Solar radio burst on 30 September 1993

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The metrewave observations of a type-III radio burst which occurred on 30 Sep. 1993 have been described. The spectrum of the burst was obtained by new Hiraiso radio spectrograph (HiRAS) and time-resolved single frequency observations were made by two 103 MHz radio telescopes located at Thaltej and Rajkot. The burst peaked at $\sim 100$ MHz with a full width at half maximum of the spectrum of $\sim 165$ MHz. The burst spikes appeared to be caused by relativistic beam of particles having velocities in the range of 0.1-0.3 c, where c is the velocity of light.

1 Introduction

The radio emission from the sun depends on the stormy processes in its atmosphere and corona. These processes lead to the appearance of local regions. The emission being sporadic in nature, increases the observed intensity value when compared with the level of 'quiet' sun. The sporadic emission, in its turn, is made up of relatively smooth and lengthy (of the order of hours and days) rises in intensity and comparatively sharp and short bursts (with a life of the order of seconds and minutes). These sporadic emission from the sun are quite well studied and their classification is discussed in detail by Zheleznyakov\textsuperscript{1}.

Type-III bursts are probably the most intensively studied form of radio emission in all of astrophysics. Immense effort has gone into the elucidation of both the observational and theoretical aspects. These have been discussed by plasma physicists. The problem of constructing a theory for type-III bursts can be broken up into three parts\textsuperscript{2}: (i) The interaction of an electron stream with a plasma and resultant distribution of plasma waves, (ii) The transformation of plasma waves into radiation which we call the radiation source, and (iii) The propagation of radiation from the source of the observer. Even then, type-III bursts are not understood properly. Several crucial observations have yet to be explained and reconciled with the theories. Some of these have been rightly reviewed by Suzuki and Dulk\textsuperscript{3}.

The main defining characteristic of type-III bursts is that their emission drifts rapidly from high to low frequencies. The type-III radio bursts originate when electrons are accelerated to $\sim 10$ keV in solar active regions and then travel outward through corona and solar wind at speeds of 0.1-0.5 c (where c is the velocity of light). At each successive height the electrons excite plasma oscillations ($f_p \propto n^{1/2}$) and some of the wave energy is converted to radio waves at frequencies $f=f_p$ and $f=2f_p$. Thus the progress of the electrons to regions of successively lower density is traced out by radio waves progressing to successively lower frequencies. The fast electrons are forced to follow the magnetic field lines rooted in the active regions in which the acceleration occurs. These field lines spread outward and permeate a limited volume of the solar wind. The spread of field lines that constrain the electrons is about 40°-70°. Dulk \textit{et al.}\textsuperscript{4} reported an extraordinary phenomenon about type-III radio bursts. In that it is argued that all type-III bursts are observable with a sensitive kilometric wavelength radio instrument wherever they occur on the sun.

The majority (97%) of type-III solar radio bursts are not associated with reported low coronal or chromospheric activity\textsuperscript{5}. Cliver and Kahler\textsuperscript{6} argued that all type-III bursts are associated with impulsive solar energetic particles (SEPs) originating from high coronal flares (HCFs). Kilometric type-III solar radio bursts were measured by ISEE-3 and compared with the relativistic electrons observed directly by HELIOS\textsuperscript{7}. In this paper simultaneous observations of solar radio bursts on 30 Sep. 1993 by HiRAS solar spectro-
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Fig. 1—Frequency-time intensity record of radio burst on 30 Sep. 1993 by HiRAS radio spectrograph

Fig. 2—Spectrum of radio burst on 30 Sep. 1993

graph\textsuperscript{8} and two fixed frequency (103 MHz) radio telescopes at Rajkot and Thaltej in India\textsuperscript{9} are presented and discussed.

2 Observations and discussion

For monitoring solar radio bursts, Communication Research Laboratory, Japan, installed a new radio spectrograph at Hiraiso Solar Terrestrial Research Center, Japan. The recording of the event (radio burst from the sun) on 30 Sep. 1993 is shown in Fig. 1. The spectrograph operates in the frequency range of 25-2500 MHz (one of the widest frequency coverage spectrograph). This event has its emission only in the metrewave band and show almost no emission beyond 225 MHz. Thus emission cuts off at the plasma density of $6.3 \times 10^8$ el./cc.

