EXPANDING ARCH STRUCTURE OF A SOLAR RADIO OUTBURST

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Abstract. A flare-associated complex outburst was observed on 1968, October 23–24 with the 80 MHz Culgoora radioheliograph. Two harmonic type II bursts were followed by two successive extended sources with arch structure which appeared further beyond the optical limb than the preceding sources. The second arch showed a remarkable expansion with a projected velocity of 1200 km/sec. At its maximum the arch extended to a height of $2R_{\odot}$. The height-time plots derived from both the radioheliograph and spectrum observations suggest that two shock waves of different propagation velocities were initiated at the flash phase of the flare: the faster one was responsible for the first type II burst and the first radio-emitting arch; the slower one for the second type II burst and the second arch whose expansion advanced with the shock front.

1. Introduction

Sources of solar radio bursts with extremely large extension of $\sim 2R_{\odot}$ have been observed on several occasions with the 80 MHz radioheliograph at Culgoora. The size of the sources is so large that it would be impossible to detect them without ambiguity using simple interferometers. Most of them are definitely associated with flare activity. They are characterized by a highly elongated or curved arch-like structure and in some cases by a gradual expansion of this structure. It was suggested in a discussion of an earlier observation of an outburst of this type that the extended component is associated with a prominence which is presumably activated by a shock wave from a remote flare (Wild *et al.*, 1968). The study of this kind of activity should provide us with useful information about shock-wave propagation, shock-wave activation of the prominence itself or its overlying structure, and magnetic field structure in the corona.

On 1968, October 23–24 a very complex outburst was observed with the radioheliograph as well as with the spectrograph at Culgoora. The outburst consisted of numerous type III bursts, complex harmonic type II bursts and a subsequent event in which the source possessed large-scale arch structure which expanded to remarkable dimensions. The associated active centre was the same centre that produced an outburst with a structure similar to the present one on 1968, November 22, one solar rotation later (Wild, 1969). In the following sections we shall describe the radioheliograph observations of the outburst of 1968, October 23–24 and then discuss its interpretation in terms of shock waves.

2. Radioheliograph Observations

A flare of importance 2B started at $23^{h}51^{m}$ in a region centred at S12°, E57°. It was

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reported that the flare contained several eruptive centres and covered a very extensive active region and that dark filaments on the Hα disk showed sudden activation (*Solar-Geophysical Data*, 1968).

A. TYPE III BURSTS

Although a weakly polarized ($\sim 10\%$ LH) storm source had been developing beyond the south-east limb before the flare started, the first event triggered by the flare was a weak type III burst at 23^h53^m (Figure 1). It was followed by a number of unpolarized,

