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Concerning spikes in emission and absorption in the microwave range

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Abstract In some events, weak fast solar bursts (near the level of the quiet Sun) were observed in the background of numerous spikes in emission and absorption. In such a case, the background contains the noise signals of the receiver. In events on 2005 September 16 and 2002 April 14, the solar origin of fast bursts was confirmed by simultaneous recording of the bursts at several remote observatories. The noisy background pixels in emission and absorption can be excluded by subtracting a higher level of continuum when constructing the spectra. The wavelet spectrum, noisy profiles in different polarization channels and a spectrum with continuum level greater than zero demonstrates the noisy character of pixels with the lowest levels of emission and absorption. Thus, in each case, in order to judge the solar origin of all spikes, it is necessary to determine the level of continuum against the background of which the solar bursts are observed. Several models of microwave spikes are discussed. The electron cyclotron maser emission mechanism runs into serious problems with the interpretation of microwave millisecond spikes: the main obstacles are too high values of the magnetic field strength in the source ($\omega_{Pe} \leq \omega_{Be}$). The probable mechanism is the interaction of plasma Langmuir waves with ion-sound waves ($l + s \rightarrow t$) in a source related to shock fronts in the reconnection region.

Key words: solar flare — radio emission — spike-bursts

1 INTRODUCTION

Radio bursts that are called “spikes” were isolated in a special kind of the shortest bursts in the narrowest band in the meter and decimeter wave bands at the beginning of high-resolution observations by Elgarøy (1961) and independently by Droge & Riemann (1961) and De Groot (1962). There are bursts with a duration of $d_{\rm f} < 0.1$ s at one frequency. Spikes were also observed in the microwave range (Droege 1977; Staehli & Magun 1986), where they differ in duration by several milliseconds.

Now, microwave spikes are a well-known structure in solar radio emission (Benz 1986; Benz & Guedel 1987; Fleishman & Mel'Nikov 1998; Chernov 2011). Recently spikes were observed not only in emission but also in absorption (Chernov et al. 2010) in a large radio burst using the Chinese spectrometer in the range 2.6–3.8 GHz (Fu et al. 2004). Spikes in emission and absorption were recorded at the limit of instrumental resolution (10 MHz and 8 ms). But sometimes we observe similar point-like spikes in very weak radio bursts. It is necessary to find out whether the specified pixels are real solar spike-bursts or if they arise from an instrumental effect. It is possible that such spikes are already present at the level of the quiet Sun. This is a very crucial point for theoretical models: whether the appearance of such weak spikes should be expected, or if the large bursts represent the high level of the continuum. This paper is devoted to answering this question.

Rozhansky et al. (2008) gathered all currently available measurements on spike duration and they found a power law with exponent 1.29 for the spectral range 237–2695 MHz. This law predicts that the duration of spikes at $f > 4.5$ GHz should be less than 2 ms, which is well below the temporal resolution of the spectrometer. However a significant correlation between a few adjacent channels (of 10 MHz) clearly indicates that each spike is seen through several spectral channels.

The spikes immediately attracted the attention of researchers, since the brightness temperatures of the spikes $T_{\rm b}$ can reach (and even exceed) 10^{15} K. Such a high brightness temperature, along with the extremely short duration of the bursts and the strong circular polarization of radio emission, can only be provided by some coherent mechanism. From the early years of the study, the spikes have generally been believed to be emission closely connected with particle acceleration and primary energy release in flares.

Thanks to Fleishman & Mel'Nikov (1998), we obtained an exhaustive review of all basic mechanisms of the excitation of spikes and their relevance to observed parameters. However, the nature of the spikes has remained completely unexplained for a long time (Sect. 3). Section 2 gives detailed observations of millisecond spikes in the 2005 September 16 event. Section 3 describes known theoretical models of the microwave spikes. Section 4 contains main conclusions.

2 OBSERVATIONS

2.1 Spectral Data

Sometimes spikes in emission and absorption appear as white and black points (with size of one pixel) randomly distributed over the frequency range of the spectrograph (Fig. 1). They were observed in the very strong 2006 December 13 event (X3.4/4B flare), in the background of the strong continuum emission of some tens of thousands of sfu.

