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A Probable Short Decimetric Type I-like Noise Storm: Associated with Type III Bursts? *

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Abstract A rare Type I-like noise storm was observed with the solar radio spectrometers (1.0–2.0 GHz and 2.60–3.8 GHz) at National Astronomical Observatories of China (NAOC) on September 23, 1998. We concentrate on checking the Type I-like noise storm occurred in the decay phase of a Type IV radio burst. This noise storm consists of many Type I bursts and isolated Type III or Type III pair bursts. It has a bandwidth of ≤ 0.5 GHz. The duration of each Type I burst is of the order of 100–300 ms. The total duration is greater than 11 minutes. The circular polarization degree of the components of Type I and associated Type III bursts are about 40%–100% and almost 100%, respectively, which is greater than that of the background continuum (nearly the precision of our instrument). This short decimetric Type I-like storm may be another kind or the extension of the kind of metric Type I storm, and may possess the duality of metric and decimetric radio emission. It may be in favor of an earlier emission mechanism of the fundamental plasma radiation due to the coalescence of Langmuir waves with low-frequency waves.

Key words: Sun – radio radiation – Type I noise storm

1 INTRODUCTION

Traditional long-lasting Type I or Type III storms of radio emission are commonly observed at meter to decameter wavelengths. At meter wavelengths Type I storms typically consist of myriads of Type I bursts. The stronger storms are superimposed on a continuum (Dulk, Suzuki & Sheridan 1984). At long meter and decameter wavelengths the Type III storms typically consist of myriads of Type III bursts which also may be superimposed on a continuum (Wild 1957). There are mostly Type I storms at meter wavelengths and mostly Type III storms at decameter wavelengths (Boischot, de la Noë & Møller 1970). A Type III storm usually starts near the low frequency edge of a Type I storm and continues to the lowest frequencies observable from earth (typically about 10 to 20 MHz) (Malville 1962). Decimetric solar radio

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burst observations started as early as the 1960s. Later they have been classified by Wiehl, Benz & Aschwanden (1985) according to the time constant: fast 'transients' type bursts with durations < 1 s and 'trap' type with durations ~ 5 s. The Type I storm burst should belong to the fast 'transients Type, and it release low energy, similar to weak spikes. It is a much less energetic phenomenon than the flare initial shock waves as are manifested by H_α sprays and coronal transients, which cause Type II radio bursts (Spicer, Benz & Huba 1981). All Type I storm bursts have similar radio emission properties such as a short-duration pulse series, a low intensity and a limited band width. Type I bursts and continuum are known to occur over periods of hours or days, and to occur in the range of meter waves or even longer wavelengths (Gabriel, Evans & Feynman 1990; Böhme 1990; Spicer, Benz & Huba 1981). It has been known that the Type I emission is associated with exciting sources of particle accelerations (Melrose 1980). The sites of particle accelerations are generally thought to be near the decimetric wavelengths. The cause of the accelerations is changes in the magnetic field structures in the pre-impulsive phase (Trottet 1986) or hind phase of a flare (Švestka et al. 1982). Also, the spike-like Type I storm sources are close to, or in the regions of energy release. So the observations of Type I storm may also serve as probes of micro-energy releases, e.g., radio spikes microflares or elementary flares (Benz 1985; Aschwanden et al. 1990). Theories of formation of Type I storm bursts have been cited in a number of papers (e.g., Hanasz 1966; Spicer Benz & Huba 1981; Benz & Wentzel 1981; Melrose 1980; Aubier 1980, etc.). Most authors agree that the noise storms are due to superthermal electrons emitting radio waves through a two-step mechanism: generation of Langmuir waves and their conversion to transversal waves by coalescence with some often unspecified low frequency waves.

The Type I-like storm discussed in the present paper is a rare event. It was known weak spikes (see Paper 1). Later, after more study, we termed it a "Type I-like noise storm", and was briefly presented by Xie et al. (2003). It is associated with some Type III bursts and has a shorter duration than those mentioned by Spicer, Benze & Huba (1981), while sharing some similar morphological features. It occurred at much higher frequencies (1.0–1.5 GHz) than is usually cited in the literature. There is a similar instance of such rare events. The morphology and main observational properties of this second case are presented in Appendix II. Further observations of Type I noise storms are needed to ascertain their frequency range and the assicated magnetic configuration, particularly for those occurring in the high frequency band.

