1976SSRv...19..475B

GROUND-BASED SOLAR RADIO OBSERVATIONS OF THE AUGUST 1972 EVENTS

R. V. BHONSLE, S. S. DEGAONKAR, and S. K. ALURKAR

Physical Research Laboratory, Ahmedabad-380009, India

Abstract. Ground-based observations of the variable solar radio emission ranging from few millimetres to decametres have been used here as a diagnostic tool to gain coherent phenomenological understanding of the great 2, 4 and 7 August, 1972 solar events in terms of dominant physical processes like generation and propagation of shock waves in the solar atmosphere, particle acceleration and trapping.

The basic data used in this review have been collected by many workers throughout the world utilizing a variety of instruments such as fixed frequency radiometers, multi-element interferometers, dynamic spectrum analysers and polarimeters. Four major flares are selected for detailed analysis on the basis of their ability to produce energetic protons, shock waves, polar cap absorptions (PCA) and sudden commencement (SC) geomagnetic storms. A comparative study of their radio characteristics is made. Evidence is seen for the pulsations during microwave bursts by the mechanism similar to that proposed by McLean *et al.* (1971), to explain the pulsations in the metre wavelength continuum radiation. It is suggested that the multiple peaks observed in some microwave bursts may be attributable to individual flares occurring sequentially due to a single initiating flare. Attempts have been made to establish identification of Type II bursts with the interplanetary shock waves and SC geomagnetic storms. Furthermore, it is suggested that it is the mass behind the shock front which is the deciding factor for the detection of shock waves in the interplanetary space. It appears to us that more work is necessary in order to identify which of the three moving Type IV bursts (Wild and Smerd, 1972), namely, advancing shock front, expanding magnetic arch and ejected plasma blob serves as the piston-driver behind the interplanetary shocks. The existing criteria for proton flare prediction have been summarized and two new criteria have been proposed. Observational limitations of the current ground-based experimental techniques have been pointed out and a suggestion has been made to evolve appropriate observational facilities for solar work before the next Solar Maximum Year (SMY).

1. Introduction

Solar radio astronomy has become a major branch of solar physics involving measurements such as flux densities, structures of active centres, polarization with sufficient time, frequency and angular resolution throughout the radio spectrum. Considerable effort is being made observationally and theoretically to predict and understand solar flares and associated radio burst phenomena that involve particle acceleration in the solar atmosphere. Solar radio bursts of different spectral types provide 'signatures' of various types of interactions of plasma and magnetic field occurring at different heights from the solar surface. Both thermal and non-thermal mechanisms have been invoked to explain the generation of quiet as well as disturbed components of solar radio emissions. Excellent monographs and reviews have appeared in the literature dealing with observational and theoretical aspects (see, for example, Kundu, 1965; Zheleznyakov, 1970; Krüger, 1972; Wild and Smerd, 1972 and others).

The low frequency limitation in the ground-based solar radio observations arises from the transparency of the Earth's ionosphere while the high frequency cut-off is

Space Science Reviews **19** (1976) 475–510. *All Rights Reserved*
Copyright © 1976 *by D. Reidel Publishing Company, Dordrecht-Holland*

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

determined by tropospheric absorption. This implies that with ground-based observations one can explore the solar atmosphere between the lower chromosphere and the corona up to 2 to 3 $R_\odot$ from the photosphere. From a few solar radii to the distance of the Earth's orbit observations have recently been made using satellite borne radiometers.

The variable solar radio emission extending from millimetre to decametre wavelengths observable from ground, constitutes an important 'input' not only for the proper understanding of the flare processes but also can be used as a diagnostic tool to trace the subsequent time history of the disturbances that propagate through the interplanetary medium (Malitson *et al.*, 1973; Grigorijeva *et al.*, 1975). Another ground-based technique, namely, interplanetary scintillation (IPS) pioneered by Hewish *et al.* (1964) enables observations of the interplanetary disturbances and solar wind plasma in and outside the ecliptic plane (Dennison and Wiseman, 1968).

If one considers the energetics of solar flares that give rise to interplanetary shock waves, more than half of the total energy is carried away by them in the interplanetary medium at least to 1 AU and sometimes well beyond the Earth's orbit as evidenced by fluctuations in brightness of natural probes like comets (Hundhausen, 1972; Dryer, 1975). When one tries to identify an optical flare responsible for interplanetary shock waves, the causal relationship is not always unambiguous since it may happen that even a large Hα flare may not always produce such shock waves. It is well known that ground-based radio observations of Type II/Type IV bursts associated with an optical flare facilitates unambiguous identification of the flare responsible for the shock wave generation.

It is generally accepted that Type II (slow drift) bursts are generated by plasma oscillations caused by the outward passage of MHD shock waves through the corona and Type IV (broad-band continuum) burst by synchrotron mechanism of near-relativistic electrons trapped in a suitable magnetic field configuration. Besides, the observation of Type II and IV radio bursts is of vital importance to the prediction of proton flares and a variety of terrestrial effects such as polar cap absorption (PCA), geomagnetic and ionospheric storms, etc. The spectacular solar events observed in the early part of August 1972 provided a unique opportunity to study solar, interplanetary and terrestrial phenomena simultaneously.

This review article deals with the ground-based solar radio observations of the August 1972 events made at many observatories in different parts of the world. Section 2 briefly describes general characteristics of the events. In section 3 we give an account of radio observations of the slowly varying component (SVC) and flare events on 2, 4 and 7 August, 1972, designated as F-1 through F-4. We conclude this review with discussion and some suggestions for further work.

2. General Description of the August 1972 Events

It is well known that August 1972 events occurred on a grand scale and were the most significant of solar cycle 20 (1964 to 1975). Prior to August 1972, the solar cycle 20 appeared to be somewhat disappointing in comparison with the solar cycle 19 (1954 to 1964) since it did not produce major flare activity. The mean sunspot number at the peak of the solar cycle 20 was only about half ($\sim$105) of that observed ($\sim$200) in the previous cycle and hence, the flare activity was considerably less. However, in the declining period of the sunspot cycle 20, the solar activity during the first 12 days of August 1972 unexpectedly became very intense surpassing all the previous active periods in that cycle (Dodson and Hedeman, 1973).

These unusually intense events occurred in the McMath plage region 11976 which crossed the east limb of the Sun on 29 July, 1972 and went behind the Sun's disk crossing its west limb on 11 August, 1972. During its east–west transit across the visible disk of the sun from 29 July to 11 August with central meridian passage occurring on 4 August, a total of 67 solar flares, large and small, took place in the same active region 11976. Out of these, 56 were of class C, 7 of class M and 4 of class X according to the classification based on X-ray flux measurements by satellites. Optically and from 10.7 cm radio flux measured at the ground, four flares (designated F-1 through F-4) were outstanding amongst the numerous ones observed during this period. Many of these large flares lasted for more than two hours optically and were composed of a number of smaller flares in succession.

This was the first opportunity when extensive observations of these spectacular solar events during August 1972 were made by all available means such as spacecraft, balloons, lunar-based instruments, and rockets in addition to numerous ground-based solar observations both in optical and radio regions. There are reports of large-scale terrestrial effects caused by these solar events, particularly on the radio wave transmission from very low frequency (VLF) to ultra-high frequency (UHF) bands, causing extensive disturbances and fadeouts of VHF transmissions over long distances (Lincoln and Leighton, 1972; McKinnon, 1972).

The proton events associated with the large solar flares F-1 through F-4 caused intense polar cap absorptions (PCA) for long durations, thus blocking all radio communication via, as well as to the Arctic and Antarctic regions. The fluctuating geomagnetic field during the geomagnetic storm on 4 August was so great that it induced quasi – DC ground currents of 200 amperes which, in turn, entered power system transformers and transmission lines causing difficulties in the normal power supply in the USA and Canada (Lincoln and Leighton, 1973).

It is interesting to note that from the magnetic field configuration of the McMath region 11976 and the large ratio of 3 cm to 8 cm radio flux of the slowly varying component (SVC) from the Sun on 31 July, 1972, a successful prediction of the X-ray events on 2 August and the proton event on 4 August was made well in advance by some stations. However, based on the same criteria, the proton flare on 7 August could not be forecast, though it was also very intense (Simon, 1973; Tanaka and Enomé, 1973). This calls for critical reappraisal of the presently used criteria to predict such events.

Though the four major events, F-1 through F-4, are studied in detail in this review,

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

it is seen that some similarities in radio, X-ray and proton flares exist in the first two events (F-1 and F-2) and in the other two (F-3 and F-4) but remarkable differences in those features are seen between the former two and the latter two events (Hakura, 1975). Considering that all the flares originated from the same active region 11976 within a period of seven days, the differences in radio, X-ray and proton characteristics in the two groups of flares, need to be understood in terms of the physical processes.

It is pertinent to mention that the measurements made at Ahmedabad during August 1972 of the total Faraday rotation occurring between the burst-source in the solar corona and the Earth with the help of a two-bandwidth (7.5 and 12.5 kHz) time-sharing polarimeter at 35 MHz, showed its mean value was of the order of 10^3 radians. Of this, about 10% was attributed to the ionosphere and still less to the interplanetary medium. Thus, about 85–90% of the total Faraday rotation must occur near the burst-source in the solar corona. It was suggested that such low values of the Faraday rotation could be explained on the basis of generation of Type III burst primarily at the second harmonic of the local plasma frequency (Bhonsle and Mattoo, 1974).

3. Observations

Preliminary compilation of data during 26 July–14 August, 1972 was brought out promptly by Lincoln and Leighton (1972) and by Mckinnon (1972) as these events were exceptional and aroused world-wide interest. More comprehensive data reports from various workers have been collected in reports on 'August 1972 Solar–Terrestrial Events' in three parts and were brought out within one year by Coffey (1973).

Table I summarizes the relevant information of the solar events F-1 through F-4. It can be seen from Table I that the F-2 event produced maximum 10 cm radio peak flux of 10 000 f.u. (1 f.u. $= 10^{-22}$ W m^{-2} Hz^{-1}) though optically it was a 2B flare. Besides, there were other flares of importance 2B in that period which produced 10 cm radio peak flux as low as 55 f.u. This suggests that the energetics of these flares were not identical. It should be noted that each flare has its own peculiarities and hence, needs to be investigated individually.

Detailed information on X-ray, γ-ray and energetic charged particle emissions is available during these events. Several interplanetary shocks have been noted and extremely large solar wind speeds (>1000 km s^{-1}) occurred on several occasions in this interval. The proton flux in the interplanetary medium was highest on record; ground-based neutron monitors recorded two major flare-associated ground level enhancements (GLE) and a major Forbush decrease; the geomagnetic storm of 4–6 August was a great one and that of 9 August was the third largest of the year; the accompanying ionospheric and auroral phenomena were correspondingly severe and complex with at least two polar cap absorption events (Hakura, 1975).

3.1. THE SLOWLY VARYING COMPONENT (SVC) OF THE SUN

The daily variation of microwave SVC at 3 cm is shown in Figure 1. Also shown in

TABLE I

Characteristics of four major flares (F-1 to F-4) in August 1972

	Radio burst					Optical flare		Proton burst					
	Microwave impulsive burst and Type IVμ				Type II	Peak time	Imp.	Pioneer 9			Earth		
	Onset time	Peak time	Peak freq.	Peak flux dens. $\times 10^3$ f.u.				Flare mer. dist.	Onset time	Delay time	Flare mer. dist.	Onset time	Delay time
	(UT)	(UT)	(GHz)		(UT)	(UT)			(UT)	(h)		(UT)	(h)
F-1	2/0310	0330	10	2	0345								
								W14	2/05	2	E34	2/10	7
	0348	0405	4	3	NO	0355	1B						
F-2	2/2035	2045	10	6	2040	2058	2B						
								W19	2/22	1.5	E28	3/03	6.5
	2140	2145	4	10	2146								
F-3	4/0621	0626	20	25	0630	0639	3B	W39	4/07	1	E08	4/08	2
												GLE	
												4/13	7
F-4	7/1515	1522	20	27	1521	1534	3B	W82	7/16	1	W37	7/16	1
												GLE	
												7/1540	0.6

1 f.u. $= 10^{-22}$ W m^{-2} Hz^{-1}

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

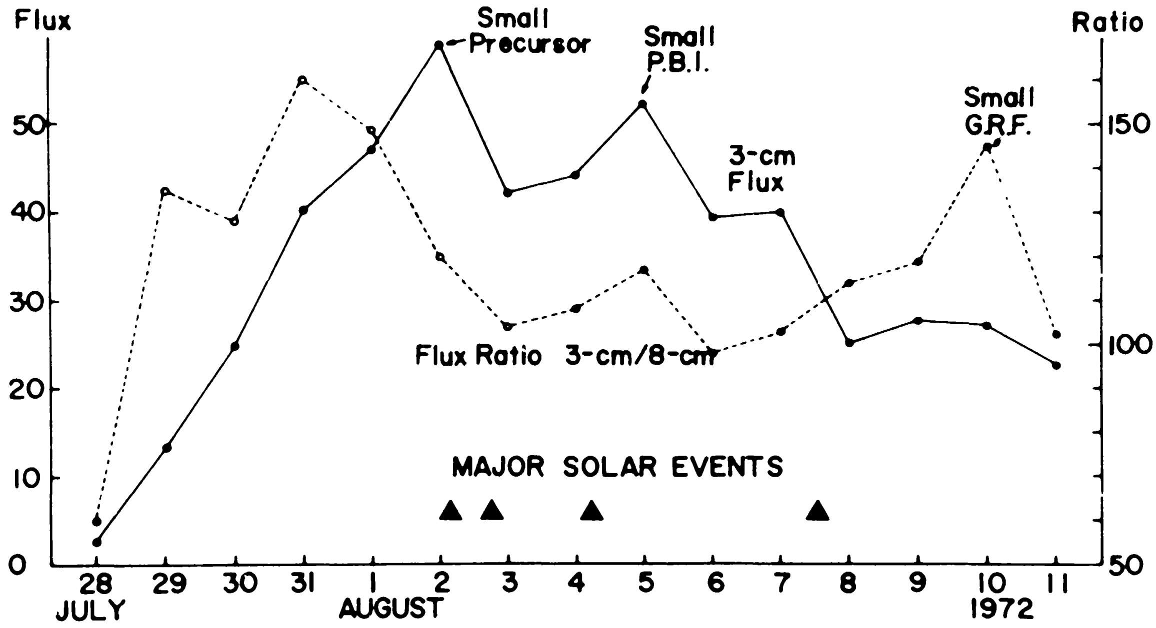

Fig. 1. Daily variation of microwave SVC at 3 cm and the ratio of radio flux at 3 cm to that at 8 cm, at Toyokawa (Tanaka and Enomé, 1973).

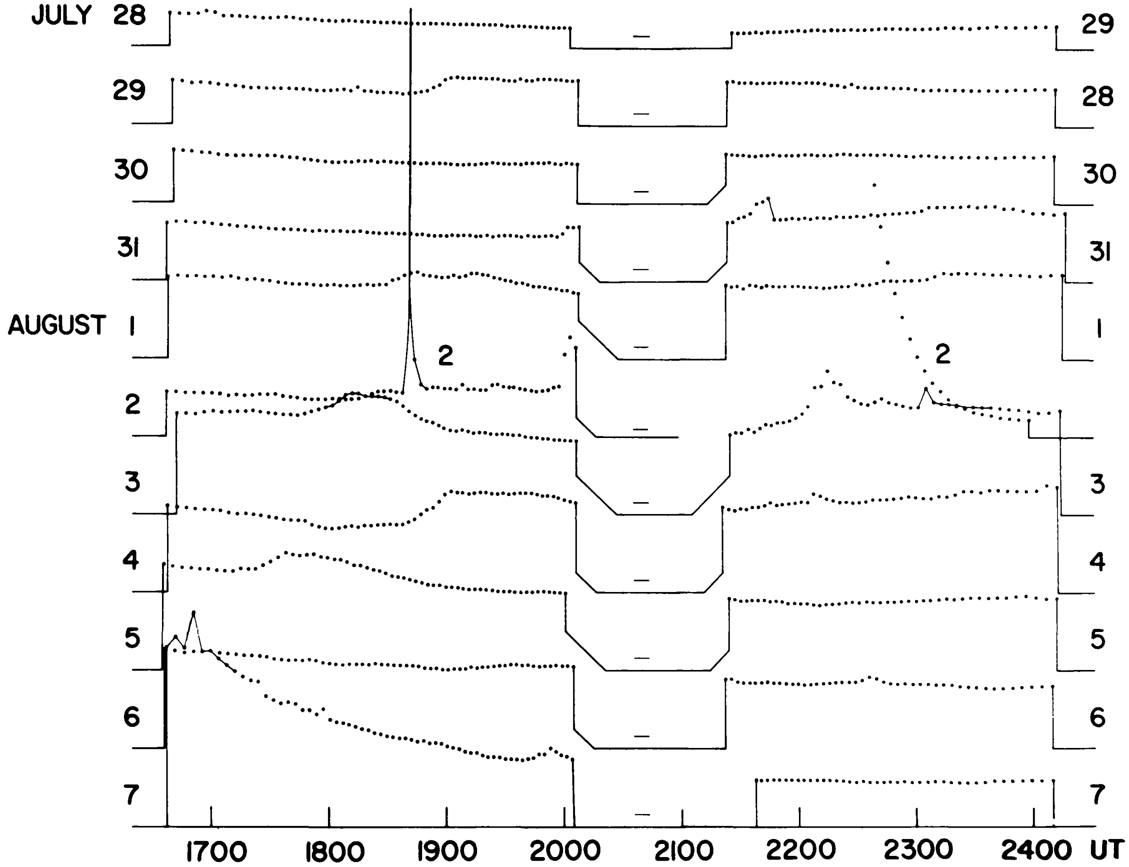

Fig. 2. Peak flux values of McMath region 11976 extracted from Stanford University 9.1 cm East–West scans. Horizontal dashes at 2040 UT show estimated quiet Sun level compared to cold sky level. On 2 August the event which occurred at 1840 UT went off-scale (Graf, 1975).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv....19..475B

Figure 1 is the ratio of radio flux at 3 cm to that at 8 cm from 28 July to 11 August. The ratio is seen to be greater than 1 most of the time in this period. A high ratio of 3 cm to 8 cm flux of SVC is known to be favourable for the occurrence of proton flares (Tanaka and Enomé, 1973).

