ACCELERATION REGION OF ENERGECTIC PARTICLES ASSOCIATED WITH TYPE III AND X-RAY BURSTS DURING SOLAR FLARES

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Abstract. We investigated the association between type III decimetric bursts mainly having center frequency above 1000 MHz, and hard X-ray flares, observed by Phoenix radio spectrometer and Yohkoh satellite, respectively. Assuming an improved density model of the solar chromosphere, the average electron beam velocity ($\sim$ 0.16 c) and hence the average electron energy ($\sim$ 7 keV) was inferred from the average frequency drift rate ($\sim$ 1350 MHz/s) of the 160 isolated type III bursts. The height of acceleration region of the energetic electrons was estimated (1.2-4.5 $\times$ 10^9 cm), assuming the electrons lose energy primarily by collisions with chromospheric plasma. In majority of flares analysed, decimetric and X-ray emissions started almost simultaneously. However, in two flares, radio emission started earlier ($\sim$ 5-10 sec), suggesting that the acceleration region is located near to where the decimetric emission is generated, about 10^9 cm above the photosphere. In two flares, the correlation between X-rays and radio was better at lower frequencies ($\leq$ 100-600 MHz) at the onset of the bursts. However, during the evolution of those flares, the correlation improved for higher and higher frequencies ($\geq$ 600 MHz), suggesting that the acceleration region was displaced towards the photosphere. The estimated velocity of the acceleration region is $\sim$ 3-8 $\times$ 10^3 km/s.

1 INTRODUCTION

The first hypothesis of a common origin for non-thermal electrons responsible for hard-X ray and type III emissions and their simultaneous acceleration was proposed by Kane (1972), suggesting that the electrons are accelerated during the impulsive phase of solar flares and escape from the acceleration region in the chromosphere towards the corona and photosphere following the magnectic lines of the loops, producing type III radio bursts by beam-plasma interaction and hard-X ray emissions at the loop footpoints by bremsstrahlung.

Simultaneous observations of type III and hard X-ray bursts indicate the presence of moving beam particles accelerated during the flares. The frequency drift rates of type III bursts give the velocities and/or energy of the electrons in the beam. The spectral analysis of hard X-ray emissions also yields information about the energy of the particles injected in the acceleration region.

However, there is only few simultaneous observations of solar bursts in X-rays and radio decimetric band above 1000 MHz (Crannel et al., 1978; Kundu et al., 1986; Sawant et al., 1990; Aschwanden et al., 1985; Aschwanden et al., 1993).

Here we analyse solar decimetric type III bursts mainly observed above 1000 MHz, and most of them having Reverse Slope (RS) drifting rates, associated with hard X-ray emissions. The height of acceleration region of the energectic electrons was estimated, assuming a density model of solar chromosphere and the electrons losses energy primarily by collisions with chromospheric plasma.

2 DATA SELECTION

The data sets analysed included 7 solar flares that have been simultaneously observed in hard X-ray by Yohkoh satellite and in radio frequencies by the broadband (100-3000 MHz) spectrometer Phoenix (Benz et al., 1991) (Table 1), as shown in Figure 1.

3 ANALYSIS OF TYPE III-LIKE DECIMETRIC BURSTS

Out of 416 bursts, 160 isolated type III bursts were analysed. By using digital data gaussian profiles were fitted for the type III bursts and starting and ending frequencies leading to the frequency range, flux density, and half power duration were determined. The frequency drift rate, leading to the average velocity and energy of the beam, was estimated from linear regression of the peak fluxes of the gaussian profiles in the frequency-time plane. The highlights of the statistical analysis are given below (Meléndez *et al.*, 1998).

(a) Most of bursts have less than 250 MHz frequency range.

(b) The number of bursts decreases with increasing starting frequency.

(c) The relation between half power duration and observed frequency is $t_{1/2} = 1.7 \times 10^4 f^{-0.60}$.