The rare Type I noise storm which we describe in this paper is superimposed on a complex Type IV radio burst reported in elsewhere (Wang et al. 2003, hereafter Paper 1). In Sect. 2 we describe the relevant instruments and radio observations and in Sect. 3 we present the results obtained and their interpretation. Finally in Sect. 4 we give a qualitative discussion of Type I-like noise storms associated with the Type III bursts.

2 OBSERVATIONS

2.1 Instruments

This event was observed with a decimetric radio spectrometer in the range of 1.0–2.0 GHz and a microwave spectrometer in the range of 2.6–3.8 GHz at National Astronomical Observatories of China (NAOC), as well as with the Siberian Solar Radio Telescope (SSRT) of Russia. The parameters of the instruments have been given in Paper 1 and in Altyntsev et al. (2002).

2.2 Overview of the 1998 September 23 Event

This radio burst was associated with a flare of importance 3B/M7.1, located at N18 E09 (NOAA Region 8340), that started at 0640 UT, reached maximum at 0713 UT, and ended at 0731 UT. The radio activity at different frequencies are listed in tables 1 and 2 of the Paper 1. Figure 1 shows the radio flux evolution of the event at the selected frequencies. From Fig. 1 we can see the following features:

1) In the region 1.0–3.8 GHz four groups of Type III bursts and weak Type I-like noise storm (A, B, C, D, and E, marked in Fig. 1, respectively) and multiple pulsations are superimposed on a Type IV continua emission (see, Paper 1 and Xie et al. 2002).

2) The four Type III bursts and the associated Type I-like noise storm occurred in different phases of the flare and in different frequency bands (see Paper I for detail).

3) The Type I-like noise storm emission (E in Fig. 1) appeared only in the lower frequency range ($\leq$ 1.52 GHz) during the decay phase of the burst. Its time profiles at the selected frequencies are given in Fig. 2.

Moreover, in the decay stage (after 07:14 UT) two major sources were observed, and a strongly polarized source near the leading sunspot and a source extending from the north to the south above the eastern ribbon are seen in H_α and UV in the 1550 Å line (see fig. 5 of Altyntsev et al. 2002).

In particular, post-flare loops in the decay stage were found (in figure 10 of Altyntsev et al. 2002). The structure of the loop observed in the EUV 195 Å line is remarkably close to the calculated magnetic field lines. These phenomena show that in the course of the flare, the magnetic configuration tends to change from a relaxed state to a potential sate, and new magnetic reconnection may exist between the post-loop and the preexisting source.

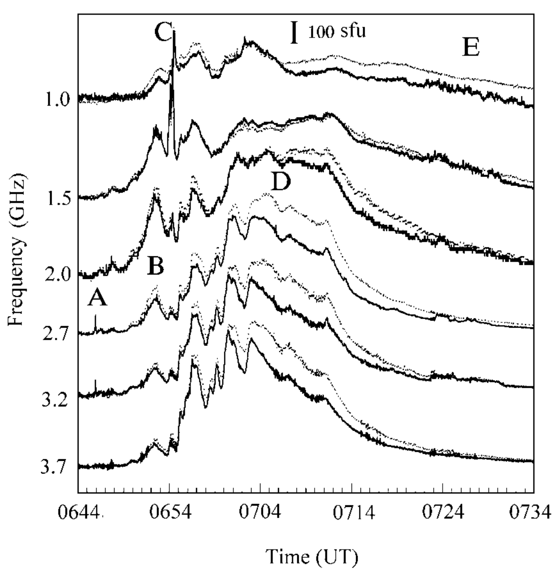

Fig. 1 Spectrogram (time profiles) of radio bursts of 1998 September 23 at selected frequencies, thin lines for left polarization, thick lines for right polarization. Capital letters A, B, C, D and E mark the places o the four groups of Type III bursts and the period of the Type I-like noise storm, respectively.