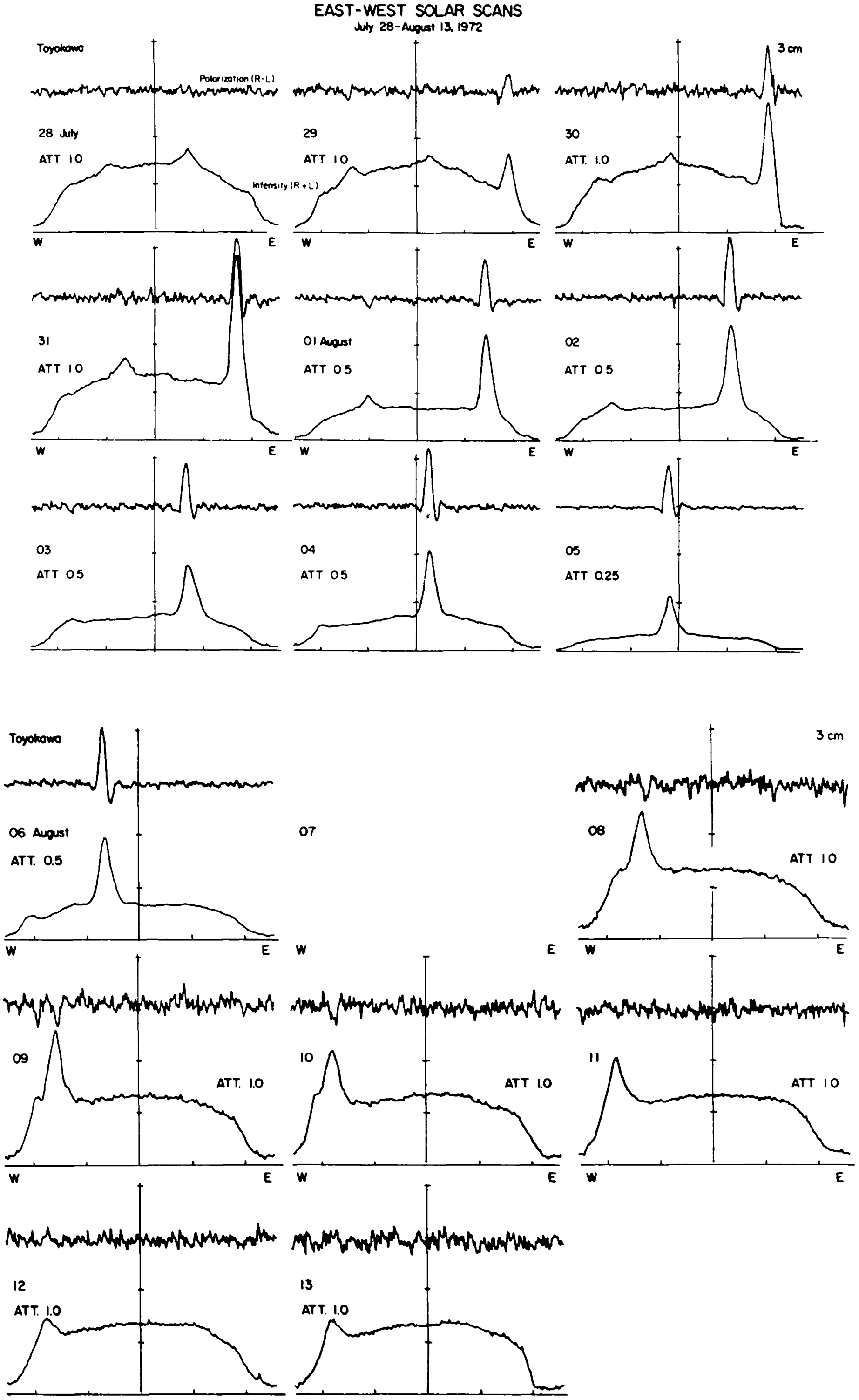

Fig. 3. East–West solar scans of $(R-L)$ and $(R+L)$ at 3 cm from 28 July to 13 August, 1972, at Toyokawa (Tanaka and Enomé, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

Day-to-day variation of peak flux values of McMath region 11976 from 28 July to 7 August, 1972 are depicted in Figure 2 as observed by 9.1 cm radio heliograph at Stanford University (Graf, 1975). Note the event on 2 August at 1840 UT which went off-scale on the record. The radio output from this region has displayed significant changes from day-to-day, particularly on 2 to 7 August except on 6 August. The

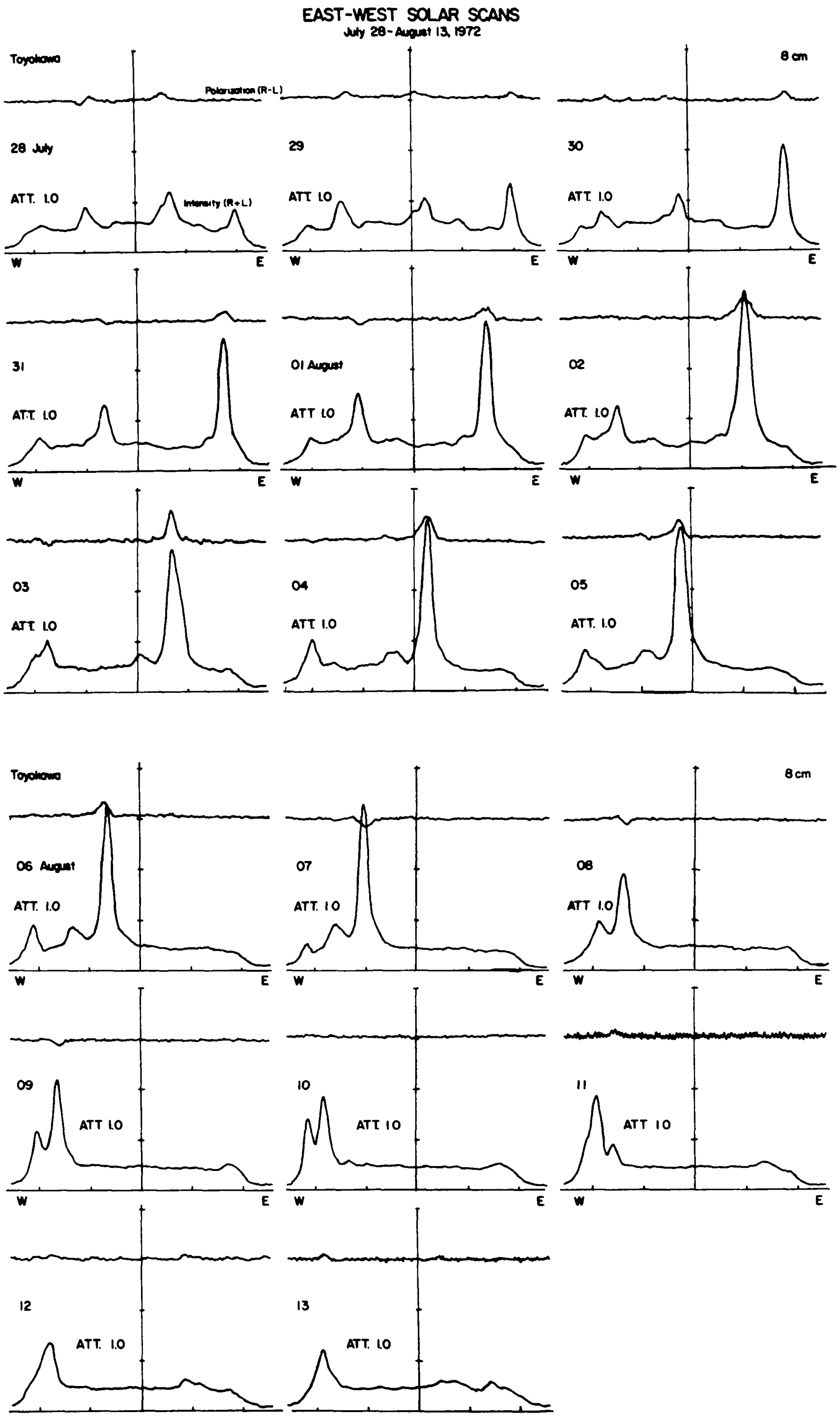

Fig. 4. East–West solar scans of $(R-L)$ and $(R+L)$ at 8 cm from 28 July to 13 August, 1972, at Toyokawa (Tanaka and Enomé, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

intensity fluctuations at 9.1 cm of individual centers of activity as shown in Figure 2 could be used as one of the indications of ensuing proton flare activity, if one considered only those periods when the intensity remained elevated for several hours.

Brightness or intensity ($R+L$) distribution and polarization ($R-L$) distribution of the Sun on 3 cm and 8 cm from 28 July to 13 August, 1972 are shown in Figures 3 and 4 respectively as observed by high resolution radio interferometers at Toyokawa (Tanaka and Enomé, 1973). These figures show that a proton flare-producing centre has a definite feature of circular polarization at 3 cm across the active region. It can be seen from ($R-L$) records from 29 July to 6 August, 1972 particularly at 3 cm that the active region 11976 had a polarization distribution having right-handed polarized central peak and left-handed polarized sub-peaks on either side. They have classified this type of polarization configuration as the *P*-type and have shown it to be very favourable for proton flare occurrence (Tanaka and Enomé, 1973). Although this finding is significant we feel that two-dimensional heliographic polarization distribution would be preferable as it would reveal reversal of polarity occurring along any direction across the solar disk and thus help in more consistent proton flare predictions.

Figure 5 shows the contour map of percent flux in frequency-time domain from 25 June to 1 September, 1972 as reported by Decker and Wefer (1973) from the fixed frequency radiometers operated at the Sagamore Hill Solar Radio Observatory of the Air Force Cambridge Research Laboratories (AFCRL) and the Pennsylvania State University Radio Astronomy Observatory (PSURAO) covering the frequency range from 245 MHz to 15.4 GHz. The interval from 26 July to 14 August, 1972 is indicated by the black line at the top. It may be noted that due to the region 11976, considerable enhancement both in frequency and time is evident during its disk passage in August

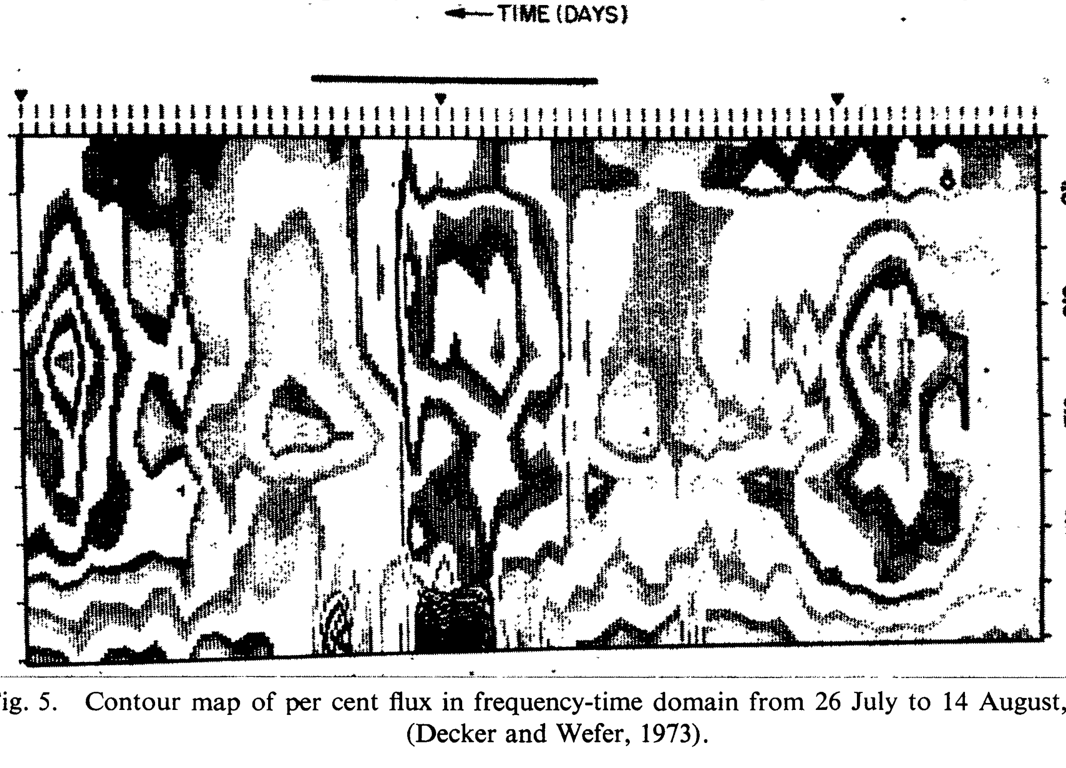

Fig. 5. Contour map of per cent flux in frequency-time domain from 26 July to 14 August, 1972 (Decker and Wefer, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

1972 as compared to its previous and following disk passages. Further, in addition to the enhancement of solar radio emission towards high frequency side (~10 GHz), long lived intense emission was observed in the metre wavelength region in August 1972 (dark shaded portion at the bottom of the Figure 5). This implies existence of closed magnetic field loop structures up in the corona (~0.5 to 1 $R_\odot$) which permits trapping of electrons responsible for the generation of the intense metre wavelength radiation by gyrosynchrotron mechanism. The enhanced metre wavelength activity simultaneously with the large microwave slowly varying component (SVC) appears to favour the occurrence of proton flares.

The high resolution drift curves taken simultaneously with 1.5 and 0.5 min arc fan beams by Covington and Bell (1973) and shown in Figure 6 are useful in other respects, the former to provide an estimate of the flux within a given strip and the latter to reveal the structure and the position of the regions on the disk. Figure 7 shows the daily observed flux at 2800 MHz from radio sources associated with region 11976 and follower and from all other radio regions in this interval. The broken line shows the assumed cosine curve with maximum when the region 11976 was near central meridian passage (CMP) and it can be seen that it fits in well with the rising and falling parts of the total flux from the two sources, with the peak coinciding on 4 August. The flattening of the observed flux at the peak may be an effect on SVC of the flares during this period.

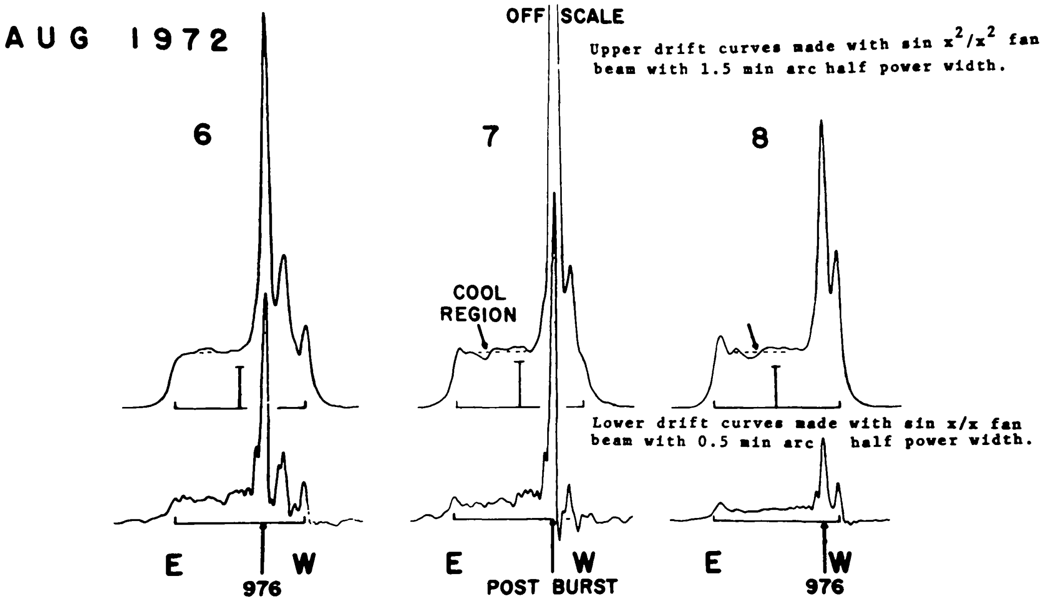

Fig. 6. Simultaneous high resolution drift curves taken on 6, 7 and 8 August, 1972 (Covington and Bell, 1973).

