THE ASTROPHYSICAL JOURNAL, **179**:L141–L144, 1973 February 1

ABSENCE OF VARIATIONS IN THE NUCLEUS OF VIRGO A

K. I. KELLERMANN AND B. G. CLARK
National Radio Astronomy Observatory*

M. H. COHEN† AND D. B. SHAFFER
Owens Valley Radio Observatory,
California Institute of Technology, Pasadena, California

AND

J. J. BRODERICK AND D. L. JAUNCEY‡
National Astronomy and Ionosphere Center,
Cornell University, Ithaca, New York
Received 1972 November 24

ABSTRACT

Repeated observations of M87 at 3.8 cm, between 1971 February and 1972 August, show no change in intensity or size of the compact radio nucleus.

Subject headings: galaxies, individual—galactic nuclei — radio sources

In a previous paper (Cohen *et al.* 1971) we have described high-resolution observations made at 7840 MHz (3.8 cm) of the compact radio source in the nucleus of Virgo A (M87). These observations were made with the "Goldstack" interferometer (the 64-m telescope at Goldstone, California, and the 37-m Haystack telescope near Tyngsboro, Massachusetts) in 1971 February. The baseline was $100 \times 10^6\ \lambda$.

Observations made at 5 GHz (Graham 1971) with a resolution of 6″ have indicated significant changes in the intensity of the nuclear region of M87. In an attempt to detect directly any possible changes in the size as well as the intensity, we have made further very high resolution observations during 1972 using the same baseline and the NRAO Mark II VLB recording system described by Clark (1973). The frequency of the new observations was 7850 MHz, or nearly the same as used earlier. The interferometer data were integrated coherently for either 15 seconds or 1 minute, and the resultant fringe amplitudes were incoherently averaged for about 5 minutes. These raw fringe amplitudes were then corrected for variations in system temperature and gain at the two telescopes and also for the effects of moisture on the Haystack radome. The scale of flux density was established by reference to the unresolved sources OJ 287 and OR 103. These sources could not be observed each time; therefore, unfortunately, the calibration procedure was somewhat different for each run, resulting in a rather large uncertainty of about 15 percent in comparing the results between different periods. The relative error for points within one run is much smaller, about 5 percent.

The dependence of fringe amplitude with interferometer hour angle for Virgo A is shown in figure 1 for the data of 1971 February and for the new data for 1972 April, June, and August. The track in the (u, v)-plane for these observations is shown in figure 2.

It is clear that during the 18-month period covered by the observations there has

---

* Operated by Associated Universities, Inc., under contract with the National Science Foundation.
† Supported by NSF grant GP 19400 and ONR contract N00014-67-A-0094-0019.
‡ Supported by NSF grant GP 28942. The National Astronomy and Ionosphere Center is operated by Cornell University under contract to the NSF.