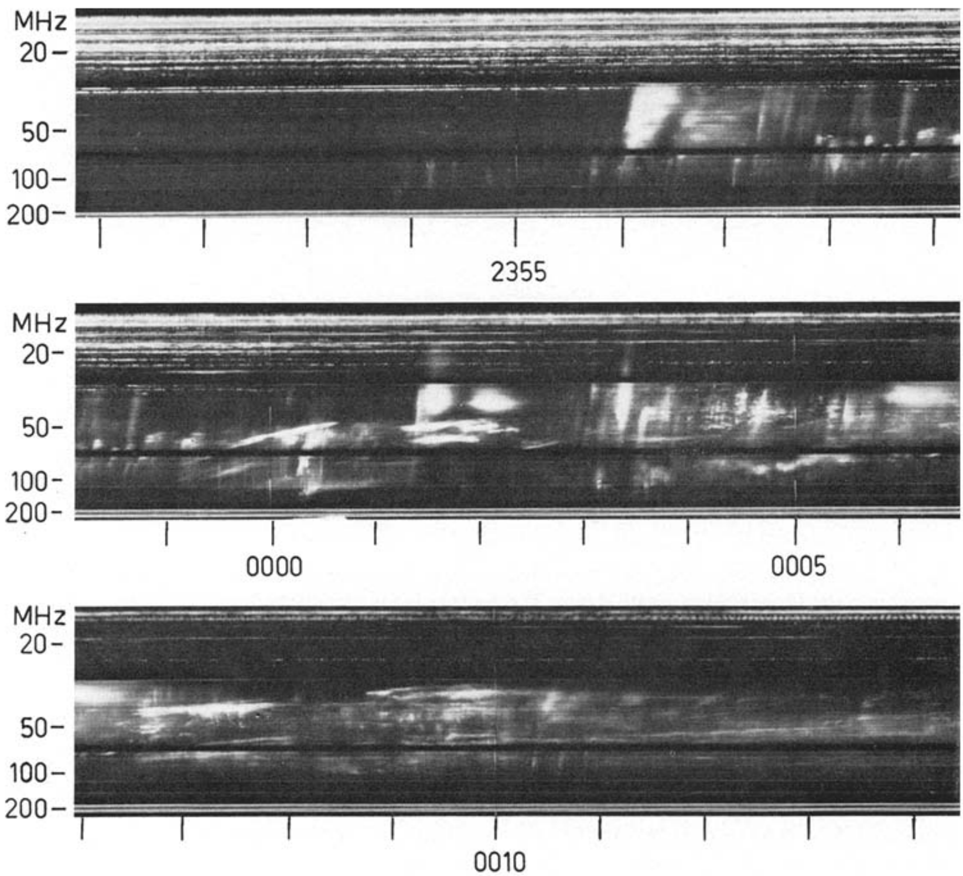

Fig. 1. Dynamic spectrum of the complex type II bursts on 1968, October 23–24.

strong type III bursts which were located closer to the flare centre than the source of the preceding storm. The 80 MHz sources of the type I and type III bursts are shown in Figure 2 in which outlines represent half-power contours produced by a computer directly from the digital magnetic tapes recorded by the radioheliograph. All type III bursts occurred from Source III except a burst of peculiar type III at $00^h00^m16^s$ (Source III′).

B. TYPE II BURSTS

A complex type II burst with two distinct drifting features was seen between 23^h59^m and 00^h01^m on the dynamic spectrum (Figure 1). The first part started at 23^h59^m, 8 min after the flare onset. Its fundamental band crossed 80 MHz between $23^h59^m10^s$ and 20^s and what appeared to be its second harmonic band at around $00^h00^m40^s$. The second part of the type II burst contained two split-band features which were observed at

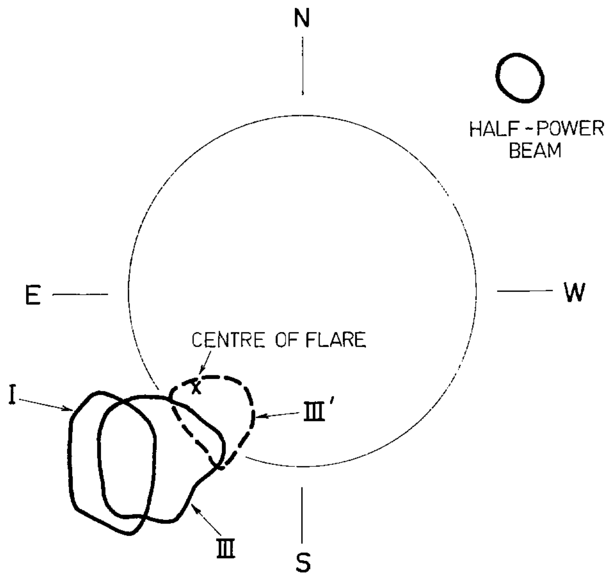

Fig. 2. 80 MHz sources of the type I storm and the type III bursts. The outlines represent half-power levels. Source I: the preceding type I storm. The contour is for 23^h53^m. Source III: a type III burst at $23^h54^m07^s$. Source III′: a burst of peculiar type III at $00^h00^m16^s$]. N in this and the Figures 3 to 5 indicates the north point of the Sun.

80 MHz at around $23^h59^m40^s$. All type II bursts were essentially unpolarized. The 80 MHz sources of the type II bursts are summarized in Figure 3. Although the different features occurred in roughly the same area, their precise locations and shapes were different. It is hard to decide whether the position difference between the fundamental and second harmonic bands of the first type II burst has a special significance, since the brightness distribution tended to change rapidly even within a single band of the type II burst. At lower frequencies ($\sim$30 MHz) another harmonic type II burst, which was not the continuation of the earlier one, started at 00^h05^m and the second harmonic band was visible until 00^h20^m.