3.2. Radio observations of flares F-1 through F-4

3.2.1. *F-1 Flare of 2 August, 1972*

This major flare of importance 1B occurred in the region 11976 at 13°N and 35°E on the solar disk at 0316 UT, reaching its maximum at 0355 UT on 2 August. The rio-

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

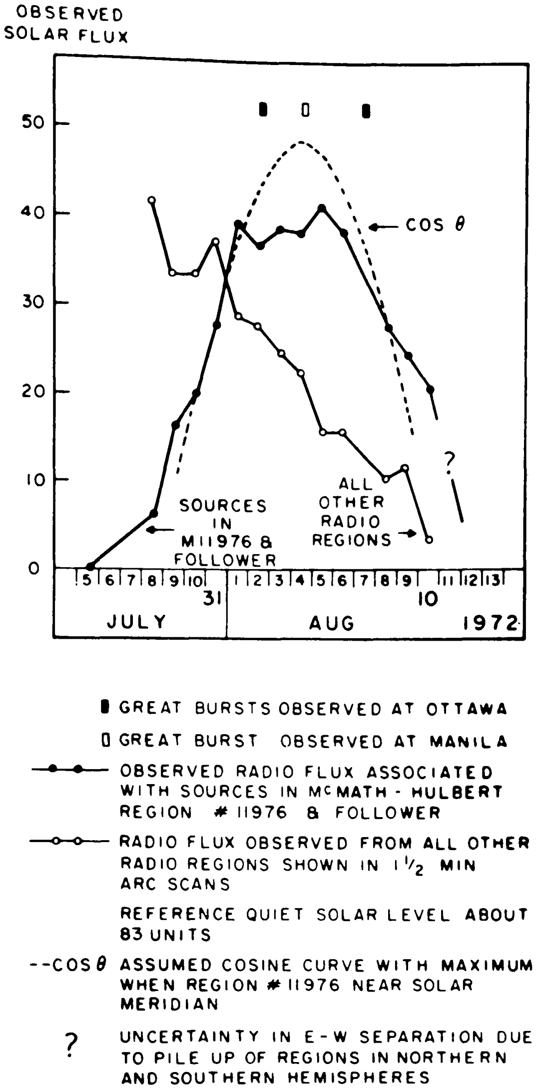

Fig. 7. Observed daily flux at 2800 MHz from radio sources associated with McMath region 11976 and follower. Open circles show flux values from all other radio regions (Covington and Bell, 1973).

meter operating at 25 MHz at Ahmedabad, India recorded the SCNA and the radio noise storm (Figure 8) at this time (Bhonsle *et al.*, 1973). The radio spectral information is available in a frequency range 10 MHz to 35 GHz from 13 single-frequency observations at three Japanese stations (Yamashita *et al.*, 1974), a Philippine Station (Castelli *et al.*, 1973), from a swept frequency (10 MHz to 1000 MHz) radio spectrograph and the 80 MHz radioheliograph at Culgoora, Australia (Cole, 1973). Figure 9 shows the synthetic spectrum of radio burst inferred from the above mentioned observations from 0200 to 0600 UT. The synthetic spectrum shows the complex nature of the radio bursts having very intense emission ($\sim$3200 f.u.) at 0328 and 0405 UT near 10 GHz coinciding with the peak in hard X-ray and soft X-ray bursts respectively. As shown in Figure 10, a large radio outburst associated with region 11976 began with two intense groups of Type III bursts between 0243 and 0250 UT well before preburst phase soft X-ray enhancement beginning at 0254 UT indicating electron acceleration

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

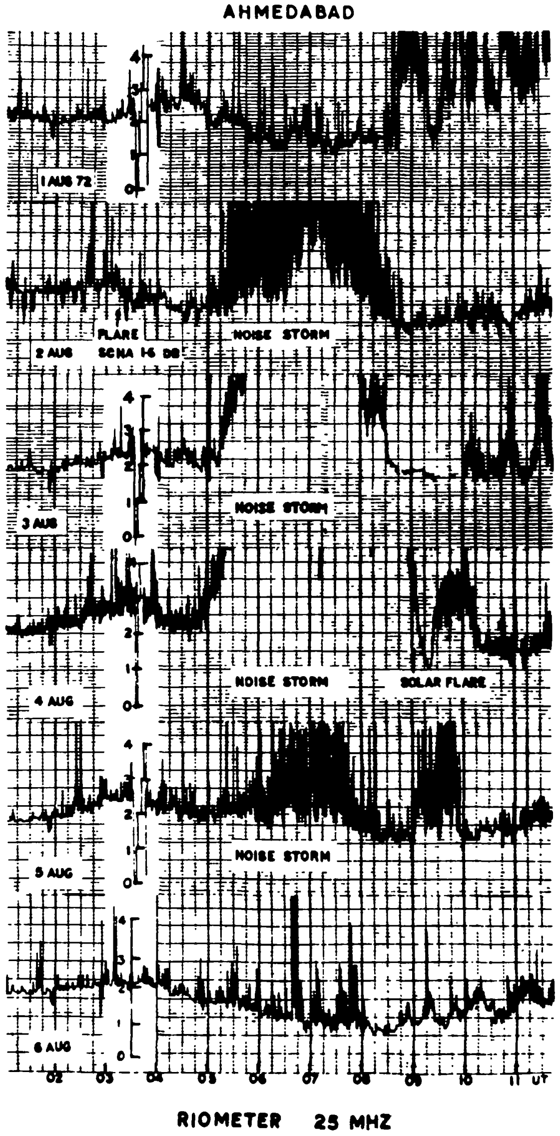

Fig. 8. Riometer records at 25 MHz at Ahmedabad from 1 to 6 August, 1972 showing SCNA and intense solar noise storm (Bhonsle *et al.*, 1973).

in the solar atmosphere (Cole, 1973). Type I metric storm in the frequency range of 100–200 MHz was already in progress which extended at 0312 UT in 30–100 MHz range for about 2 min resembling Type V burst. This implies acceleration as well as trapping of additional electrons which gave rise to smooth continuum radiation. Incidently, at about the same time a very long duration shortwave fade out began which continued until 0500 UT. This involves considerable X-ray activity that gave rise to SIDs. Further, from careful examination of the dynamic spectra of this event made at Culgoora, one can see the radio emissions spreading both on the higher and lower frequency side of 100–200 MHz which could possibly be attributed to some explosive event around 0326 UT. This is substantiated by Hα observations from Palehua, Hawaii which showed maximum phase at 0327 UT for the approximate position 11°N, 37°E (Solar Geophysical Data, NOAA, Boulder, 1972). The extension

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

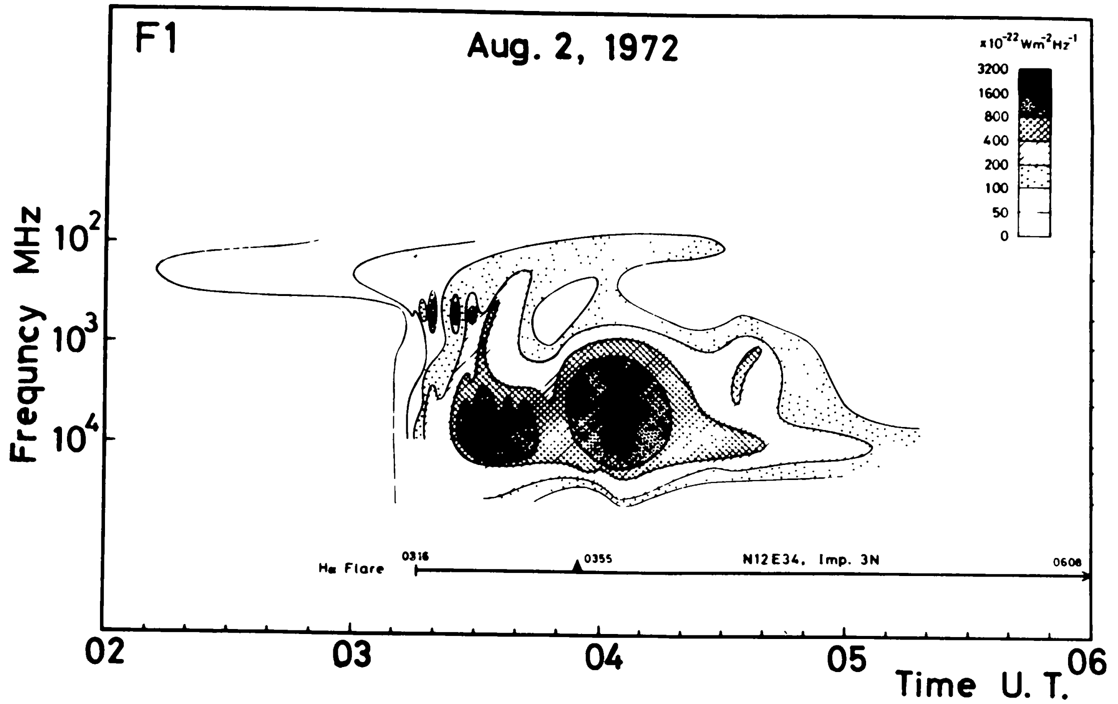

Fig. 9. Synthetic spectrum of the 2 August, 1972 event (F-1) derived from fixed frequency data (Yamashita *et al.*, 1974).

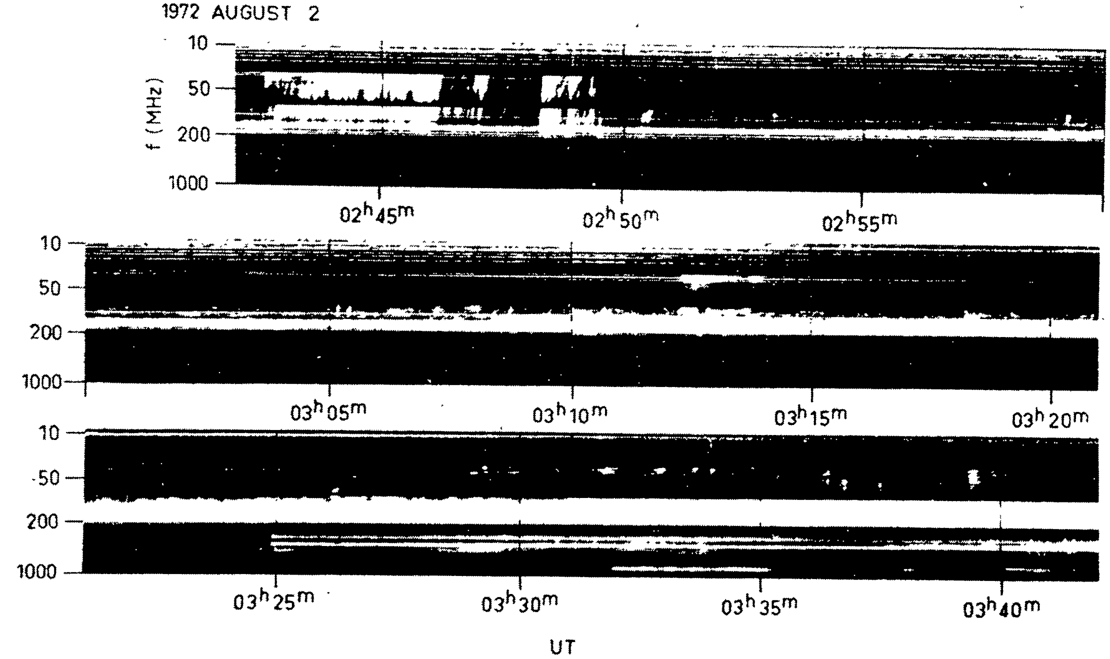

Fig. 10. Dynamic spectrum of the 2 August, 1972 event observed at Culgoora (Cole, 1973).

to frequencies lower than 100 MHz does display some Type II-like drifting features of few minutes duration starting 0326 UT which may possibly be related to sudden commencement (SC) geomagnetic storm starting at 0119 UT on 4 August. This is at variance with Pintér's suggestion (1973), namely, the Type II radio bursts from 0345 to 0407 UT deduced from Culgoora spectrogram was responsible for the SC of the geomagnetic storm at 0119 UT yielding 1100 km s^{-1} speed for the Type II shock wave.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

From the synthetic spectra shown in Figure 9, near about 0327 UT, it can be seen that the frequency of maximum intensity shifted from 10 GHz to 500 MHz in a minute or two, thereafter the frequency-drift from 500 to 100 MHz took about an hour. Pintėr (1973) has probably identified the latter as Type II metre wavelength burst. It is likely that the real disturbance culminating in Type II burst may have started at 10 GHz at about 0327 UT. By and large, the particles remained confined for a period more than an hour in the lower chromosphere as is evident from the synthetic spectrum.

Another great radio burst at 1837 UT was observed at Sagamore Hill by AFCRL, which rose to its peak value of 990 f.u. at 5 GHz (peak flux 16.6 f.u. at 606 MHz to 810 f.u. at 35 GHz) in less than two minutes (Castelli *et al.*, 1973). This event had an extremely hard spectrum (which means large intensity at higher frequencies and weak at lower frequencies). The 24–48 MHz interferometer at Sagamore Hill recorded a continuum event from 1200 to 2024 UT on 2 August. The great burst at 1837 UT

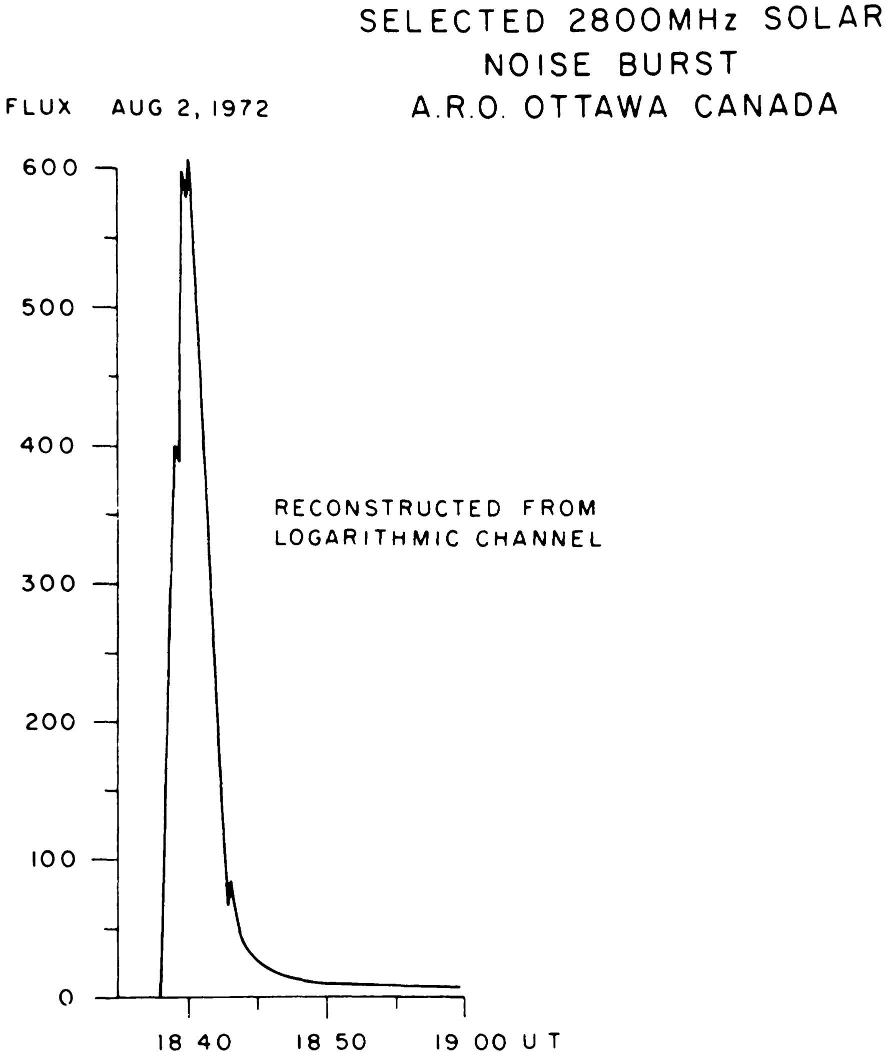

Fig. 11. Impulsive, narrow profile component of great radio burst of 2 August, 1972 at ARO Ottawa (Covington and Bell, 1973).

1976SSRv...19..475B

originated at the site of the Hα flare of importance 1B which took place at 1839 UT at 13°N and 25°E on the sun. The radio burst at 2800 MHz at 1838 UT shown in Figure 11 was recorded at ARO, Ottawa, Canada, with peak flux of about 600 f.u. at 1841 UT (Covington and Bell, 1973).