(d) About 64 % are reverse slope and 36 % are normal drifting bursts.

(e) The relation between drift rate and observed frequency (0.3 - 3.0 GHz) is $\mid df/dt \mid = (0.09 \pm 0.03) f^{(1.35 \pm 0.10)}$.

(f) The average velocity and energy of the electron beam are $\sim$ 0.16 c and $\sim$ 7 kev, respectively.

Table 1 - Hard X-ray flares (Yohkoh) and associated decimetric emission (Phoenix)

#	DATE	YOHKOH START (UT)	YOHKOH MAX (UT)	YOHKOH END (UT)	PHOENIX START (UT)	PHOENIX END (UT)
1	Sep/05/92	11:22:54	11:27:02	11:31:12	11:25:31	11:31:13
2	Sep/06/92	09:02:08	09:04:08	09:10:40	09:03:25	09:04:35
3	Sep/06/92	11:47:06	11:51:26	11:51:28	11:48:48	11:58:48
4	Jan/18/93	13:02:41	13:02:59	13:03:29	13:01:07	13:01:36
5	Oct/02/93	07:39:50	07:40:10	07:45:34	07:39:39	07:45:09
6	Oct/03/93	09:24:54	09:27:32	09:30:24	09:26:27	09:31:19
7	Oct/03/93	12:42:30	12:42:42	12:45:36	12:42:08	12:44:36