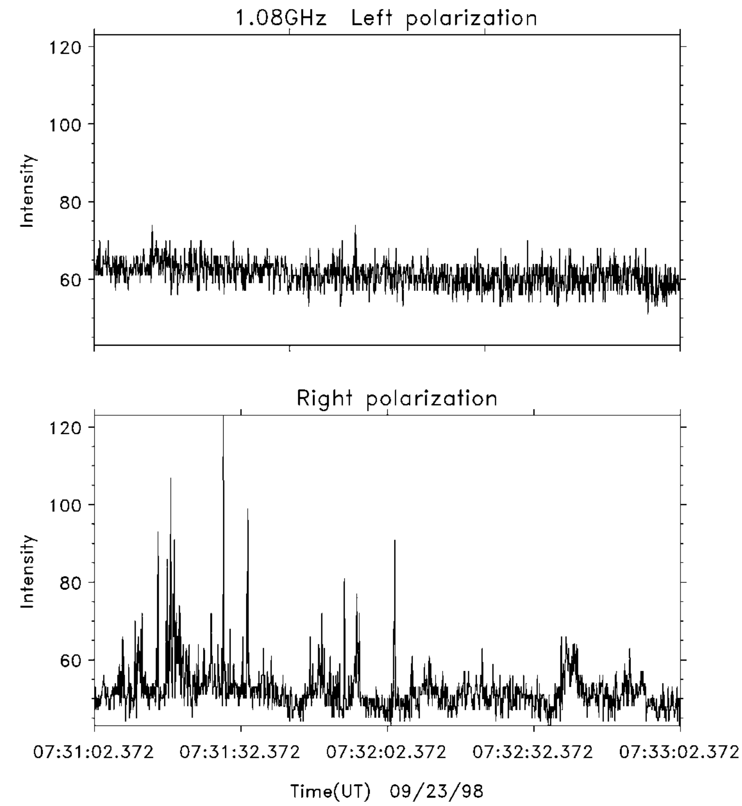

Fig. 2 Enlarged time profile of the Type I-like storm over 2 minutes at a selected frequency (1.08 GHz).

3 OBSERVED PROPERTIES AND INTERPRETATION

To display the Type I-like noise storm, we give its fast fine structures in the decaying phase (Fig. 2). This storm consists of many simple Type I and isolated or paired Type III bursts (Figs. 3–5). This Type I-like noise storm has lifetimes of 100–300 ms, a bandwidth of ≤ 0.5 GHz, and a degree of polarization of 40%–100% (the average value is about 60%) and is superimposed on a Type IV burst. From Fig. 3 we can see that the Type I-like storm with lower intensity is superimposed on a continuum emission. In particular, the isolated Type III and spike bursts included in the Type I-like storm have strong polarization near to 100%. For both the first case (1998/09/23) and the second case (2001/04/10, see Appendix II), the lifetimes and the degrees of polarization of the Type I storms are in agreement with those of meter - decameter wavelengths, but their relative bandwidth of the order of 40%–60% are greater than those of meter - decameter wavelengths (Melrose 1980). The Type I-like storms may be another kind of storm or a variant of the classical Type I storm at meter wavelengths, because of the existence of large bandwidth (0.5–1.0 GHz) and short duration ($\sim$ 11 min) as well as occurring in the hind phase of a flare. The statistical results by Dulk, Suzuki & Sheridan (1984) indicated that the degree of polarization of Type I storms was generally $\geq 50\%$, and that of Type III storms, almost always $< 50\%$. Compared to these results, polarizations of Type I-like storms we obtained are basically in agreement, while the polarization of the associated Type III bursts of 2001/04/10 is, and that of 1998/09/23 is not in agreement. The disagreemnt may be because the Type III bursts were not part of a Type III storm, and particularly, these Type III bursts that occurred above 1.0 GHz might belong to the regime of microwave Type III bursts. We think that the high polarization (in the O-mode) in Type I-like storms associated with Type III and spike bursts is due to fundamental plasma mechanism (Melrose 1980; Paper 1; Xie et al. 2000), and their occurrence in the same frequency region and height may be attributed to different magnetic structures (different locations). As an alternative possibility, for Types I and III bursts occurring in the same frequency region, only the Type III bursts occur at the harmonic plasma frequency, while the Type III bursts must occur at a much greater height (Aubier 1980). The location of electron acceleration may be in an interconnecting active region between a preexisting large-scale magnetic structure and a newly emerging small post-flare loop (Spicer, Benz & Huba 1981). In the present paper the long lasting ($\geq$ 11 min) noise storm exhibits a weak spikes-like time profile. Such long lasting event indicates the presence of trapped particles in the magnetic field. Such short wavelengths require either a reduction of the effective scale height of the active region in the beam model or a different explanation than the conventional beam model (Wiehl, Benz & Aschwanden 1985).