3.2.2. *F-2 Flare of 2 August, 1972*

This was one of the largest solar radio events which was associated with the flare of importance 2B at 13°N, 28°E and had a precursor of 40–50 min duration having intensities of several hundred flux units. The burst was impulsive and complex, having three maxima. The maximum peak flux of 190 000 f.u. occurred at 410 MHz at 2141.2 UT. The radiometer records from Sagamore Hill from 1930 to 2330 UT at various frequencies from 35 GHz to 245 MHz are shown in Figures 12a, 12b, 12c. It can be seen that large spikes or pulsations denoting intense oscillations within the burst (period ~ 1 min) appear at 1415 MHz and at still lower frequencies. These

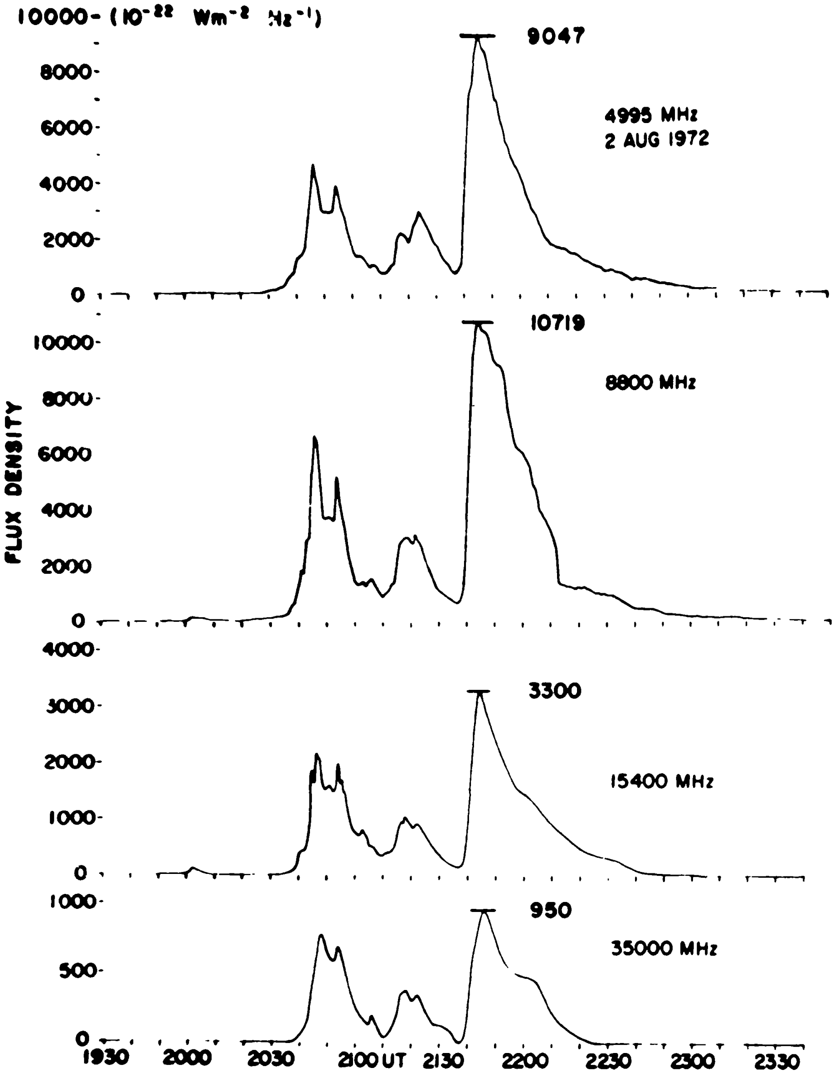

Fig. 12a. Great Burst on 2 August, 1972 at Sagamore Hill, from 35 GHz to 4995 MHz. Three distinct peaks are seen with fine structure (Castelli *et al.*, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

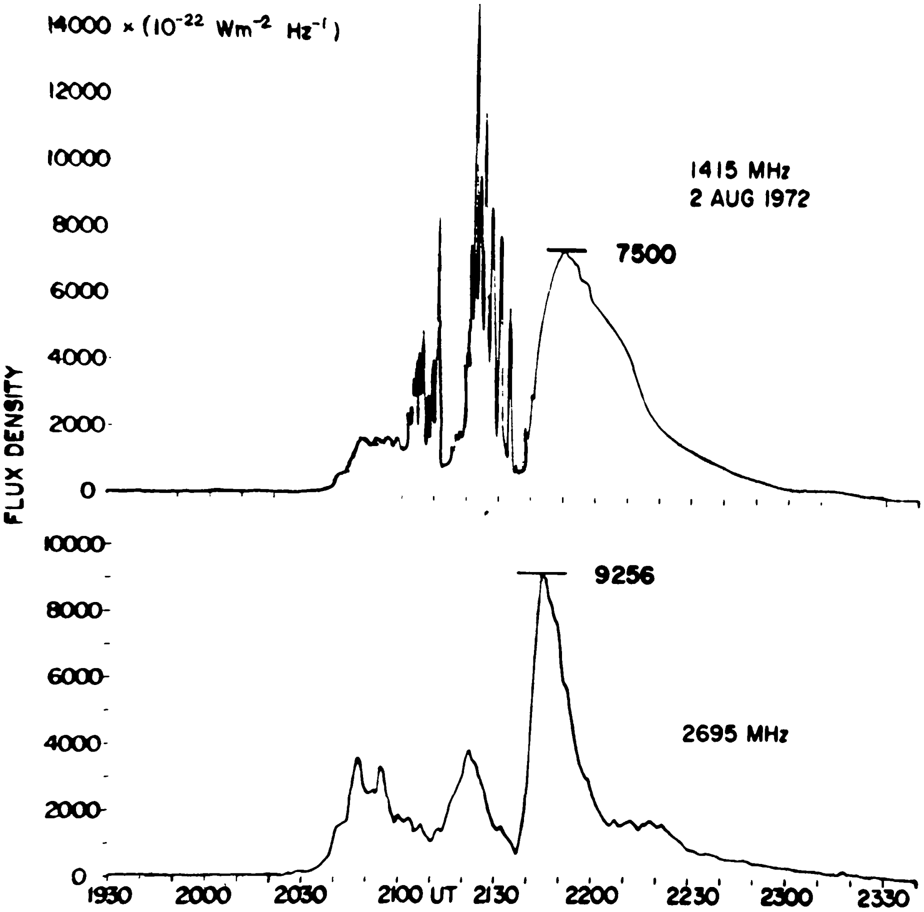

Fig. 12b. Great Burst on 2 August, 1972 at Sagamore Hill, at 2695 and 1415 MHz. Note the pulsations on 1415 MHz record between 2040 and 2140 UT (Castelli *et al.*, 1973).

pulsations appear to build up prominently at 1415 MHz in the first two bursts occurring between 2030 and 2140 UT but they appear in all the three bursts at still lower frequencies. McLean *et al.* (1971) have shown that the flares with pulsations tend to be proton flares. Pulsations at frequencies greater than 1 GHz are analogous to pulsations observed in Type IV emission at metre wavelengths, which are caused by MHD shock waves propagating along the magnetic flux loops (Fokker, 1960; Rosenberg, 1970; Chiu, 1970). A similar argument can be extended to microwave bursts associated with major flares, which occur at heights closer to the solar surface where magnetic field strength is high. It is likely that the fluctuations which are seen at 1415 MHz on 2 August between 2030 and 2040 UT are an evidence of pulsations occurring at the microwave frequencies according to the mechanism proposed by McLean *et al.* (1971). Why the pulsations are not seen over a wide frequency range could be due to the finite volume over which Fermi-like acceleration mechanism within a flux tube takes place (Wild and Smerd, 1972).

A Type II burst was also observed at Sagamore Hill from 36 to 48 MHz from 2145.7 to 2149.5 UT. The decametre continuum broke into Type IV burst at 2024 UT and slowly increased in intensity at 2045 UT. It declined to a continuum of long duration on 2 and 3 August and increased again in strength to a Type IV on 3 and 4

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

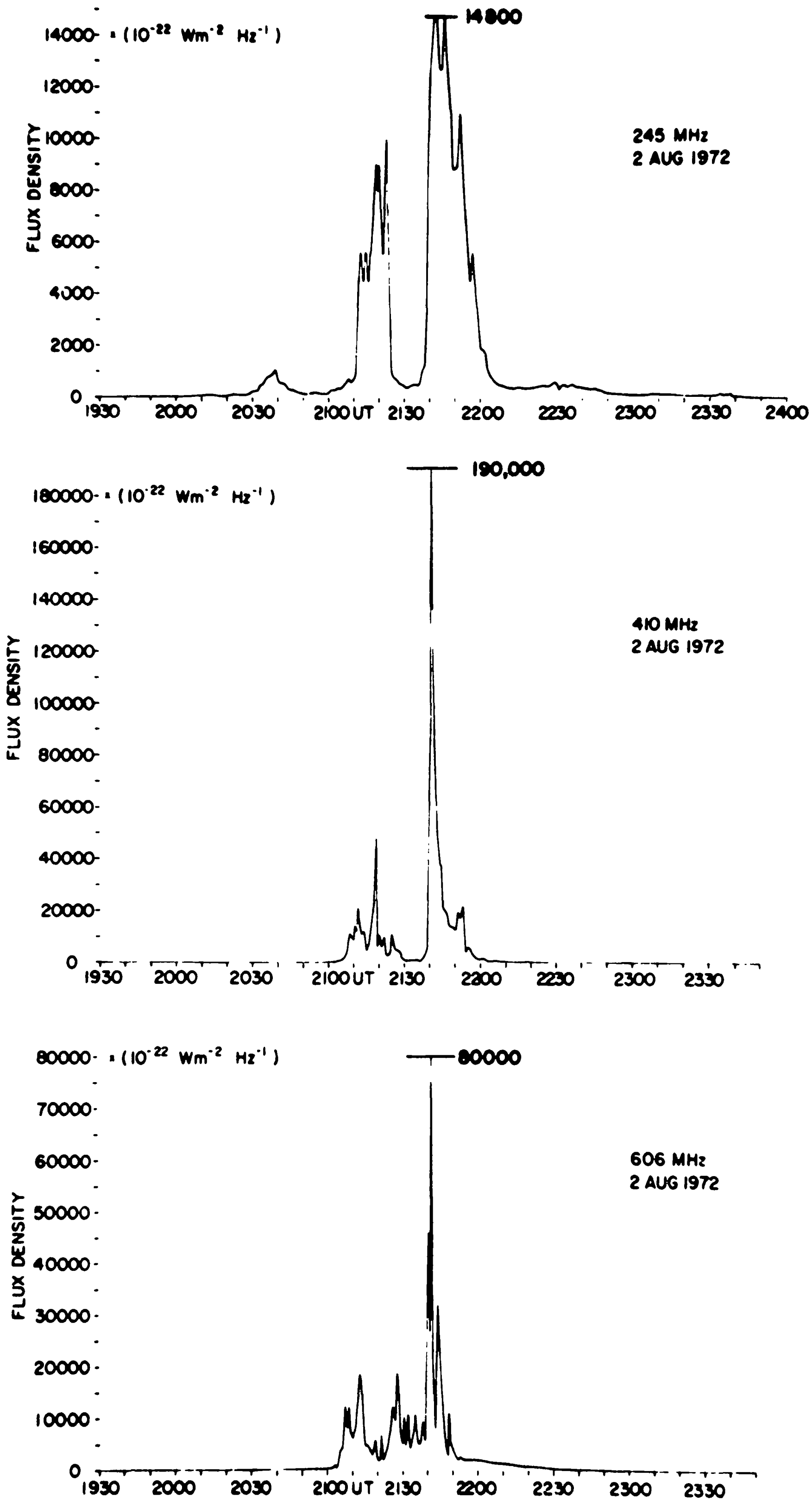

Fig. 12c. Great Burst on 2 August, 1972 at Sagamore Hill, at 606, 410, and 245 MHz. Note the strong pulsations on all the three frequencies. Highest flux density (190 000 f.u.) occurred at 410 MHz (Castelli *et al.*, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

August and back again to a continuum. A pronounced increase in intensity to Type IV occurred on 4 August at 0635 UT, which lasted for the next 5 or 6 hours and afterwards a continuum persisted up to 1800 UT on 5 August (Castelli *et al.*, 1973). The three impulsive radio bursts at 2800 MHz recorded at Ottawa are shown in Figure 13 (Covington and Bell, 1973). The peak flux of 2800 MHz at 2200 UT was 9700 f.u.

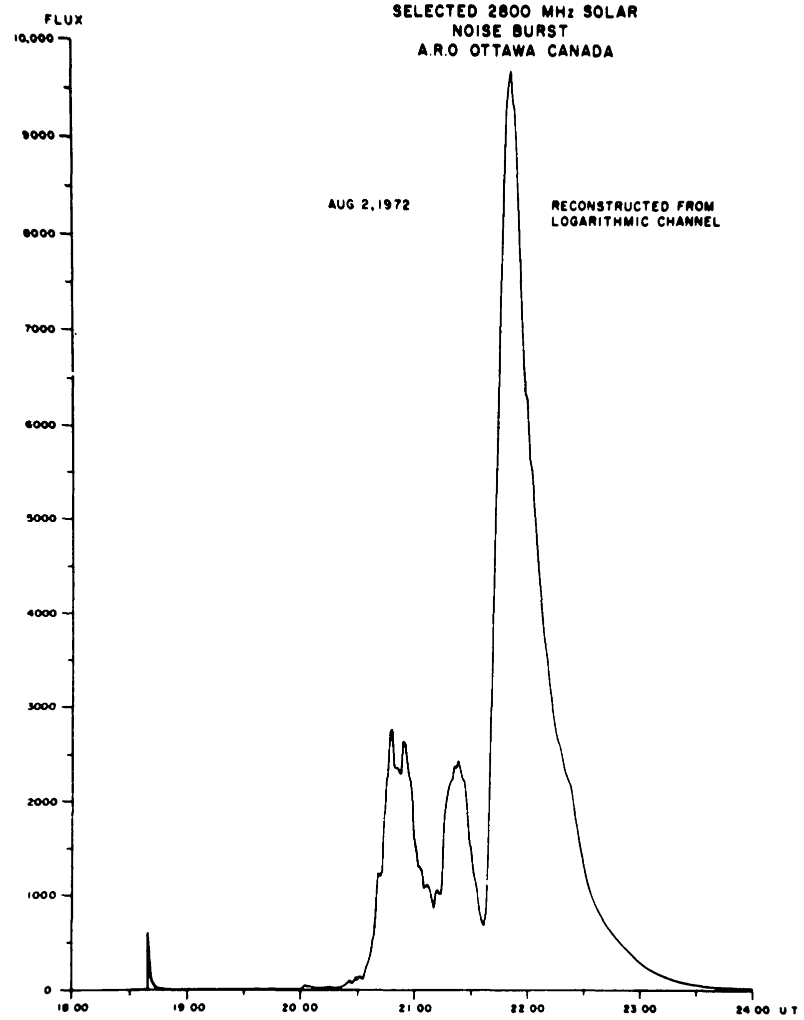

Fig. 13. Profile of burst on 2 August, 1972 from 1800 to 2400 UT taken at 2800 MHz, ARO, Ottawa. The initial narrow-profile burst at 1840 UT is followed by 3 broad profile impulsive bursts (Covington and Bell, 1973).

