SHORT COMMUNICATIONS

EVIDENCE FOR THE TRANSFER OF CORPUSCLES TO DISTANT PARTS OF THE SUN FOLLOWING A SOLAR RADIO BURST*

By R. F. Mullaly†

The brightness distribution of 21-cm radiation over the Sun's surface has been studied for the past four years with the Christiansen crossed-grating interferometer (Christiansen *et al.* 1961) at Fleurs near Sydney. The observations described here were made using one arm of this cross as a simple grating interferometer, providing a transit instrument with a fan beam of about 2′ of arc resolution to half-power points in the east-west direction and very low resolution north-south. The Sun was scanned repeatedly from east to west at time intervals of approximately 4 min.

Observations have been made for several hours a day on most days during the past few years. The most prominent features of these records are the peaks due to the slowly varying bright regions on the Sun with an average lifetime of some weeks. In addition a number (35) of bursts have been seen, located always near the position of a previously existing radio bright region. Simultaneously with the bursts, and in the same vicinity, flares are often observed optically. During burst events the level of radiation suddenly increases for a period of from a few minutes to a few hours. The high level typically fluctuates, sometimes violently, and on different occasions the peak intensity has ranged from less than twice up to several hundred times the previous steady level. These observations will be described in detail elsewhere.

On three occasions it was found that, on the second scan after the onset of a small burst (8 or 9 min later) another bright region, distant about a solar radius, showed a small but definite increase in its emission. In one instance (December 13, 1958) this was noted on only one scan, after which the augmented region returned to its previous level; on another (July 29, 1958) the increase persisted for at least four scans (after which observation came to an end); and, in the third case (May 13, 1959) the increase certainly persisted for many scans. (See Fig. 1.)

Before accepting these secondary increases as physically associated with the main bursts it is necessary to inquire if they might not be due to independent small bursts or to receiver gain fluctuations, which happened by chance to occur at almost the same time as the main bursts. Over 600 east-west scans were examined for evidence of such small increases when no other burst had occurred. None were found (confirming a subjective impression from a much larger sample

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† Division of Radiophysics, C.S.I.R.O., University Grounds, Chippendale, N.S.W.

that they are very rare). Let p be the probability of a random small increase occurring in a single scan. To estimate an upper bound for p, suppose that the occurrence of no increase in a sample of 600 is a *rare* event, say with a probability of $0\cdot001$. Then $(1-p)^{600}=0\cdot001$, giving $p=0\cdot01$; there is only one chance in 10^3 that p exceeds this value. Out of 35 scans each next but one after the scan on which a burst was first seen, three show small increases; the probability of this happening by chance is

$$\binom{35}{3}(1-p)^{32}p^3,$$

which, with the above value for p, is about $0\cdot006$. The possibility that the observed small increases might be due to side lobes in the instrument must also

