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MICROWAVE TYPE III-RS BURSTS

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ABSTRACT

A decimetric (1600 ± 100 MHz), high-sensitivity digital spectroscope has been put into regular operation at São José dos Campos, Brazil, since 1991 March. The dynamic spectra are recorded on 35 mm film while 20 frequencies each separated by 10 MHz are digitized with time resolution of 100 ms. So far, about 350 groups of solar bursts have been observed by this system. These have been classified as microwave type and decimetric reverse slope (RS) type III bursts. Here, we report statistical investigations of the properties of the 44 moderately strong groups of decimetric type III-RS bursts. The average total duration of these bursts is ~0.7 s, the drift rate varied between ~400 and 3000 MHz s^{-1}, and average decay time is ~120 ms. These observed drifts and timescales suggest that decimetric type III-RS bursts are generated by beam plasma interaction at second harmonic in the inhomogeneous chromosphere, and that the acceleration region is located at a density level of $\leq 10^9$ cm^{-3}.

Subject heading: Sun: radio radiation

1. INTRODUCTION

Skylab observations suggested that X-rays occur near the region of acceleration of the particles. In the acceleration region the densities are of the order of 10^9–10^{10} cm^{-3} (Sturrock 1980) which correspond to plasma emission in the decimetric range. The decimetric spectroscope has been in operation since 1991 March at INPE (Sawant et al. 1992; Sawant et al. 1993), and several types of solar bursts have been observed since then.

Since the beginning of solar radio astronomy, type III bursts in the meter wavelength band have been observed. Benz et al. (1981) reported solar bursts named "blips" in the frequency range of (0.5–1) GHz, and later it was shown that blips are a variant of type III bursts (Benz, Bernold, & Dennis 1983). For the first time, Sawant et al. (1987) noted the occurrence of blips above 1 GHz at 1.6 GHz. Sawant et al. (1990) inferred the presence of decimetric type III-RS bursts at 1.6 GHz associated with hard X-rays. Stähli & Benz (1987) reported the presence of microwave type III bursts in the frequency range 3.40–3.55 GHz and Benz et al. (1992) in the frequency range 6.2–8.4 GHz. So far, only one dynamic spectrum has been published in the literature in the frequency range 0.1–3 GHz (Benz et al. 1991); there is a lack of systematic investigations of type III-RS bursts in the frequency band of 1–3 GHz.

Here, for the first time, we report systematic studies of decimetric type III-RS bursts observed near 1.6 GHz by a high-sensitivity digital spectroscope. Type III bursts are signatures of moving electron beams accelerated during solar flares. Observations of decimetric type III-RS bursts provide direct evidence of accelerated electrons over short timescales and traveling toward the photosphere. In the modeling of hard X-rays, it is commonly assumed that electron beams are traveling toward the photosphere, and when these encounter high densities, X-rays are produced.

2. INSTRUMENTATION

A high-sensitivity decimetric digital spectroscope is in operation over the frequency range 1.6 ± 0.1 GHz with 3 MHz frequency and 100 ms time resolution, on a 9 m diameter polar mounted antenna. The half-power beamwidth of the antenna is ~1.5°, and its efficiency is about 65%. The receiver noise temperature is ~300 K, and the dynamic range is ~100 dB. The sensitivities for different combinations of observing bandwidth and resolutions are in the range of 1–2 SFU (Sawant et al. 1992).

Solar observations are recorded on black and white 35 mm film and simultaneously 20 frequencies equally spaced are digitized with time resolution of 100 ms. Continuous monitoring of the spectra integrated over the observing frequency range (100 or 200 MHz) and time (1 s) is done on paper chart recorder.

Soon, this system will start operating over the frequency range 0.2–2.5 GHz and the observations over a decided band of frequencies, with variable time (1–250 ms) and frequency (0.1–3 MHz) resolutions, simultaneously in two circular polarizations (Sawant et al. 1993).

3. OBSERVATIONS

Up till now, about 650 hours of observations have been carried out with the decimetric spectroscope, and we have participated in international solar campaigns since 1991 and observed many bursts during *Compton Gamma Ray* observing time. Joint analysis of decimetric type III-RS bursts with hard X-rays measured with the BATSE experiment will be reported elsewhere. So far, we have observed a total of 350 groups of solar bursts.

In the frequency range 1.6 ± 0.1 GHz, the mechanisms gyrosynchrotron and beam plasma interaction can generate microwave or decimetric bursts, respectively. The duration of these two types of the bursts can be as small as 100 ms. However, bursts generated by gyrosynchrotron emission will not show spectral fine structures and frequency drift rates, whereas bursts generated by beam plasma interaction can exhibit both.