C. EXTENDED SOURCE

A diffuse source with a large extension appeared first at 00^h01^m, 10 min after the flare onset, along an arch located at a distance of about $1R_\odot$ from the optical limb (Figure

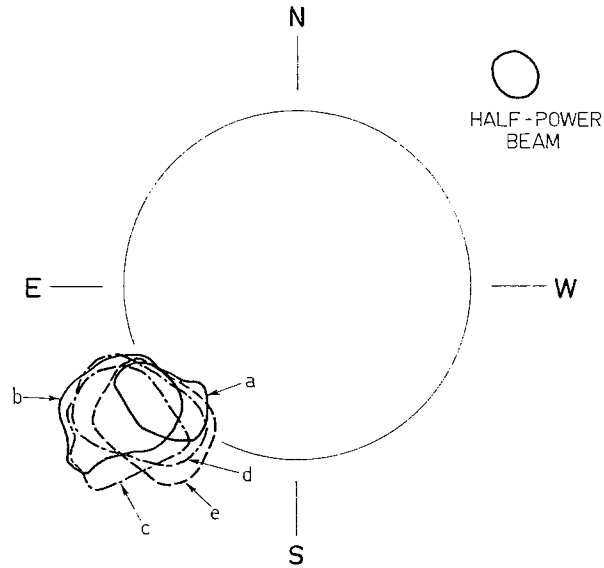

Fig. 3. Summary of 80 MHz sources of the type II bursts. The outlines represent half-power levels. – Sources (a) and (b): the fundamental band of the first part of the type II burst at $23^h59^m14^s$ and 17^s respectively. – Sources (c) and (d): the fundamental band of the second part of the type II burst (not harmonically related to the first one) at $23^h59^m38^s$ and 55^s respectively. – Source (e): the possible second harmonic band of the first part of the type II burst at $00^h00^m38^s$.

4a). The shape of the source remained essentially unchanged up to 00^h05^m without showing pronounced expansion, although the distribution of brightness within the source often changed rapidly. Then, a strong unpolarized source appeared at 00^h06^m approximately at the northern end of the arch; almost simultaneously another weaker source, partially LH polarized, appeared at the southern end (Figure 4b). In the following minutes the sources which lay along the arch as well as these new sources showed an expansion away from the limb. In particular the source near the top of the arch developed a remarkably hump-like feature (Figure 4c). The expansion continued until 00^h20^m, about 30 min after flare onset, when the highest part of the source was located at a distance of about $2R_\odot$ from the limb in the south-east direction. The expansion is schematically illustrated in Figure 5 by thick lines which were drawn joining the bright sources along the arch. All sources along the arch except one of its northern edge were partially LH polarized ($10 \sim 20\%$).

D. STATIONARY TYPE IV

After 00^h20^m all sources became invisible except the southern source which started to return to the limb. The movement continued slowly until 00^h40^m when the source settled down in a region close to the limb (Figure 4d). The source was moderately polarized ($30 \sim 40\%$ LH) and steady during the next half hour; it may be classified as a stationary type IV burst.

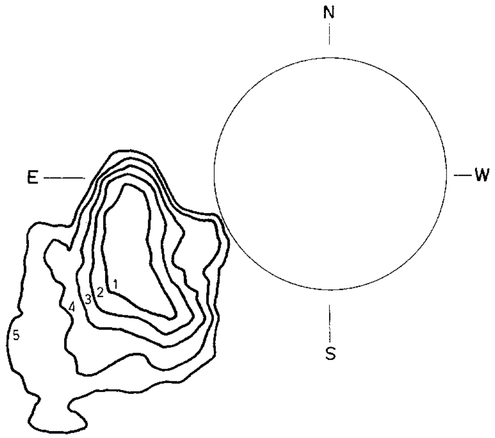

Fig. 4a.

