Relations between solar radio millisecond spike-type III bursts in metric waves and acceleration processes of coronal electrons

MA Yuan¹,³ XIE Rui-xiang¹,³ ZHENG Xiang-ming¹,³ WANG Min¹,³ HUANG Guang-li²,³

¹Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011
²Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008
³National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012

Abstract This paper presents a comprehensive account of the data obtained with the metric wave radio spectrograph of Yunnan Observatory during the maximum of 22nd solar activity cycle and some type III bursts of symbiotic millisecond class spikes discovered in the data reduction. The various morphologies reveal the relation between the occurrences of type III bursts and millisecond spikes. From an analysis of two typical events according to the time sequence of appearances of spikes and type III bursts as well as the characteristics of continuity and transformation in morphology, it is verified that the region of acceleration of coronal electrons is located above the sources of millisecond spikes and type III bursts. The authors' observations show that the interface frequency corresponding to type III bursts lies near 250 MHz. Finally, the authors attempt to interpret qualitatively the generation mechanism of the metric wave millisecond spike-type III bursts with the plasma hypothesis.

Key words solar radio burst—fine structures—electron acceleration

1. INTRODUCTION

As is well known, at various heights of the solar atmospheric layers and via various processes of emission, radiations of different kinds are produced. It is also recognized that the non-thermal electrons propagating in various magnetic structures may generate characteristic
radio signals of different types\cite{1}. During solar flares the acceleration and pouring in of electrons play a very important role in the transfer and release of energy. This may interpret many radiative phenomena and in the flare theory the behaviour of electron beams cannot be ignored. However, up to now the time, location and mode of production of electron acceleration are still not well understood. Hence observations of type III bursts in various frequency intervals are very important for the diagnosis of the process of electron acceleration in flares\cite{2}.

In the early 1960s the fine structures superimposed on or close to metric and decimeter type III bursts were already discovered. At that time it was suggested that they are accidental events in the dynamical spectra with high temporal resolution. Type III bursts with short durations (1s) and millisecond spikes in broadband (30 MHz) ranges are still scarcer than standard type III bursts and spikes\cite{3}. The classical metric wave type III bursts and decimetric wave spike radiations are fine structures of a common class. They often commence as type III bursts of several hundred MHz and rapidly drift towards low frequencies below 1 MHz. Observations and analyses of their various morphologies have been reported in many articles\cite{4-10}. Observations over a long time have since established that not all type III bursts possess symbiotic spike radiation of the millisecond class. Although it is known that the observational characteristics of metric wave type III bursts and millisecond class spike radiation have some distinctive features, it is unclear whether the distinctions are due to the different conditions of their source regions or their differing radiation processes\cite{9,11}.

This paper presents an analysis of the 34 metric wave type III bursts and symbiotic spike events observed at Yunnan Observatory during the maximum of the 22nd cycle. It also introduces two rare events, especially the one which differs from previously reported events\cite{9,11}. This millisecond spike burst occurred at a frequency that is beyond the frequency interval of the related type III bursts. In general, spike bursts appear before the beginning frequency of type III bursts. This implies that spikes and type III bursts are continuous in morphology, and their locations are interchangeable. Our event poses a new problem on the mechanism of generation of radio fine structures in metric wavelength range and we need to construct a model for symbiotic events with interchangeable spike and type III burst morphologies. Although this work does not emphasize the radio phenomena produced in different phases of flares, there will be some discussions about the millisecond spikes and type III bursts that occur simultaneously in the higher coronal layers (230-300 MHz) during flares. Because this is a rare phenomenon in radio emission and it reveals the height of electron acceleration and site of energy release, so in our discussion we shall make a qualitative analysis of its mechanism of generation.