The 2005 September 16 event was connected with small flare M4.4/1B in AR 10808 (S13W26). The maximum flux at the frequency near 5 GHz was 350 sfu (*http://www.solarmonitor.org/data/2005/09/16/*). The general view of the PMO spectrum in the range 4.5–7.5 GHz, with a duration of about two minutes, is shown in Figure 2. The burst appears to have a gradual rise and fall with several weak vertical pulsations.

Figures 3 and 4 show point-like spikes in an enlarged part of the spectra taken with the PMO spectrograph in the frequency range 4.8–5.8 GHz from the 2005 September 16 event. In these two fragments, we can see numerous black and white pixels almost randomly distributed in frequency and time. The burst was observed simultaneously by the Huairou Station (Beijing), the Nobeyama Observatory at 17 GHz and the Siberian Solar Radio Telescope (SSRT) in Irkutsk. This verifies the solar origin of the burst.

The PMO profile at 5.7 MHz (Fig. 3) shows that the maximum intensity equals about six times the quiet Sun level. For a comparison, in the 2005 December 13 event (Fig. 1) such a ratio is about ten times greater (Chernov et al. 2010). The burst was also observed at the Huairou Station in the range 5.2–5.84 GHz (Fig. 5). The burst's emission and background also reveal a spiky character but

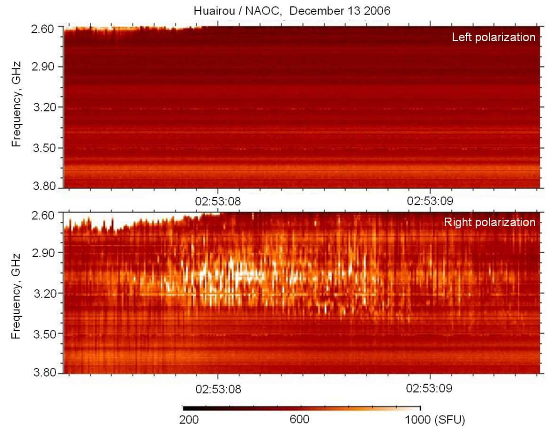

Fig. 1 Spikes in emission and absorption in the strong 2006 December 13 event in L and R polarization channels of the Huairou spectrometer in the frequency range 2.6–3.8 GHz. The data that we use here were collected by the radio spectrometer at PMO, China (Xu et al. 2003). This instrument has 300 frequency channels per 3 GHz band at 4.5–7.5 GHz, with a spectral resolution of 10 MHz and a time resolution of 5 ms, and it observes daily between 1:00 and 9:00 UT.

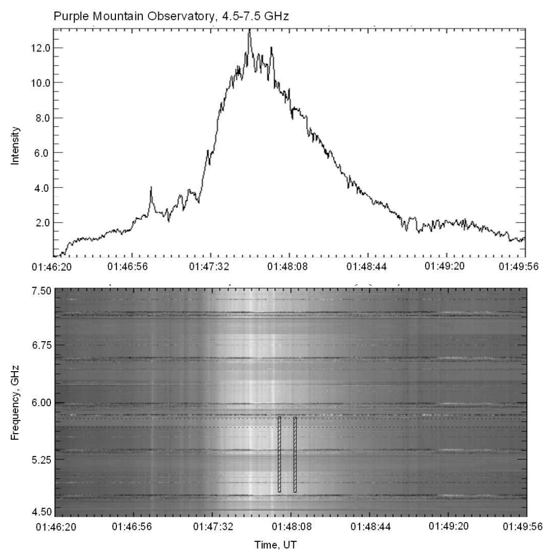

Fig. 2 A general dynamic spectrum of a weak burst on 2005 September 16 observed by the PMO spectrometer in the range 4.5–7.5 GHz (*lower panel*) and the corresponding intensity profile (in arbitrary units) at 5.7 GHz (*upper panel*). Two short intervals marked by the shaded vertical segments will be discussed in detail below (Figs. 3 and 4).

the frequency resolution here is 20 MHz, and we do not recognize any conformity in terms of noisy spikes between the PMO and Huairou spectra.

