changing position angles and acceleration (Biretta *et al.* 1983; Moore, Readhead, and Baath 1983). It has not been possible to test 3C 273 for this behavior because of the poor north-south resolution.

To improve the north-south resolution we have instrumented the Itapetinga (Brazil) radio telescope with a 10.7 GHz receiver for VLBI. This *Letter* reports the first results obtained with Itapetinga arrayed with other telescopes in Europe and the USA.

Throughout this *Letter* we will assume $H_0 = 100$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$. For $z = 0.158$ the linear scale is 1.77 pc per milli-arcsecond (mas). The uncertainties quoted are 1.0 σ.

II. OBSERVATIONS

Very Long Baseline Interferometric (VLBI) observations of 3C 273 were made on 13 February 1984 (1984.12) with a 1.8 MHz bandwidth centered at 10650.89 MHz. The antenna array consisted of M.P.I.f.R., West Germany (100 m diameter) and Itapetinga, Brazil (14 m) along with four stations of the US VLBI network: Haystack (37 m), Green Bank (43 m), Fort Davis (26 m), and Owens Valley (40 m). At Itapetinga the room temperature parametric amplifier receiver gave a system temperature of about 400 K. The frequency/time standard was a rubidium oscillator; its time setting relative to UTC was verified by making 22 GHz VLBI observations of the W49 H_2O maser. The characteristics of the other stations are well known.

Calibration was provided by hourly system temperature measurements along with antenna temperature measurements or a gain curve. Details of the data reduction and mapping procedures will be given elsewhere (J. A. Biretta *et al.*, in preparation). The beam has a central component of size 0.43×0.65 mas (FWHM) and strong north-south side lobes; the strongest side lobes are 86% of the central peak. To compensate for these strong side lobes a 2% loop-gain was used while CLEANing the map. The side lobes are strong because of the large "Amazon Gap" in the (u, v) coverage; hence, information on intermediate north-south scales is missing. We have implicitly constrained the source structure to be simple in the north-south direction in making the maps shown below. The shortest baseline has $\lambda/2D \approx 7$ mas, and there is little information about scale sizes larger than this.

III. RESULTS

The hybrid map is presented in Figure 1. Figure 1*a* shows the CLEAN components smoothed with a circular Gaussian similar in size to the beam's central component. The map in Figure 1*b* was derived with a larger beam which includes the strong side lobes. This larger beam is essentially that which would be obtained without the Itapetinga data. Features in these maps weaker than 3% of the peak intensity are thought to be unreliable. Comparison of these two figures shows the obvious advantage of using a southern hemisphere telescope on an equatorial source. Even though the side lobes are strong, the detection of a significant fraction of the total flux on baselines to Itapetinga indicates that the north-south structure must be compact. The alternate possibility is periodic north-south structure which mimics the dirty beam; this seems contrived and is therefore rejected.