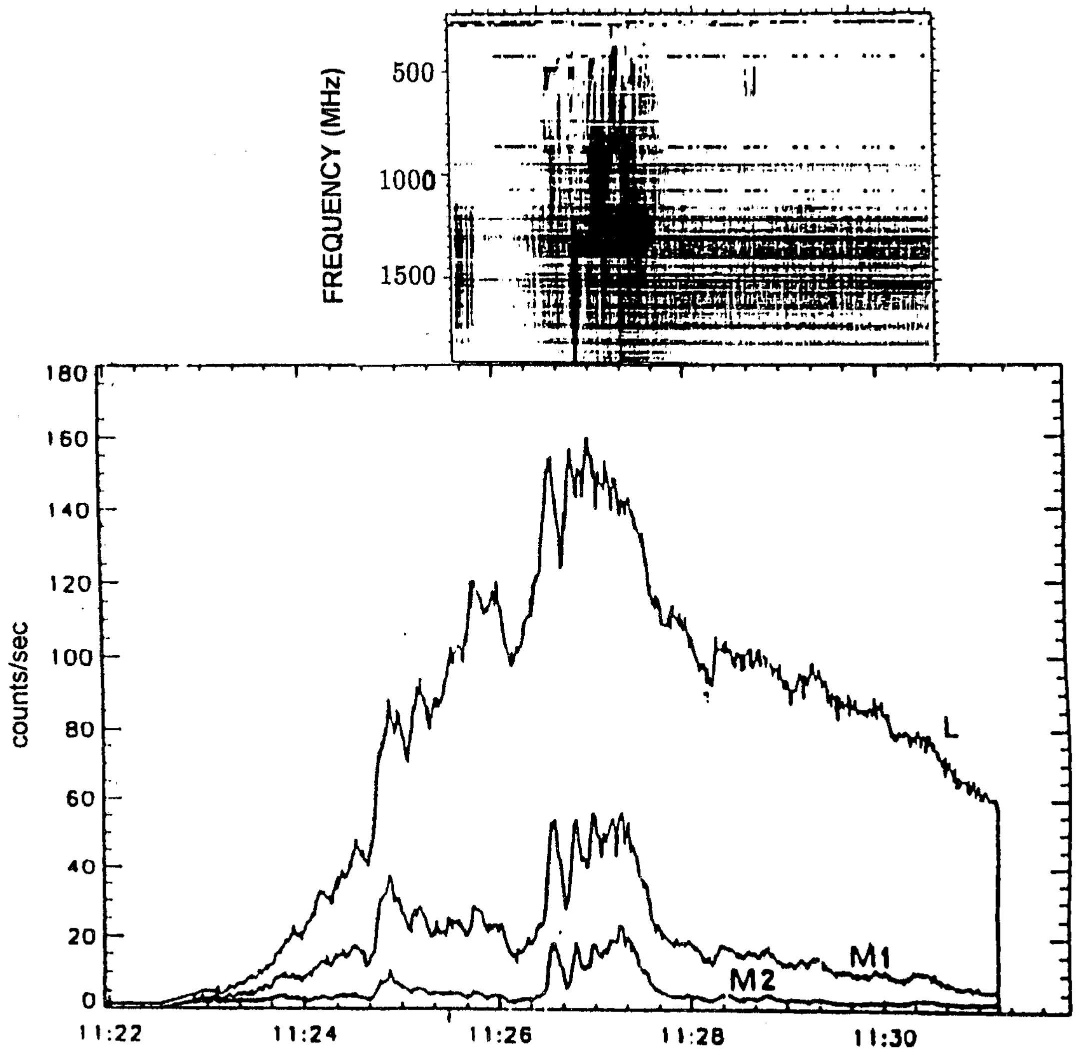

Figure 1: Flare observed in Sep/05/92 (~ 11:24:47 UT). (Top) Dynamic spectrum of decimetric (100-3000 MHz) solar bursts. (Bottom) Time profiles of hard X-ray emissions (L: 14-23, M1: 23-33, M2: 33-53 keV).

4 HEIGHT OF ACCELERATION REGION OF ENERGECTIC ELECTRONS

Considering the electron beam average energy obtained from drift rates of type III bursts, and assuming an energy loss rate as a function of height (dE/dh) mainly due to collisions, as given below (Kane and Anderson, 1970), we estimated the height above the photosphere where the energetic electrons are accelerated.

$$\frac{dE}{dh} = -2,6 \times 10^{-18} N_e(h) E^{-1} . \quad (1)$$

For outgoing electrons, we integrated the equation 1 for $\Delta E = E_f - E_o$, and $\Delta h = h_f - h_o$, where E_o is initial (injection) energy, E_f is final energy (average beam energy), h_f is the final height associated to the decimetric emission observed and h_o is the height of the acceleration region. Aschwanden et al.'s (1995) electron density-height model, modified by type III analysis (Meléndez *et al.*, 1998), is used for this calculation.

The height of the acceleration region was estimated for E_o = 10-100 keV and E_f = 7 keV, and for final heights of $h_{f1} = 6 \times 10^9$ cm and $h_{f2} = 9 \times 10^9$ cm, corresponding to regions of harmonic emissions in 2500 MHz and 900 MHz, respectively (Figure 2). We obtained $h_o \simeq 1.2$ - 4.5×10^9 cm above the photosphere, for initial energies between 10 and 100 keV. For $E_o >> 100$ keV, h_o tends to $\sim 1.2 \times 10^9$ cm, suggesting that electrons injected below this limit do not reach the decimetric emission region with enough energy (Fernandes, 1997; Fernandes et al., 1998) (Figure 3).

