MEASUREMENTS OF THE SIZE AND MOTION OF THE IRREGULARITIES IN THE INTERPLANETARY MEDIUM

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IT is known that radio sources having a sufficiently small angular diameter exhibit scintillation phenomena which are caused by irregularities of electron density in the interplanetary medium. Investigations of the spatial and temporal variations of the diffraction pattern across the surface of the Earth should therefore yield valuable data concerning the structure and motion of irregularities within the interplanetary medium over a wide range of distance from the Sun. To gain a reasonably complete picture of the diffraction pattern at least three suitably disposed observing sites are needed. In this note we describe some preliminary observations using only two sites which were carried out on the radio source 3C 48 at a wavelength of 3·7 metres during the period February-July 1965.

The two sites were separated by a distance of 53 km in a north-easterly direction. At the local site (the Mullard Radio Astronomy Observatory) the aerial system was a 90° corner reflector of length 720 ft. in an east-west direction. The aerial system at the distant site (Elveden, near Thetford) had similar dimensions and comprised two dipole arrays above a narrow reflecting screen; this array was slightly off-set from an east-west line so that the source would be in transit simultaneously at both sites. Phase-switching receivers were used and in each case the two halves of the aerial were combined as a simple interferometer. Recorder signals from the distant site were returned by way of a G.P.O. telephone line so that the fluctuations at both sites could be displayed on a single twin-track recorder having a time constant of 0·25 s; the receiver time constant was 0·2 s in each case. A typical record showing a complete transit of the radio source at one site is shown in Fig. 1*a*. Fig. 1*b* shows a recording made of the fluctuations at both sites at a higher chart speed; the scintillations are highly correlated and a delay of about 0·2 s, in the sense Elveden-early, is apparent. The relative positions of the Sun and 3*C* 48 during the observations are depicted in Fig. 2*a*. Observations at the distant site were not commenced until the latter half of April and measurements of drift motion were therefore only possible as 3*C* 48 receded from the Sun.

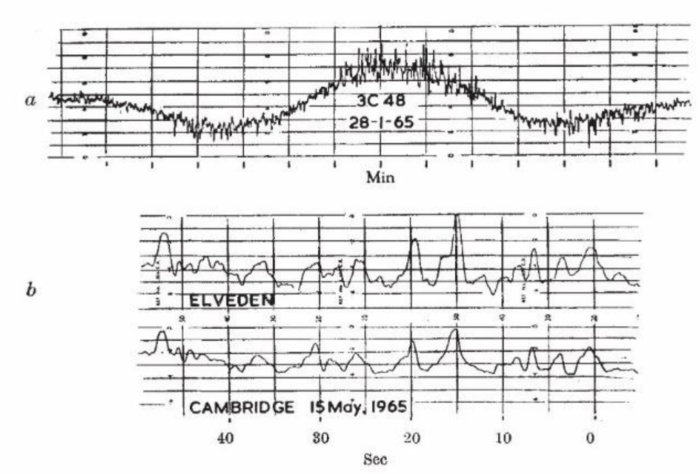

Fig. 1. *a*, A record of a transit of the radio source 3*C* 48 showing moderate interplanetary scintillation. *b*, Simultaneous recordings of intensity fluctuations at two sites using a chart speed of 12 in. per min. There is a time delay of 0·2 s in the sense Elveden-early.

The occurrence of interplanetary scintillation during the observing period is shown in Fig. 2*b*. We define a scintillation index *F* given by

$$F^2 = \frac{\langle (I - \bar{I})^2 \rangle}{\bar{I}^2}$$

where *I* is the intensity of the incident field. Corresponding values of the scintillation rate, the number of maxima per min on the fluctuation record, are shown in Fig. 2*c*. It is seen that the scintillation index varies considerably from day to day while increasing systematically as the radio source approaches the Sun. The scintillation rate, on the other hand, is remarkably constant apart from a tendency to decrease with increasing distance from the Sun. There seems to be no detailed correlation between these parameters and the occurrence of solar activity or geophysical phenomena, although the large increase of *F* around May 20 coincided with a notable increase of sunspot number.

A value for the scale of the diffraction pattern in a direction parallel to the line joining the two sites was derived from a cross-correlation analysis of the two recordings. The records (*f* and *g*) were sampled at 0·3 s intervals and the coefficient:

$$\rho(\xi) = \frac{\langle (f - \bar{f})\,(g - \bar{g}) \rangle}{\sqrt{\langle (f - \bar{f})^2 \rangle \langle (g - \bar{g})^2 \rangle}}$$

was computed, where ξ corresponds to the separation of the sites. Each value was corrected for the effects of noise, which must

