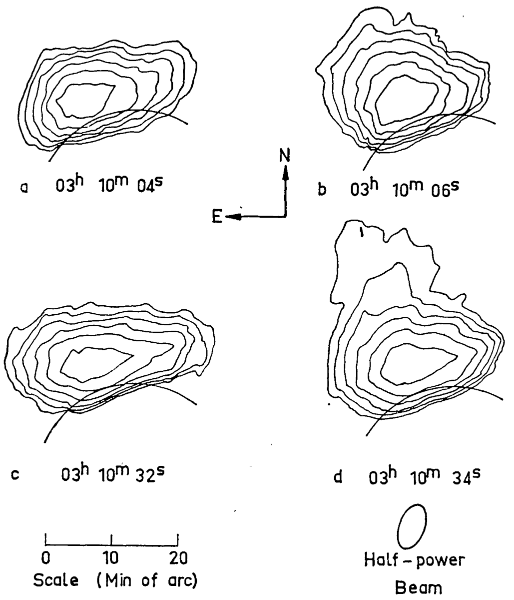

Figure 3. Two pairs of sets of contours showing the sudden appearance of a diffuse halo above the source region. This figure and the previous one were produced by computer direct from the digital magnetic tape recorded by the radioheliograph. Maximum beam temperatures in units of 10^7 °K are: (a) 4.5, (b) 4.5, (c) 4.9, (d) 6.4.

theoretical problems raised by a large source of type II emission (which is supposed to originate from a thin region close to the critical plasma level) have already been pointed out by Wild, Sheridan and Kai.[1]

A close examination of the heliograms b, c and d, and possibly e, suggests that although the position of the type II source, as determined by the weaker contours, remained approximately constant, the region of maximum brightness appeared to be moving outwards with a projected velocity of 500-1000 km/s. Although this result still needs confirmation by a careful study of more of the records it raises some interesting questions. Does the type II source move physically as a whole (in which case the emission could not all be from plasma oscillations), or is the bright maximum the region of intersection of a type II-producing shock-wave with the 80 MHz or 40 MHz plasma level (as a simple adaptation of the model proposed by McLean[2] might suggest)? Alternatively, could we be observing the combination of two sources, one to the north-east (due to the moving dark filament) and one further to the south-west (initiated by the sudden expansion of the flare in that direction)?

Another interesting feature of this event appeared as frequent, extremely rapid changes of source structure. Two striking examples of this are illustrated in Figure 3. Between $03^h10^m04^s$ and 06^s and again between $03^h10^m32^s$ and 34^s (both times during the quiet period between the two type II bursts) a large diffuse region of faint emission suddenly appeared on the side of the source away from the Sun. Once again we are left speculating about the manner in which this diffuse region could appear so suddenly. Are we observing the emission from fast particles moving outward from the source at speeds approaching the velocity of light, or radiation scattered from this region when the main source is suitably beamed; or could this appearance be due to another weak sporadic source very high in the corona?

The strongly polarized post-II enhancement appeared in the same region as the first unpolarized type II burst (Figure 2f) although possible variations of the ionospheric refraction make it difficult to compare absolute positions with accuracy. Presumably we must look for the explanation of the change of polarization in the same emitting region either in the emission mechanism or in a flare-induced modification of the coronal structure.

In this preliminary account we have noted a number of features of the intensity distribution in the type II source which we believe may prove very significant—in particular the rapid variations in the source structure, the existence and sudden appearances of a diffuse halo component, and the apparent outward motion of the region of maximum intensity.

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[1] Wild, J. P., Sheridan, K. V. and Kai, K., *Nature*, **218**, 536 (1968).
[2] McLean, D. J., *Proc. ASA*, **1**, 47 (1967).