The synthetic spectrum of radio bursts of this event is shown in Figure 14 (Yamashita *et al.*, 1974). In the case of this flare, intense impulsive radio emissions were observed at 10 GHz and 200 MHz nearly 10–15 min before the maximum phase of the Hα flare (Hakura, 1975). A minimum intensity was observed around 1 GHz. Thus, this flare satisfies the criterion of U-shaped spectrum which has been successfully used by AFCRL to predict proton events. A Type II burst was observed at 2040 UT in 30–100 MHz band which possibly indicates the passage of a shock wave

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

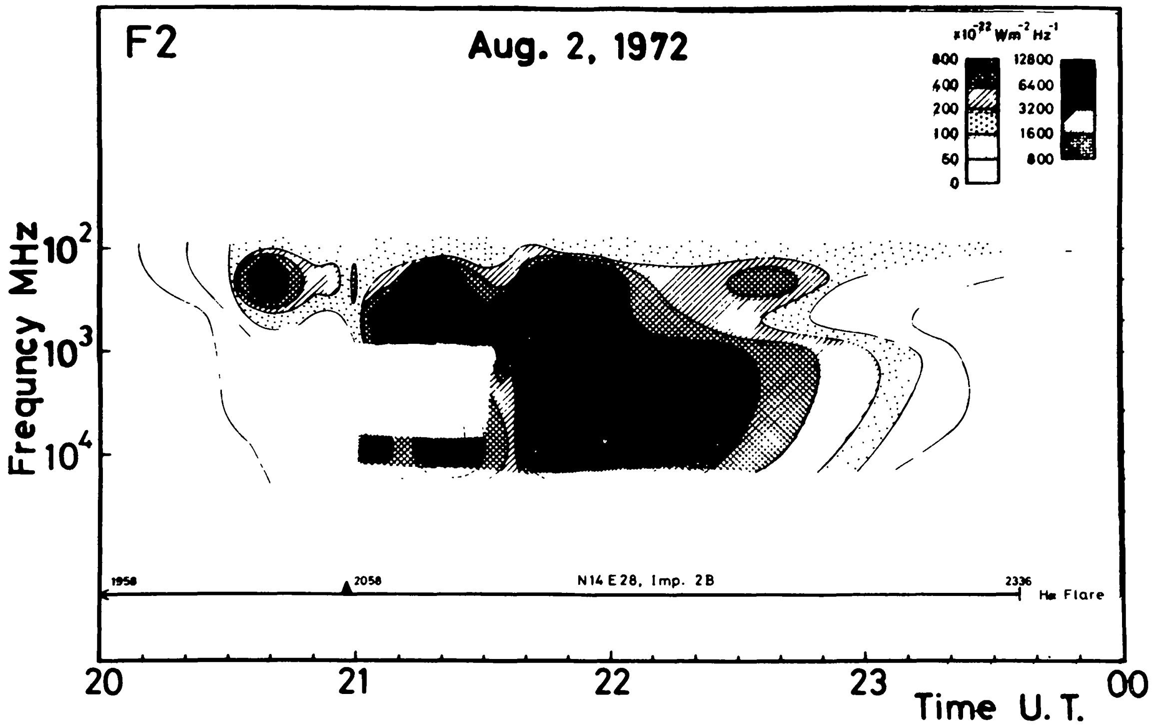

Fig. 14. Synthetic spectrum of the 2 August, 1972 event (F-2) (Yamashita *et al.*, 1974).

with the velocity of the order of 1000 km s^{-1} through the outer corona (Maxwell, 1973) which caused SC geomagnetic storm at the Earth at 0221 UT on 4 August. A second enhancement of radio emission was characterized by very shallow U-spectrum compared to the previous one. This is probably associated with another explosive event since one more Type II burst was reported by Castelli *et al.* (1973) at 2145 UT by a 24–48 MHz interferometer. One can clearly see that the F-2 event, which started with particle confinement in chromospheric and coronal regions, merged into one region after the second explosive event at 2145 UT and continued thereafter as broadband Type IV continuum storm.

3.2.3. *F-3 Flare of 4 August, 1972*

One of the largest solar radio and X-ray events in the solar cycle 20 occurred in association with a bright flare in Hα of importance 3B at 0617 UT at 14°N, 09°E on 4 August reaching maximum at 0640 UT. A synthetic spectrum of the radio bursts is shown in Figure 15 (Böhme and Krüger, 1973), which shows that initially it had extremely wide frequency coverage from 71 GHz down to 23 MHz and lower. It appears that the duration of Type IV radiation is a function of frequency; at higher frequencies duration is relatively short compared to that at lower frequencies. The time of an outstanding flash phase started at 0621 UT in the microwave region, reaching peak flux of 25 000 f.u. at 20 GHz at 0626 UT (Tanaka and Enomé, 1973; Böhme and Krüger, 1973). The flare which started at 0621 UT accelerated electrons that were confined at various levels in the solar atmosphere as is evident from the

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

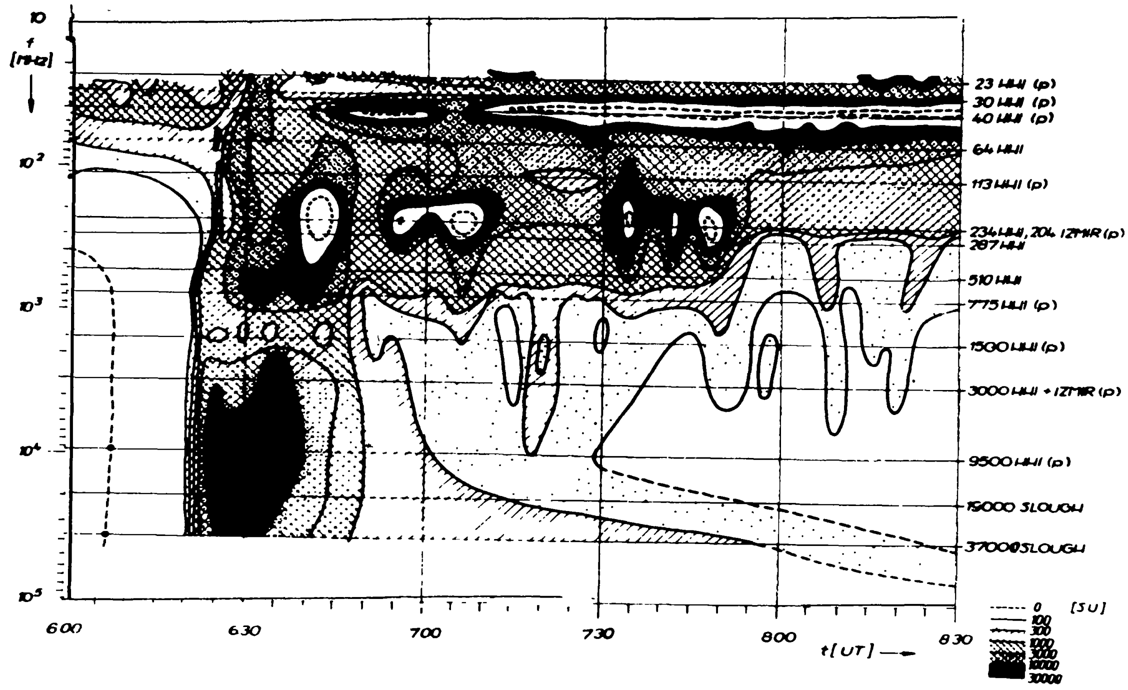

Fig. 15. Synthetic spectrum of the 4 August, 1972 event (F-3) (Böhme and Krüger, 1973).

intense broad band peaks centered around 10 GHz, 290 MHz and 40 MHz. The peaks at the latter two frequencies underwent modulation in intensity with time presumably due to fresh injections of electrons and Fermi-like acceleration caused by MHD shock waves produced by subsequent multiple flares. Outstanding Type IVμ and IV$_{\mathrm{dm}}$ radio bursts followed the impulsive phase with peak flux 37 000 and 76 000 f.u. occurring at 10 GHz and 1 GHz respectively at 0636 UT. Pulsations modulating continuum emission in Type IV$_{\mathrm{m}}$ were also observed with periods 100–300 s lasting more than 6 h (Akinyan *et al.*, 1975). It seems reasonable to think that these subsequent flares might have stretched the magnetic field loops such that the conditions for trapping corresponding to 10 GHz region were no longer favourable. This explains why burst radiation centred around 10 GHz was of shorter duration compared to that at decimetre and metre wavelengths. The emission of γ-ray lines was observed for the first time in cycle 20 peaking at 0628 UT during the flash phase (Chupp *et al.*, 1973) implying that the solar protons were produced at the very beginning of the flash phase. The time profiles of millimetre radio bursts observed at Slough on 4 August, on 9.4, 19, 37 and 71 GHz are shown in Figure 16. Their flux densities were 14 370; 25 000; 13 780 and 11 500 f.u. respectively. Small and rapid oscillations are superimposed on the major events of 4 August on 9.4, 19 and also on 37 GHz burst profiles (Croom and Harris, 1973).

Badillo (1973) has observed at Manila observatory at 0621 UT Type II bursts at decametre wavelengths (24–48 MHz) just prior to the pulsation period at decimetre wavelengths. Figure 17 shows the fixed frequency burst profiles observed at Manila from 0620 to 0650 UT on 4 August. It may be noted that the higher frequency records

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

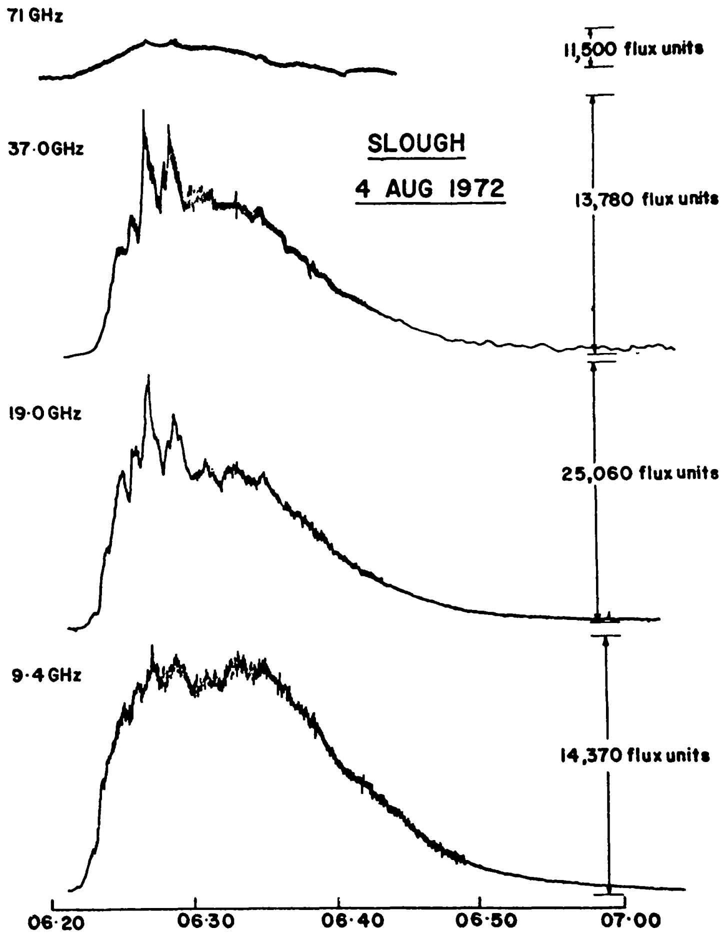

Fig. 16. Radio burst profile at Slough on 4 August, 1972 at 9.4, 19.0, 37.0, and 71.0 GHz. Note strong pulsations on 19.0 and 37.0 GHz profiles (Croom and Harris, 1973).

are featureless and so no complex structure is evident (Castelli *et al.*, 1973). Another Type II burst was observed between 0629.5 and 0633.5 UT over 24 to 48 MHz on sweep frequency interferometer record (SFIR) at Manila. The integrated flux density was the highest at 8800 MHz and the proton event was the largest of the series. The PCA event recorded on riometer at 30 MHz was as high as 30 db at Thule and other Arctic stations at 1200 UT on 4 August.

At Ahmedabad, we had in operation the solar radio spectroscope (40–240 MHz), polarimeter (35 MHz), microwave radiometer (2800 MHz) and riometer (25 MHz). Their records are shown in Figures 18, 19, 20 (Bhonsle *et al.*, 1973). The swept frequency record (40–240 MHz) shows Type III bursts at 0626 UT showing fine structure in time and frequency starting around 140 MHz. Type II burst is not clearly seen due to simultaneous occurrence of Type IV or 'flare continuum'. But some drifting features were evident throughout the event. Broad-band fluctuations of Type IV appear clearly throughout the record and it is seen that the spectrum is extending to higher frequencies from 0639 UT. The polarimeter record (Figure 19) shows *L*-polarization before 0624 UT and then *R*-polarization between 0625 and 0650 UT and back again to *L*-polarization thereafter. The microwave record (Figure 20) at 2800 MHz shows a

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

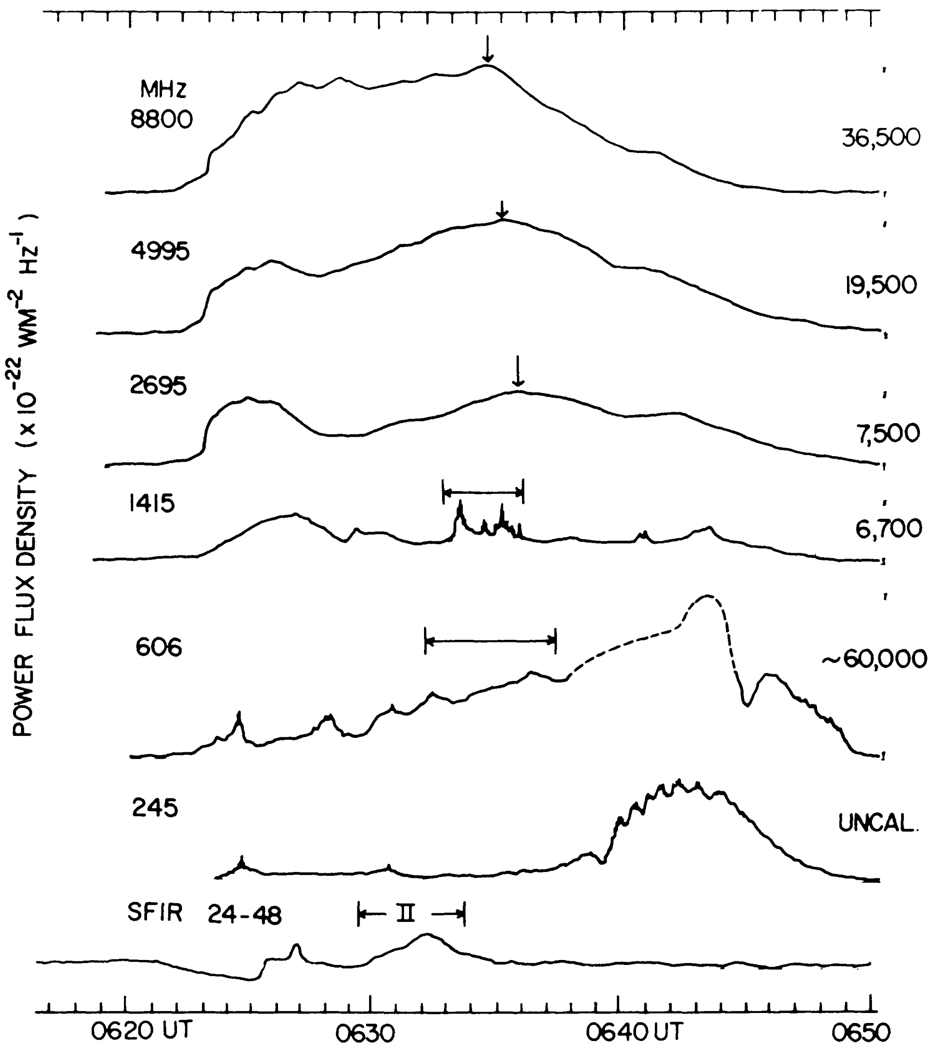

Fig. 17. Radio bursts on 4 August, 1972 at Manila at fixed frequencies from 245 MHz to 8800 MHz. Note the Type II burst at 0630 UT on sweep frequency interferometer (24–48 MHz) record (Badillo, 1973).

number of bursts including the major one starting at 0617 UT and lasting for about 35 min.

The Culgoora radio spectroscope record from 10 to 8000 MHz (Figure 21) shows a large Type III group between 0610 and 0613 UT on 4 August, 1972 superimposed on strong continuum. No Type II is evident from the record (Cole, 1973). A sudden intensity enhancement occurred at 0622 UT at 2–8 GHz band and then at lower frequencies (<300 MHz) at 0625 UT. In the Weissenau broadband radio spectrograph, an intense Type IV emission masked Type II burst and hence, could not be clearly seen (Urbarz, 1973). However, according to Pintér (1975), a Type II radio burst was observed at 0626 UT at 86 MHz at Ondrejov Observatory and assuming $10 \times$ BA model (Baumbach-Allen) of coronal density, he estimated the radial velocity of the shock wave to be 3950 km s^{-1}. The SC geomagnetic storm associated with this shock front was recorded at 2054 UT at the Earth. This shock front was observed by

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

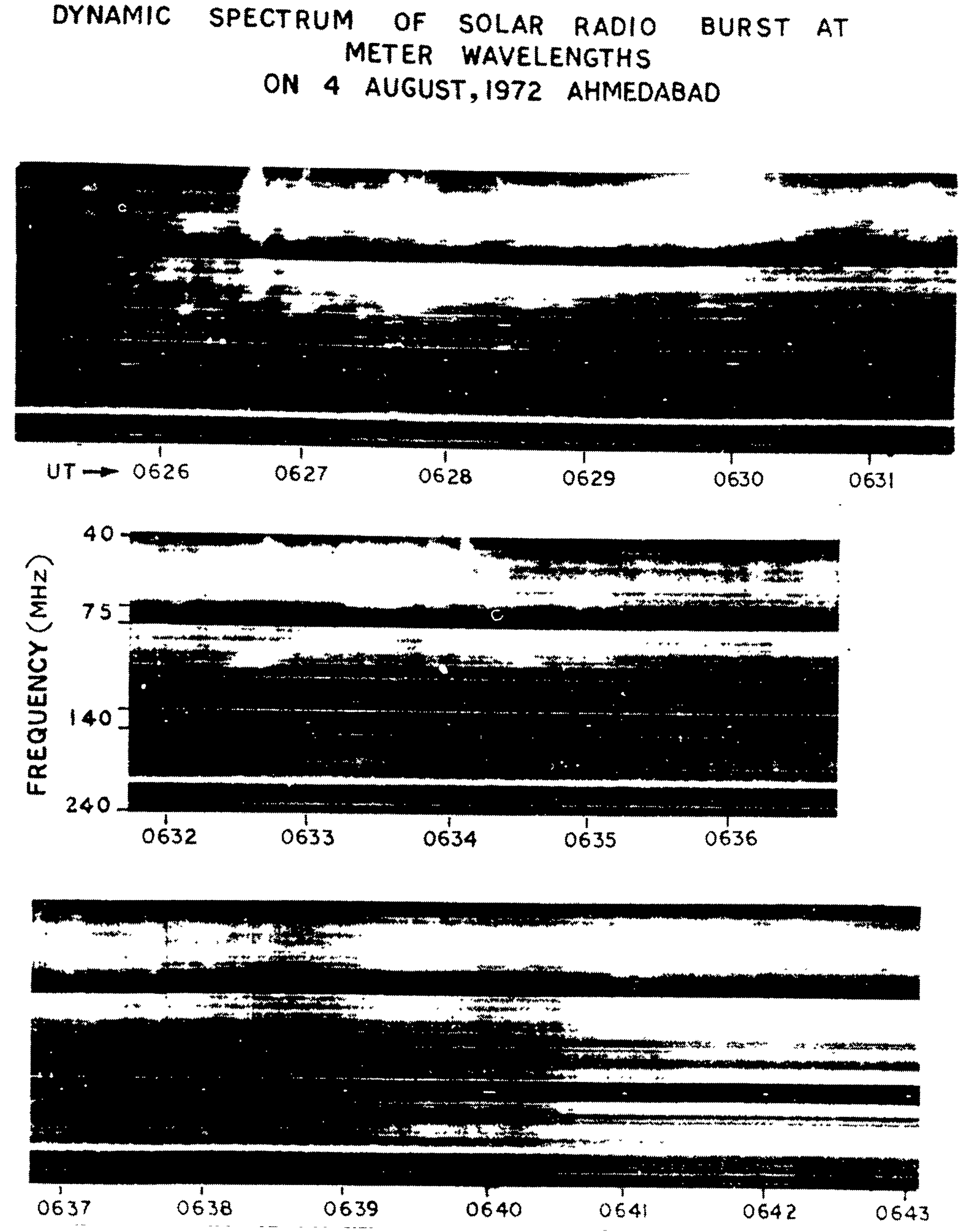

Fig. 18. Dynamic spectrum (40–240 MHz) of the event on 4 August, 1972 recorded at Ahmedabad, showing Type III's at 0626 UT with fine structure in time and frequency around 140 MHz. A Type II burst starting at 0628 UT is not clearly seen as it was masked by Type IV continuum (Bhonsle *et al.*, 1973).

