THE ASTROPHYSICAL JOURNAL, 315:L89–L92, 1987

EVOLUTION OF 3C 273 AT 10.7 GHz

M. H. COHEN AND J. A. ZENSUS
California Institute of Technology
J. A. BIRETTA
Harvard-Smithsonian Center for Astrophysics
G. COMORETTO
Istituto di Radioastronomia, C.N.R.
AND
P. KAUFMANN AND Z. ABRAHAM
Instituto de Pesquisas Espaciais
Received 1986 November 24; accepted 1987 February 2

ABSTRACT

The quasar 3C 273 has been observed at 10.7 GHz at three epochs spanning 1984.1–1985.6. Two new superluminal components, C5 and C7a, are separating from the core with apparent transverse velocity $v/c = (8.0 \pm 0.2)h^{-1}$ and $(5.1 \pm 0.3)h^{-1}$. The old components C3 and C4 may still be recognizable, with C4 having moved from 2.5 to perhaps 10 mas from the core in 7 yr. Nonmonotonic curvature near the core is confirmed.

Subject headings: galaxies: jets — quasars

I. INTRODUCTION

The quasar 3C 273 has a bright compact radio core with a curved core-jet structure. The jet contains several components apparently traveling with $v/c = 5–7h^{-1}$ ($z = 0.158$, $H_0 = 100h$ km s^{-1} Mpc^{-1}, and $q_0 = 0.5$) (Pearson *et al.* 1981; Unwin *et al.* 1985, hereafter U85). 3C 273 is at declination $\delta = +2°$ so that VLBI experiments in the northern hemisphere give poor N-S resolution; typical effective beams are 6 times longer N-S than E-W. For this reason, we have been observing this source with a southern hemisphere telescope added to the northern array. Our first observations at 10.7 GHz with the Itapetinga Observatory in Brazil were reported by Biretta *et al.* (1985, hereafter B85). We now have two more 10.7 GHz observations to Brazil, and in this *Letter* we discuss the changes of the source structure.

II. OBSERVATIONS

Table 1 lists the telescopes, and some of their characteristics, for the three epochs. We used the Mark II VLBI recording system with a bandwidth of 1.8 MHz at 10.651 GHz, and left-circular polarization. The tapes were correlated on the "Block 0" five-station processor in Pasadena. For 1984.12, the fringe-fitting was done for each baseline independently, but for 1984.93 and 1985.60 we used the global fringe-fitting algorithm developed by the NRAO AIPS group (Schwab and Cotton 1983). Flux calibration and mapping were done in the Caltech package.

Figure 1 shows the three maps. Each is composed of the CLEAN components smoothed with a circular Gaussian beam with FWHM 0.6 milliarcsecond (mas), which is a little larger than the FWHM of the central peak of the dirty beam. The maps have been rotated counterclockwise by 32°, and the direction to the outer jet, at PA = −137°, is shown by the arrow. We refer to the successive maps as I, II, and III. Map I has half the dynamic range of the others, as described in the legend, and was published in B85. The quality of the maps improves through this sequence of observations; and the later ones show more detail. The first epoch was hurt by the lack of simultaneous data between Germany and Brazil, and the last one was helped by a better system temperature in Brazil.

III. RESULTS

a) *Morphology*

We fitted the visibility functions for the three epochs with models consisting of a string of elliptical components. For epochs I and II, five components gave adequate fits, but for epoch III seven components were needed. We adopt the convention of U85 and B85 in labeling the components. The easternmost is the core, D; and the others form the jet.

The components are well defined in the models, but the maps (Fig. 1) show that the bright regions in fact are not well isolated. They are blended, and they merge or change in an indistinct fashion. In map III, D and C8 are two distinct components separated by about one beamwidth. C8 is a strong new component, and it appears to be starting along the track of the others. Map II does not show C8, but model fitting indicates that D was elongated, so there is some evidence for the existence of C8 in 1984.93 also. C7a and C5 appear to keep their identity through the three epochs, and Figure 1 contains diagonal lines which represent fits to their

TABLE 1

JOURNAL OF OBSERVATIONS

Telescope	Location	Size (m)	1984.12	1984.93	1985.60
Max-Planck Institut für Radioastronomie	Effelsberg, FRG	100	x	x	...
Istituto di Radioastronomia	Medicina, Italy	32	...	x	x
Instituto de Pesquisas Espaciais	Atibaia, Brazil	14[a]	x	x	x
Haystack Observatory	Westford, MA	37	x	x	x
National Radio Astronomy Observatory	Green Bank, WV	43	x	x	x
G.R. Agassiz Station	Fort Davis, TX	26	x	x	x
Owens Valley Radio Observatory................	Big Pine, CA	40	x	x	x
Hat Creek Radio Observatory	Hat Creek, CA	26	...	x	...