Preliminary Observations of the Effects of a Corotating Stream on Interplanetary Scintillation

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Since its discovery in 1964,[1] interplanetary scintillation has become recognized as a valuable method for investigating the solar wind[2, 3, 4] and the small-scale structure of the interplanetary medium.[5, 6] A particular advantage of the method lies in the ability to study those regions of the medium outside the plane of the ecliptic. To date little has been written about the relation between interplanetary scintillation and solar activity, although regular observations of the source 3C48 during 1965-6[3] have indicated that a small correlation may exist between the scintillation index and sunspot number. It also appears that anomalous increases in the scintillation index are, on occasion, related to strong flare activity on the Sun.[7, 3]

In this paper we describe observations of a 'grid' of radio sources which, over a period of several days, have shown systematic changes in their scintillation indices and in the power spectra of the scintillations apparently related to the passage of a corotating stream through the interplanetary medium.

OBSERVATIONS

The observations were carried out during the period 1968 May 24-29 using the 80 MHz radioheliograph[8] at the CSIRO Solar Observatory, Culgoora. The radioheliograph produces 48 beams in a north-south direction, each of width 3′.5 to half-power, and with a separation between adjacent beams of 2′.1 in the zenith. The procedure adopted was to track a source on the central beam and record this signal and signals from adjacent off-source beams on a 3 channel pen-recorder. On and off-source data were also recorded digitally on magnetic tape at a sampling rate of 32 s^{-1}, and with a time-constant of 0.05 s. Subsequent analysis was performed using the CDC 6400 computer of the University of Adelaide. Each source was observed for 15-30 min in order to obtain a representative sample of its scintillation. Records were analysed to determine the power spectra of the scintillations, and the scintillation index

$$F = \langle (\Delta I/I)^2 \rangle^{\frac{1}{2}},$$

where I is the apparent intensity of the source. The index is primarily determined by the rms fluctuation in electron density ΔN_e along the line of sight to the source, and also by the scale ξ_0 of these fluctuations,[9]

$$F \propto \Delta N_e(\xi_0 L)^{\frac{1}{2}},$$

where L is the thickness of the scattering region along the line of sight.

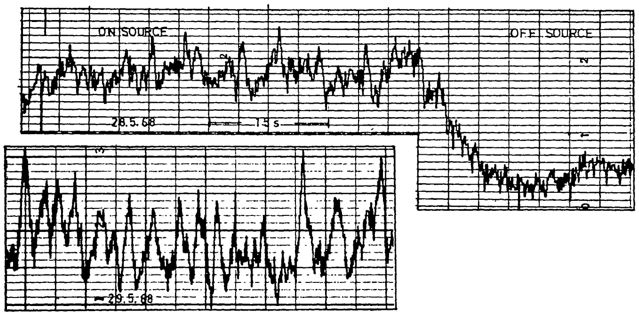

Figure 1. Interplanetary scintillation of the source 2313+03.

Nine sources showed significant changes in their scintillation indices, and in Figure 1 are shown sections of record for one of these, 2313 + 03, taken on 28 and 29 May when the index increased by about a factor of 2. In Figure 2*a* the scintillation indices for the 9 sources are given and the events under consideration are indicated by arrows. In Figure 2*b* the lines of sight to the sources are shown projected onto the plane of the ecliptic, and ecliptic latitude is indicated against each source number. The enhancements in scintillation occur sequentially when the sources are considered in order looking to the east of the Sun and it is difficult to explain the observations in terms of a radially moving blast of plasma, particularly when the spectral data to be discussed later are considered. However, the observations do appear consistent with the passage of a corotating stream through the medium and we shall discuss the variations in the indices in the light of such a model.

In Figure 2*b* are sketched the positions of the leading edge of the stream which appear to fit best with the observations. The stream configuration corresponds to a radial solar wind velocity of 400 km/s. The extent of the stream both in and perpendicular to the plane of the ecliptic is not indicated in the figure although the observations enable some useful limits to be placed on these dimensions. The time at which the stream meets the Earth has been estimated from its effects on the sources 1226 + 02, 1309 − 22 and 0134 + 32, since the lines of sight to these sources lie approximately parallel to the leading edge of the stream. As indicated in Figure 2 the line of sight to 1226 + 02 is affected first, followed closely by 1309 − 22 and 0134 + 32 both of which are affected late on May 27^{d}. By 28^{d} the Earth is embedded in the stream. The indices for the sources 2313 + 03 and 0003 − 00 then increase by about a factor of 2 between $28^{\mathrm{d}}.0$ and $29^{\mathrm{d}}.0$ (U.T.). It is of interest to note that a small Forbush decrease (~ 2%) was recorded by the Deep River neutron monitor, centred on $28^{\mathrm{d}}.8$.