HEOS-2, Prognoz-1, Pioneer-9 and -10 satellites at various distances from the Sun. Grigorijeva *et al.* (1975) have reported the Type II and possibly Type IV radio bursts in the frequency range 755–80 kHz observed at 0717 and 1340 UT respectively on Prognoz-1 satellite and calculated the average velocity of the shock wave from the frequency-drift of Type II as 3750 km s^{-1} at 0.08 AU, 3600 km s^{-1} at 0.16 AU and 2625 km s^{-1} at 0.46 AU. This shows that moderate deceleration of the shock wave has occurred up to 0.46 AU and still larger deceleration thereafter.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

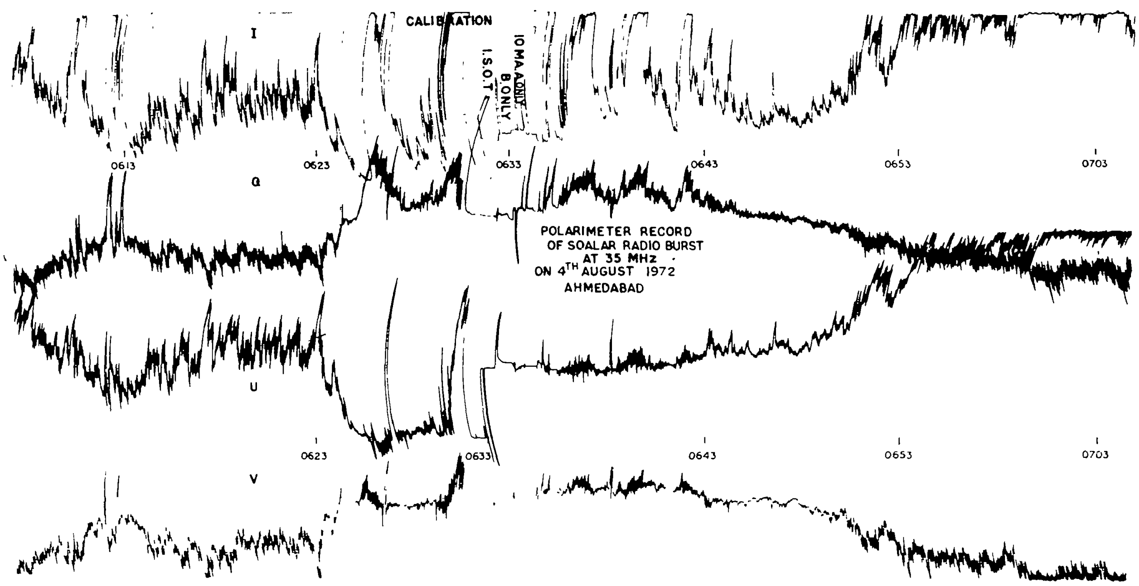

Fig. 19. 35 MHz polarimeter record at Ahmedabad on 4 August, 1972. Note the change from L to R polarization and again L-polarization as seen from 'V' channel, where V denotes one of the four Stokes parameters (Bhonsle *et al.*, 1973).

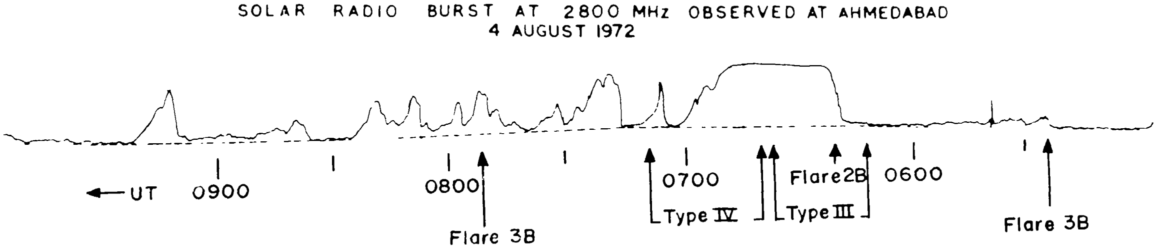

Fig. 20. Solar microwave bursts on 4 August, 1972 (Bhonsle *et al.*, 1973).

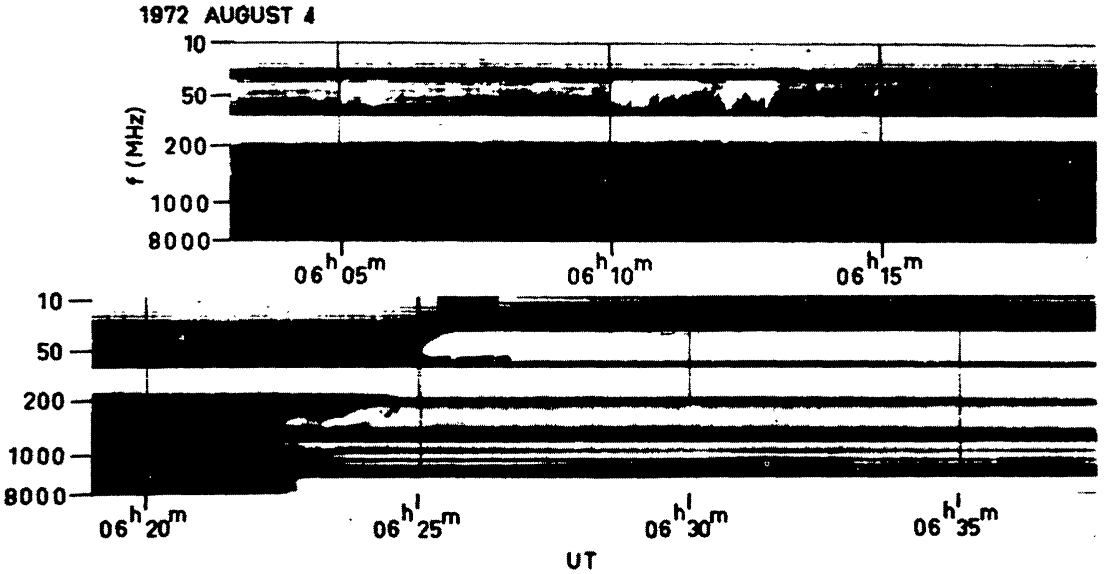

Fig. 21. Dynamic spectrum (10–8000 MHz) of a strong Type IV event on 4 August, 1972 recorded at Culgoora. Note the Type III group at 0610–0613 UT (Cole, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

Böhme and Krüger (1973) have described some remarkable features of the radio bursts of Type II and IV on 4 August from their fixed frequency radiometer records from 23 MHz to 9500 MHz obtained at Tremsdorf near Potsdam. A very strong emission of 500 000 f.u. was observed by them at 234 MHz at 0621 UT. The sense of circular polarization on 3000, 1500 and 775 MHz changed repeatedly during the event. Between 1500 and 775 MHz, a reversal of the sense of polarization (from right to left) was seen in the post-maximum phase of the event. Exceptionally strong pulsations were recorded at decametre waves (maximum between 40 and 23 MHz) with periods ranging from 2 to 5 min. Low frequency pulsations with high amplitudes ($\sim 10^4$ f.u.) are relatively rare. Similar pulsations are seen on the polarimeter records also. Usually these pulsations are restricted to frequency 200–100 MHz range with periods on the order of 1 s and the modulation lasting for one minute or more during strong flare bursts (Abrami, 1970; Rosenberg, 1970; McLean *et al.*, 1971). Akinyan *et al.* (1975) have proposed a model for the generation of such low frequency (periods ~ 2 to 5 min) pulsations on the basis of a coherent synchrotron emission mechanism and concluded that the dimension of the magnetic flux tube should be of the order of the wavelength of the travelling disturbance, which in this case was $\sim 10^5$ km. As Type IV is typically associated with an enhanced outflow of high energy protons from the Sun (Böhme, 1972; Akinyan *et al.*, 1971), its near absence could be interpreted as the absence of second stage acceleration at greater coronal heights, since the main part of the particle acceleration evidently took place in the deeper levels of the solar atmosphere as indicated by the high intensity of the microwave emission. Santin and Zlobec (1973) also have polarimetric measurements at 237 MHz and recorded *L*-polarization.

3.2.4. *F-4 Flare of 7 August, 1972*

This is the second 3B flare at 1449 UT in Hα at 14°N, 37°W and the last of the four major solar events of the region 11976. This event started at 1436 UT on 7 August with an enhancement of soft X-ray emission. The synthetic spectrum of radio bursts inferred from fixed frequency radio observations in the range 23 MHz to 37 000 MHz is shown in Figure 22 (Böhme and Krüger, 1973). A Type III burst extending from metre (Maxwell, 1973; Dodge, 1973a) to kilometre wavelengths (Kellogg *et al.*, 1973) was observed starting at 1512 UT. In this event, it is remarkable that although U-shaped radio spectrum was observed, the peak at centimetre wavelength far exceeded that at decimetre and metre wavelengths. This is in contrast with the 2 and 4 August events. The time variability of flux observed in Figure 22 below 100 MHz can be attributed to a series of Type II's superimposed on Type IVμ continuum reported by Dodge (1973a, b). Detailed burst profiles from 245 to 35 000 MHz from 1455 to 1550 UT on 7 August recorded at Sagamore Hill are shown in Figure 23 (Castelli *et al.*, 1973). At the top of Figure 23 is shown the sequence of radio bursts (observed from the dynamic spectrum at Boulder) which followed the flare at 1449 UT. It shows a series of Type II bursts, Type IIIs and Type IV beginning 1514.6 UT covering the

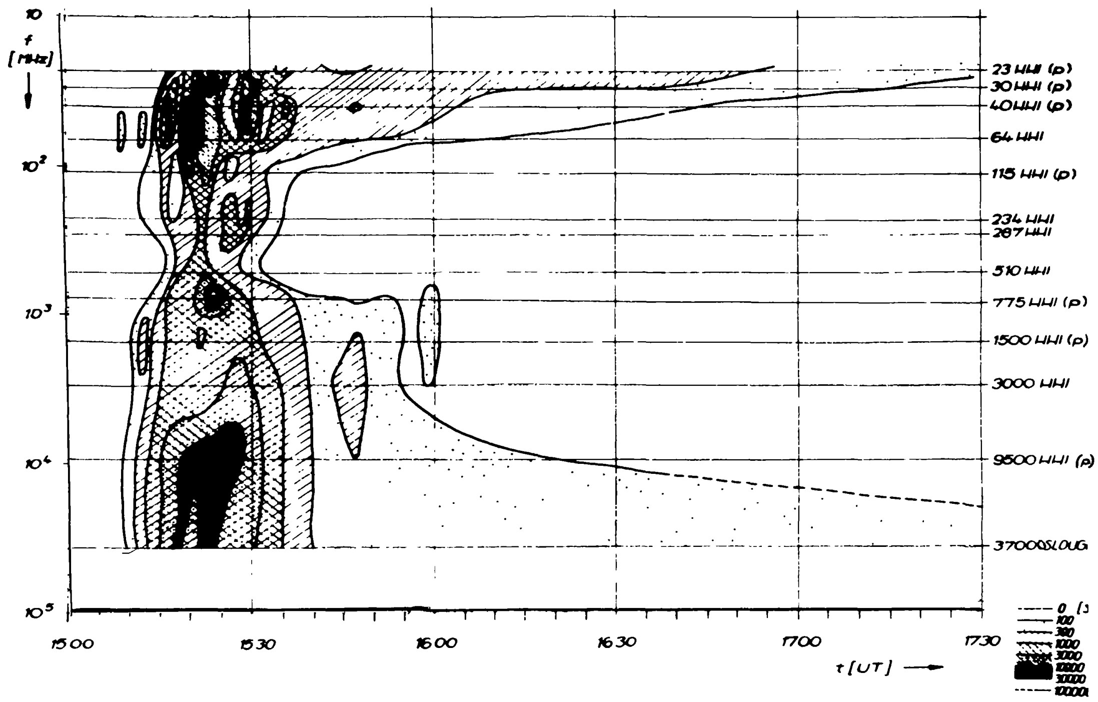

Fig. 22. Synthetic spectrum of burst from 23 MHz to 37 GHz of 7 August, 1972 (Böhme and Krüger, 1973).

whole frequency range 20–70 MHz until 1552 UT, followed by a frequency-dependent fade-out. Here also the flash phase of millimetre and hard X-ray bursts consisted of elementary flare bursts (EFBs) which correspond well with the peaks on 15.4 and 35 GHz curves shown in Figure 23. Each of these EFBs produced significant changes, well correlated in time, in the rate of change of the total electron content as observed by ATS-1 Faraday rotation measurements at Boulder (Mendillo *et al.*, 1974). Since these EFBs and corresponding peaks on 15.4 and 35 GHz curves have occurred successively in time, it is possible that there was a single initiating event which set off a chain of individual flares separated in time and space. Simultaneous observations of different parts of the flare region, with angular resolution ($\sim 1''$) at millimetre and optical wavelengths would help in delineating the trigger mechanism of multiple flares. This flare was clearly visible in white light at Sacremento Peak Observatory for 7 or 8 min around 1520 UT (Rust, 1973).