[a] Effective size = 10 m because linear polarization was used.

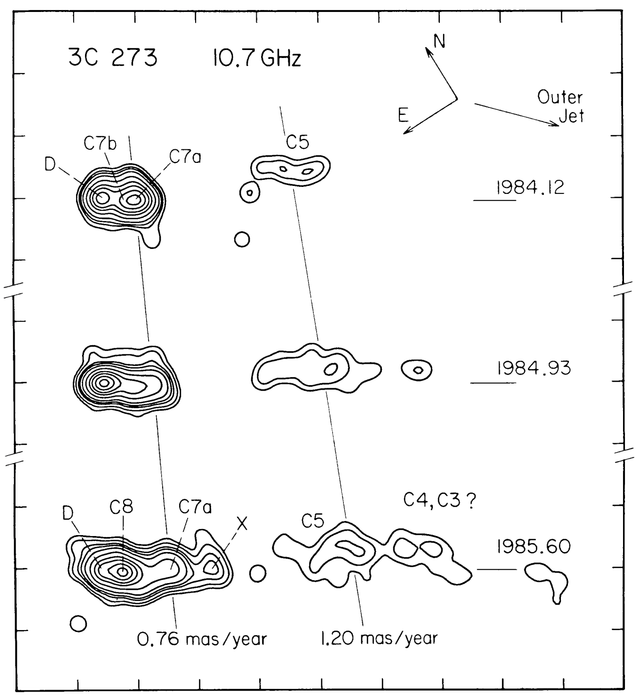

FIG. 1.—Maps of 3C 273 at 10.7 GHz, smoothed with a circular Gaussian beam with FWHM = 0.6 mas. Contour levels map I (*top*): 2, 4, 6, 10, 20, 35, 50, 70, 90% of peak; maps II (*center*) and III (*bottom*): 1, 2, 4, 6, 10, 20, 35, 50, 70, 90% of peak. No negative contours reach these levels. The peak brightnesses are 8.2, 11.0, and 9.1 Jy per beam for maps I, II, and III, respectively. The scale is 2 mas per tick. The maps are aligned on the eastern component D, rotated counterclockwise by 32°, and spaced vertically according to epoch. The diagonal lines represent fits to the proper motions as shown in Fig. 2.

proper motions relative to D (see Fig. 2). U85 also show components C6, C4, C3, and C2. C6 was weaker than D at 10.7 GHz in 1981.10, when it was about 1.0 mas from the core. In map I, C7a is substantially stronger than D; this plus the fact that otherwise there would have been no motion led B85 to assume that C7a was a new component and that C6 had become weak and invisible since 1981.

The positions of C4 and C3 can be extrapolated from U85; at the epoch of map III they would have been at 9.5 ± 1.7 and 12.1 ± 0.3 mas, respectively. This brackets the western blob labeled C4, C3? in map III. It is safe to conclude that the emission regions between 6 and 12 mas in map III are the descendents of components C3, C4, and C5.

Component C2 (U85) should have been roughly between 20 and 25 mas from D during 1984 and 1985. Our data for epochs 1984.93 and 1985.60 in fact show evidence for emission in that general area, but it cannot be mapped. The outer components all have a steep spectrum and are more easily seen at lower frequencies. Zensus, Bååth, and Cohen (1987) have 5 GHz maps which clearly show blobs of emission which might correspond to C5, C4, C3, and C2.

Map III shows a component, labeled X, which does not appear in earlier maps. It is relatively strong, and limited dynamic range would not have prevented us from seeing it earlier. We caution, however, that there is ambiguity in its exact north-south location. Different mapping trials moved X around more than the other components, and it might be about one beamwidth to the south. If we identify X with C6 its average velocity has been about 0.4 mas yr^{-1}, which is half or less than all the other proper motions seen in 3C 273. If it is somehow associated with C7a in map II, then its velocity is 2.0 mas yr^{-1} or about twice that reported for the other components. This suggests that either (*a*) components may have widely different proper motions, as in 3C 120 (Walker *et al.* 1984), or (*b*) components may appear spontaneously far from the core. We have no evidence favoring either of these explanations.

b) *Motions*

Figure 2 shows an "expansion diagram" for C5 and C7a. The points represent centers of elliptical components which are fit to the visibility data, and the error bars show formal uncertainties, as discussed by Biretta, Moore, and Cohen (1986). The errors for C7a are smaller than the points. These model-fit errors, of course, are smaller than the true uncertainties, which, especially for diffuse components like C5, are much larger. The straight lines are least-squares fits, and they show that it is appropriate to identify the C5 components in Figure 1 with the old C5 discussed by U85, although the 3 yr gap introduces ambiguity. The proper motions of C5 and C7a correspond, respectively, to apparent transverse motions $(v/c) = (8.0 \pm 0.2)h^{-1}$ and $(5.1 \pm 0.3)h^{-1}$. The straight lines in Figure 1 are the same as the lines in Figure 2.