We have projected original films on the screen amplifying them enough to classify observed bursts in the above-men-

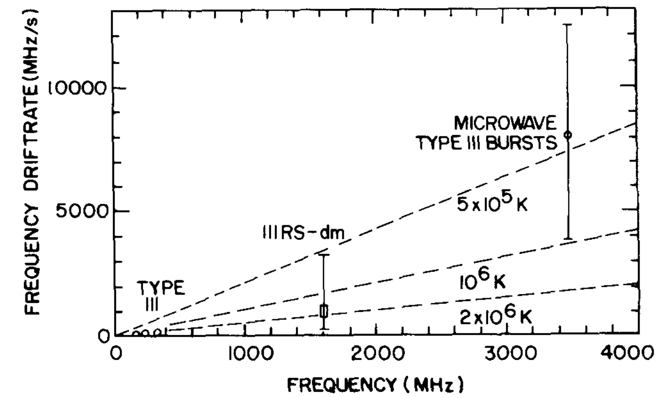

FIG. 1.—Plot of frequency drift rate vs. frequency. Average frequency drift rate of decimetric (1.6 GHz) type III-RS bursts is plotted on the same curve. Original figure is taken from Benz & Güdel (1987).

tioned two categories and to make measurements of drift rates. This analysis lead us to classify about 100 groups of bursts due to gyrosynchrotron microwave bursts and about 250 groups of decimetric types due to beam plasma emission (Sawant et al. 1993). Out of these 250, about 160 groups of bursts are available for digital analysis out of which we have selected 44 intense, well-observed groups of type III bursts for detailed analysis, consisting of 100 individual bursts.

4. DATA ANALYSIS AND RESULTS

4.1. *Flux Density*

On quiet days, one can use the Sun as a calibrator as suggested by Guidice & Castelli's (1971) method. The background solar flux values published in Solar Geophysical Data (SGD) can be used. Knowing the background flux and calibration of the system, flux values of the bursts are estimated. The weak decimetric and microwave bursts were having flux values to the limit of the sensitivity of the system whereas maximum values of the fluxes, so far measured, were of about 150 and 350 sfu, respectively.

4.2. *Drift Rate*

Narrow-band (200 MHz) observations make it difficult to observe drift rate directly on the film or photographic records, as normaly seen on a large-bandwidth conventional spectrograph; however, all of the 100 bursts analyzed showed reverse slope drift rates. These drift rates lie in the range 350–3000 ± 300 MHz s^{-1}. These drift rates are ploted on the curve of drift rates versus frequency (Fig. 1) of Benz & Güdel (1987), and Figure 2*a* shows the frequency histogram of these drift rates.

4.3. *Timescales*

Total half-power duration of these 100 bursts ranges between 280 and 1500 ms and is shown in a frequency histogram (Fig. 2*b*). As can be seen from this histogram, the majority (75%) of these bursts have total duration less than 0.60 ± 0.15 s.

To make accurate measurements of the excitation and decay time we have plotted, assuming the damping to obey an exponential law, the logarithm of the flux density versus time for one burst (Fig. 3). The values obtained for excitation time are 206 ± 75 ms, and those of decay time are 122 ± 75 ms and are also plotted on the curve of decay time versus frequency of Benz & Güdel (1987) (Fig. 4); subsequent discussions refer to all the bursts as a statistical sample.

5. DISCUSSIONS

All the 100 individual decimetric type III bursts showed reverse slope, that is, low frequencies drifting to high frequencies because the beam of electrons coming from above is going from low densities to high densities. Drift rates vary from as low as 350 to 3000 MHz s^{-1}. Observed drift rates are a function of the density gradient and the velocity of exciter-beam electrons, in the case of type III bursts. One can obtain velocities of these electron beams assuming some density model. An attempt to estimate their velocities using the model of Cilliè & Menzel's (1935) suggests that there are present density gradients larger than suggested by the model, hence making it difficult to estimate such velocities. However, an important implication of this is that the medium where type III–like radiation is generated is inhomogeneous. Henceforth, we will assume that the velocities of these beams are of the order of ≤0.3 *c* or energies of these electrons are of order of 20–30 keV.

From Figure 1 it is clear that drift rates of decimetric type III bursts are on the extrapolated part of the frequency dependence of the drift rates of metric type III bursts. Benz et al.