This Type I-like noise storm is most likely plasma emission caused by mode coupling between low-frequency waves (e.g., lower hybrid or ion-acoustic waves) and Langmuir waves (or upper hybrid waves), as suggested by Spicer, Benz & Huba (1981), Melrose (1980), Gopalswamy (1990), Sawant et al. (1987) and Wentzel (1981). The trapping of accelerated electrons in the coronal magnetic field is possible after the anomalous gyroresonance instability has scattered the particles. Anisotropy in the velocity space drives electrostatic upper-hybrid waves. Since both the lower and upper-hybrid waves are nearly perpendicular to the magnetic field, they can interact efficiently to create radio waves. Whenever a region with a high level of lower hybrid waves (shock) overlaps with a region of upper-hybrid waves, a Type I radio burst is emitted (Spicer, Benz & Huba 1981; Benz & Wentzel 1981). Moreover, Benz & Wentzel (1981) also proposed a plausible energizing mechanism associated with coronal evolution, namely, the generation of intense current-driven ion-acoustic wave in a small portion of the corona. The ion-acoustic wave cause anomalous electrical resistance and produce radio emission at the plasma frequency by combining with Langmuir plasma waves. The electrons heated in sites of the anomalous resistance escape into the ambient corona and may become trapped. They could result in two important consequences: first, the associated Langmuir wave yields the observed radio continuum; secondly, the supra-thermal electrons at the sites of anomalous resistivity lead to the Langmuir waves that cause the Type I storm due to coalescence of Langmuir waves (or upper hybrid waves) and low-frequency waves (Benz & Wentzel 1981; Wentzel 1981). The required level of low-frequency weakly plasma turbulence is likely to be present in the heated corona region (Fleishman & Mel'nikov 1998). The Type I continuum as background may be the emission from a large loop with the Langmuir waves generated by trapped electrons. If the electrons are not trapped, Type III bursts may result. The main implications of this theory are the limits on the brightness temperature of the continuum and on the size of continuum source in the bursts (Melrose 1980). Therefore, we examine the brightness temperature and the size of source in Appendix I below, which shows that the conditions required for the emission mechanism are satisfied.

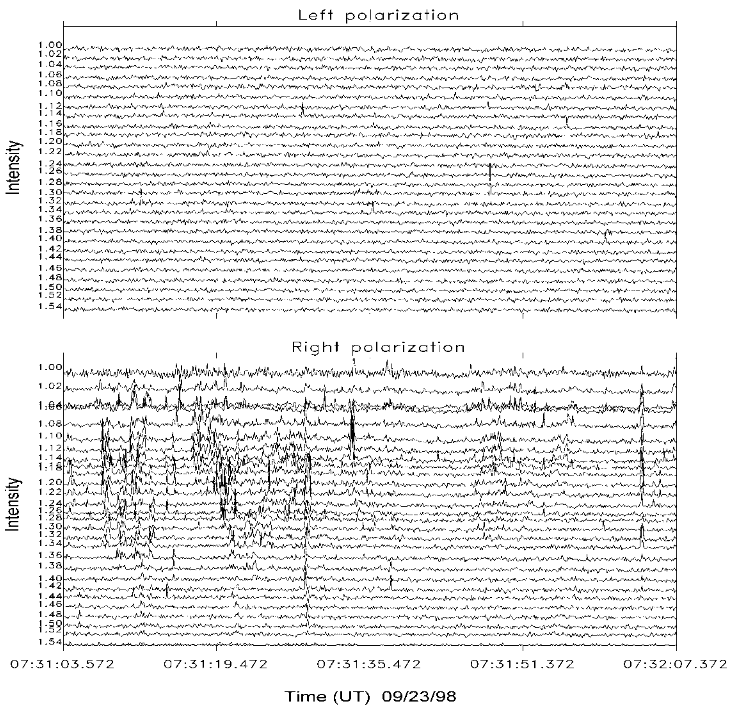

Fig. 3 Spectrogram of fast fine structures of the Type I-like storm over 64 s in the region 1.0–1.54 GHz.