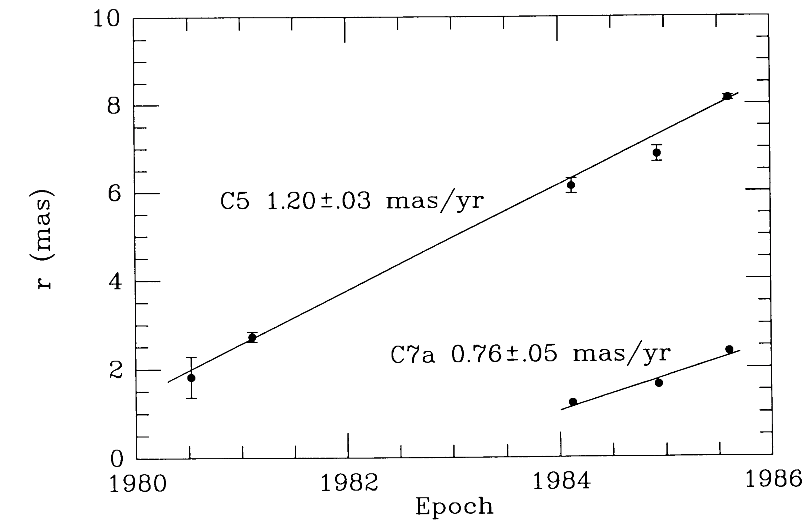

FIG. 2.—Expansion diagram. See text.

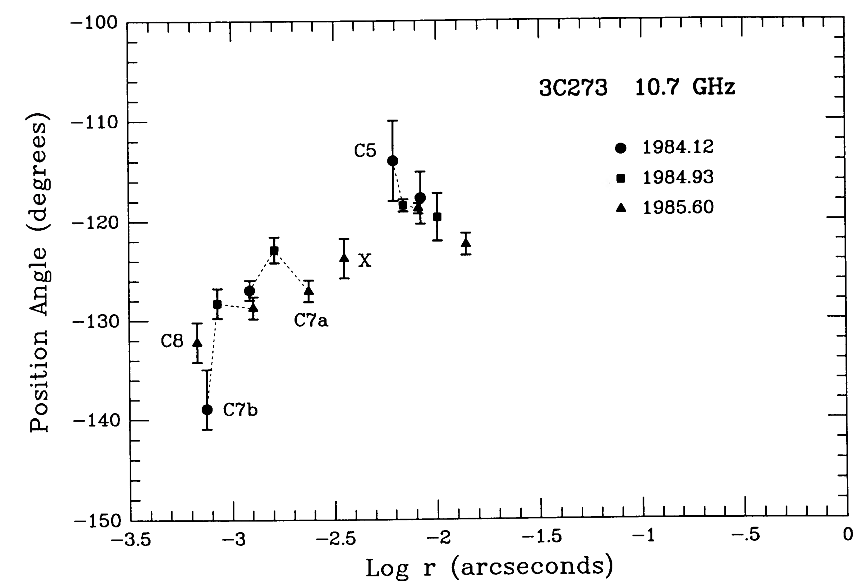

FIG. 3.—Location of the centroids of components of 3C 273 relative to the core. See text.

C4 and C3 were moving with v/c = 1.0 and 0.8 mas yr^{-1}, respectively, during 1978–1981 (U85). Map III is consistent with their having moved at constant speed from 1978 to 1985, and with C4 moving from about 2.5 to 10 mas. This corresponds to a projected range of $4.5h^{-1}$ to $18h^{-1}$ pc.