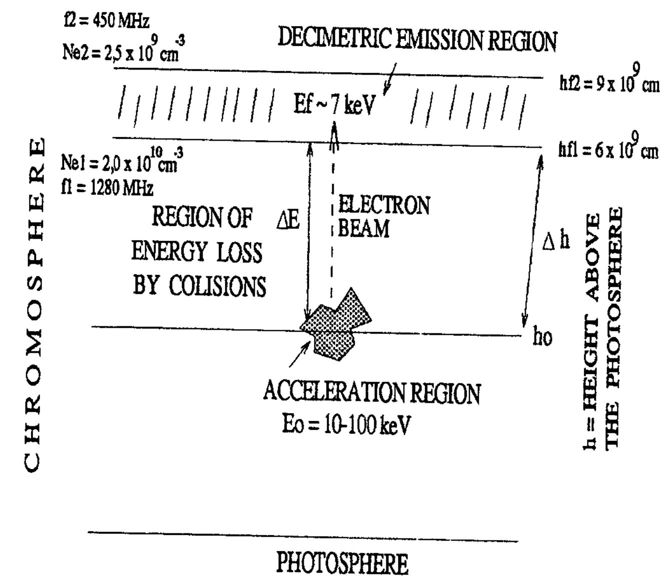

Figure 2: Schematic representation (not to scale) of the height (h_o = 2,5-7,0 × 10^9 cm) of acceleration region above the photosphere where energectic electrons are injected with energies E_o = 10-100 keV and loose energy by colisions with plasma until to reach the final height (h_f), where the electron density (2,5 × 10^9 cm^{-3} - 2,0 × 10^{10} cm^{-3}) is associated to the decimetric emission range ~ (1000-2500) MHz on second harmonic.

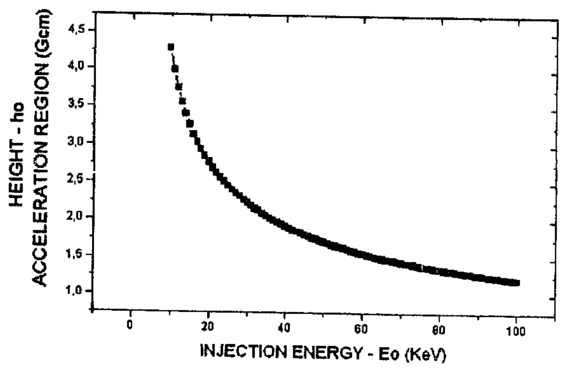

Figure 3: Height of energetic electron acceleration region (h_o) as function of injection (initial) energy (E_o).

5 GENERAL CORRELATION BETWEEN RADIO AND X-RAY EMISSIONS

For the flares observed simultaneously in radio frequency (100-3000) MHz and in hard X-rays the main features of general intensity correlation are discussed bellow.

5.1 Starting Time

For about 67 % of the flares analysed, radio and hard X-ray emissions started almost simultaneously. However, in two flares (1 and 7 of Table 1) radio emissions in the frequency range of 500-2000 MHz started earlier (~ 5-10 s) than hard X-rays, suggesting the acceleration region is located near to where the decimetric emission is generated, supporting the hypothesis that decimetric bursts are originated near the region of acceleration of the particles and they are associated with the regions where the flare energy is released. Also, it can be an evidence that before the occurence of X-ray emissions and, consequently, before the chromospheric evaporation, responsible for the gradual enhacement of plasma density inside the magnectic loops, they have high density enough for the occurrence of decimetric emissions from the beam-plasma instability mechanism.

Benz et al. (1983) have showed evidencies of radio emissions (10-1000 MHz) ocorring before the pre-flash phase of the flares, characterized by broad band (400-1000 MHz) quasi-periodic disturbances simultaneouly with soft X-ray emissions.

5.2 Displacements of acceleration region

In two flares (5 and 6 of Table 1) we found evidence that the global intensity association among hard X-ray and radio emissions is better for low frequencies (~ 100-500 MHz) at the flare onsets and it becomes better for higher frequencies (~ 600-1700 MHz) during ~ 25-50 sec, while the flares evolve. This evidence can be interpreteted as a result of the displacement of the acceleration region toward the photosphere. Assuming radio emission at the second harmonic and the electron density model we estimated heights of emission and knowing the time difference (~ 25-50 sec), we estimated the velocity of displacement of the acceleration region is ~ 3000 - 8000 km/s.

6 DISCUSSIONS AND CONCLUSIONS

The highlights of analysis of hard X-ray emissions associated with decimetric type III bursts are given below.

