THE ASTROPHYSICAL JOURNAL, 265:L43–L47, 1983 February 15

3C 395—A QUASAR WITH ASYMMETRICAL RADIO STRUCTURE

K. J. JOHNSTON AND J. H. SPENCER
E. O. Hulburt Center for Space Research, Naval Research Laboratory

A. WITZEL
Max-Planck-Institut für Radioastronomie

AND

E. B. FOMALONT
National Radio Astronomy Observatory, Charlottesville

Received 1981 May 22; accepted 1982 October 14

ABSTRACT

The milli-arcsec (mas) structure of the radio radiation at 5 GHz associated with 3C 395 has been resolved into two components of almost equal intensity of 0.8 Jy along a position angle of $+118°$ with a separation of 15.9 mas. The symmetry in the mas structure appears to be reversed from that in the large $\sim 1''$ structure because the component which has a resolved steep spectral index is located on the opposite side of the compact flat spectral index structure. The quasar 0836+714 was also mapped and consists of a dominant compact source with extended structure 3 mas away along P.A. $-142°$. The intensity ratio of the components is 3:1.

Subject headings: interferometry — quasars — radio sources: galaxies

I. INTRODUCTION

VLBI maps of compact extragalactic radio sources have been much improved by use of closure phase (Jennison 1958; Readhead and Wilkinson 1978). This has not only improved the dynamic range of maps made with amplitude data but also allows the unambiguous determination of component locations. Extragalactic sources morphologically seem to fit into two categories: one in which the compact emission is approximately symmetrically placed on either side of the optical nucleus, and a second group in which the radio emission is compact and coincides with the optical object. In the first group the radiation is usually spread over hundreds of kiloparsecs, while in the second group the radiation is usually found over less than a kiloparsec. The second group of sources (D2 quasars, Miley 1971) has been found to consist of an optically thick core with optically thin emission emanating from one side, as is the case of 3C 345 and 3C 273 (Readhead *et al.* 1978). In these two sources, this optically thin emission is seen in the arc second structure of these radio sources (Perley and Johnston 1979; Perley, Fomalont, and Johnston 1980). The alignment of this emission changes with scale size and is interpreted as a bending in the jet.

3C 147, which has a 9 mas (milli-arsecs) core and an asymmetric 200 mas jet (Readhead and Wilkinson 1978) along a position angle of $-127°$ from the compact core, has been found to have an additional extended ($0\farcs5$) component on the side of the core opposite the jet (Readhead, Napier, and Bignell 1980). We report here the discovery of a similar misalignment for 3C 395 (1901+319).

II. OBSERVATIONS

On 1979 December 6 a six station VLBI experiment at 5009 MHz was performed using the 100 m antenna of the Max-Planck-Institut für Radioastronomie at Effelsberg, Germany, the 37 m Haystack antenna, the 26 m antenna of Maryland Point Observatory, the 43 m antenna of the National Radio Astronomy Observatory,[1] the 26 m antenna of the Harvard Radio Astronomy Station, and the 40 m antenna of the Owens Valley Radio Observatory. Hydrogen maser frequency standards were used at all the observatories to generate the local oscillator frequencies. The antenna feeds were linearly polarized with the *E*-vector aligned east-west with the exception of the Haystack station where the antenna feed was right circularly polarized.

The Mark II VLB recording system (Clark 1973) with 2 MHz bandwidth was used. The data were correlated on the CIT/JPL processor. In the case of 0836+714, where the tapes from the 43 m antenna were erased, we processed in five station mode. For 3C 395, the data were processed in two passes of five station mode and finally one pass of two station mode.

[1]The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract to the National Science Foundation.