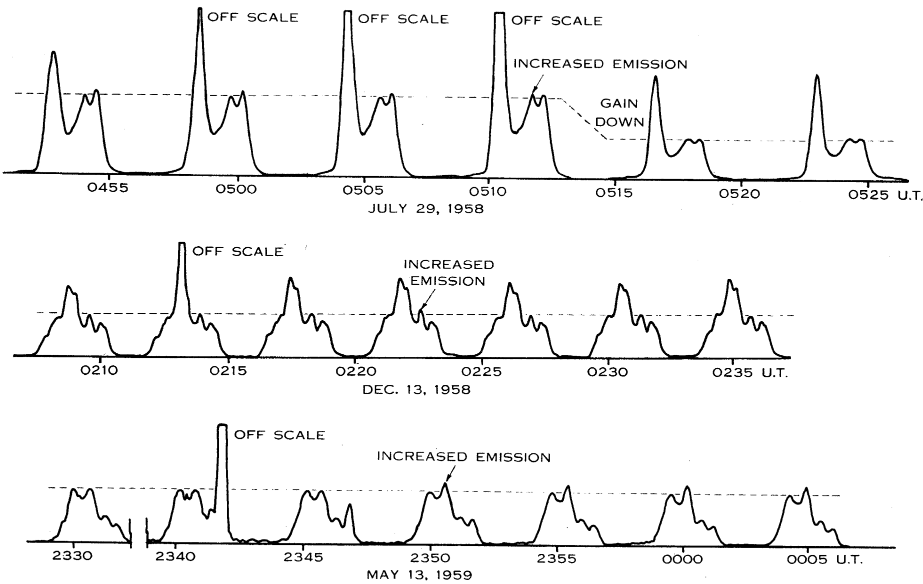

Fig. 1.—East-west strip scans of the Sun at 21 cm. Beamwidth about 2′ of arc east-west. In each case a burst is followed, two scans later, by a small increase in the emission from a distant bright region.

be discussed. The answer is twofold: first, that the side lobes are known to be much too small, both in theory and from the absence of side-lobe effects even comparable to our increases with many much larger bursts; secondly, that the amount of the enhanced emission in the three cases being considered shows no kind of proportionality to the simultaneous level of the main burst.

The immediate deduction from the observations is that the secondary increases are stimulated by something (e.g. a plasma cloud or a shock wave) propagated from the region of the main burst. The velocity of propagation appears in all cases to lie between 1000 and 2000 km/s; uncertainty in the precise time interval and in the path (which might follow the Sun's surface or arch high into the corona) precludes more exact calculation.

For two of the three events optical data are available. For December 13, 1958 a class 1 flare was observed at 0° N., 21° W. during the period $02^h 12^m$ to $02^h 47^m$ U.T. and this was accompanied by a surge. Photographs of this event taken by the C.S.I.R.O. Division of Physics are shown on Plate 1. The probable region of the augmented radio emission was scrutinized on a number of photographs but no definite evidence of brightening or change could be detected. For May 13, 1959 a class 1+ flare accompanied by a bright surge going over the limb was observed (I.G.Y. World Data Centre A 1959) commencing $23^h 40^m$ U.T. and situated at 8° S., 87° E. The positions of the flares and the radio bursts coincide well for both these days, and the direction of motion of the surge of December 13, 1958 appears to be roughly towards the assumed seat of the secondary enhanced radiation.

The surges at the time of the two above events represent matter with a line of sight velocity much less than 1000 km/s, otherwise the Doppler shift would have made them invisible. Very recently, however, Moreton (Athay and Moreton 1961; Moreton 1961), using an extremely wide-band filter, has reported disturbances, which he believes to be plasma clouds, moving out from the region of flares with velocities of from 1000 km/s to as high as 2500 km/s. Further, he states that on some such occasions sudden optical changes have been observed in filaments distant as much as 700 000 km from the seat of the main disturbance.

The radio observations we have described suggest that, when the burst occurred, matter was ejected or escaped from the active region, followed some trajectory, perhaps an arched one guided by the lines of force of the leakage flux between magnetic fields near the two regions, and descended on the second region, augmenting its emission, either by some heating or other effect of impact or simply by increasing the amount of hot gas present. Since certainly two of the three events were associated with optical surges it might plausibly be suggested that such secondary radio activity may be associated with surge flares. Some support for this idea comes from the facts that, while most radio bursts are associated with flares (though not most flares with bursts), only a small fraction (about 10% on our data) of bursts give enhanced emission of distant regions and only a minority of flares are seen to be accompanied by surges. Moreton's observations show that with at least some surge flares, plasma clouds as he thinks, or possibly shock waves, are ejected to great distances with velocities of the right order (1000–2000 km/s) to agree with the radio results. The long persistence of the augmented brightness of the 1959 event and, with less certainty, of the event of July 29, 1958 suggests as the mechanism the transfer of a substantial mass of corpuscles rather than the propagation of a shock wave. The event of December 13, 1958, for which the augmentation is small, and seen on only one scan, is more open to a shock-wave or impact interpretation. Possibly two different mechanisms operate on different occasions.