The swept-frequency (10–2000 MHz) observations at Fort Davis, Texas, are shown in Figure 24 from 1507 to 1533 UT (Maxwell and Rinehart, 1974). The onset of the burst took place at 1508 UT with Type III-like bursts in the microwave band. Intense Type IV emission began at approximately 1512 UT in 1000–2000 MHz band and gradually spread to lower frequencies. In the 500–2000 MHz band, Type IV emission was relatively of high intensity until 1609 UT after which it became intermittent and of lower intensity until 1807 UT. From 30–300 MHz, Type IV radiation had shorter duration and persisted until 1540 UT. Pulsations with quasi-periodicity of 2 s were

1976SSRv...19..475B

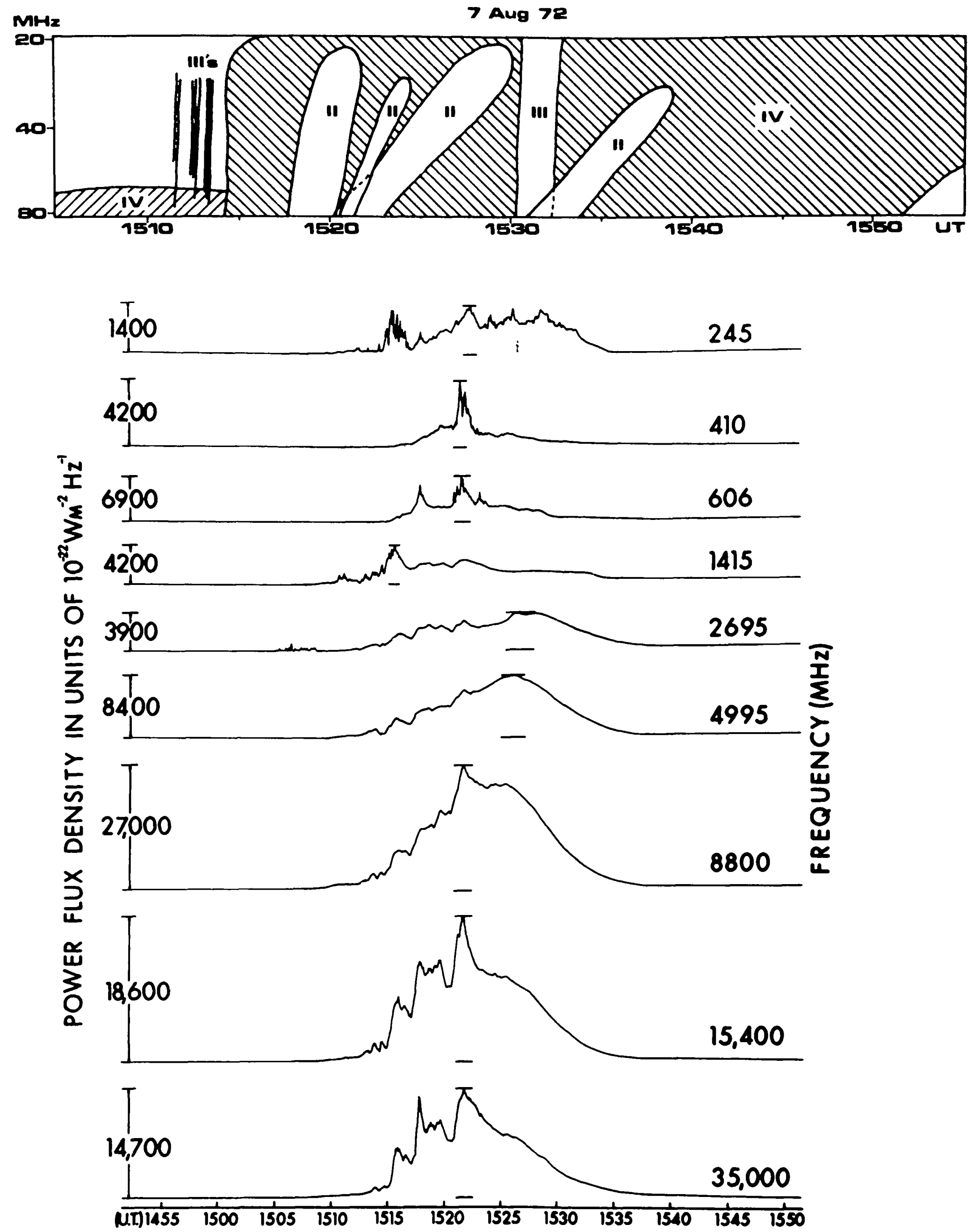

Fig. 23. Great Burst observed on 7 August, 1972 at Sagamore Hill (AFCRL). Note the multiple peaks superimposed on the main burst (Castelli *et al.*, 1973). At the top of the figure, schematic dynamic spectrum of Type IIIs, IIs and IV continuum observed by Dodge (1973) at Boulder.

evident from 1527 to 1531 UT in the frequency range 100–200 MHz. Type II bursts began at 1518.8 UT in the band 25–150 MHz and lasted till 1548 UT. It had at least two components each having different radial velocity range of 1000–1500 km s^{-1} for the slower component and 2000–3000 km s^{-1} for the faster component. These estimates are comparable with those made by Dodge (1973a, b) from the sweep frequency interferometer measurements covering the frequency range 20–80 MHz. He found

1976SSRv...19..475B

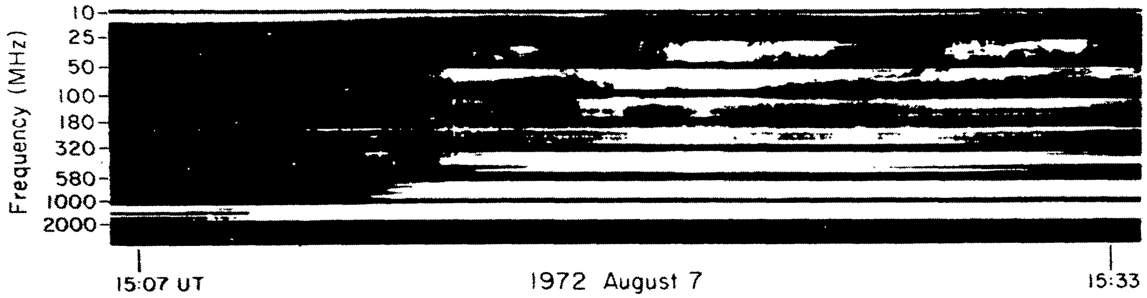

Fig. 24. Dynamic spectrum of the radio burst of 7 August, 1972. Note Type II onset in the band 25–150 MHz at 1519 UT and pulsations in the band 100 to 180 MHz during the period 1527 to 1531 UT (Maxwell and Rinehart, 1974).

radial velocity components of the order of 3900, 4900, 1400 and 900 km s^{-1} corresponding to four Type II bursts shown schematically in Figure 23. Using receivers covering frequency range of 30 kHz to 2.6 MHz on board the IMP-6 satellite, Malit-

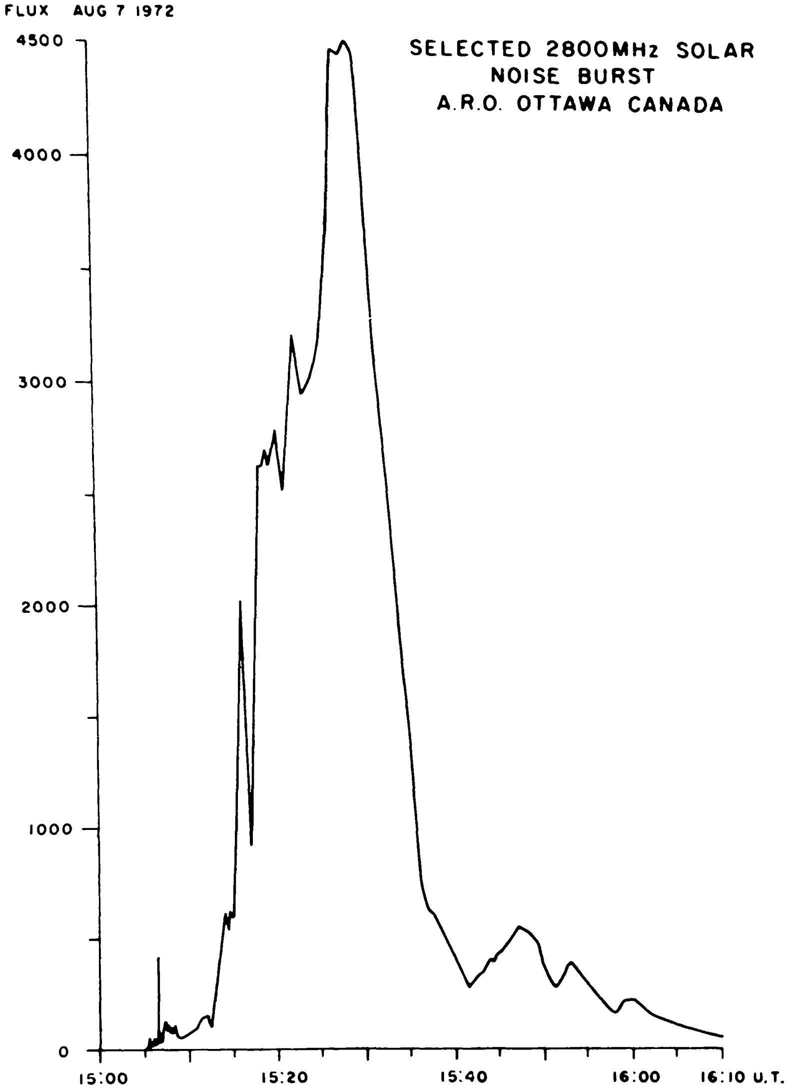

Fig. 25. Profile of great burst of 7 August, 1972 at 2800 MHz, ARO, Ottawa (Covington and Bell, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

son *et al.* (1973) tracked the Type II shock wave from the corona to the Earth's orbit and deduced an average velocity of 1270 km s^{-1} for the shock wave, which remained nearly constant from a distance of 500 000 km above the photosphere to 1 AU. The arrival of the shock at the Earth was evident from the SC geomagnetic storm at 2354 UT on 8 August (Lincoln and Leighton, 1972).

Croom and Harris (1973) have reported exceptionally high flux densities of 13 750, 27 200 and 11 100 f.u. at 9.4, 19 and 37 GHz respectively. At 17 GHz, the peak flux was 25 000 f.u. and the degree of circular polarization showed an increase to 25% during the ascending phase while the polarization was very small during the maximum and descending phases of the burst (Fürst *et al.*, 1973). The intensity of the bursts also was considerably weaker at low frequencies and the sense of polarization appeared reversed. On metre waves the burst profile structure and the polarization characteristics were rather complex. A rather complicated magnetic field structure at heights greater than 0.5 $R_\odot$ above the photosphere may be deduced from this event (Böhme and Krüger, 1973).

The burst profile at 2800 MHz starting from 1505 UT recorded at Ottawa is shown in Figure 25 (Covington and Bell, 1973). The peak flux of 4500 f.u. occurred at 1527.5 UT.

4. Discussion

The SVC is a measure of solar activity and depends upon the number of centres of activity present at any one time on the solar disk. It is of thermal origin with a spectral peak around 10 cm (Kundu, 1965). Physical conditions (temperature, density and magnetic field) of the region in which SVC originates can be derived from its high angular resolution spectrum, polarization and position information over wavelengths ranging from millimetre to metre. The source of SVC may last for several solar rotations. It was observed that there occurred significant changes in the normal spectral character of SVC on 31 July, 1972. Observations at centimetre and decimetre wavelengths provide clues for the prediction of proton flares. The following are the criteria used at present for the prediction of proton flares:

(1) High (>25 f.u.) SVC flux at 3 cm and ratio of 3 cm to 8 cm flux greater than unity and *P*-type 3 cm polarization configuration (Tanaka and Enomé, 1973).

(2) U-shaped spectrum of peak fluxes at decimetric wavelengths (Castelli *et al.*, 1973).

(3) Exceptionally high burst intensities ($> 10^4$ f.u.) at or above 10 GHz and percent increase in the radio burst intensities above 10 GHz much greater than that at 2.8 GHz (Croom, 1971).

(4) Occurrence of Type II–IV radio bursts (Kundu, 1965).

(5) Flares followed by pulsations in Type IV continuum (Wild and Smerd, 1973; McLean *et al.*, 1971).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

We suggest two additional possible criteria for the prediction of proton flares made on the basis of radio observations of the SVC of the August 1972 events, namely, (i) peak flux variations of individual active regions on the time scale of hours like those for the region 11976 using 9.1 cm high resolution measurements at Stanford (Graf, 1975). In order to study the feasibility of this idea, one should critically examine whether the amplitude of hourly variations of radio flux of a given region must exceed a certain threshold value before it can be associated with proton flares. And (ii) from the observation of overall broadening and intensification of SVC from millimetre to decimetre wavelengths (Decker and Wefer, 1973) together with intense and persistent continuum storm at metre and decametre wavelengths. Indeed, these suggestions are borne out from the SVC observations prior to the August 1972 events.

The causal relationship between the optical flares and the interplanetary disturbances is often ambiguous but this association becomes more definite, as mentioned earlier, if one combines the data of Type II and IV radio bursts with the optical data. Hence the importance of ground-based radio observations. Gross magnetic field configuration (open and closed field lines) has been derived during the August 1972

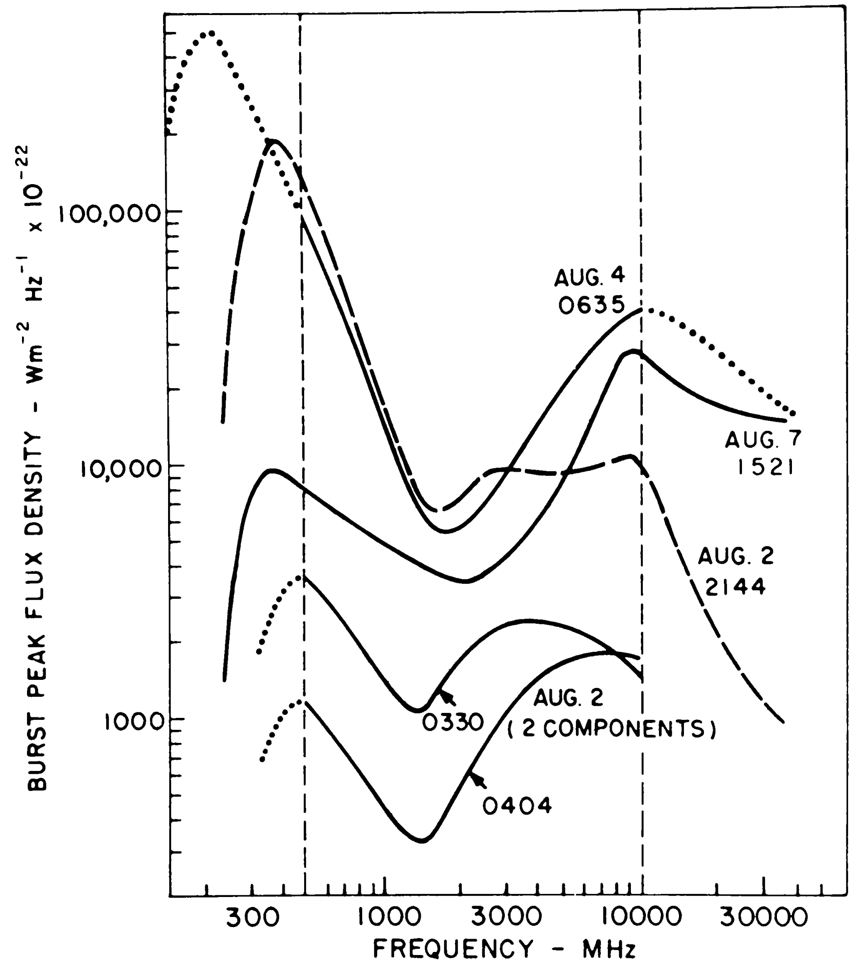

Fig. 26. Peak flux density spectra of radio events (F-1 through F-4) during August 1972. Note U-shaped spectra between broken lines used for prediction of proton flare activity and emission peaks and spectral hardness on 4 and 7 August, 1972 (Sagamore Hill and Manila Data; Castelli *et al.*, 1973).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

events from position measurements of metre and decametre Type III and IV bursts by Kundu and Erickson (1974a).

The peak flux density spectra of the bursts in all these flares from 2 August to 7 August are shown in Figure 26 (Castelli *et al.*, 1973). It can be seen that all the major August 1972 events had the U-shaped spectrum. All of the four flares F-1 through F-4 produced Type II and Type IV bursts, which is an evidence of energetic proton production as observed by Pioneer-9 and 10 spacecrafts. The plasma cloud which is instrumental for Type II and IV radio emission is ejected from the flare region into the outer corona at the time of the explosive or flash phase of a flare. A major Type IV event is often observed over a wavelength range extending from few millimetres to decametre from ground-based observatories. The plasma in the moving Type IV burst is referred to as the piston which initiates the shock (Uchida, 1968; Kai, 1969) as it passes through the outer corona (Dryer, 1975). It is worth mentioning here that in addition to the 'Flare Continuum' (Robinson and Smerd, 1975) three types of moving Type IV burst (Smerd and Dulk, 1971) namely, advancing shock front, expanding magnetic arch and ejected plasma blob (Wild and Smerd, 1972) have been identified using high resolution 80 MHz Culgoora radioheliograph. It would be interesting to verify which of these moving Type IV serves as a piston that initiates a coronal shock wave. From the observations of the major August 1972 events, F-1 through F-4 described earlier, one can conclude that at least four shock waves were emitted into the interplanetary space. It is interesting to note that for the 4 August event the coronal shock wave velocity estimated by Pintér (1975) was 3950 km s^{-1}. This shock was subsequently tracked by Prognoz-1 satellite and caused SC geomagnetic storm at 2054 UT at the Earth. But although Dodge (1973) identified as many as four Type IIs on 7 August, 1972 occurring in quick succession with velocities 3900, 4900, 1400 and 900 km s^{-1}, apparently only one shock front moving with average velocity of 1270 km s^{-1} was tracked by IMP-6 (Malitson *et al.*, 1973) all the way to the earth. Thus it appears that the ability of the shock to reach 1 AU and beyond depends mainly on the energy of the shock and not its velocity alone. The mass behind the moving shock front may be the dominating factor which decides its range in the interplanetary space. It should be noted that for the 7 August event, Chertok and Fomichev (1975) found evidence for deceleration of the shock wave from the analysis of IMP-6 data assuming that the emission frequency of Type II corresponds to the electron densities 'behind' the shock front and not in 'front' of it as was assumed by Malitson *et al.* (1973). They have also commented that the assumptions made by Malitson *et al.* (1973) in deriving the average value of 1270 km s^{-1} for the 7 August, 1972 interplanetary shock wave were unrealistic.