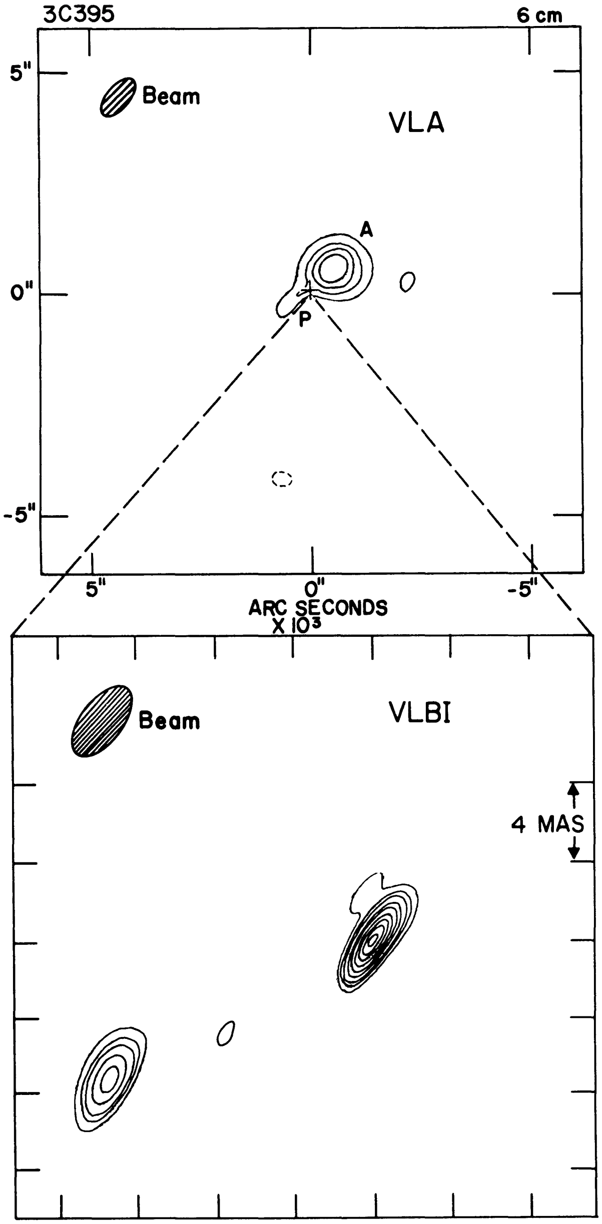

FIG. 1.—VLA and VLBI maps of 3C 395. The half-power width of the restoring beam is shown as a shaded ellipse. The contour levels for the VLA map are equal interval up to the peak brightness of 0.11 Jy per beam area. The contour interval is 0.02 Jy per beam. A 1.5 Jy point source has been removed from the center of the map. Map taper = 17.6 km. For the VLBI map, the contour levels are 10%, 15%, 25%, 35%, 50%, 65%, 80%, and 95% of the peak brightness which is 9.2×10^9 K. The coordinates are angular offsets from the radio core.

The data were calibrated using unresolved sources on the short baselines where possible and crossing points (in the case of 3C 395 only) in the (u, v)-plane to relate the different baselines. The accuracy of this calibration is estimated to be 10%.

The Cal Tech VLBI package was used to make the hybrid maps of the two sources. This procedure is described in detail by Readhead and Wilkinson (1978); and Readhead *et al.* (1979).

III. RESULTS

The map of 3C 395 is presented in Figure 1 along with the VLA map of Perley, Fomalont, and Johnston (1980). This clearly shows the mas scale structure of 3C 395 to consist of two components separated by 15.9 mas along a position angle of 118°. The two components are of almost equal flux density.

Inspection of the correlated fringe amplitude and closure phase (Fig. 2) shows component 1 to be a double. The best "model" fit to the VLBI data at 5009 MHz is given by the three-component model listed in Table 1 and denoted by 1a, 1b, and 2. Component 1a is unresolved. Component 1b is a resolved jetlike structure at a position angle aligned with component 2. This is based upon a model fit to the data shown in Figure 2 and is well below the resolution of the synthesized beam of 3×1 mas at a position angle of 30°. This result must be viewed as tentative.

We think Table 1 includes all the flux density for 3C 395. The total flux density at the time of the VLBI based on the antenna temperature from the 100 m Effelsberg antenna was 1.85 ± 0.09 Jy. The total flux density of the components in Table 1 is 1.90 Jy, well within the errors. The VLBI components 1 and 2 have a total flux density that is different from the 1.5 Jy measured with the VLA in the period 1978 October through 1979 June because of time variations. We do not expect component 3 to vary significantly in flux density between the two observations.

The map of 0836+714 is displayed in Figure 3 again along with the VLA map of Perley, Fomalont, and Johnston (1980). This map shows the small-scale structure to consist of a dominant compact source with extended structure approximately 3 mas away along a position angle of $-142°$. The ratio of flux density in the two major components is 3:1. The large scale VLA structure alignment is along a position angle of $-153°$ of flux density 0.05 Jy. The structure of this source is more complex than Figure 3 indicates. The total flux density accounted for in the VLBI map is 1.8 Jy while the total source flux density from the VLA and single antenna measurements indicate a total source flux density of 2.4 and 2.5 Jy respectively. This leaves a flux density of 0.6 Jy unaccounted for which we expect to be in intermediate-size structure in the range from 0.″01 to 0.″5 that probably connects the VLBI extended structure to the VLA extended structure.