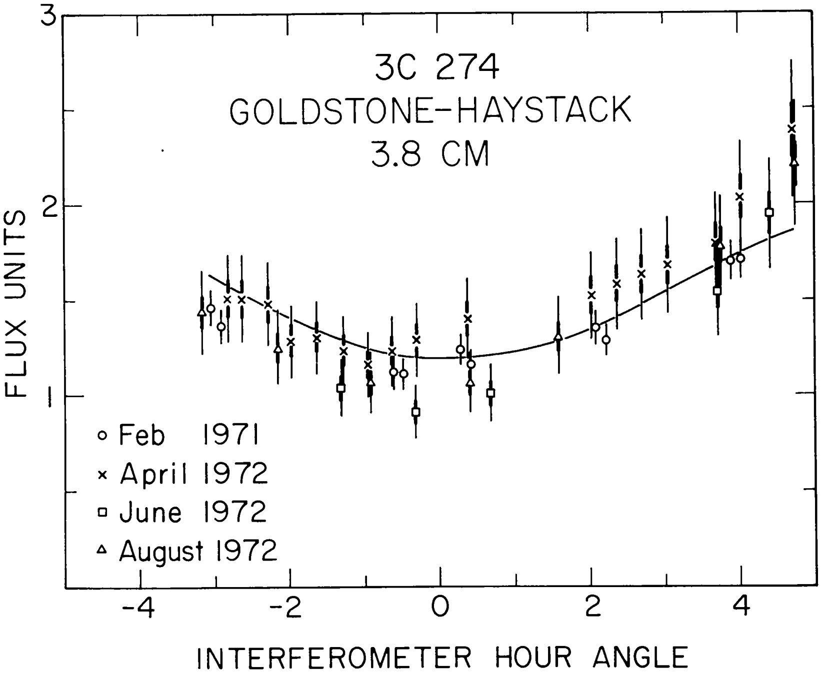

FIG. 1.—Fringe amplitudes with Goldstack interferometer. Heavy central portions of error bars represent errors internal to one run; overall error bars include an allowance for systematic scaling errors between runs.

been no significant change in the shape or amplitude of the visibility function. The data at all epochs can be fit by a single model with angular diameter about 0″.0013 (4 light-months) and strength between 2 and 2.5 f.u. Any change in intensity during this period is less than 0.3 f.u. and in size less than 0″.0002 (20 light-days). Thus it is very unlikely that this source has any systematic expansion with rate greater than 10,000 km s^{-1}. This stability is in marked contrast to the rapid changes observed for the quasars 3C 273 and 3C 279 (Whitney *et al.* 1971; Cohen *et al.* 1971), the radio galaxy 3C 120 (Shaffer *et al.* 1972), and the peculiar rapid variable object BL Lac (Clark *et al.* 1973).

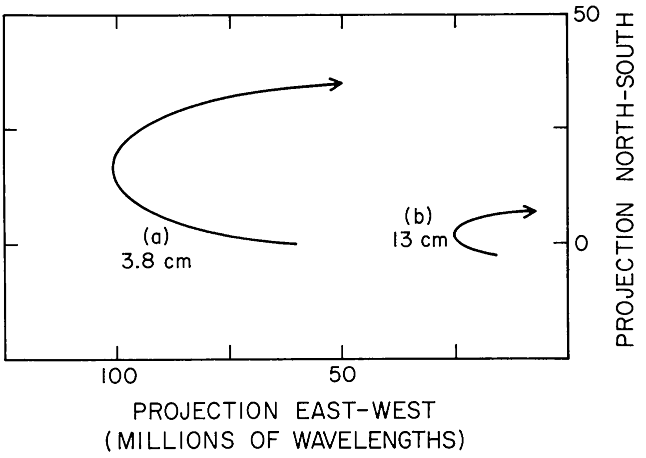

FIG. 2.—(u, v) tracks for the data shown in (a) fig. 1, and (b) fig. 3. Hour angle increases in the direction of the arrow.

In most of the other compact sources for which we have data at more than one epoch, the visibility functions show pronounced changes, even over time scales as short as a few months. It is somewhat surprising, therefore, that in this, the smallest known extragalactic radio source, there appears to be no significant change in the size or intensity.

It is not clear whether our observations are consistent with those of Graham (1971) which show an apparent change of about 0.9 f.u. at 5 GHz, between 1969 March and 1971 March. We are observing at very different angular scales, and furthermore there is no direct overlap in time between the two sets of observations. It seems peculiar that the smallest radio component in the nucleus is stable whereas a (possibly) larger component is variable.

The expected visibility curve for a uniform circular source of 2.0 f.u. with a diameter of 0″.0013 is shown as the solid line in figure 1. The measured data are systematically different from this curve, so that the source does not have circular symmetry. The fringe visibility is high at IHA $\geqslant +2$ and low at IHA $\leqslant -2$ so that the visibility function has a gradient toward the northwest (see fig. 2). This means that the source is elongated roughly along a northwest-southeast line. This is not inconsistent with this component being aligned along the jet, at P.A. $\approx 290°$.