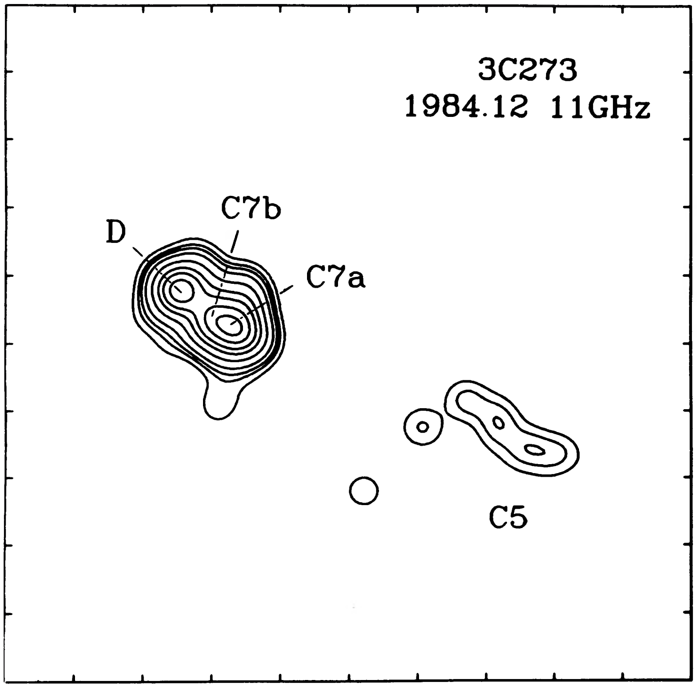

FIG. 1*a*

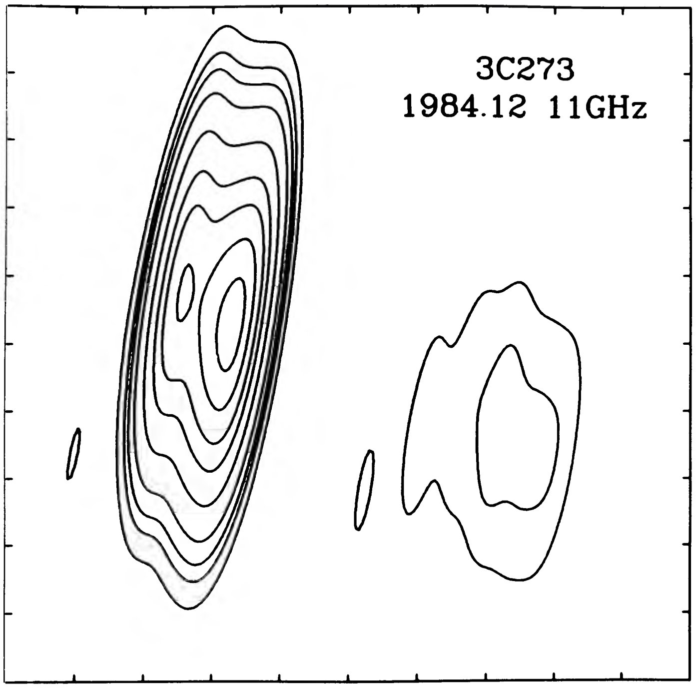

FIG. 1*b*

FIG. 1.—Hybrid map of 3C 273 at 11 GHz for 1984.12 epoch. North is at the top, and east is at the left. Contours are at −2, 2, 4, 6, 10, 20, 35, 50, 70, and 90% of the peak intensity. The scale is 1.20 mas per tick mark. The beam is a 0.6 mas diameter circular Gaussian function in (*a*), and a 4.2 by 0.6 mas elliptical Gaussian function in (*b*).

Three major components are present in the map. The easternmost is bright and compact, and we will assume it to be identical with the component labeled D by U85. The brightest component in the middle is labeled C7a, following the notation of U85. This component is brightest at its southwestern edge and is extended along a line toward the western component. We have labeled the extension C7b. The western component, which is weak and extended, is labeled C5 since an extrapolation of the data presented by U85 would put their component C5 at about this position in early 1984. This identification must be tentative until maps at intervening epochs are considered (J. A. Biretta *et al.*, in preparation). Component C6 of U85 is not seen in our map.

IV. DISCUSSION

The high north-south resolution permits us to examine two aspects of the source which were previously obscured: the curvature of the jet near the core, and the sizes of individual components. We will interpret our data in terms of the relativistic jet model for superluminal radio sources (Blandford and Königl 1979). The merits of this model are discussed by Scheuer (1984) and Begelman, Blandford, and Rees (1984).

Our data show that there is a substantial change in the P.A. of the jet near the core. The P.A.'s are plotted in Figure 2, as a function of distance from the core. At small radii ($r \lesssim 1$ mas) components C7a and C7b have P.A. ≈ $-127° \pm 1°$ and $-139° +4/-2°$, respectively. The best comparable data are from U85 who find P.A. ≈ −129° and −134° for component C6 when at $r \approx 0.8$ and $r \approx 1.3$ mas, respectively. At $r \geq 6$ mas we find that component C5 has P.A. ≈ $-114° \pm 4°$. Data from the literature give similar P.A.'s for other components when near this radius. Hence there appears to be an $18° \pm 5°$ change in the P.A. of the jet at projected distances of ~ 2 pc from the core. This result is similar to that found for 3C 345 by Readhead *et al.* (1983); they found a ~ 45° change in P.A. of the jet at projected radii of ~ 2 pc.

Our observations show further that the curvature of the jet is not monotonic. The P.A. of the jet increases between $r \approx 1$ and $r \approx 5$ mas, but then decreases between $r \approx 5$ and $r \approx 40$ mas (Fig. 2). Hence the direction of curvature changes at projected radii of ~ 10 pc. This behavior is quite different from 3C 345 in which the direction of curvature is constant from projected radii of 2 pc to 4 kpc (Browne *et al.* 1982; Readhead *et al.* 1983).