IV. DISCUSSION

In 3C 395 the secondary resolved component, 2, appears to be slightly resolved having a size ~ 2.9×1.2

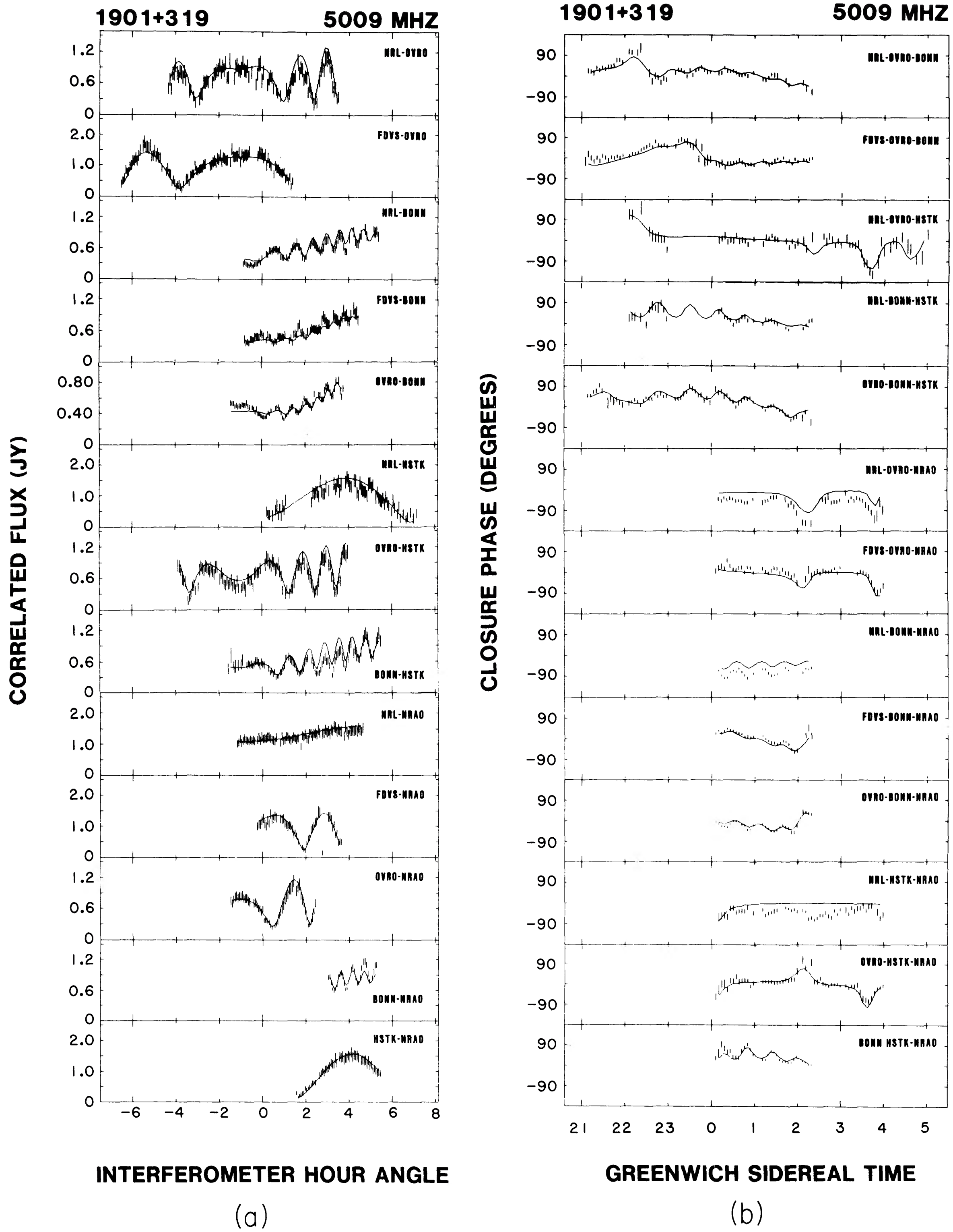

FIG. 2.—(*a*) Fringe amplitude versus interferometer hour angle for 3C 395. (*b*) Phase closure versus Greenwich sideral time. Error bars represent standard errors of the mean for 240 s averages and also, in the case of the fringe amplitude, errors in the flux density scale. The smooth line through the data is the fit to the data of the model in Table 1.