2. INSTRUMENTATION AND OBSERVATION

The working frequency range of the acousto-optic spectrometer of Yunnan Observatory is 230-300 MHz. Its temporal resolution is 10 ms, the frequency resolution is 0.5 MHz and the diameter of the parabolic antenna is $D = 10$ m. In our mode of work, the threshold value controls the data storage in discs. When the radio flux exceeds a certain prescribed threshold value, the computer begins to collect data and store them in hard discs.

From July 1990 to December 1991, a total of several hundred metric wave spike events
were recorded. In order to investigate the relation between metric wave spikes and type III bursts, we have selected 34 events in which spikes and type III bursts coexisted. These events are associated with either Hα flares or metric wave events published in S.G.D.

3. DATA ANALYSIS

3.1 Observational Characteristics of Spike-Type III Bursts

As pointed out by Benz et al., the occurrence of metric wave spikes may possibly be related to the beginning frequencies of the type III burst. For this, in the following we classify spikes according to their time of occurrence and frequency in relation to the beginning time and frequency of the type III bursts:

A - The spike radiation occurs at the same time as the type III burst and at a frequency slightly lower than the beginning frequency of the type III burst;

B - The spike radiation occurs at the same moment as the type III burst and at a frequency slightly higher than the beginning frequency of the type III burst;

C - The spike radiation is later than the type III burst and the frequency of the former is lower than the beginning frequency of the latter.

The statistics of our sample are: 24 events belong to Class A, 6 events to Class B, and 4 events to Class C. So events of Class A are more common than those of Classes B and C. In contrast, Benz et al. found that events of Class B are more numerous than those of Classes A and C and account for 60% of all events.

Our measurements show that the bandwidth of a single spike is 3-10 MHz and the mean value is 5 MHz; the bandwidth of a spike in a group is wider than that of a single spike, and on the average it is 14 MHz. More specifically, for Class A it is 10.5 MHz; for Class B, 21 MHz; and for Class C, 10 MHz. The distribution of bandwidths in grouped spikes observed by Benz et al. in Classes A, B and C are, respectively, 35, 41 and 30 MHz. For the events recorded at Yunnan Observatory, the bandwidths of single spikes do not differ much from Benz et al.'s results, but our bandwidths of grouped spikes are narrower than theirs. However, the tendencies are consistent. This is possibly because the frequency range of our spectrometer is narrower than theirs and because the characteristics of spike events in different activity maxima are different.

Frequency drift is a main characteristic of type III bursts. For this, we measured the frequency drifts of type III bursts and spike events in the frequency range 230-300 MHz. For Class A, the average frequency drift is 83 MHz/s, for Class B, 58 MHz/s and for Class C, 43 MHz/s. According to the classification of Tarnstrom et al., the frequency drifts of all these three classes are “moderate” (< 100 MHz/s). As may be seen from the results of our statistics, there is no one-to-one correspondence between spike events and type III bursts. During the maximum of the 22nd cycle there were recorded a total of 195 groups of type III bursts, and only 34 of them coexisted with spike events. This is only 18% of the total number of bursts. The result of Benz et al. is 20%, and is close to ours. In these coexisting events, grouped spikes are more common than single ones. Spikes of Classes A and C occurred in the frequency range of 250–280 MHz, while those of Class B, in the range 235–275 MHz.

3.2 The Relation Between Spike-Type III Bursts and Optical Activities
Among the 34 events analyzed in this work, 20 or 59% occurred during Hα flares (spikes occurring within 20 minutes before the Hα flares, are included.) 7 or 35% of these events happened within 3-20 minutes before the flares. The other 13 or 65% occurred during the ascent, maximum and descent of the flare. Among the 20 flare-associated events, 18 took place in complex magnetic structures (B, BD, BG, BGD) and complex active regions (FKC, FKI, BXO, EAI, DXI, EKO etc.). So it is evident that 90% of spike-type III burst events are closely associated with magnetically complicated active regions. In contrast, the correlation with soft X-ray events is not close, only 7 or 35% are so associated.