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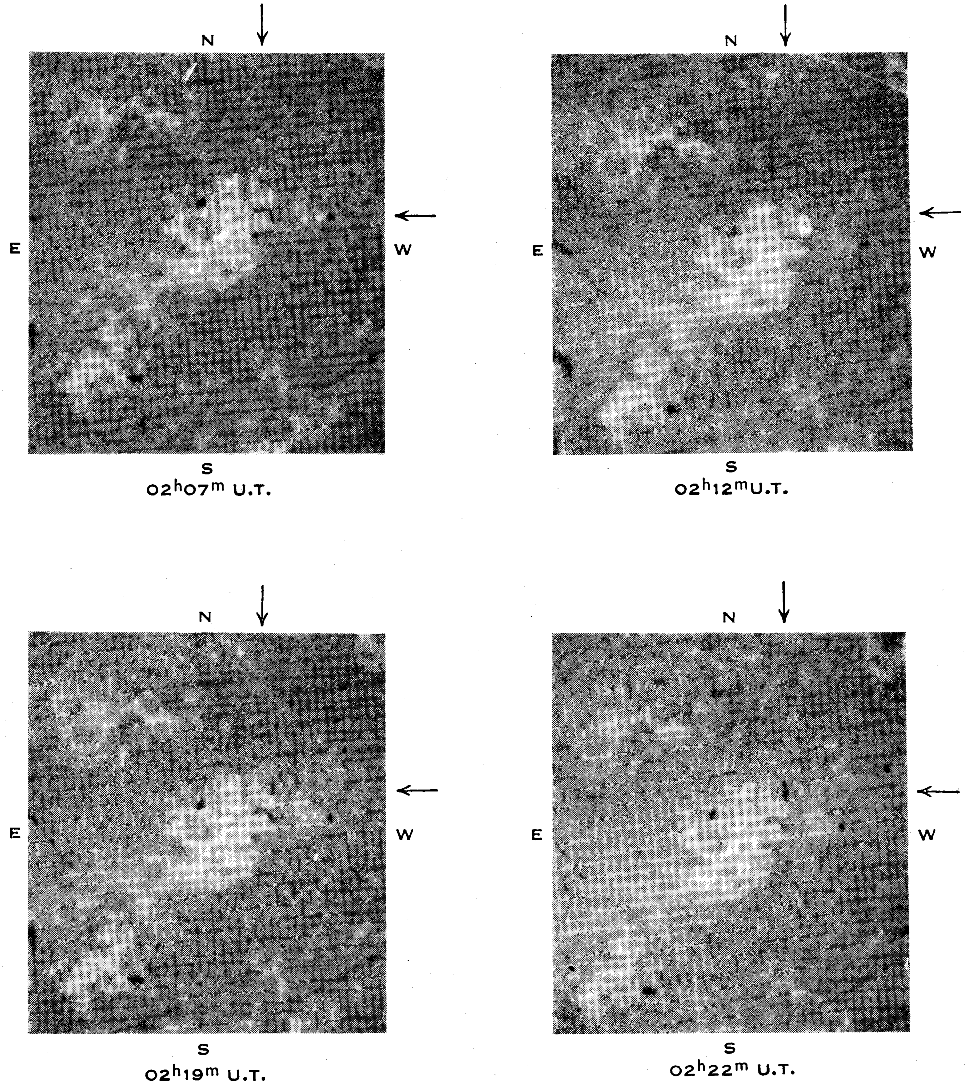
TRANSFER OF SOLAR CORPUSCLES



Photographs in Hα light of a surge flare on December 13, 1958. The surge is seen on the third and fourth photographs as a dark streak extending roughly to the north of the position of the bright flare. (Photographs by courtesy of the Division of Physics, C.S.I.R.O.)

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