THE ASTROPHYSICAL JOURNAL, 198:L123–L124, 1975 June 15

HIGH-RESOLUTION OBSERVATIONS OF THE RADIO EMISSION FROM BETA PERSEI

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

AND

D. SHAFFER
Yale University Observatory
Received 1975 February 7; revised 1975 March 12

ABSTRACT

The angular size of the radio emission from β Persei (Algol) was measured during a flare and found to be about 4 milli-arcsec equivalent Gaussian diameter, corresponding to linear dimensions of 0.1 AU and mean brightness temperature 4×10^8 K. The observed change in the interferometer fringe visibility in a few hours corresponds to a mean apparent expansion velocity of 500–1000 km s^{-1}, or to a stationary, slightly elliptical source.

Subject headings: binaries — interferometry — radio sources, variable — stars, individual

We have measured the dimensions of the radio emission from β Persei (Algol) during a flare on 1974 May 4/5, using a tape recording interferometer with a spacing of 20 million wavelengths. The observations were made using the NRAO 140-foot (43 m) antenna and Haystack[1] 120-foot (37 m) antenna as elements of the interferometer. The observations were made at 7850 MHz (3.8 cm) using the NRAO Mk II data recording and processing system.

The observations began at 1445 UT on May 4 when the flux density of β Per was 0.6 Jy. As shown in Figure 1*a*, the flux density, as measured with the 140-foot telescope, decreased until the source reached the hour angle limit of the telescope at 0030 UT, May 5. Figure 1*a* shows the observed interferometer fringe amplitude as a function of time.

The absolute scale for the total flux density is based on observations of several nonvariable sources (3C 231 and 3C 71) whose spectra are well determined (Kellermann, Pauliny-Toth, and Williams 1968), while the variation of antenna gain with hour angle was determined by frequent reference to 3C 84 which is located only several degrees away from β Per. The scale of interferometer fringe amplitude was determined from measurements of the total system temperature and the antenna temperature of β Per at each telescope, using the known sensitivity of the record playback system (e.g., Cohen *et al.* 1975).

On our scale of flux density the fringe visibility of OJ 287 is close to unity, consistent with other measurements of this source at comparable wavelengths and resolutions (Wittels *et al.* 1975; Cohen *et al.* 1971).

When the interferometer observations began just before 1500 UT, the observed fringe visibility was $\gamma \sim 0.7$. As shown in Figure 1, this decreased within a few hours and then appeared to remain constant near $\gamma \sim 0.5$.

This variation of fringe visibility may be due to an expansion of the source during the observing period, or to the rotation of the interferometer baseline with respect to an elongated source as the Earth rotates, or to a combination of such effects.

Assuming a constant size, the best fitting elliptical Gaussian and elliptical disk models have dimensions 3.6×4.6 (FWHM) and 5.5 by 7.2 milli-arcsec, respectively, which are oriented roughly in the north–south direction. The corresponding linear dimensions are 0.09 by 0.11 and 0.14 by 0.18 AU, respectively.[2] The

* Operated by Associated Universities, Inc., under contract with the National Science Foundation.

[1] Radio Astronomy programs at the Haystack Observatory are conducted with support from the National Science Foundation grant GP-25865.

[2] Distance = 25 pc.

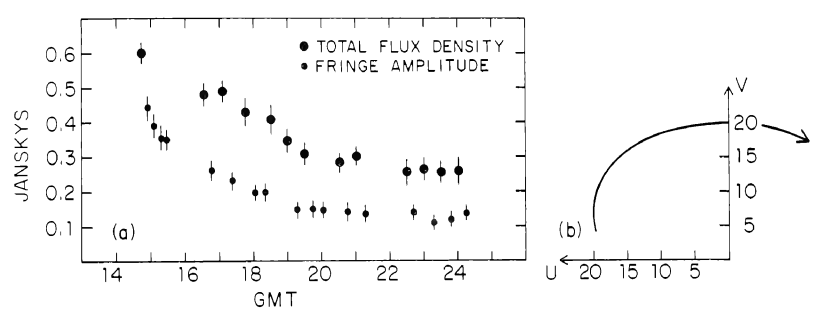

FIG. 1.—(*a*) Large dots show the flux density of Algol as measured on the 140-ft telescope as a function of time. The small dots show the observed interferometer fringe amplitude. (*b*) The track in the (u, v) plane covered by the data, where u and v are in millions of wavelengths.

mean surface brightness near the start of the measurement was 4×10^8 K (uniform disk model).

The measured dimensions of the Algol radio source are considerably greater than the diameters of the stars comprising the binary system (~0.03 AU), but are comparable with their separation (0.2 AU).