It is unlikely that the curvature of the jet can be explained as a simple precession. There is no geometry which can account for both the straightness of the jet between ~ 20 mas and 20″ (Conway *et al.* 1981; Perley 1984) and the non-monotonic curvature near the core. A more complex model might invoke both precession at $r < 20$ mas and a collimation at $r \geq 20$ mas to explain the straightness of the large-scale jet. For this model, our data imply a precession period $\leq 300(20°/\theta)$ yr, where θ is the angle between the jet axis and

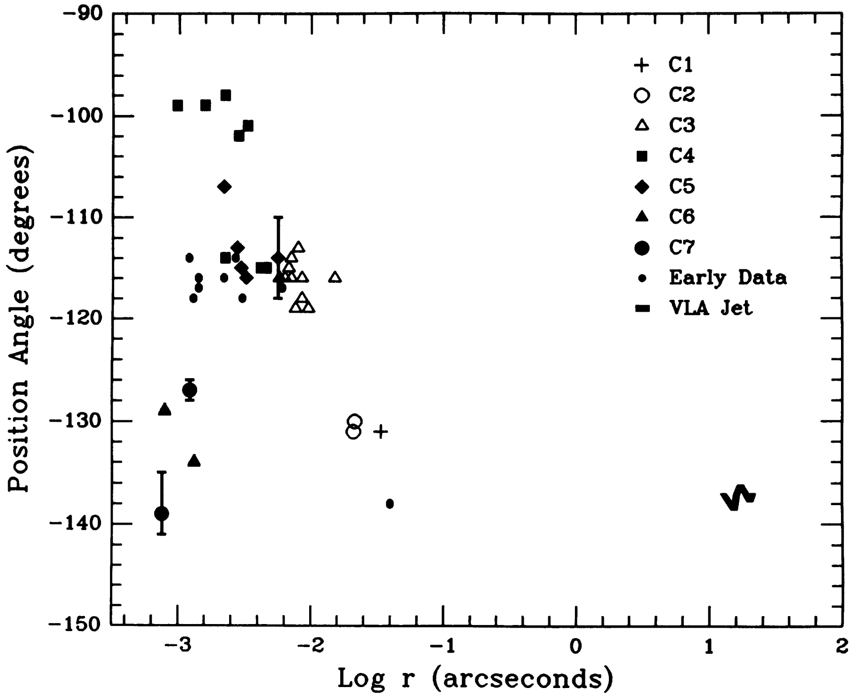

FIG. 2.—Position angles of components plotted against *r* (distance from the core component D). Data with error bars are from this paper. Other data are from Niell *et al.* (1975, early data); Schilizzi *et al.* (1975, early data); Readhead *et al.* (1978, early data); Readhead *et al.* (1979, component C4); Perley (1984, VLA jet); Pearson *et al.* (1981, C4); Cohen *et al.* (1983, C1, C2, C3); and U85 (1985, C2, C3, C4, C5, C6). Niell *et al.* (1975) and Schilizzi *et al.* (1975) assumed the components were collinear, so their P.A.'s are averages for the three components they detected. Niell *et al.* (1975) indicate that models with collinear components gave a poor fit to the data.

the line of sight. The proper motion of the superluminal knots requires $\theta < 20°$ (U85), and the likelihood of a certain geometry decreases as θ becomes small. For example, if $\theta \geq 5°$ the required period is $\leq 10^3$ yr. Such a rapid precession could be produced by a pair of orbiting supermassive objects (Begelman, Blandford, and Rees 1980), but the orbit would decay by gravitational radiation in $\sim 10^6$ yr. This explanation is unattractive since the required precession would occur for only a short time. Other arguments against precession are presented by Conway *et al.* (1981).