3.3 Analysis of Two Events

(1) On 1991-03-07, at 074859 UT, a type III burst with millisecond spikes was observed (Fig. 1). This event was superimposed on a slowly varying emission (248-265 MHz). The spikes became less conspicuous with increasing frequency. After 265 MHz it developed into a type III burst, and the beginning frequency drift is 44 MHz/s. This shows that electron beams moved rapidly from higher to lower layers in the corona. This event occurred in the active region No.6542 and during the ascent phase of a flare of Class 2N.

(2) The event of 1991IO6--15 at 063730 UT and in the ascent phase of a 3B/X12 flare. The type III burst occurred in the low frequency interval (230-270 MHz). There were both negative and positive frequency drifts. From 250 to 230 MHz the drift was negative, and its speed was 46 MHz/s. In the course of the drift the flux gradually diminished. After arriving at the boundary frequency of about 250 MHz, the drift became positive, i.e. in the direction from lower to higher frequency. The speed of the positive drift was 65 MHz/s. At the high frequency end the event was a spike event occurring in the active region No.6659. It is one of the most intense active regions in the 22nd maximum. It produced not only many flares and X-ray events, but also a lot of bursts in the radio wavelengths.

4. RESULTS AND DISCUSSION

From the above analyses the following points emerge: (1) The distribution of metric wave millisecond spike-type III bursts in the three classes A, B and C is somewhat different from that given by Benz et al. But the distribution of bandwidths does not differ much from theirs, and the tendencies are the same. This is possibly because the frequency range of the spectrometer of Yunnan Observatory is narrower than theirs and, also, the characteristics of spike events as well as type III bursts in different activity maxima may not be the same. (2) The rate of association of these events with Hα flares is 59%. Between their occurrences and the various phases there is no conspicuous relation. They may take place in various processes of energy release in the flare. (3) These events are closely correlated with magnetically complex active regions. But their relation with soft X-rays is not close. (4) Most of these events occurred in the eastern hemisphere.

It was stated in Ref. [11] that the type III bursts which coexist with metric wave spikes tend to possess a beginning frequency in the low frequency range. The statistics of 175 events shows that all the type III bursts which coexist with spikes occur in the range of 200–500 MHz. It was also pointed out that the type III bursts coexisting with spikes constitute a special class of events whose process of acceleration takes place at rather high altitudes. In
the year near the solar activity maximum there happened in metric wavelength interval some 7000 type III bursts. Among them 2000 were accompanied by spike bursts. From July 1990 to December 1991, a total of 195 type III bursts were observed at Yunnan Observatory, and among them only 34 events had coexisting millisecond spike bursts. As fine structures of type III bursts, millisecond spikes occurring in the frequency interval of type III bursts are not numerous\[31. Although in the 1960s similar events were already accidentally observed, yet the relation between millisecond spike bursts and type III bursts is still unclear. For a long time since such problems as the continuity of their morphologies and the mutual transformation of their radiation processes, as well as their relation with electron acceleration, have been of much interest to astronomers. By using our material, several questions may be discussed as follows:

(1) The morphology of bursts.—We have discovered that between the coexisting millisecond spike bursts and short duration ($\approx 1$ s) type III bursts in the same frequency interval there exist morphological continuity and mutual transformation (see Figs.1 and 2). It can be seen in the figures that in the frequency distribution there is no sharp demarcation between millisecond spike bursts and type III bursts, rather, it seems that there is a smooth transition. However, Figs.1 and 2 are obviously different. Fig. 1 shows the millisecond spike bursts occurring near the beginning frequency of type III bursts, while Fig. 2, near the ending frequency. These phenomena are similar to the mutual transformation of metric wave fringe bursts and filament bursts. Therefore, they are possibly the fine structures caused by a whistler wave instability in different frequency intervals\[13].