In Figure 5, we do not see any conformity between spikes in the Left (L) and Right (R) channels: the polarization is noisy. However the continuum emission has a very weak right polarization at 01:48:01.5 UT.

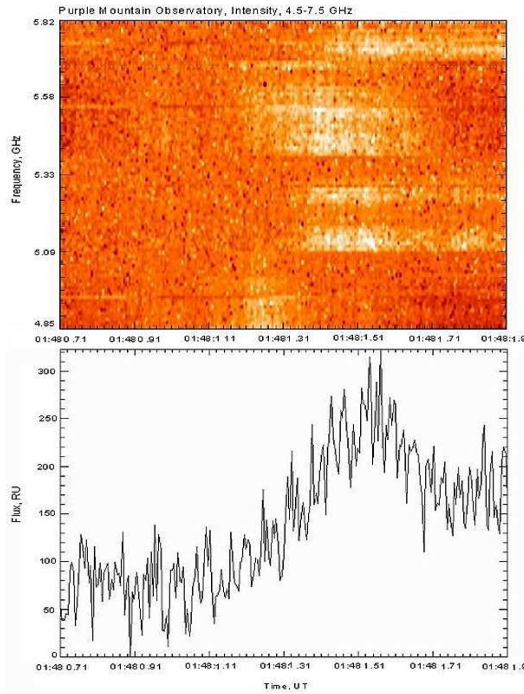

Fig. 3 Increased spectrum (*upper panel)* and intensity profile (*lower panel)* at $\sim$ 5.7 GHz (in arbitrary units) with duration of about 1.2 s from the PMO spectrum shown in the lower panel of Figure 2. Spikes in emission (*white*) and absorption (*dark*) are arbitrarily distributed over the entire selected range of 4.85–5.82 GHz and, as is shown in the intensity profile, they appear to be similar both before the burst and when compared to its background.

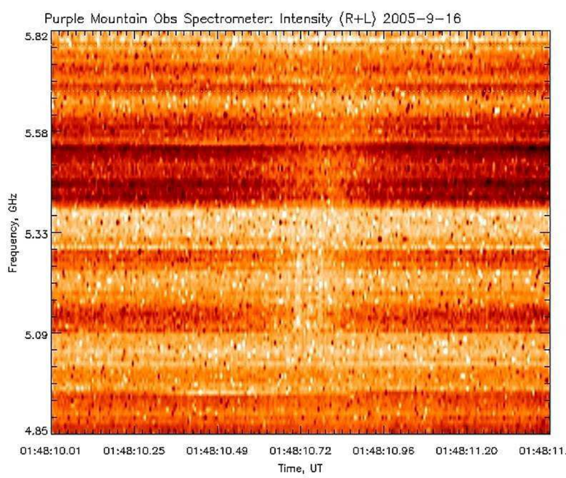

Fig. 4 Second fragment displaying an increase from the PMO spectrum shown in the lower panel of Fig. 2 marked by a right vertical segment. Point-like spikes in emission (white) and in absorption are randomly distributed throughout the selected frequency range 4.85–5.82 GHz in the other temporal interval.