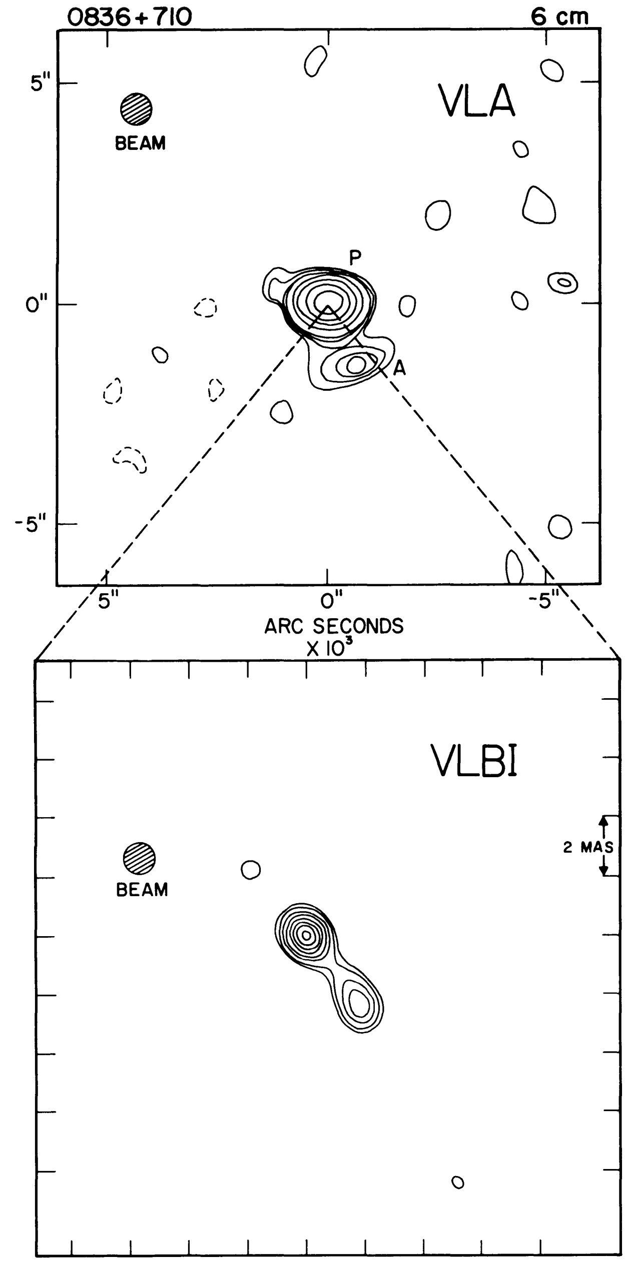

FIG. 3.—VLA and VLBI maps of 0836+714. The contour levels for the VLA maps are equal intervals up to the peak brightness of 2.33 Jy per beam. Contour interval 0.2%. The VLBI map has contour intervals of 10%, 15%, 25%, 35%, 50%, 65%, 80%, and 95% of the peak brightness which is 2.5×10^{10} K. The coordinates are angular offsets from the radio core.

mas along P.A. 153° based on the visibilities and long baseline closure phase. We believe that the compact object, component 1, probably coincides with the center of optical emission. This places the mas scale structure on the opposite side of the compact component from the large-scale VLA structure denoted by A in Figure 1. The position angle of this large-scale structure is $\sim -47°$ and is $\sim 1''$ in size and of flux density 0.32 Jy. These three components making up 3C 395 appear to lie along a straight line with a compact source similar to the central component of many radio galaxies.

Further reinforcement of these ideas is given by the high-resolution 1671 MHz map of 3C 395 by Phillips and Mutel (1980) made on 1978 May 24–25. Their map shows two components of flux density 1.5 and 1.0 Jy separated by 15.6 mas. The strong source is located southwest of the weaker source. If the components in the 1671 and 5009 MHz maps are the same objects, the spectral index ($S \propto \nu^{+\alpha}$) of component 1 is -0.2, while that for the secondary component 2 is -0.6. These spectral indices are typical for compact D2 quasars, in which the central compact component has a spectral index close to 0.0, while the optically thin, extended emission has a spectral index of -0.5 to -1.0. These spectral indices are questionable since, at 5 GHz, 3C 395 increased in flux density by 0.4 Jy in the time interval between the 1671 and 5009 MHz maps.

The optical counterpart of 3C 395 identified by Véron, Véron, and Witzel (1974) has a redshift of $z = 0.635$ (Wills and Wills 1979). The separation of the two major components is 142 pc using $H_0 = 50$ km s^{-1} and $q_0 = 0.05$. As pointed out by Phillips and Mutel (1980), it may be possible to measure the velocity of separation of the two major components. The measurement of the separation of these two components at 1667 MHz by Phillips and Mutel (1980) of 15.6 ± 0.2 mas (139 pc) made in 1978 May 24–25, and the separation of these two components listed in Table 1 would indicate a velocity of separation equal to $6c$. However, this must be looked upon as very tentative, as it is within the errors of the measured positions, and the shapes of the components are probably not similar at the frequencies of 1667 and 5009 MHz.