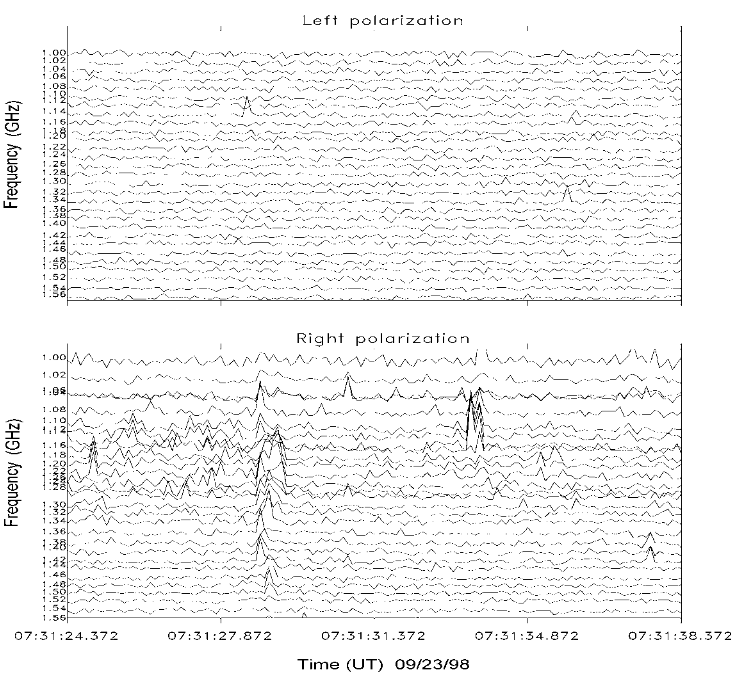

Fig. 4 Enlarged fast fine structures of the pair of Type III bursts associated with the Type I-like noise storm.

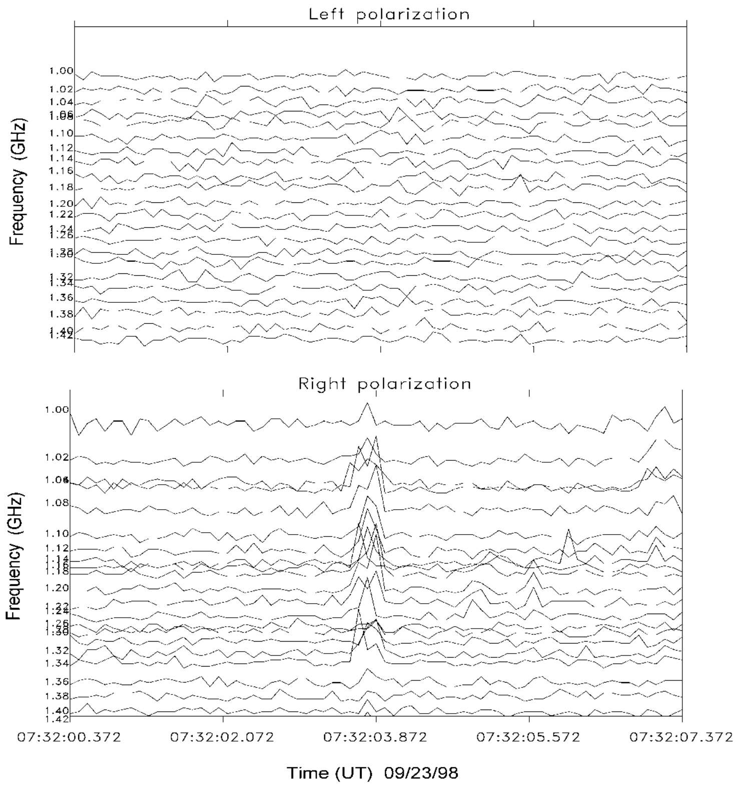

Fig. 5 Enlarged fast fine structures of one Type III burst with positive frequency drifting rate associated with the Type I-like noise storm.

4 DISCUSSION

4.1 Region-covering Frequency of the Type I-like Storm Associated with Type III Bursts

We have measured different characteristics of the Type I-like storm and the Type III bursts at 1.0–1.52 GHz. In view of the coexistence of Type III bursts with positive drifting rate and the pair of Type III bursts, the acceleration region of electrons or bidirectional electron beams may be at the separatrix frequency of closed and open magnetic fields (Klein et al. 1997; Bastian, Benz & Gary 1998; Xie et al. 2000). We think that this region is also the transition region of the Type I storms and Type III bursts, but the region is shifted downwards by about 1.5 GHz (from decameter to short decimeter wavelengths) as compared with the traditional transition region of storms (several tens of MHz level, in Aubier 1980). Aubier (1980) has shown that the perpendicular momentum of the electrons remaining after the Type I process is transformed into parallel momentum during the propagation along the decreasing magnetic field, and that Type III emission can occur when the parallel velocity component reaches a critical value (Aubier 1980). This model can explain the low frequency cut-off of Type I emission, the characteristics of the Type III bursts near their starting frequency and the transition between Type I and Type III decametric emissions. Generally, there is a separated frequency region (gap) between the Types I and III emissions. However, if the Type III emission is harmonic plasma emission, then the separated region does not exist (Aubier 1980).