In B85 we argued that the curvature was nonmonotonic, and this now is confirmed by maps II and III, which are more reliable than map I. It is of interest to ask if the motions are ballistic, or possibly along a fixed track. In the former case the flow is on radial lines, and any curved feature moves with the flow; we might expect this if the primary mechanism, for example, expelled plasma bullets into a radial magnetic field. If, however, there is a steady beam which is bent by a pressure gradient, or if the jet outlines a flow along a twisted magnetic field, then the track projected on the sky will be curved but stationary. To try to answer this question, we show the position angles of the components, relative to the core, in Figure 3. This is a version of Figure 2 in B85. The three points for C7b, C7a, and C5 are joined by dashed lines. The error bars are derived from the model-fitting, and if the model is unambiguous the error bars represent the accuracy of the location of a component. Component X in map III is ambiguous, and its point should be given low weight. At all epochs, there is ill-defined structure beyond C5 and the three outer points in Figure 3 show how the model accommodates this. It appears that between 1984.12 and 1984.93 C7b moved in PA and is roughly following the track of C7a. However, we note that this is based on one point, the first for C7b, and if that is discounted the ballistic model (constant PA) fits both C7a and C7b. More data are needed to see if C7a, C7b, and C8 move in PA to about $-120°$, to match the earlier location of the outer components. The outer components have a changing PA, but we could equally say that they are moving on a nonradial straight line. As shown by the arrow in Figure 1, this motion is a few degrees off that for the outer jet. We find it interesting that for $r < 1$ mas the PA of the jet ($-130°$ to $-140°$) is roughly the same as that of the outer jet ($-137°$) at 100 kpc, even though there is substantial bending and wiggling along the way.

IV. CONCLUSIONS

We have verified superluminal motion in components C5 and C7a; this makes a total of four distinct moving components which have been tracked in 3C 273. Motions have been monitored from about 2 to 8 mas (a projected range of $3.6h^{-1}$ to $14h^{-1}$ pc), and one component, C4, has perhaps kept its identity from $4.5h^{-1}$ to $18h^{-1}$ pc. The measured proper motions range from 0.76 to 1.20 mas yr^{-1}. C5 is significantly faster than the others, unless the 3 yr gap in the data (Fig. 2) is hiding a more complex situation.

3C 273 definitely has compound (nonmonotonic) curvature near the core. There is some evidence for nonballistic motion; i.e., that the blobs move along a fixed curve. However, this is based on one point, and confirmation is needed.

The present maps also reveal that the morphology of 3C 273 is somewhat different from that of 3C 345. In 3C 345 there are few superluminal components; and they are well separated, nearly circular, and define a projected opening angle of approximately 27° (Biretta *et al.* 1986). 3C 273 is more complex; the jet appears to be smoother, individual knots are less distinct, and they define a smaller projected opening angle, about 11°. These differences may be intrinsic, or due to orientation effects if 3C 273 lies farther from the line of sight than 3C 345 (Jones 1985). Placing 3C 273 far from the line of sight would also ease statistical problems discussed by Pearson *et al.* (1981).

This work was done under the auspices of the Global VLBI Network. We are grateful to the staffs of the observatories for their support, and to S. C. Unwin for help with the data analysis. Telescopes at Haystack, NRAO, Agassiz Station, OVRO, and Hat Creek are supported, in part, by the National Science Foundation. The work at Caltech was supported by NSF grant AST85-09822.

REFERENCES

Biretta, J. A., *et al.* 1985, *Ap. J.*, **292**, L5 (B85).
Biretta, J. A., Moore, R. L., and Cohen, M. H. 1986, *Ap. J.*, **308**, 93.
Jones, D. L. 1985, *A.J.*, **90**, 1446.
Pearson, T. J., Unwin, S. C., Cohen, M. H., Linfield, R. P., Readhead, A. C. S., Seielstad, G. A., Simon, R. S., and Walker, R. C. 1981, *Nature*, **290**, 365.
Schwab, F. R., and Cotton, W. D. 1983, *A.J.*, **88**, 688.
Unwin, S. C., Cohen, M. H., Biretta, J. A., Pearson, T. J., Seielstad, G. A., Walker, R. C., Simon, R. S., and Linfield, R. P. 1985, *Ap. J.*, **289**, 109 (U85).
Walker, R. C., Benson, J. M., Seielstad, G. A., and Unwin, S. C. 1984, in *VLBI and Compact Radio Sources*, ed. R. Fanti, K. I. Kellermann, and G. Setti (Dordrecht: Reidel), p. 121.
Zensus, J. A., Bååth, L. B., and Cohen, M. H. 1987, in preparation.

Z. Abraham and P. Kaufmann: Instituto de Pesquisas Espaciais, 12200—Sao Jose dos Campos, SP, Brazil

J. A. Biretta: Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

M. H. Cohen and J. A. Zensus: 105-24 Robinson Laboratory, Caltech, Pasadena, CA 91125

G. Comoretto: Istituto di Radioastronomia, Via Irnerio 46, I-40126 Bologna, Italy