The sequence of events for the above sources indicates that the velocity of the solar wind associated with the stream was in the range 350-500 km/s. A lower velocity, for example, would produce a more tightly wound spiral causing the source 0134 + 32 to be affected before 1226 + 02.

It may also be seen from Figure 2*b* that the duration of the enhanced scintillation (2-3d) for the sources 1226 + 02 and 1309 − 22 must be closely related to the width of the stream in the plane of the ecliptic. The duration indicates a width of 0.5-0.6 A.U. at the orbit of

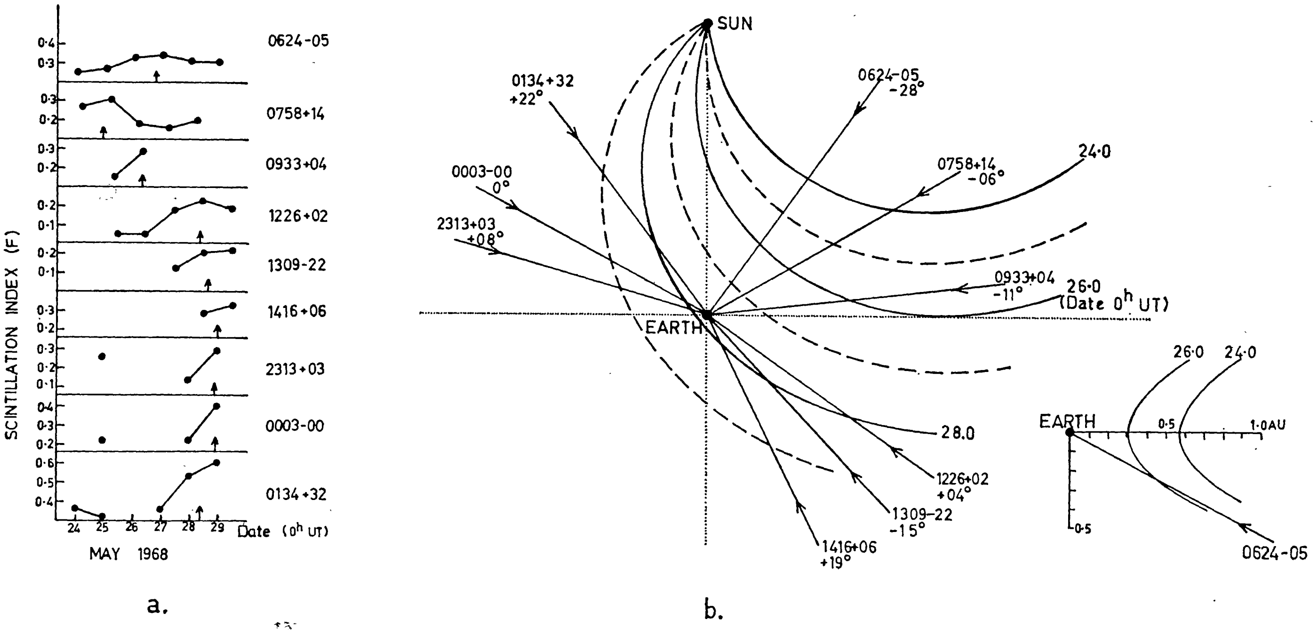

Figure 2. *a* Values of the scintillation index. *b* Lines of sight to the sources projected onto the plane of the ecliptic, and the deduced positions of the leading edge of the stream. Inset is a possible stream configuration perpendicular to the ecliptic.

the Earth. However, because of the curvature of the stream regions of the line of sight far from the Earth continue to be affected after the stream has passed over those regions close to the Earth, so that the above value represents an over-estimate. The contribution of these regions to the total scattering varies with the inverse square of their distance from the Sun, and on this basis we estimate the true width to be smaller than the above value by about 20%.