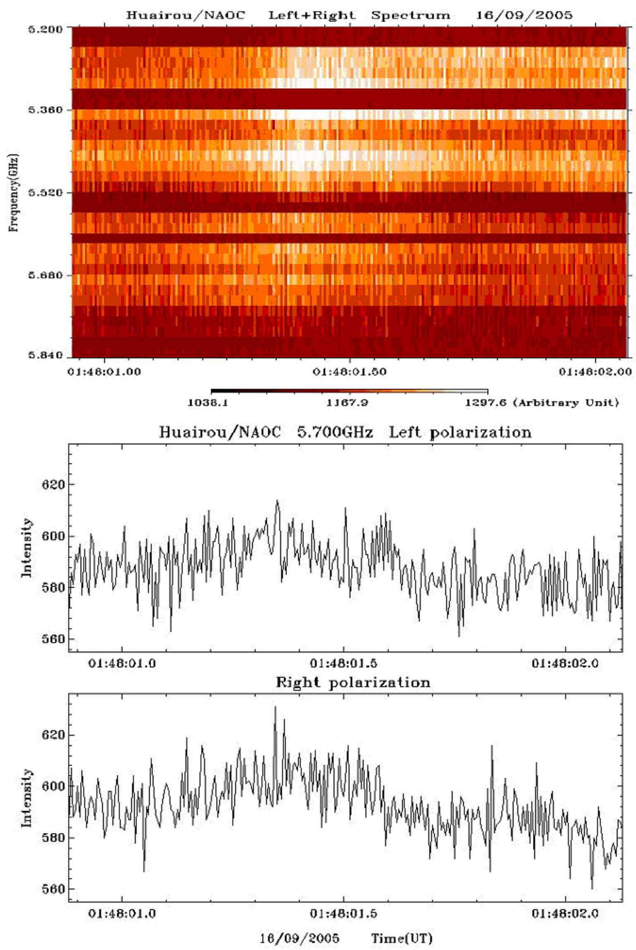

Fig. 5 Huairou spectrum of the 2005 September 16 event in the range 5.2–5.8 GHz (*upper panel)* and intensity profiles in L (*middle panel)* and R (*lower panel)* polarization channels at 5.7 GHz.

2.2 Positional Observations

The Nobeyama data at 17 GHz help to define the position of radio sources. At moments during the bursts (Fig. 2) the Nobeyama maps show, in the intensity channel, a new source arcade between bipolar sources (Fig. 6). According to the magnetogram, many short loops were located above this arcade. Thus, the emission of many fast bursts at the interval 01:48:01–01:48:11 UT was probably related to the fast particle acceleration during consecutive magnetic reconnections of these loops.

Two dimensional maps of SSRT data are constructed for several minutes of observations, and the nearest one to the bursts under consideration (in the polarization channel) is presented in Figure 7. A new source appeared in the eastern part of the active region (AR) and it is related to our bursts. The spatial position of the SSRT source coincided with the position of the new source in the Nobeyama 17 GHz maps (Fig. 6).

Figure 7 shows that the radio source at 5.7 GHz was bipolar. The spikes in emission were observed in both polarization sources (R and L). Left-polarized bursts (dark) took place in the eastern

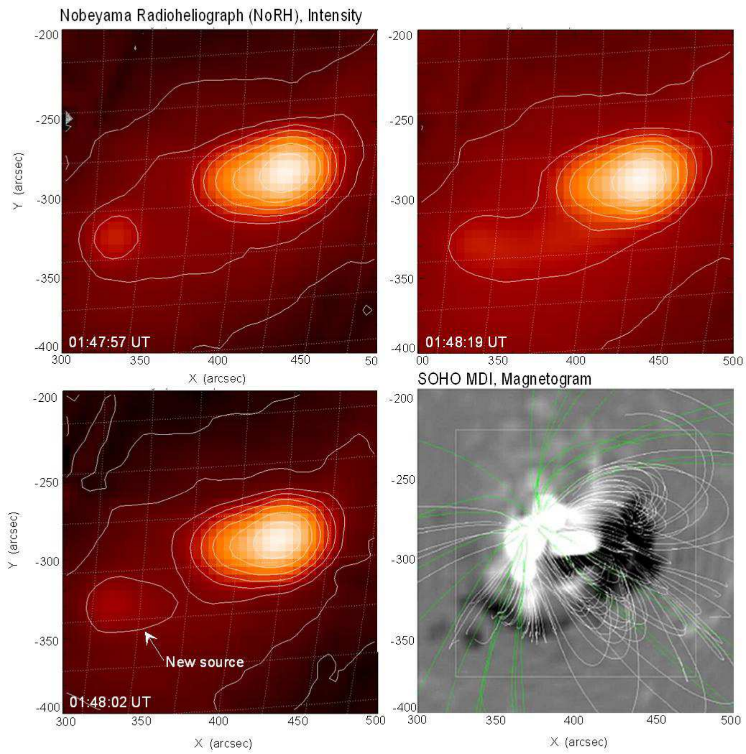

Fig. 6 Nobeyama maps at 17 GHz and the MDI magnetogram with extrapolated magnetic force lines.