If the brightness distribution is assumed to be circular, and the variation of fringe visibility with time is interpreted as an expansion, then the corresponding expansion velocity is 500–1000 km s^{-1} depending on whether a Gaussian or uniform disk distribution is assumed. This may be compared with the escape velocity at the stellar surface of about 600 km s^{-1} (Jones and Wolfe 1973) which may be a typical velocity for material motions.

Although the data do not distinguish uniquely between an expanding circular source and an elongated stationary one, the former interpretation appears more probable since (*a*) it seems unlikely that the flux density would vary by more than a factor of 2 without some change in size, and (*b*) the change in fringe visibility occurred only during the period where the total flux density was changing most rapidly.

Simultaneous observations made between 18 hours and 22 hours UT on the NRAO three-element interferometer at 2695 MHz (11.1 cm) and 8085 MHz (3.7 cm) show that Algol was considerably weaker at the longer wavelength and had a spectral index of about +0.7. Thus, at the time of these observations, the radio source was apparently partially opaque.

If the radiation is due to thermal bremsstrahlung, as proposed by Hjellming (1972), then the electron temperature $T_e \approx 10^9$ K, the emission measure is $\sim 10^{15}$ cm^{-6} pc, and the electron density $n_e \approx 10^{11}$ cm^{-3}. The spectrum must be roughly flat from the frequency of unit optical depth (~5 GHz) to the frequency of the Planck function peak for this temperature, 10^{20} Hz (about 400 keV). At the time of the 2U survey (Giacconi *et al.* 1972), the hard X-ray emission was at least 100 times below this extrapolated spectrum. X-ray observations made in 1972 February, during the time of several weak radio flares, were also lower by one to four orders of magnitude than the expected X-ray emission corresponding to thermal bremsstrahlung radio emission (Canizares *et al.* 1973).

On the other hand, the comparatively large size of the source seems also to rule out the model of Jones and Woolf (1973), in which the radiation is generated in the stellar atmosphere a few thousand kilometers above the photosphere. A plasma radiation model requires an emitting region of substantial density a few times larger than the star. The line emission spectrum of such a region should be prominent unless its temperature is very high, 10^6 K or more.

On at least one previous occasion (1972 January 22/23) the observed radio spectrum required a nonthermal process (Hjellming, Wade, and Webster 1972). If the radio emission is due to synchrotron radiation, then the positive spectral index suggests that the source is self-absorbed below 5 GHz. The relatively low brightness temperature then corresponds to a magnetic field strength of about 10 gauss. The relativistic particles are only mildly relativistic, and the radio emission would be in low-order harmonics of the gyrofrequency rather than classical synchrotron radiation.

It is also possible that the observed radio emission is synchrotron radiation with the low-frequency spectrum modified by the Razin-Tsytovitch effect. For values of B in the range 10^{-4} to 1 gauss, the necessary thermal electron density is only 0.025 to 250 cm^{-3}, respectively.

REFERENCES

Canizares, C. R., Neighbours, J. E., Clark, G. W., Lewin, W. H. G., Schnopper, H. W., and Sprott, G. F. 1973, *Ap. J.* (*Letters*), **183**, L95.
Cohen, M., Cannon, W., Purcell, G., Shaffer, D., Broderick, J., Kellermann, K., and Jauncey, D. 1971, *Ap. J.*, **170**, 207.
Cohen, M. H., Moffet, A. T., Romney, J. D., Schilizzi, R. T., Shaffer, D. B., Kellermann, K. I., Purcell, G. H., Grove, G., Swenson, G. W., Yen, J. L., Pauliny-Toth, I. I. K., Preuss, E., Witzel, A., and Graham, D. 1975, *Ap. J.*, **196**, 179.
Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., and Tananbaum, H. 1972, *Ap. J.*, **178**, 281.
Hjellming, R. 1972, *Nature Phys. Sci.*, **238**, 52.
Hjellming, R. M., Wade, C. M., and Webster, E. 1972, *Nature Phys. Sci.*, **236**, 43.
Jones, T. W., and Wolfe, N. J. 1973, *Ap. J.*, **179**, 869.
Kellermann, K. I., Pauliny-Toth, I. I. K., and Williams, P. J. 1969, *Ap. J.*, **157**, 1.
Wittels, J. J., Knight, C. A., Shapiro, I. I., Hinteregger, H. F., Rogers, A. E. E., Whitney, A. R., Clark, T. A., Hutton, L. K., Marandino, G. E., Ronnang, B. O., Rydbeck, O. E. H., Klemperer, W. K., and Warnock, W. W. 1975, *Ap. J.*, **196**, 13.

B. G. Clark and K. I. Kellermann: National Radio Astronomy Observatory, P.O. Box 2, Green Bank, WV 24944

D. Shaffer: Department of Astronomy, Yale University Observatory, New Haven CT 06520.