Having fixed the time at which the stream meets the Earth we may now consider the remaining sources 0624 — 05, 0758 + 14 and 0933 + 04, to examine their agreement with the overall picture. The source 0758 + 14 shows enhanced scintillation up to day $25^{\rm d}.3$ after which the index decreases considerably (from 0.3 to 0.16), even though the line of sight was still intersected by the stream up to $28^{\rm d}.0$. The most reasonable explanation for this decrease would appear to be related to the finite width of the stream in the ecliptic, mentioned above. It may be seen from Figure 2*b* that a stream of width 2d intersects the line of sight over the region 0.5-2.5 A.U. distant from the Earth on $25^{\rm d}.0$. On $26^{\rm d}.0$, however, only the region 0.32 to about 0.75 A.U. is affected. This represents a considerable reduction in the extent of the scattering region, and after allowing for the dependence of the scattering on distance from the Sun is still sufficient to explain the observed decrease in scintillation.

The source 0933 + 04 was unfortunately observed on only two days, May 25 and 26, during which time the index increased from 0.17 to 0.29. Referring to Figure 2*b* it can be seen that this increase agrees well with the proposed stream location.

The source 0624 — 05 showed moderate scintillation during the whole of the observing period, and the enhancement on $26^{\rm d}.2$ and $27^{\rm d}.2$ seems barely significant. The reason for the effect being so small compared to the other sources observed might be due to the relatively small region of the line of sight which is affected. The fact that the enhancement occurs 1d later than for the source 0758 + 14 appears at first sight to disagree with the overall sequence of events. However, the line of sight to 0624 — 05 lies in a direction almost 30° below the ecliptic, so that unless the stream were of indefinite extent perpendicular to the ecliptic the line of sight would be affected only when the stream had progressed sufficiently close to the Earth. The point is illustrated by the inset to Figure 2*b*, where a possible stream configuration in a plane perpendicular to the ecliptic is shown. The dimensions indicated by the inset must not be taken too literally; it has been included purely to illustrate the point that future observations of a more complete 'grid' of sources may enable valuable information to be derived on stream configurations outside the ecliptic.

POWER SPECTRA OF THE SCINTILLATIONS

In the discusson so far, which has been based upon the observed changes in the scintillation index (the integrated frequency spectrum), perhaps the greatest uncertainty lies in the location of the scattering region along the line of sight. Additional information can be derived, in principle, from the form of the power spectrum, which depends on the distance of the observer from the scattering region ('screen'). Close to the screen the scattered amplitude is in quadrature with the unscattered field and only phase fluctuations exist. Moving away from the screen the wide-angle components of the angular power spectrum rotate their phases more quickly relative to the specular component than do the small-angle components. Intensity fluctuations due to the wide-angle components therefore develop first as the observer-screen separation increases, with the result that close to the screen the frequency (power) spectrum of the intensity fluctuations is expected to show a depression at low frequencies.[10]

In the present observations the spectrum for a particular source was computed as the Fourier transform of the autocorrelation function; the spectrum of the scintillations was obtained by subtracting the off-source spectrum from that computed on-source. On particular occasions the spectra do indeed show depressions at low frequencies. The data are in good agreement with the model summarized in Figure 2*b*, in that the depression tends to occur on those occasions when the stream intersects a limited region of a line of sight, close to the Earth. M. Golley (personal communication) has computed theoretical spectra at various distances from a thin, weakly scattering screen containing irregularities of scale $\xi_0 \sim 150$ km. The distance of the screen from the Earth may be estimated by comparing the form of these theoretical spectra with those derived from the observations. Since the spectral data, both theoretical and experimental, will be discussed in detail elsewhere, we consider here only the spectra for the source 0134 + 32 (Figure 3) as an example of the effect. For each day 4 spectra are shown which have been computed from independent 90 s samples of the scintillation. The shapes of the spectra change considerably over the four days and those for $28^{\rm d}$ show marked depression at low frequencies. Comparison with the theoretical spectra of Golley indicates that on the $28^{\rm d}$ the mean distance of the screen from the Earth was $\lesssim 0.2$ A.U., a value in good agreement with the position of the stream (Figure 2*b*) deduced from the changes in scintillation index. The undisturbed spectra, on the $25^{\rm d}$ for example, were often