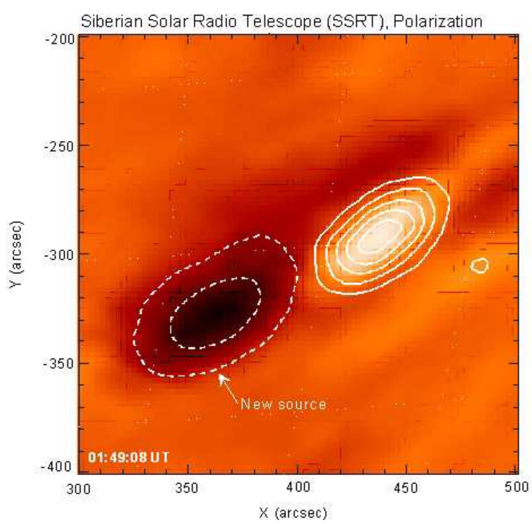

Fig. 7 The two-dimensional map of SSRT at 5.7 GHz in polarization (R-L) channel. The source reveals a bipolar structure: L-polarized source is shown by broken contours. R-polarized source is shown by solid contours.

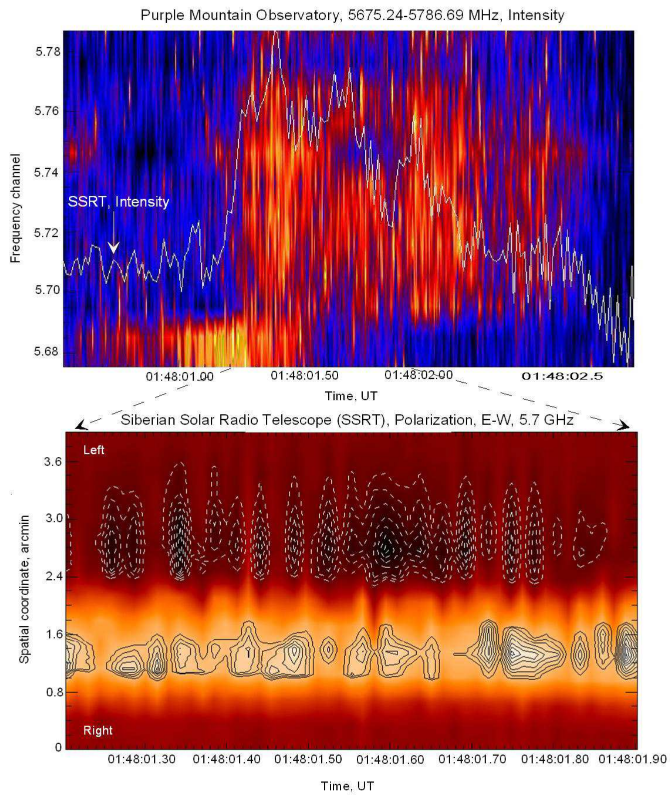

Fig. 8 One dimensional (East–West) brightness distribution of polarization $(R - L)$ observed by SSRT at 5.7 GHz (*bottom panel*), and the intensity profile of SSRT superimposed on the dynamical spectrum of PMO in the narrow frequency band of SSRT (*top panel*).

part of the AR coinciding with the new arcade in the Nobeyama maps (Fig. 6). This arcade was located above the neutral magnetic line, so it is difficult to define the radiative wave mode. In addition, the polarization degree was small, 15%.

The time resolution of the one dimensional scan of SSRT is about 14 ms (Smolkov et al. 1986; Grechnev et al. 2003), and the instantaneous frequency band of SSRT (of 112 MHz) can simultaneously reveal several spikes visible in the PMO spectrum in one pixel with dimensions of 5 ms and 10 MHz. The top panel of Figure 8 presents the intensity profile of SSRT superimposed on the dynamical spectrum of PMO in the frequency band of SSRT. We can define what kind of spikes in emission (yellow and red) and in absorption (black and blue) are included in the profile of SSRT.

Figure 8 also shows good accordance between the SSRT profile and the intensity of the PMO spectrum in the frequency band of SSRT (5.675–5.786 MHz), taking into account the greater time resolution of the PMO spectra (5 ms).