In our case (1998/09/23) the coexistence of Type I-like noise storm and Type III bursts may signify that the Type III bursts arise from harmonic plasma emission together with the appearance of a strong polarization. In our second case (2001/04/10, see Fig. A2 in Appendix II), however, the polarization is weak. The difference in the degree of polarization intensity between the two cases may have something to do with different locations of the sources or the depolarization. The two cases could mean that the classical coexistence region of Type I noise storms and Type III bursts is shifted downwards to the low corona. The short decimeter wavelength may also be a transition region of the Type I storm and Type III bursts from meter to microwave bands.

4.2 Magnetic Configuration of the Concurrent Sources of Type I-Like Noise Storm Associated with Type III Bursts

The radio source configuration is consistent with the electron beam production in the current sheets separating regions of open and closed magnetic flux near the base or top of the streamer. The electron acceleration site may be at this separating region (Klein et al. 1997; Xie et al. 2000). This indicates that the location of electron acceleration can vary from the higher corona to the lower corona (about 1.5 GHz, say), rather than being restricted to only the low frequency region of 0.4–1.0 GHz (Bastian, Benz & Gary 1998).

Just as with the reconnection of magnetic field when the interaction of post-flare loops with a preexisting large loop, illustrated as emerging flux (e.g., figure 1 in Spicer, Benz & Huba 1981), the electrons will be accelerated and captured in the closed loops and compressed downwards in the corona. Then it is probable that local accelerations at the top of the loop are set up since the magnetic field changes drastically there. The accelerated beams of electrons propagate downwards and excite at each level a plasma emission which gives rise to a Type III burst with positive drifting rate. The accelerated bidirectional beams in the separating region of fields produce the pair of Type III bursts (Figs. 4 and 5). If we deal with the proposed model of arch structure (see figure 4 of Aubier 1980) where the Type I and Type III bursts take place, the Type III emission will occur at a higher frequency limit usual for microwave Type III bursts. Also, in the opened field lines with a high magnetic field, both Type I and Type III bursts can be emitted. Moreover, in our case the Type I and III bursts extended to much higher frequencies (1.0–1.52 GHz), that are generally impossible with open field lines. However, in the closed field where bidirectional electron beams occur, Type III burst pairs cannot be produced. Therefore, the acceleration site should be in the separating region of the open and closed magnetic flux (Klein et al. 1997; Bastian, Benz & Gary 1998). In a reconnecting region of strong magnetic field, if the electrons have a large perpendicular velocity component, then Type I emission can take place, and the parallel velocity component of the electrons will also be large enough to produce Type III emission at a higher height (Aubier 1980). The observational result that the Type I bursts are associated with the Type III bursts leads us to the following suggestion: first, the Type I emission originates in the strong magnetic fields of opposite polarity, which may be near the top of the magnetic loop; secondly, the Type III bursts which originate in weak magnetic field may occur in sources close to, but different from the concurrent Type I sources (Kai 1970). The Type I-like storm occurs in the closed magnetic configuration, the microwave Type III burst with the positive frequency drifting rate may also occur in the same magnetic configuration (as figure 4 of Kai 1970).

4.3 Emission Process of Type I-Like Noise Storm and Type III Burst

It is early known that the Type I storms do occur in a closed magnetic field while the Type III bursts (normal) occur in an open field (Kai 1970; Aubier 1980). Moreover, Kai (1970) also indicated that Type III bursts are transient and are weakly or not at all polarized, while Type I storms are persistent and fairly strongly polarized although their individual bursts may be very short-lived ($< 1\,\mathrm{s}$). Therefore, the two Types of bursts may originate from sources with different physical conditions. However, in our case the Type III bursts are strongly polarized, which may belong to the kind of microwave Type III burst. This kind of burst generally originates in a closed magnetic structure (Stähli & Benz 1987). Before long Aubier, Leblanc & Møller (1978) have discussed very few observations of the positions of Type I and Type III storms to be available.