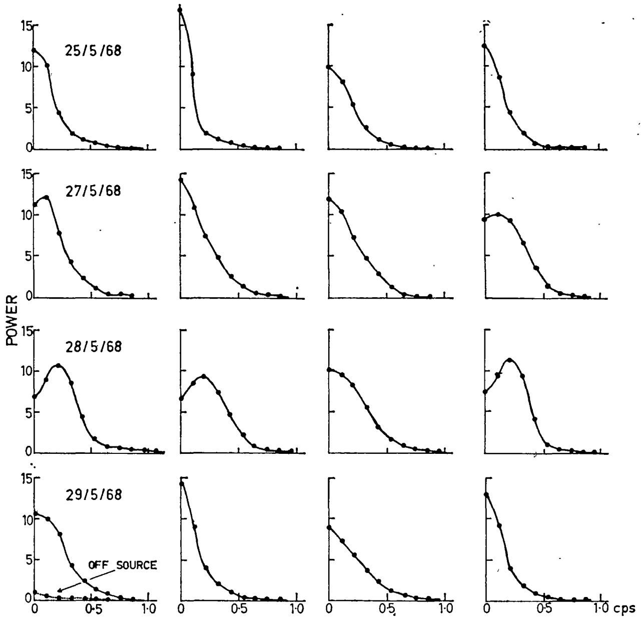

Figure 3. Power spectra of the interplanetary scintillations of the source 0134+32.

close to Gaussian. The absence of a deep depression on the 29^d is interpreted as being due to the stream intersecting the line of sight over an extended region, causing the depression to be blurred out.

Figure 3 also indicates that the width of the frequency spectrum increased during the passage of the stream across the line of sight; an effect almost certainly due to the enhanced solar wind velocity within the stream.

DISCUSSION

Comparison with other data lends support to the proposed corotating stream model. For a solar radiation period of 27d the stream would be expected to reach the spacecraft Pioneer VI 5d after meeting the Earth, that is on June 11 or 12. The solar wind velocity measured by Pioneer remained constant at about 370 km/s from June 7^d–10^d, and then increased to $\sim$ 540 km/s on 11^d. This enhanced velocity persisted on 12^d, returning to $\sim$ 360 km/s on 13^d.

The indices of magnetic activity K_p indicate that the effects of the stream on the Earth varied considerably during successive rotations. During the period of observation the only effect was a small increase from May 27-30, but the effects were more pronounced during the following 2 rotations (Figure 4); note the sudden commencement on 25 June. The K_p indices also suggest that the stream may have been present during the previous 6 solar rotations.

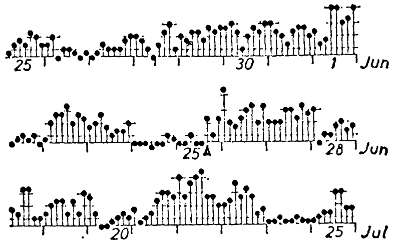

Figure 4. Values of the K_p index during the period of observation, and for the following 2 solar rotations.

It has been noted in previous work[5] that the scale ξ_0 of the plasma irregularities is comparable to the ion gyroradius in the medium, and it is possible that they are produced by plasma instability. The enhanced scintillation described in this report may be related to the irregular magnetic fields known to be associated with such plasma streams.[11]

The data we have described are regarded as preliminary in that the 'grid' of sources, and the length of the observing session, were both rather limited. Nevertheless it appears that this type of study can provide useful information about the effects of solar activity on the interplanetary medium, and on large-scale movements of plasma through the medium.