The shortest strong spikes of solar origin were observed mainly in L polarization corresponding to dark sources in the one dimensional scans (in the bottom panel of Fig. 8) in accordance with Huairou polarization profiles shown in Figure 5 (around 01:48:01:50 UT). The average source size of strong spikes is about $0.5'$, in accordance with such an observation using a two-element interferometer at a frequency 2.8 GHz (Gary et al. 1991). All other oscillations were randomly distributed in the spectrum (as noise) and they present both R and L sources.

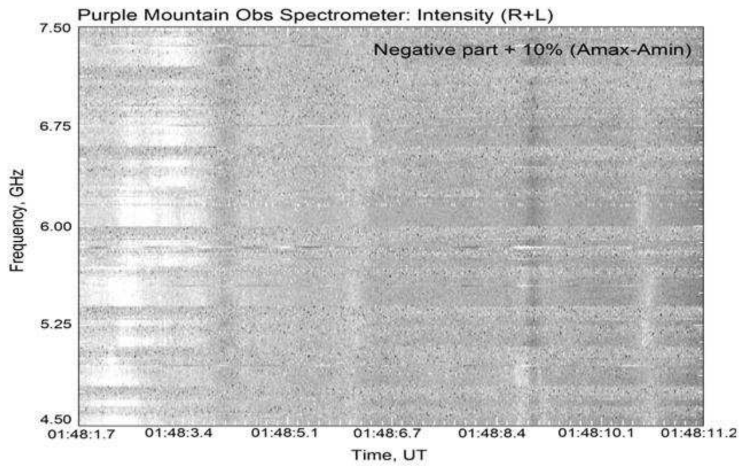

Fig. 9 A spectrum constructed with zero level being increased by 10%.

We assume that existence of spikes in emission and absorption in the PMO and Huairou dynamic radio-spectra and the simultaneous appearance on the one-dimensional radio-scans of the thin spatial structure of sources is a reflection of the same processes of particle acceleration. Fast intensity variations of the polarized radiation sources in L and R lead to variations in the intensity channel (R+L) relative to the average noise component. This leads to the appearance of spikes in emission or absorption. The acceleration of energetic particles can occur during the rapid reconnection of the magnetic field in the arcade of the elementary magnetic loops, caused, for example, by the emergence of the new field, with opposite sign compared to the overlying arcade. This assertion is confirmed by comparison with the position of the source of hard X rays (RHESSI) in the 12.0–25.0 keV energy band. Its center was located just above the neutral magnetic line with coordinates of $(+435'', -285'')$ (see Fig. 6).

2.3 Noisy Character of Spikes in Emission and Absorption

The 2005 September 16 event was very weak, but the output of the PMO and Huairou spectrographs was less than the level of the quiet Sun (Fu et al. 2004). In such a case, the spectra show noise in the signal (from the receiver).

The wavelet spectrum reveals no strict periodic signals with millisecond period, confirming a noisy character of the signal at the limit of instrumental resolution.

This assertion is easy to verify by a change in the zero level, subtracted during the construction of the spectrum. In Figure 9, the subtracted level was increased to 10% in comparison with the level used for the construction of Figures 3 and 4. As a result, the number of noise points sharply decreased. Dark points remained only in several horizontal bands, which are probably local radio interference.

Such a conclusion is confirmed by the comparison of the spectra of other weak bursts with a similar structure. For example, in the PMO spectrum on 2002 April 14 (shown in Fig. 10) it is possible to see numerous black points. Simultaneously these bursts were observed by the Huairou spectrometer, and its spectrum, obtained by the subtraction of another zero level of continuum, barely contains any similar black pixels. The 2002 April 14 event gives an excellent example to compare spikes in two observatories. Besides the short spikes (in one pixel), numerous spikes have duration of 10–40 ms. All these spikes coincide in both spectra, which confirms their solar origin. At the same