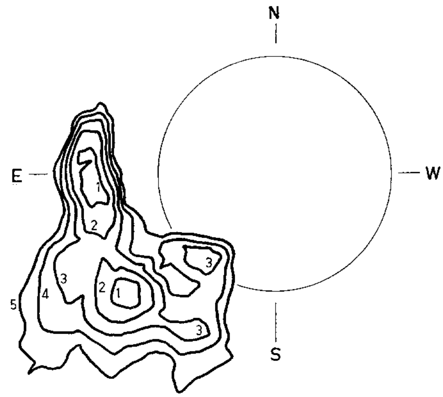

Fig. 4b.

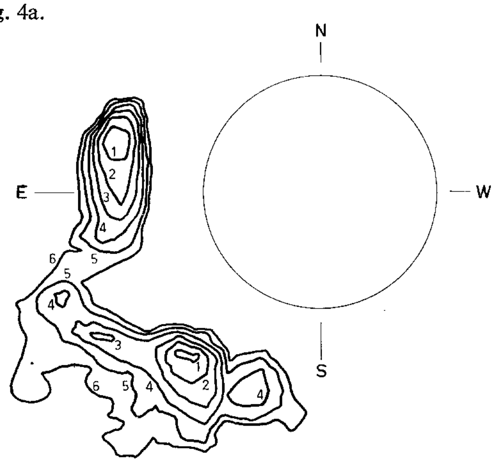

Fig. 4c.

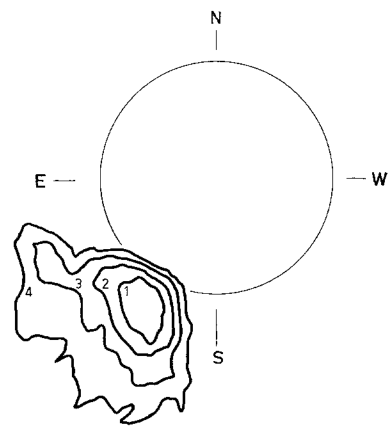

Fig. 4d.

Fig. 4. Contour plots of the source brightness distribution recorded by the radioheliograph during the expanding arch phase. The contour levels $n=1, 2, 3\ldots$ represent $2^{-n/2}$ power levels of the maximum brightness. (a) 00^h03^m; (b) 00^h06^m; (c) 00^h11^m; (d) 00^h48^m.

3. Discussion

It is generally believed that type II bursts are manifestations of shock waves which propagate in the corona. In the present case the shock wave may play two roles – excitation of the type II burst and activation of the extended source. The suggestion that the extended source with archlike structure is activated by the shock wave is based on the following spatial and temporal relations:

(a) The extended source appeared in the same direction with respect to the flare centre as the 80 MHz source of the preceding type II burst.

(b) The arch and its expansion are confined to approximately the same angle ($\sim 150°$ at the flare centre) as subtended by the type II source (cf. Figure 5).

(c) The expansion continued until the second harmonic band of the second type II

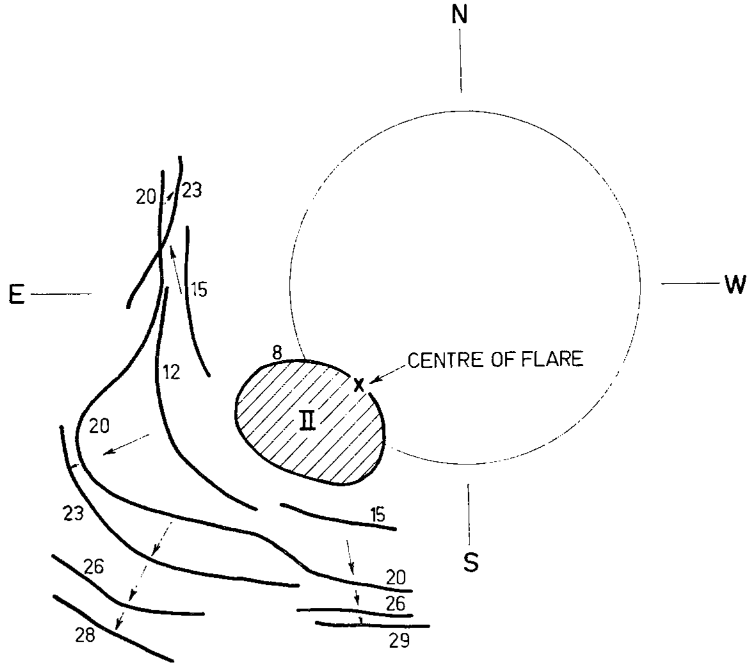

Fig. 5. Expansion of the radio-emitting arch. The shaded area shows the region in which type II bursts occur and the cross the centre of the associated flare. Thick lines represent the fronts along which arch structures form or discrete sources lie. The numbers beside them indicate the time in minutes measured from the onset of the flare (23^h51^m).

burst became invisible at the low-frequency range ($\sim$30 MHz) of the spectrum.