It is a pleasure to thank Mr O. B. Slee for invaluable assistance with the observations and for numerous discussions; Mr R. T. Stewart for the provision of digital equipment, and Mr M. Golley for assistance with the computations. We also thank Dr J. P. Wild and the staff of CSIRO for making the radioheliograph available for the observations.

[1] Hewish, A., Scott, P. F. and Wills, D., *Nature*, **203**, 1214 (1964).

[2] Hewish, A., Dennison, P. A. and Pilkington, J. D. H., *Nature*, **209**, 1188 (1966).

[3] Dennison, P. A. and Hewish, A., *Nature*, **213**, 343 (1967).

[4] Slee, O. B. and Higgins, C. S., *Aust. J. Phys.*, **21**, 341 (1968).

[5] Dennison, P. A., *Planet. Space Sci.*, in the press (1968).

[6] Cohen, M. H., Gundermann, E. J., Hardebeck, H. C. and Sharp, L. E., *Ap. J.*, **147**, 449 (1967).

[7] Sharp, L. E. and Harris, D. E., *Nature*, **213**, 377 (1967).

[8] 'The Culgoora Radioheliograph', J. P. Wild (ed.), *Proc. IREE Aust.*, **28**, No. 9 (1967).

[9] Bramley, E. N., *Proc. Roy. Soc.*, A **225**, 515 (1954).

[10] Budden, K. G., *J. Atmos. Terr. Phys.*, **27**, 1551 (1965).

[11] Ballif, J. R. and Jones, D. E., *J. Geophys. Res.*, **72**, 5173 (1967).

Corotating Forbush Decreases

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A natural introduction to this topic is a brief discussion of two phenomena observable in interplanetary space near Earth—the energetic storm particle event (ESPE), and the recurrent Forbush decrease.

The basic properties of the ESPE are demonstrated in Figure 1—a short-lived enhancement (typically one day) of the flux of low energy protons associated with a solar-flare-initiated Forbush decrease. It has a characteristically short time scale compared to the preceding solar flare proton event. Arguments against acceleration at the Sun plus evidence opposing trapping in interplanetary space support the hypothesis of acceleration of the particles observed in the enhancement occurring within the blast wave which is responsible for the Forbush decrease.

Evidence for recurrent Forbush decreases has been given by McCracken[1] *et al.* In their Figure 4 the integral >7.5 MeV count rate from Pioneer 6 shows a 27-day recurrence tendency for intensity decreases. The absence of large flares and solar cosmic-ray effects before these events precludes the possibility that they were the usual impulsive Forbush decreases generated by solar flares. The model invoked to explain these recurrent Forbush decreases suggests that a 'hot-spot' in the Sun's corona expels faster solar plasma which forms a shock-wave where it overtakes the slower ambient solar wind. While the 'hot-spot' persists, the shock corotates with the Sun, producing a Forbush decrease each solar rotation.

The observation of an ESPE in association with a solar-flare Forbush decrease leads naturally to the question of whether there may be a proton enhancement associated with a recurrent Forbush decrease. We present evidence

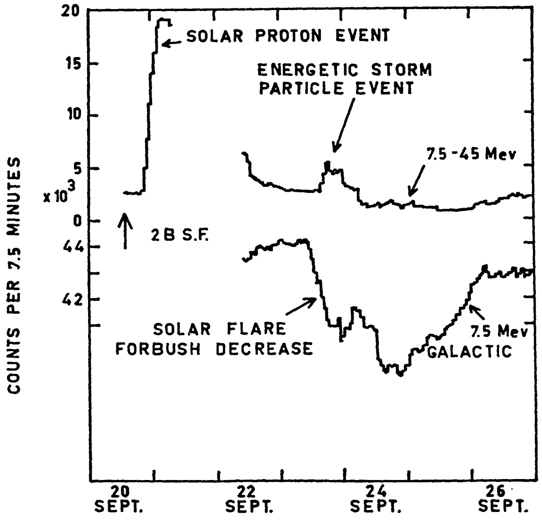

Figure 1. Energetic storm protons associated with solar-flare Forbush decrease.