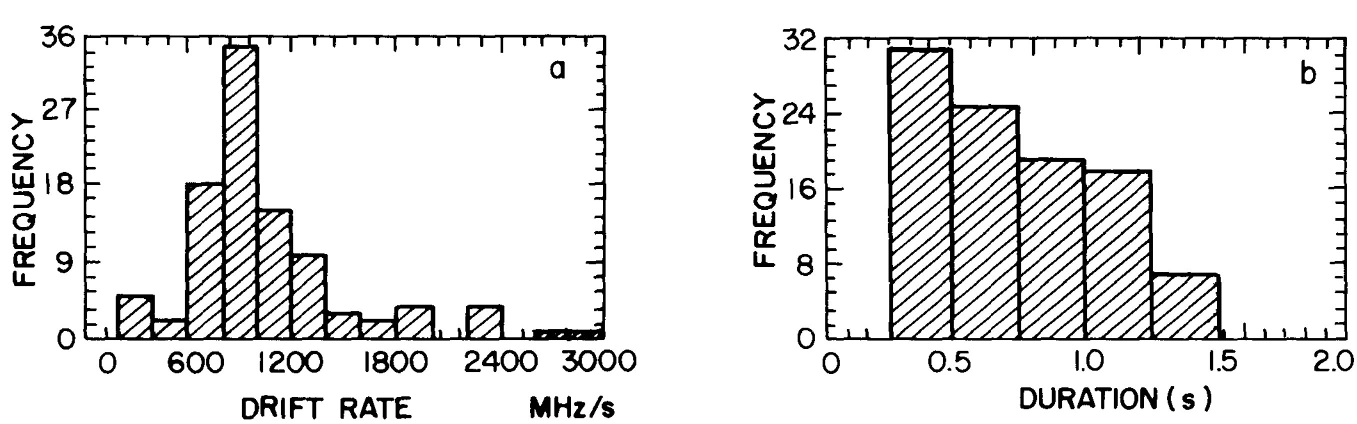

FIG. 2.—Frequency histogram of decimetric type III-RS bursts and (*a*) their drift rates and (*b*) their half-power duration

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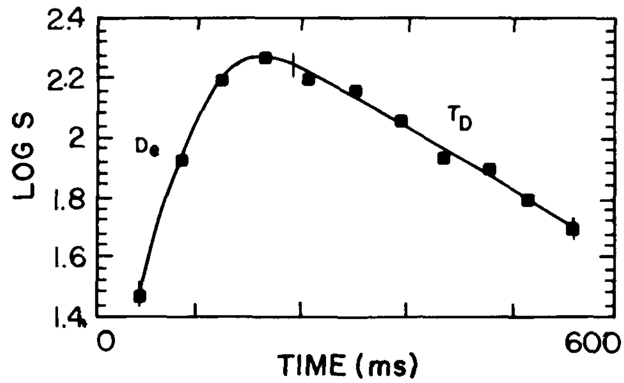

FIG. 3.—Log-linear plot of flux density (S) of a decimetric type III-RS burst, where "D_e" and "T_D" are excitation and decay times, respectively, for the burst observed on 1992 January 10 at 15:01 UT.

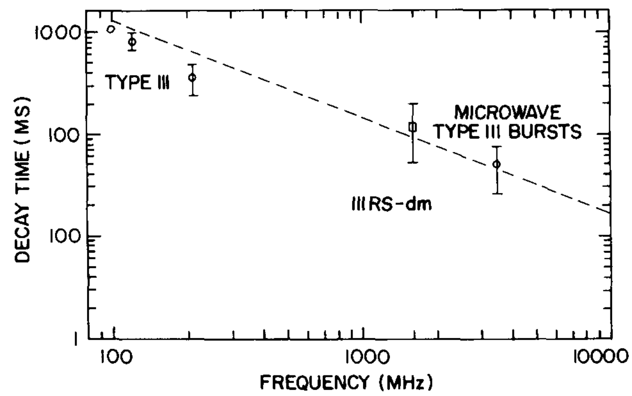

FIG. 4.—Decay time vs. frequency for metric type III bursts, decimetric (1.6 GHz) type III-RS bursts, and that of the microwave type III bursts of Benz & Güdel (1987). The dashed line is a fit to the original empirical relation of Alvarez & Haddock (1973) for metric type III bursts.

(1983) have shown the linear relationship between drift rate and frequency of observations, assuming vertical velocities of the order of $\leq 0.3\ c$ and temperature of the medium of order 10^6 K. Drift rates of the decimetric (1.6 GHz) type III-RS bursts are well fitted using this curve. Thus, the scale heights of densities will have to be appropriate to this temperature.

The fact that decay times of the bursts also fit the curve of the empirical relation given by Alvarez & Haddock (1973), for metric type III bursts, justifies the assumption that the 1.6 GHz type III-RS bursts are also generated by beam plasma interaction at second harmonic at the density level of 7.9×10^9 cm^{-3}, corresponding to 800 MHz fundamental emission. This simple fact, along with the tendency of the majority of bursts to have reverse slope (the beam of electrons going toward photosphere), suggest that the acceleration region of these flares is located at a density level of $\leq 10^9$ cm^{-3}, higher in the corona.

Using the timescales of these decimetric type III-RS bursts and assuming that the decay is due to collisional damping and using the relation given by Alvarez & Haddock (1973) or Landau damping and using equations given by Subramanian, Krishan, & Sastry (1981), we can estimate that the temperature of the region where decimetric type III bursts are generated is $\leq 10^6$ K, and the number density of the electron beam is $\sim 8.0 \times 10^4$ cm^{-3}.

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