The relative power as a function of frequency at the peak emission during this event is shown in Fig. 2. The flux is maximum at $\sim 100$ MHz (at wavelength of $\sim 3$ metres). This indicates that the radio emission maximizes from the region of solar corona where plasma density is around $1.24 \times 10^8$ el./cc. The reduction in intensity at lower frequencies could be due to self-absorption of the emission, whereas at frequencies higher than 100 MHz, the emission itself is weak from the outer solar corona during this event. The slope of the spectrum on the high frequency side is $\sim 0.5$ flux unit/MHz. Full width at half maximum (FWHM) of the spectrum is $\sim 165$ MHz.

The temporal structures with time resolution of 48 ms for this event was possible from the observations of two radio telescopes operated at 103 MHz at Thaltej and Rajkot in India. The details of these systems and recording procedures are outlined by Vats and Deshpande\textsuperscript{9}. These records are displayed in Fig. 3. From these records it is possible to divide the event in four sub-events (marked as 1, 2, 3 and 4). Sub-events 2 and 4 seem to be further split in two parts, but we ignored this aspect as the HiRAS data have lower temporal resolution and so this splitting is not resolved in that data set. The time duration of these sub-events range from 3-6 s.
The cross-correlation for the recordings of the bursts at Thaltej and Rajkot is shown in Fig. 4. In Fig. 4 there is a minor secondary peak at 7.5 s which is due to the fact that there are four sub-events in 30 s. Full widths at 0.5 and 0.0 correlations are 3.2 s and 10.1 s. The correlation at zero lag is slightly less than 1; this could be due to local and system noise difference in the two telescopes.

For these four sub-events, times of peak intensity were noted from the temporal plots of HI-RAS data which are almost similar to Fig. 3 at several fixed frequencies; e.g. 50, 100, 150, 200 and 250 MHz. Frequency-time plots for each of these events were prepared. These are shown in Fig. 5([a]-[d]) for sub-events 1-4, respectively. From Fig. 5([a]-[d]), the burst peaks are seen normally first at higher frequencies and later on at lower frequencies. The average frequency drifts \((df/dt)\) are 25, 33, 35 and 33 MHz/s for sub-events 1-4, respectively. It is generally assumed
that the solar radio bursts which drift in frequency are the result of a three-step process\textsuperscript{10}, which are as follows:

(a) The excitation and damping of plasma waves

(b) The conversion of these plasma waves in transverse electromagnetic waves, and

(c) The propagation of the transverse waves between the source and the observer.

It is also known that the same plasma waves can be converted by two different mechanisms into two different modes—one at frequency of the plasma waves, and the other at twice this frequency. The fundamental component of the bursts observed at $f$, and the harmonic observed at the same time at $2f$ are due to the conversion of the same plasma waves and then, any difference between the time profiles of the two components must be due either to a difference in the conversion processes or to a difference in propagation. The observations of radio burst on 30 Sep. 1993 discussed here are the fundamental radiation at the appropriate plasma frequency. The fast-drift can be used to estimate the component of the relativistic electron beam velocity ($V_e$) along the gradient of the plasma concentration in the corona.

According to the formula:

$$V_e = \frac{2 \ln f}{f} \left| \frac{df}{dt} \right|$$

where,

$$I_n = \frac{N}{|\Delta N|}$$

and $f$ and $N$, respectively, are the plasma frequency and density at the source region. This gives the value of $V_e$ in the range of 0.1-0.3 c. In this estimate, the standard Baumbach-Allen model of the coronal plasma density and its gradient was used. Figure 5([b] and [c]) shows that in the range of 150-100 MHz, the frequency drift is almost instantaneous giving a very large drift rate which would correspond to a large value of $V_e$ from Eq. (1).

On the other hand, in sub-event 4 [Fig. 5(d)], there is a positive frequency drift wherein the peak intensity occurred first at 150 MHz and later on at 200 MHz. In fact, here one may say that the emission began at $\sim 150$ MHz (at coronal plasma density of $\sim 2.8 \times 10^{8}$ el./cc) and later on drifted to both inward (to higher density region) as well as outward (to lower density region). It is rather difficult to understand such motions (drifts).

3 Conclusions

The example of type-III radio burst discussed in this paper occurred only at metrewave band, maximizing at a frequency $\sim 100$ MHz. This event seems to have been caused by relativistic beam of particles having velocity in the range of 0.1-0.3 c which is in general agreement with the investigations by Fleishman \textit{et al.}\textsuperscript{11} Source velocities obtained by Bakunin \textit{et al.}\textsuperscript{12} for the harmonic structure of a type-II burst on 12 May 1983 range from 1000 to 3600 km/s for the fundamental structures. These are typically 10-90 times smaller than the source velocities obtained for the type-III metrewave burst investigated here.

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References