(a) The height of acceleration region of decimetric type III emitting energetic electrons estimated is ~ 1.2-4.5 × 10^9 cm above the photosphere, for injecting energy of 10-100 keV.

(b) Simultaneous observations of radio and X-ray emissions support the hypothesis that decimetric bursts originate near to the region of acceleration of the particles at densities of ~ 10^9-10^{10} cm^{-3}.

(c) There is evidence of the acceleration region moving towards the photosphere during the evolution of the flare, with velocities of ~ 3-8 × 10^3 km/s, similar to earlier suggestions of Hamilton et al. (1990) and Kane (1981). The preliminary results need to be confirmed with observations of a larger number of bursts.

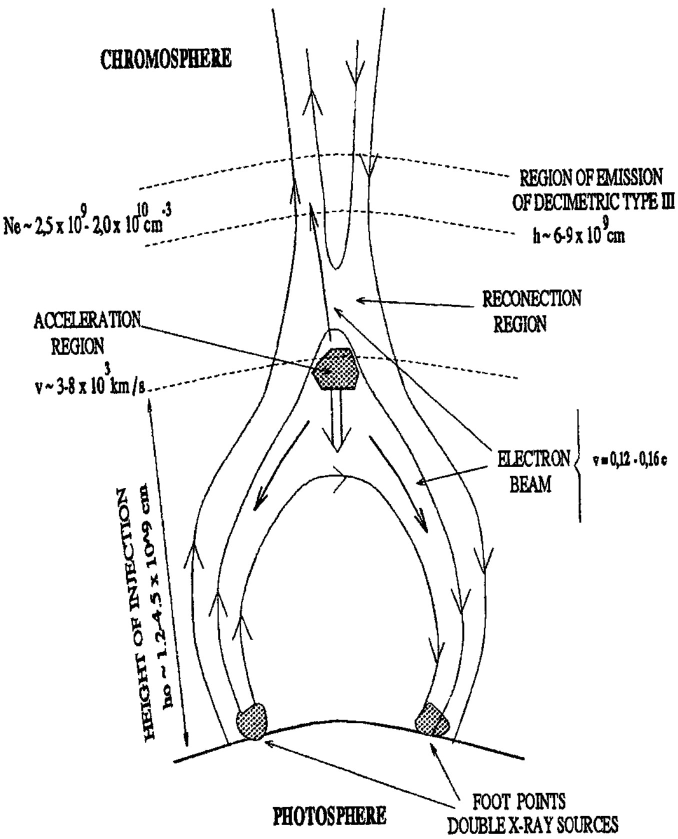

Figure 4: Schematic representation (not to scale) of a magnetic loop, showing magnetic reconnection region accelerating particles that move away and towards the photosphere. The accelerated electron beam produces decimetric emission in the chromosphere and hard X-ray emission at the footpoints of the loop.

Based on the results, a possible scenario and evolution for the flares is the following, as shown in Figure 4. First the magnetic field reconnection process takes place, creating an acceleration region of particles located at heights of the order of 1.2-4.5 × 10^9 cm above the photosphere.

Energetic electrons are accelerated and propagate along the open magnetic lines losing energy mainly due to collisions with the plasma. The beams reach the decimetric emission region (h ~ 6-9 × 10^9 cm), corresponding to densities of N_e ~ 2,5 × 10^9 - 2,0 × 10^{10} cm^{-3}, with velocities of order of 0.12-0.16 c (~ 7 keV), generating type III decimetric emissions. The accelerated electron beams also produce hard X-ray emissions at the foot points of the loop by bremsstrahlung mechanism.

7 ACKNOWLEDGEMENTS

The authors are grateful to Dr. A.O. Benz and Dr. S.R. Kane for the Phoenix and Yohkoh data, respectively, and also for comments and suggestions. F.C.R. Fernandes and J.L. Meléndez acknowledge receiving scholarships from CNPq and FAPESP.

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