Further temporal relationships are examined in Figure 6. In Figure 6a the open circle gives the average position of the type II source; the filled circles show the positions at different times of that part of the arch which lies along a line joining the centres of the flare and the type II source. All points after 00^h06^m, when the expansion of the arch started, fit well on a straight line corresponding to a projected velocity of 1200 km/sec. On the other hand the line joining the type II source and the initial source of the arch gives a faster velocity (2600 km/sec).

It is of interest to make a direct comparison of the height of the type II source derived from the spectrum with the measured positions of the type II and arch sources. Thus in Figure 6b we have plotted the derived heights of the fundamental bands of the type II features, making the customary assumption that the electron densities are twice those of Newkirk's active region model (Newkirk, 1961). We have also converted the observed displacements of Figure 6a to heights above the photosphere assuming that the sources lie radially above the flare. Inspection of this figure strongly indicates a remarkably close relationship between the type II sources and the expanding arch structures.

If Figure 6b is taken literally it implies that the 80 MHz emission from the expanding arch is generated slightly behind the type II shock front (then emitting type II radiation at lower frequencies). However it requires only a slight change in the electron

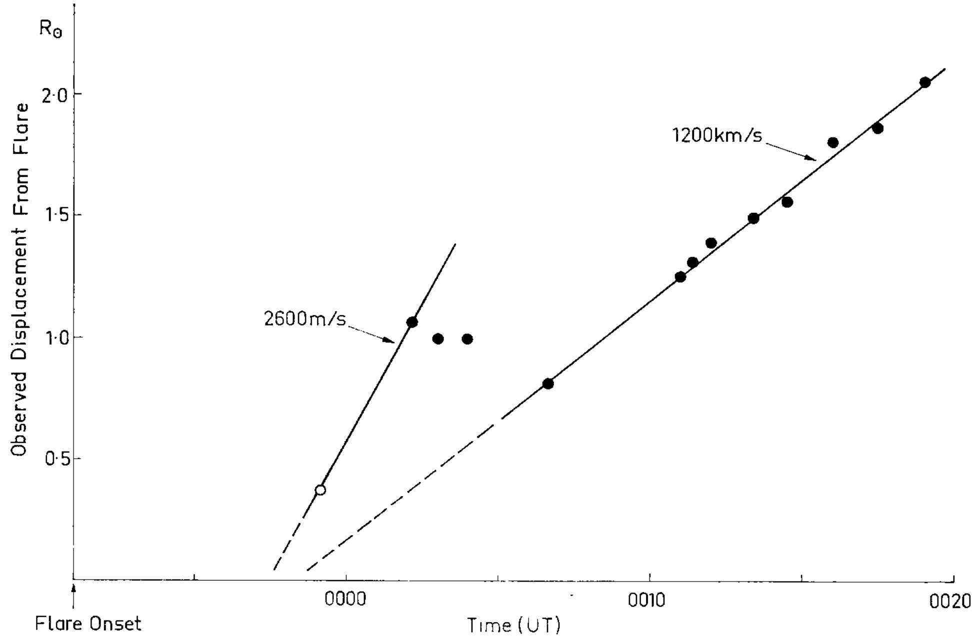

Fig. 6a. The open and filled circles show radioheliograph observations of the transverse displacement (in units of $R_\odot$) of the average 80 MHz type II source and the radio emitting arch respectively. The displacement of the arch is measured from the flare centre along the direction joining it with the centre of the type II source.

density model or in the assumed geometry to make the height-time plots of the two type II bands to lie along those of the arches.