An alternative explanation for the curvature is bending of the jet by pressure gradients (Readhead *et al.* 1978; Begelman, Blandford, and Rees 1984). Since the curvature is not monotonic, two different pressure gradients would be required at projected radii $r \approx 2$ pc and $r \approx 20$ pc. If the older data for component C4 which show P.A. $\approx -99°$ near the core are correct, then a more complex model would be needed in which components move along different paths while near the core. Such a model might invoke ejection in a wide cone (Rees 1980), instabilities in an accretion disk along with collimation at projected $r \geq 5$ pc, or instabilities in the jet itself (Hardee 1979; Ferrari, Trussoni, and Zaninetti 1981). Alternatively, components might first appear localized within or at the edges of the jet and subsequently evolve to fill the jet's entire width. Since both 3C 273 and 3C 345 show strong curvature at projected radii of ~ 2 pc, it is likely that the same mechanism is operating in both quasars.

Calculations of the inverse Compton X-ray flux for compact sources are very sensitive to the sizes of the radio emitting region. For other superluminal sources, this calculation gives direct evidence for bulk relativistic motion toward the observer (3C 345—Unwin *et al.* 1983; NRAO 140—Marscher and Broderick 1981, 1982). This calculation has been worked out for 3C 273 by U85 who assume a core diameter (component D) of 0.8 mas. This diameter is consistent with the upper limit we obtain with our better resolution. Hence, we confirm their finding that the inverse Compton X-ray calculation gives no evidence for bulk relativistic motion in the core of 3C 273. Since accurate component spectra are needed for this calculation, a discussion of components C5 and C7 will be presented elsewhere (J. A. Biretta *et al.*, in preparation).

Future observations with more complete north-south coverage are needed to check these results and study the position angles of new components while they are near the core. Unfortunately, there are very few high-frequency VLBI antennas at low or southern latitudes.

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REFERENCES

Begelman, M. C., Blandford, R. D., and Rees, M. J. 1980, *Nature*, **287**, 307.
______. 1984, *Rev. Mod. Phys.*, **56**, 255.
Biretta, J. A., Cohen, M. H., Unwin, S. C., and Pauliny-Toth, I. I. K. 1983, *Nature*, **306**, 42.
Blandford, R. D., and Königl, A. 1979, *Ap. J.*, **232**, 34.
Browne, I. W. A., *et al.* 1982, *Nature*, **299**, 788.
Cohen, M. H., *et al.* 1983, *Ap. J.*, **272**, 383.
Conway, R. G., Davis, R. J., Foley, A. R., and Ray, T. P. 1981, *Nature*, **294**, 540.
Ferrari, A., Trussoni, E., and Zaninetti, L. 1981, *M.N.R.A.S.*, **196**, 1051.
Hardee, P. E. 1979, *Ap. J.*, **234**, 47.
Marscher, A. P., and Broderick, J. J. 1981, *Ap. J.*, **249**, 406.
______. 1982, *Ap. J. (Letters)*, **255**, L11.
Moore, R. L., Readhead, A. C. S., and Baath, L. L. 1983, *Nature*, **306**, 44.
Niell, A. E., Kellerman, K. I., Clark, B. G., and Shaffer, D. B. 1975, *Ap. J. (Letters)*, **197**, L109.
Pearson, T. J., *et al.* 1981, *Nature*, **290**, 365.
Perley, R. A. 1984, in *IAU Symposium 110, VLBI and Compact Radio Sources*, ed. R. Fanti *et al.* (Dordrecht: Reidel), p. 153.
Readhead, A. C. S., *et al.* 1978, *Nature*, **276**, 768.
Readhead, A. C. S., Hough, D. H., Ewing, M. S., Walker, R. C., and Romney, J. D. 1983, *Ap. J.*, **265**, 107.
Readhead, A. C. S., Pearson, T. J., Cohen, M. H., Ewing, M. S., and Moffet, A. T. 1979, *Ap. J.*, **231**, 299.
Rees, M. J. 1980, in *IAU Symposium 94, The Origin of Cosmic Rays*, ed. G. Setti *et al.* (Dordrecht: Reidel), p. 139.
Scheuer, P. A. G. 1984, in *IAU Symposium 110, VLBI and Compact Radio Sources*, ed. R. Fanti *et al.* (Dordrecht: Reidel), p. 197.
Schilizzi, R. T., *et al.* 1975, *Ap. J.*, **201**, 263.
Schmidt, M. 1963, *Nature*, **197**, 1040.
Unwin, S. C., *et al.* 1983, *Ap. J.*, **271**, 536.
Unwin, S. C., *et al.* 1985, *Ap. J.*, **289**, 109 (U85).

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