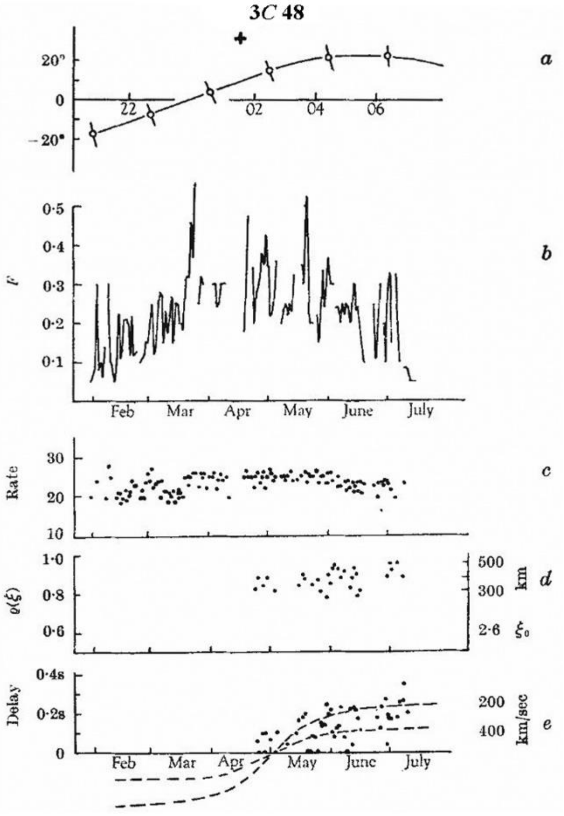

Fig.2. a, The relative positions of 3*C* 48 and the Sun during the period of observation. *b. c* and *d*, Measurements of the scintillation index *F*, the rate of fluctuation (maxima per min) and *e*, The observed delays compared with values predicted by simple models of radial outflow (dotted curves)

always decrease the correlation. The analysis was confined to portions of the records in the vicinity of the centre of the reception pattern and the values derived are shown in Fig. 2*d*. On the supposition that $\rho(\xi)$ is of the form $\exp-(\xi^2)/(\xi_0^2)$ we obtain $\xi_0 = 143 \pm 25$ km as an average for all the data. It may be seen from Fig. 2*d* that there is a tendency for $\rho(\xi)$ to increase with increasing angular separation of 3*C* 48 from the Sun, but the variation is slight. The separation of maxima in a random diffraction pattern of this form is given by 2.6 (ξ_0) (ref. 3), which yields a value 370 ± 60 km; this value is in general agreement with a previous estimate of 270 km derived from independent observations of the angular spectrum of radiation scattered by irregularities at lower heliographic latitudes.[1]

It is interesting to note that the scale of the diffraction pattern appears to be the same at wavelengths of 3·7 m and 1·7 m. This follows from the observed rate of fluctuation which, at 3·7 m, is of the same order as that obtained previously when 3*C* 48 was observed at a wavelength of 1·7 m (ref. 1). This point has been further investigated by L.T. Little (personal communication), who has found that simultaneous recordings of 3*C* 48 at wavelengths of 1·7 m and 3·7 m exhibit fluctuations with a considerable degree of correlation.

These results lead to the important conclusion that, for radial distances exceeding 0·5 A.U. and at wavelengths smaller than 3·7 m, the interplanetary irregularities constitute a weak scattering medium. That is, the total phase deviation introduced along a line of sight through the interplanetary medium is less than 1 radian. For this case it is well-known that the scale of the diffraction pattern is the same as that of the irregularities themselves. It follows that the auto-correlation function of the variations of electron density in the interplanetary medium is characterized by a scale $\xi_0 \approx 143$ km as already derived above.

This remarkably small scale is considerably less than a previous upper limit of 5,000 km derived from measurements of radio scattering at distances closer to the Sun.[4] An estimate of the mean electron density along a line of sight may now be made by combining the known scale of the irregularities with the total phase deviation as deduced from the scintillation index, *F*. For the case when the mean square phase deviation ρ_0^2 is less than 1 radian. Mercier[5] has shown that $F^2 \approx 2\,\rho_0^2$. Taking $F \approx 0.3$ as a mean value for the closest approach of 3*C* 48 to the Sun we calculate a root-mean-square phase deviation of about 0·2 radians. Adopting a simple model in which it is assumed that the irregularities are distributed contiguously over a distance of 0·5 A.U. a typical line of sight will pass through approximately 2 x 10^5 irregularities. A mean density of ≈ 0·4 electrons cm^3 is then required to account for the observed phase deviation.

The drift motion of the diffraction pattern was studied from an analysis of the time delays, a typical example of which is exhibited in Fig. 1*b*. A chart speed of 36 in. per min. was used, and a simple analysis procedure was adopted in which the recordings were superposed and adjusted to give the highest correspondence. A significant delay was usually apparent although the error of a single measurement was ± 0·1 sec. The values obtained are plotted in Fig. 2*e*. Significant delays always occurred in the sense Elveden-early, indicating a drift motion from east to west which corresponds to an outward movement of irregularities from the Sun. The delays were of greatest magnitude when 3*C* 48 was farthest from the Sun.

It is not possible to derive the true velocity of the diffraction pattern across the ground from delays measured at two points unless particular assumptions are made concerning the direction of motion and the spatial isotropy of the pattern. These preliminary measurements have therefore been compared with a model in which it was assumed that isotropic irregularities streamed radially from the Sun at constant velocity. The expected delays are shown in Fig. 2*a*, where it was assumed that the diffraction pattern was dominated by the region of greatest scattering which is located where the line of sight is closest to the Sun. It is seen that the observed increase of delay during the period April-July is consistent with such a model. The points show a considerable scatter, however, and correspond to a mean radial velocity in the range 200-400 km/sec. This value is somewhat lower than previous estimates of the solar wind carried out over an extended period in 1962 by *Mariner* 2 (ref. 6). It is possible that this implies a decrease in the solar wind towards sunspot minimum but further measurements at three sites are needed to establish unambiguously the true wind velocity.

Previous estimates of drift motion derived from the observed rate of fluctuation also gave values which were lower than space-probe measurements of the solar wind[1]. It was suggested that this might be accounted for by a system of filamentary irregularities confined by a co-rotating magnetic field. This model would, however, lead to drift velocities which increase with radial distance and the present observations do not support this suggestion.

This work was undertaken as part of a programme financed by the Science Research Council. One of us (P.A.D.) thanks the Science Research Council for a maintenance grant. We also thank Viscount Elveden for his co-operation in providing an outstation site, and Miss J.A. Bailey for assistance with the computations.

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