In our case a Type I-like noise storm is associated with some Type III bursts at a higher frequency. This relationship implies a probable physical similarity between the two. Their coexistence supports the hypothesis that a Type I-like noise storms and its associated Type III bursts might be caused by the same electron beams (Aubier 1980), but in two separate sites, while originating in a common site of particle acceleration (Willson 2000).

Let us consider an active region with closed and open field lines, into which accelerated electrons are injected. The theory of Type I emission from plasma beam instability has early been studied by Mangeney & Veltri (1976). They analyzed the evolution of a cyclotron beam plasma instability in a weakly turbulent medium. This mechanism includes electron beams with a large perpendicular velocity component and a relatively low velocity dispersion, gyrating along a strong magnetic field. These accelerated electrons may occur in the reconnection region of a post-flare loop (it has been observed by Altyntsev et al. 2002) with a preexisting loop. If the magnetic lines are closed and the arch does not extend very high into the corona, then only Type I emission occurs and only at high frequencies. However, if the arch reaching a low value of magnetic field is much higher up (at the height of decimeter wavelengths), then both Type I and Type III emissions can occur, and the Type I emission is at higher frequencies than the Type III emission. If the Type III emission is radiated on the harmonic mode, it may overlap the Type I emission (Aubier 1980). This is what happens in our case. Moreover, a small part of the Type III bursts in the case may be due to variation of the magnetic configuration from meter through decameter to short decimeter wavelengths, in a predominantly closed field.

4.4 Association of Type I-like Noise Storm with other Activities

Ogir & Iurovskaia (1976) indicated that the noise-storm phenomenon was associated not only with the growth or maximum-development stage of sunspot groups but also with enhanced surge and filament activities in the chromosphere. Type I radio bursts are a signature of localized acceleration of electrons by the so-called nanoflares (Mercier & Trottet 1997). In addition, Type I storms are strongly correlated with emerging magnetic flux which is a good indicator of Type I noise activity (Spicer, Benz & Huba 1981). Although our observed event of 1998/09/23 occurred at the decay stage of the burst, the post-flare loops could be seen (see figure 10 bottom, in Altyntsev et al. 2002), and a probable filament ejection was noticed by observers in San Vito (Solar Geophysical Data, Altyntsev et al. 2002). This signifies that it was followed by a short-term disruption of the closed magnetic field lines, a temporary opening of the magnetic configuration, and then the reconstruction of the arcade through the post-ejection reconnection (Altyntsev et al. 2002). Spicer, Benz & Huba (1981) pointed out that Type I storms were well correlated with magnetic activity and high magnetic flux levels. Our observations support the important suggestion that Type I storms are driven by newly emerging magnetic flux (e.g., the generation of post-flare loop mentioned above).

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APPENDIX A: I

According to Kundu & Vlahos (1982), the observed brightness temperature T_b is

$$T_b(\mathrm{K}) = 10^8[f(\mathrm{GHz})]^{-2} I\ (\mathrm{sfu}) L_9^{-2}\,,$$

where f is the observed frequency, I the flux density and L_9 the size of the continuum source in cm divided by 10^9. In this event (1998/09/23), for simplicity, we take $f \approx 1.3\,\mathrm{GHz}$, $I \approx 100$ (sfu). Depending on the observed value of Altyntsev et al. (2002) (see fig. 8 of his paper), L is about $0.5'$ at 5.7 GHz, according to the empirical formula of source size on frequency presented by Bastian & Gary (1992), $L = L_0(f/f_0)^{-0.8}$, we obtain the $L \approx 1.6'$ at 1.3 GHz, i.e., $L \approx 7.0 \times 10^9\,\mathrm{cm}$. Thus we can obtain the $T_b \approx 1.2 \times 10^8\,\mathrm{K}$.

This is particularly important because the coalescence process should result in $T^t = T^l$, where T^t is the effective temperature of the escaping transverse waves at the source, and T^l the effective temperature of the Langmuir waves. For a 'large' source one has $T_b \approx T^t = T^l \leq 10^{10}\,\mathrm{K}$; Langmuir waves with $T^l \leq 10^{10}\,\mathrm{K}$ could be generated by a trapped distribution of electrons without any instability of the Langmuir waves (Melrose 1980). Moreover, it is a key step to decide whether the source is 'large', because in the large source case the observed brightness temperature T_b could equal to the effective temperature T^t at the source (Melrose 1980).