When extrapolated backwards the lines converge towards the photosphere at between 23^h56^m and 58^m. It is noteworthy that at 23^h56^m the first *strong* type III burst occurred. Thus it is suggested that the flash phase of the flare occurred at 23^h56^m (5 min after the onset of the flare) and that at that time two shock waves with different propagation velocities emanated from the flare centre: the faster shock wave ($\sim$3100 km/sec) produced the first type II burst and the first radio-emitting arch, which stayed at approximately the same position for 4–5 min; the slower shock wave ($\sim$1400 km/sec) produced the second type II burst and the second radio-emitting arch whose expansion advanced with the shock front.

The radio-emitting arch could possibly be associated with the kind of faint optical arch systems sometimes seen over limb prominences on eclipse photographs (e.g., Newkirk, 1967; Saito and Hyder, 1968). Such arch systems are likely to be of magnetic origin. This identification is consistent with the previous suggestion by Wild (1969) based on polarization observations of a radio-emitting arch (which actually occurred above the same active region as the one under consideration but one solar rotation later).

Finally we list some questions raised by the present observations and suggest some speculative answers.

(i) Is the second radio-emitting arch a reappearance of the first? If so, why did it

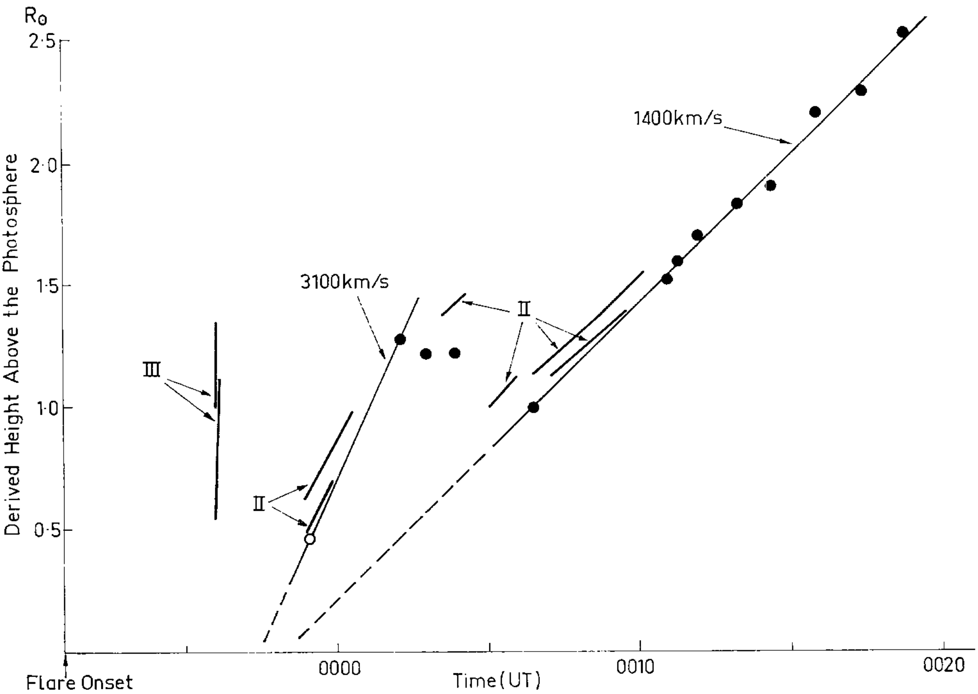

Fig. 6b. The heavy lines show height-time plots derived from the spectral record of the type II and III sources on the assumption that the radio source lies radially above the flare and the electron densities are given by 2 × Newkirk's model. The observed displacement plotted in Figure 6a has been converted to the height above the photosphere on the assumption that the sources lie radially above the flare (the open and filled circles).

expand – unlike to first which stayed in approximately the same position? It is possible that at its first appearance the arch may have possessed sufficient magnetic strength either to withstand the shock or prevent its penetration, whilst on its second appearance it yielded to the possibly greater pressure of the second shock.

(ii) Did the second arch originate from the same source as the second type II source, as suggested by Figure 6b?

If so, we have to postulate two different kinds of emission mechanisms in the shock front – presumably radiation from coherent plasma wave for the type II source and gyrosynchrotron radiation for the arch.

However, a problem still remains in identifying the emission mechanism of part of the arch (near its south-western end) which returned later to near the limb to a similar height to that of the earlier type II source.

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