We have also observed the nucleus of M87 at 13 cm over a range of baselines smaller by a factor of 4 than those covered at 3.8 cm. The data from observations on a Green Bank–Goldstone baseline (25×10^6 λ) for the epoch 1970 November (Broderick *et al.* 1972) and more recent data on the same baseline taken in 1971 August are shown in figure 3. The data for the two epochs agree well except for a difference of 0.1 f.u., which is well within our calibration uncertainty of ±0.3 f.u. The data in figure 3 suggest an unresolved source of about 1 f.u. which we associate with the 0″.0013 component seen at 3.8 cm, plus a larger component of the order of 0″.01 and containing about 2 f.u. Both of these components are seen by Donaldson, Miley, and Palmer (1971) as an unresolved source of 3.5 f.u. and less than 0″.03 at 11 cm. They have remained essentially constant between 1970 November and 1971 August. In addition Donaldson *et al.* (1971) see a larger component, with length about 0″.3 and position angle near that of the jet. This component contains about 1 f.u. at 11 cm and 2.5 f.u. at 21 cm.

Our data show that the smaller component is stronger at 3.8 than at 13 cm, and this suggests that it is still opaque at wavelengths shorter than 13 cm. If the self-absorption cutoff frequency is near 5 GHz, the corresponding peak brightness temperature is about 5×10^{10} ° K or comparable with that of other compact radio sources. Assuming that the cutoff frequency is uncertain by a factor of 2, we may readily

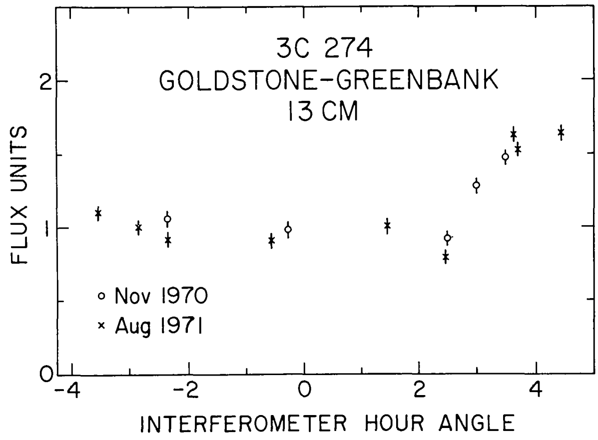

FIG. 3.—Fringe amplitudes at 13 cm.

compute the magnetic field strength B, the total magnetic energy E_m, and the total relativistic electron energy E_e as

$$B \sim 3 \times 10^{-2\pm1.5}\ \text{gauss}, \qquad E_m \sim 10^{48\pm3}\ \text{ergs}, \qquad E_e \sim 10^{50\pm3}\ \text{ergs}.$$

The magnetic field will be reduced and the particle and field energies increased and decreased respectively if our measured angular size of 0″.0013 refers to the separation of two or more smaller components rather than to the size of any individual one.

We wish to acknowledge the extensive assistance during these observations of G. Grove, G. Purcell, A. Rogers, L. Skjerve, and D. Spitmesser.

REFERENCES

Broderick, J. J., Kellermann, K. I., Shaffer, D., and Jauncey, D. 1972, *Ap. J.*, **172,** 299.

Clark, B., 1973, *Proc. I.E.E.E.*, in preparation.

Cohen, M. H., Cannon, W., Purcell, G. H., Shaffer, D. B., Broderick, J. J., Kellermann, K. I., and Jauncey, D. L. 1971, *Ap. J.*, **170,** 207.

Cohen, M. H., Moffet, A. T., Shaffer, D. B., Clark, B. G. Kellermann, K. I., Jauncey, D. L., and Gulkis, S. 1969, *Ap. J.*, **158,** L83.

Donaldson, W., Miley, G. K., and Palmer, H. P. 1971, *M.N.R.A.S.*, **152,** 145.

Graham, I. 1971, *Nature*, **231,** 253.

Shaffer, D. B., Cohen, M. H., Jauncey, D. L., Kellermann, K. I. 1972, *Ap. J.* (*Letters*), **173,** L147.

Whitney, A. R., Shapiro, I. I., Rogers, A. E. E., Robertson, D. S., Knight, C. A., Clark, T. A., Goldstein, R. M., Marandino, G. E., and Bandenberg, N. R. 1971, *Science*, **173,** 225.