The piston-driven model of 4 August shock proposed by Dryer (1975) needs to be revised in view of the recent Prognoz-1 data of Grigorijeva *et al.* (1975) which definitely show deceleration from 0.08 to 0.46 AU. Thus it would be appropriate to consider this interplanetary situation as a blast/weak piston (hybrid) that suffered deceleration continuously from 0.01 AU onwards, but somehow was still able to cause SC at 2054 UT on 4 August at the Earth. The interplanetary shock waves may be detected

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

either directly by plasma probes and magnetic field sensors aboard satellites and spacecrafts or indirectly by observing their effects on the atmosphere of the planets and comets (Dryer *et al.*, 1975a). Simultaneous observations of interplanetary scintillation (IPS) of compact radio sources yield a gross picture of propagation of shock waves as well as co-rotating streams in the interplanetary medium (Houminer, 1973). The IPS measurements detected a sudden increase in solar wind velocity on 9 August associated with that detected by Pioneer-9 on 9 August (Watanabe *et al.*, 1973; Armstrong *et al.*, 1973). According to their estimate, this shock wave had an extent of at least 50° in the direction of heliocentric latitude and 160° in the direction of heliocentric longitude.

The time of arrival of the interplanetary shock wave in the vicinity of the Earth can be known fairly accurately from the time of the sudden commencement (SC) of a geomagnetic storm which is produced when the magnetosphere is compressed by the impact of the interplanetary shock wave. Four main sudden commencement type geomagnetic storms were recorded in this period at 0119 UT, 0220 UT and 2054 UT on 4 August, and at 2354 UT on 8 August (Lincoln and Leighton, 1972).

Dryer *et al.* (1975b) have analysed the dynamical behaviour of the interplanetary medium in more detail using the particle and field data of Pioneer-9 and have provided estimates of energy and mass ejection during the flares of 2, 4 and 7 August, 1972. They have also solved the detailed shock wave characteristics and have computed numerical simulations of the flare-generated disturbances. The energy calculated for each individual flare is of the order of 10^{32} erg and the mass ejected is of the order of 10^{16}–10^{17} gm.

With all the information available on the August 1972 events, there are difficulties in understanding as to why the deceleration of shock seems to start around 0.4 AU, although the velocities inferred from Type II bursts were in the range 1000–4000 km s^{-1}. Does this imply that the deceleration comes into play at this distance from the sun irrespective of initial shock wave velocities? If so, which other parameters of the interplanetary medium such as density and its variations, temperature, magnetic field and its variations control the deceleration process?

Some insight into the interplanetary shock trajectories can be gained from Figure 27 wherein the shock trajectories from the four major flares in August 1972 are traced progressively with heliocentric distance R in AU (Dryer *et al.*, 1975a). Since Jupiter's non-I_0 related emission and sudden cometary brightness fluctuations of P/Schwassmann-Wachmann I were not noticed during this period, Dryer *et al.* (1975a) surmised that the shocks decelerated rapidly to about 2.2 AU and became MHD waves as soon as their velocities were equal to the sum of the local fast mode velocity and the ambient bulk velocity of the solar wind. Since it is known that in the case of the June 1972 event, the interplanetary shock wave travelled at least to 5 AU, it would be rewarding to compare critically the ambient conditions of the interplanetary medium into which the shock waves were launched during the June and August 1972 events. The shock velocities near the Sun based on Type II velocities corresponding to F-1,

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1976SSRv...19..475B

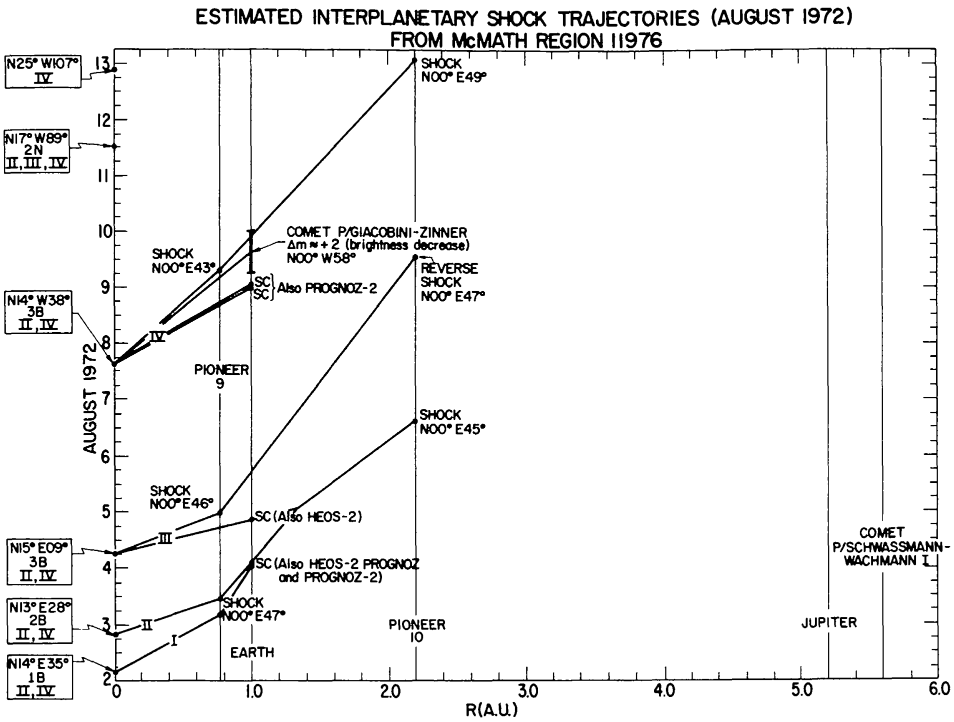

Fig. 27. Estimated interplanetary shock trajectories from the four major flares in McMath region 11976 during August 1972 (Dryer *et al.*, 1975).

F-2, F-3 and F-4 events were, as mentioned earlier, about 1130, 1000, 3950 and 1400–1500 km s^{-1} respectively (Pintér, 1973; Maxwell, 1973; Dodge, 1973).

While the synthetic spectrum constructed from fixed frequency observations is more or less a satisfactory method from decimetre to millimetre wavelengths to get an approximate burst profile in frequency–time domain, the dynamic spectrum recorded with the help of sweep frequency receivers is more suitable for rapidly varying burst phenomena such as those observed at metre and decametre wavelengths. But whenever complex solar events, like those of August 1972, are in progress, the commonly used low angular resolution dynamic radio spectroscopes may not always reveal a Type II burst in the presence of strong Type IV continuum or noise storm. On the other hand, Dodge (1973) was able to infer with his sweep frequency interferometer the occurrence of Type IIs even in the presence of strong Type IV continuum in the case of the August 1972 events. Ideally, what one would prefer is a multifrequency heliograph capable of yielding information regarding spectrum, two dimensional position and polarization as a function of frequency and time on the lines proposed by Kundu and Erickson (1974a, b). Such an instrument would go a long way in understanding the dynamic behaviour of coronal disturbances.

Millimetre wave radiation originates in the chromosphere which is optically transparent from 1000–3000 km from the photosphere where the magnetic fields of the active centres play an important role in the flare events. High resolution is important at millimetre wavelengths as they are related to optical as well as X-ray events which display considerable fine structure. Moreover, millimetre wave observations are suitable

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

for understanding chromospheric conditions that lead to flares. Conventionally, the SVC has been studied mainly at centimetre and decimetre wavelengths with fixed frequency, low resolution radiometers and the structure of centres of activity with multi-element interferometers having angular resolution of the order of a minute of arc. Now, this resolution limit is pushed to 10 arc sec or better (Kundu, 1973) revealing much finer structure even under quiescent conditions. Particularly, it has shown existence of regular patterns similar to supergranulation cells and a compact precursor region ($\sim 4''$) of a flare.

It has been proposed by the Committee of European Solar Radio Astronomers (CESRA) that a two-dimensional instrument of ultra-high resolution of $5''$ or less in the wavelength range of 6 cm to 3 mm capable of performing one spectroheliogram per second be developed. This would provide the first observations of the radio properties of granulation patterns, dark and bright mottles, oscillatory motions, plasma nodules and magnetic field configurations in active and quiet regions (Castelli *et al.*, 1974).

As seen from the ground-based solar radio data available for the August 1972 events, considerable observational effort was concentrated on fixed frequency radiometers in different parts of the world but the number of sweep frequency instruments are very few. Polarimeters and multi-element interferometers are at a few scattered places. There is a pressing need for well-coordinated ground-based network for continuous monitoring of the Sun from millimetre to decametre wavelengths with variety of techniques having high angular resolution. This requires setting up of new solar observatories and strengthening of already existing ones with similar experimental set up in different longitude zones so that the sun could be kept under constant surveillance. Thus, there is urgent need to organize a workshop of solar radio astronomers from different countries around the world to recommend an optimum experimental facility which should be in operation before the Solar Maximum Year (1979–80).

Acknowledgements

The overwhelming response of a large number of solar radio astronomers the world over to our request for sending the material which has gone in the preparation of this article is gratefully acknowledged.

We thank Prof. K. R. Ramanathan, Emeritus Professor, Physical Research Laboratory (PRL), for his keen interest in this work and Prof. D. Lal, Director, PRL, Ahmedabad for encouragement. Assistance of M/s. A. H. Desai, V. C. Mathew, D. Stephen and N. V. Dalal in the preparation of the manuscript is highly appreciated. We thank Drs J. C. Dodge and M. Dryer for their critical reading of the manuscript and for useful suggestions.

This work is supported by the Department of Space, Government of India.

References

Abrami, A.: 1970, *Solar Phys.* **11**, 104.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

Akinyan, S. T., Mogilevsky, E. I., Böhme, A., and Krüger, A.: 1971, *Solar Phys.* **20**, 112.

Akinyan, S. T., Chernov, G. P., Chertok, I. M., Fomichev, V. V., Karachun, A. M., Kovalev, V. A., and Markeev, A. K.: 1975 (Private Communication).

Akinyan, S. T., Iskov, V. N., Mogilevsky, E. I., Böhme, A., Fürstenberg, F. and Krüger, A.: 1975 (Private Communication).

Armstrong, J. W., Coles, W. A., Harmon, J. K., Maagoe, S., Rickett, B. J., and Sime, D. G.: 1973, *Rep. UAG-28*, Part II, WDC-A 371.

Badillo, V. L.: 1973, *Rep. UAG-28*, Part I, WDC-A, 231.

Bhonsle, R. V., Degaonkar, S. S., and Sawant, H. S.: 1973, *Rep. UAG-28*, Part I, WDC-A, 234.

Bhonsle, R. V. and Mattoo, S. K.: 1974, *Astron. Astrophys.* **30**, 301.

Böhme, A.: 1972, *Solar Phys.* **25**, 478.

Böhme, A. and Krüger, A.: 1973, *Rep. UAG-28*, Part I, WDC-A, 260.

Castelli, J. P., Barron, W. R., and Badillo, V. L.: 1973, *Rep. UAG-28*, Part I, WDC-A, 183.

Castelli, J. P., Guidice, D. A., and Kalaghan, P. M.: 1974, *IEEE, MTT-22*, Part II, 1292.

Chertok, I. M. and Fomichev, V. V.: 1975 (Private Communication).

Chui, I. T.: 1970, *Solar Phys.* **13**, 420.

Chupp, E., Forest, D., Reppin, C., Suri, A., and Tsai, C.: 1973, *Rep. UAG-28*, Part II, WDC-A, 325.

Coffey, H. E. (ed.): 1973, *Rep. UAG-28*, Part I, II, and III, WDC-A, Boulder.

Cole, T. W.: 1973, *Rep. UAG-28*, Part I, WDC-A, 222.

Covington, A. E. and Bell, M. B.: 1973, *Rep. UAG-28*, Part I, WDC-A, 168.

Croom, D. L.: 1971, *Solar Phys.* **19**, 152.

Croom, D. L. and Harris, L. D. J.: 1973, *Rep. UAG-28*, Part I, WDC-A, 210.

Decker, W. J. and Wefer, F. L.: 1973, *Rep. UAG-28*, Part I, WDC-A, 202.

Dennison, P. A. and Wiseman, M.: 1968, *Proc. Astron. Soc. Austr.* **1**, 142.

Dodge, J. C.: 1973a, *Rep. UAG-28*, Part I, WDC-A, 242.

Dodge, J. C.: 1973b, *Rep. SN-1*, Dept. Astro-geophys., Boulder.

Dodson, H. W. and Hedeman, E. R.: 1973, *Rep. UAG-28*, Part I, WDC-A, 16.

Dryer, M.: 1975, *Space Sci. Rev.* **17**, 277.

Dryer, M., Eviatar, A., Frohlich, A., Jacobs, A., Joseph, J. H., and Weber, E. J.: 1975a, *J. Geophys. Res.* **80**, 2001.

Dryer, M., Smith, Z. K., Steinolfson, R. S., Mihalov, J. D., Wolfe, J. H., and Chao, J. K.: 1975b, *J. Geophys. Res.* (in press).

Fokker, A. D.: 1960, Doctoral Thesis, Leiden University.

Fürst, E., Hachanberg, O., and Hirth, W.: 1973, *Solar Phys.* **28**, 533.

Graf, W.: 1975 (Private Communication).

Grigorijeva, V. P., Zastenker, G. N., and Temny, V. V.: 1975, *Space Res. Instit., Acad. Sci., U.S.S.R.* A-189.

Hakura, Y.: 1975 (Private Communication).

Hewish, A., Scott, P. F., and Wills, D.: 1964, *Nature* **203**, 1214.

Houminer, Z.: 1973, *Rep. UAG-28*, Part II, WDC-A, 375.

Hundhausen, A. J.: 1972, *Coronal Expansion and Solar Wind*, Springer-Verlag, NY.

Kai, K.: 1969, *Solar Phys.* **10**, 460.

Kellogg, P. J., Lai, J. C., and Cartwright, D. G.: 1973, *Rep. UAG-28*, Part II, WDC-A, 288.

Krüger, A.: 1972, *Phys. of Solar Continuum Radio Bursts*, Akademie-Verlag, Berlin.

Kundu, M. R.: 1965, *Solar Radio Astronomy*, Interscience Publishers, NY.

Kundu, M. R.: 1973, *IAU Symp.* **56**, Australia.

Kundu, M. R. and Erickson, W. C.: 1974a, *Solar Phys.* **36**, 179.

Kundu, M. R. and Erickson, W. C.: 1974b (Private Communication).

Lincoln, J. V. and Leighton, H. I.: 1972, *Rep. UAG-21*, WDC-A, Boulder.

Malitson, H. H., Feinberg, J., and Stone, R. G.: 1973, *Astrophys. J. (Letters)* **183**, L35.

Maxwell, A.: 1973, *Rep. UAG-28*, Part I, WDC-A, 255.

Maxwell, A. and Rinehart, R.: 1974, *Solar Phys.* **37**, 437.

Mckinnon, J. A.: 1972, NOAA TM ERL SEL-22, Boulder.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

McLean, D. J., Sheridan, K. V., Stewart, R. T., and Wild, J. P.: 1971, *Nature* **234**, 140.

Mendillo, M., Klobuchar, J. A., Fritz, R. B., da Rosa, A. V., Kersley, L., Yeh, K. C., Flaherty, B. J., Rangaswamy, S., Schmid, P. E., Evans, J. V., Schodel, J. P., Matsoukas, D. A., Koster, J. R., Webster, A. R., and Chin, P.: 1974, *J. Geophys. Res.* **79**, 665.

Pintér, S.: 1973, *Nature* **96**, 243.

Pintér, S.: 1975 (Private Communication).

Robinson, R. D., and Smerd, S. F.: 1975, *Proc. Astron. Soc. Austr.* **2**, 374.

Rosenberg, H.: 1970, *Astron. Astrophys.* **9**, 159.

Rust, D. M.: 1973, *Solar Phys.* **33**, 205.

Santin, P. and Zlobec, P.: 1973, *Rep. UAG-28*, Part I, WDC-A, 279.

Simon, P.: 1973, *Rep. UAG-28*, Part I, WDC-A, 12.

Smerd, S. F. and Dulk, G. A.: 1971, *Proc. IAU Symp.* **43**, Ed. R. Howard, P.616.

Solar Geophysical Data (Prompt Rep.), Sept. 1972, 337-Part I, WDC-A, 10.

Tanaka, H. and Enomé, S.: 1973, *Rep. UAG-28*, Part I, WDC-A, 215.

Uchida, Y.: 1968, *Solar Phys.* **4**, 30.

Urbarz, H.: 1973, *Rep. UAG-28*, Part I, WDC-A, 269.

Watanabe, D., Kakinuma, T., Kojima, M., and Shibasaki, K.: 1973, *J. Geophys. Res.* **78**, 8364.

Wild, J. P. and Smerd, S. F.: 1972, *Ann. Rev. Astron. Astrophys.* **10**, 159.

Yamashita, F., Mitobe, A., and Isobe, T.: 1974, *J. Radio Res. Lab.* **21**, 303.

Zheleznyakov, V. V.: 1970, *Radio Emissions from Sun and Planets*, Pergamon Press.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System