As mentioned above, the proposed emission mechanism should result in $T^t \approx T^l$. In a large-source Langmuir waves with $T^l \leq 10^{10}\,\mathrm{K}$ are required. It is conceivable that such a distribution of Langmuir waves could be maintained in a steady state through emission and absorption. In our case the Type I continuum source has a large source ($\approx 1.6'$). The Langmuir waves can be generated by a trapped distribution of energetic electrons. That the conversion of into escaping O-mode waves is due to the coalescence between the Langmuir wave and low-frequency waves, which is generated and maintained at a steady level of the possibly heating region in the corona (Melrose 1980).

APPENDIX A: II

The second Type I-like noise storm associated with Type III bursts (2001/04/10) is shown in Figs. A1 and A2. The main properties are:

(1) Occurred in the hind phase of the Type IV burst; (2) Total duration is of the order of 11 min; (3) The frequency bandwidth is of the order of 0.80 GHz; (4) Associated with Type III bursts with negatively drifting rates; (5) The noise storm is in strong polarization, and the Type III bursts are in weak or strong polarization.

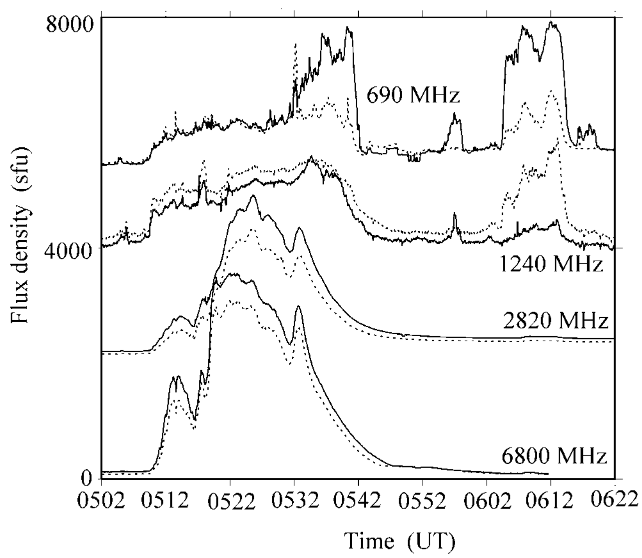

Fig. A1 Spectrogram (time profiles) of radio bursts of 10 April 2001 at selected frequencies, the thin lines represent left polarization, the thick lines, right polarization.

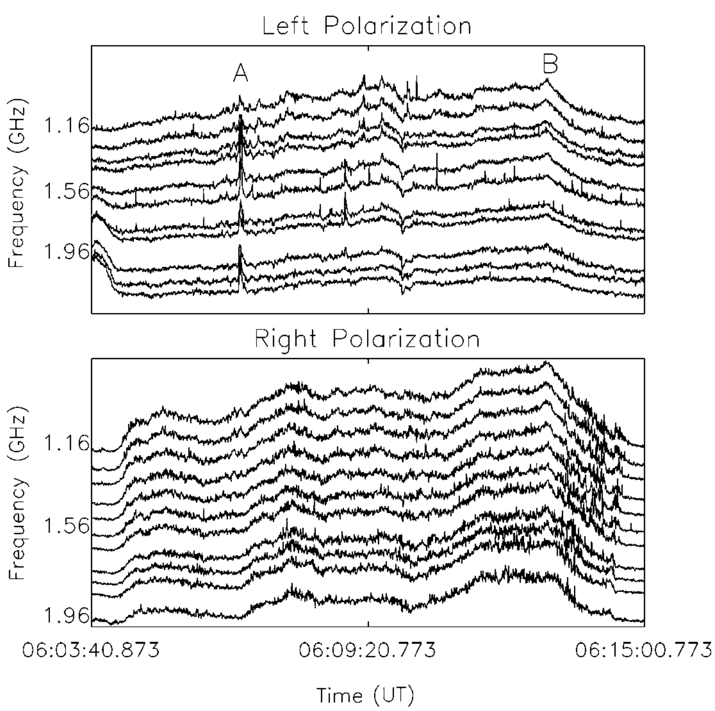

Fig. A2 Spectrogram of fast fine structures of Type I-like storm of 10 April 2001.

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