(2) The origin of spike-type III bursts and the region of electron acceleration.—From the time profiles in Figs.1 and 2 one may speculate that millisecond spikes and type III bursts are possibly caused by the same number of accelerated electrons. According to the reasoning of Ref. [11], we suppose that the origin of the spikes is situated in the path of propagation of the electron beam that excites type III bursts or in the region of origin of the electron beam. It is also assumed that both of them are produced by the propagation of the same source of excitation. Then the time delay $\Delta t$ of a spike radiation may be found from the difference of frequencies of radiations of spike and type III burst. Namely, $\Delta \nu = \nu_{\text{spike}} - \nu_{\text{III}}$ or $\Delta \nu = i_{\text{III}} \Delta t$. According to the results of actual measurements, for the two events we have $\nu_m \approx 30 - 60$ MHz/s and $\Delta t \approx 1$ s. Then we get $\Delta \nu \approx 30 - 60$ MHz. If a type III burst occurs at about 250 MHz (see Figs.1 and 2), then the frequency difference of the spike burst and type III burst is approximately 30 MHz (as shown in Fig. 2). If they take place at one and the same place, the frequency difference is at most a few percent of the beginning frequency of type III burst. This reasoning basically agrees with actual observations.

As pointed out by Refs. [3,11], the source of spike burst cannot be above the region of electron acceleration, rather, it is located near this region or below it. This agrees with our observed events. Nevertheless, it is also remarked in these papers that all the type III bursts that coexist with spikes tend to have a low beginning frequency, but this does not agree with an event observed by us (see Fig. 2). Here is a pair of metric wave type III bursts, and one of them drifted towards lower frequency. So it had a higher beginning frequency. And this implies that the region of electron acceleration was located at still lower altitudes (about 250 MHz). The site of acceleration was close to a knot of low density, where electron beams were accelerated both upwards and downwards. Herein the type III bursts with both positive
Fig. 1 The metre wave event on 1991-03-07
Fig. 2 The metre wave event on 1991-06-15
and negative frequency drifts as well as accompanying millisecond spikes were produced (see Fig. 3). It may be learned from this particular instance that the height of the region of acceleration of coronal electrons is already out of the decimetric wave range and may be completely in the metric wave range. In view of this observed fact, the statement is negated that the region of acceleration of two-way electron beams is in the range of 400-1000 MHz.

![Flare model with a higher reconnection point. A sketch](image)

(3) Mechanism of burst.—It is generally recognized that both millisecond spikes and type III bursts are related to non-thermal electron beams\(^4\). Although the range, number and energy distribution of the electron acceleration caused by magnetic reconnection are at present still not clear, yet it has been understood that microwave type III bursts and millisecond spikes originate from low sources in the transition region, and they are radiative phenomena in a closed magnetic structure. But metric wave type III bursts are radiative phenomena in an open magnetic structure\(^3,4\). Decimetric wave spikes originate from places that are far from the region of acceleration but close to the foot points of flare rings. The sources of metric wave spikes are near or exactly at the site of acceleration\(^1\). Their origins differ from those of high density flare rings. More precisely, microwave spike radiation is possibly emitted with the same characteristic frequency as that of type III burst, and the source of burst is located at higher altitudes in the corona. A possible site of energy release is the boundary between open and closed magnetic field lines\(^1\). As for the radiation mechanisms of metric wave millisecond spikes and type III bursts, we support the interpretation with the plasma hypothesis\(^3\). We think that the bursts of the three classes are generated by one and the same mechanism. According to this interpretation, it is assumed that the electromagnetic waves are scattered plasma waves affected by a source of excitation, which is composed of electron streams with a mean velocity of \(c/3\). We suppose that the environmental electron density monotonically diminishes with the height above the photospheric layer.
When it becomes equal to the average value in the corona, the excited plasma waves at a specific level in the corona may enter a narrow bandwidth range close to the local plasma frequency, and this may induce a type III or spike burst. As for whether a spike event or type III burst is finally generated, this depends on the spatial extension of the source of excitation.

References