The sample of sources thus far mapped by VLB is small. As of 1981 August, 49 sources have had their mas structure mapped. One-third of these sources are unresolved, while more than two-fifths have a core-jet morphology (Readhead and Pearson 1982). However, since the sources mapped thus far are among the most luminous quasars and radio galaxies, and the dynamic range of the maps is usually less than 20:1, a large sample of extragalactic sources with improved dynamic range has to be measured to determine the typical spatial structure of the radio emission.

For sources in which the extended emission lies on the same side as the radio jet such as 3C 273, 3C 345, and 3C 454.3 (Davis, Stannard, and Conway 1978), which are all D2 type quasars, 0836+714 is typical. For those sources which have extended large-scale emission on the side opposite the radio jet, we have 3C 395, 3C 147, and 3C 454.3 (Cotton, Geldzahler, and Shapiro 1982).

TABLE 1

COMPONENT MODEL FOR 3C 395

Component	Flux Density (Jy)	Position		Size	
		Distance (mas)	P.A. (deg.)	θ (mas)	P.A. (deg.)
1a	0.46	0.0	...	< 0.1	...
1b	0.41	0.83	127	1.3×0.1	118
2	0.74	15.9	118	2.6×1.4	157
3	0.32	~ 1000	−47	1000×1000	...
Σ	1.93				

V. CONCLUSION

3C 395 at 5 GHz in 1979 December has been shown to consist of two components of almost equal intensity of 0.8 Jy separated by 15.9 mas along a position angle of 118°. The symmetry in the mas structure appears to be reversed from that of the large ~ 1″ structure because the resolved component which has a steep spectral index is located on the opposite side of the compact flat spectral index structure. The quasar 0836+714 was found to consist of a dominant compact source separated 3 mas along a P.A. of −142° from a resolved component. The intensity ratio of the components is 3:1.

REFERENCES

Clark, B. G. 1973, *Proc. IEEE*, **61**, 1242.

Cotton, W., Geldzahler, B., and Shapiro, I. 1982 in *IAU Symposium 97, Extragalactic Radio Sources*, ed. D. S. Heeschen and C. M. Wade (Dordrecht: Reidel), p. 301.

Davis, R. J., Stannard, D., and Conway, R G. 1978, *M.N.R.A.S.*, **185**, 435.

Jennison, R. C. 1958, *M.N.R.A.S.*, **118**, 276.

Miley, G. K. 1971, *M.N.R.A.S.*, **152**, 477.

Perley, R. A., Fomalont, E. B., and Johnston, K. J. 1980, *A.J.*, **85**, 649.

Perley, R. A., and Johnston, K. J. 1979, *A.J.*, **84**, 1247.

Phillips, R. B., and Mutel, R. L. 1980, *Ap. J.*, **236**, 89.

Readhead, A. C. S., Cohen, M. H., Pearson, T. J., and Wilkinson, P. N. 1978, *Nature*, **276**, 768.

Readhead, A. C. S., Napier, P. J., and Bignell, R. C. 1980, *Ap. J.* (*Letters*), **237**, L55.

Readhead, A. C. S., and Pearson, T. J. 1982, in *IAU Symposium 97, Extragalactic Radio Sources*, ed. D. S. Heeschen and C. M. Wade (Dordrecht: Reidel), p. 297.

Readhead, A. C. S., Pearson, T. J., Cohen, M. H., Ewing, M. S., and Moffet, A. T. 1979, *Ap. J.*, **231**, 299.

Readhead, A. C. S., and Wilkinson, P. N. 1978, *Ap. J.*, **223**, 25.

Véron, M. P., Véron, P., and Witzel, A. 1974, *Astr. Ap. Suppl.*, **13**, 1.

Wills, B. J., and Wills, D. 1979, cited in Phillips, R. B., and Mutel, R. L. 1980, *Ap. J.*, **236**, 89.

E. G. FOMALONT: National Radio Astronomy Observatory, Post Office Box O, 1000 Bullock Boulevard, N. W., Socorro, NM 87801

K. J. JOHNSTON and J. H. SPENCER: Code 4130, Naval Research Laboratory, Washington, D.C. 20375

A. WITZEL: Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53 Bonn, West Germany