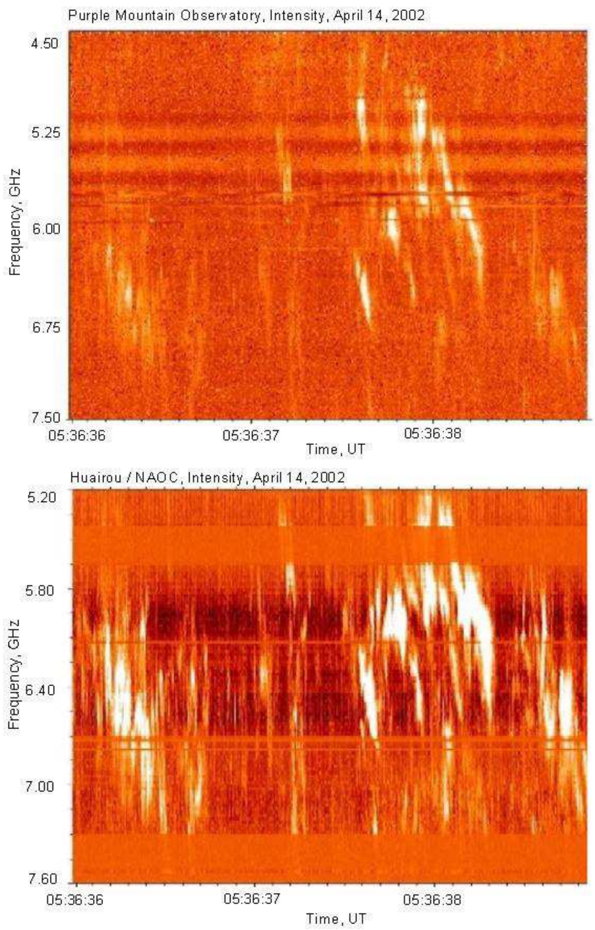

Fig. 10 2002 April 14 event observed by the PMO spectrograph (*top panel*) and Huairou spectrograph (*bottom panel*).

time, weak black point-like spikes do not coincide, and they do not have any correlation between both spectra, which confirms that they represent noise.

3 MODELS OF MICROWAVE SPIKES

It is generally agreed that spikes are non-thermal, coherent emission closely connected with the acceleration of particles and energy release in flares. During recent years, interest about doing research on spikes has increased.

However, the nature of the microwave spikes has remained unexplained for a long time. Finally, thanks to Fleishman & Mel'Nikov (1998), we obtained an exhaustive review of all the basic mechanisms of the excitation of spikes and their relevance to observed parameters. After a short examination of some variations of the plasma mechanism (Zheleznyakov & Zaitsev 1970; Zaitsev 1975; Melrose 1991), the authors concluded that none of the modifications of the plasma mechanism can explain all of the observational data. Based on the observations of spikes at the harmonic frequencies and the partial record of radio emission of spikes in the extraordinary mode, they concluded that the spikes could only be excited by the electron cyclotron maser (ECM) mechanism (the loss-cone instability of the 1st and 2nd electromagnetic cyclotron harmonics, see also Kuznetsov & Vlasov 2003).

Huang & Nakajima (2005) determined the location of microwave spikes (in the range 2.6–3.8 GHz) using simultaneous source positions at 17 GHz with the Nobeyama Radio Heliograph. The source at 17 GHz was located in one foot-point of a small bright coronal loop with a strong photospheric magnetic field, and the authors assumed that the ECM instability and gyro-resonance absorption respectively dominate the rising and decay phase of the spike event. The authors believed that a strong magnetic field of 800 G on the photosphere is a favorable condition for both the ECM mechanism and gyro-synchrotron emission.

The ECM mechanism is examined in Fleishman & Mel'Nikov (1998) in detail. The content of this large review is outside the scope of the present article. Let us simply note that the basic objection against this mechanism was based on the estimations of the absorption of radio emission at the third gyro-resonance level in the corona as suggested by many authors. Furthermore, this mechanism is effective only in the sources where the ratio of plasma and cyclotron frequencies is less than unity ($\omega_{Pe}/\omega_{Be} < 1$), but practically all observational data provide evidence of the inverse relationship ($\omega_{Pe}/\omega_{Be} \gg 1$), not only in the meter but even in the microwave range.

Fleishman et al. (2003) presented only indirect evidence for the ratio, related to the flat spectrum of gyrosynchrotron emission. This means that no indication of the Razin effect in the spike-producing bursts is present because the Razin effect begins to suppress the low frequency part of the spectrum, which can affect this ratio. However, a contribution into the low frequency part can give another radiation mechanism (for example, plasma emission).

To overcome such a difficulty, Rozhansky et al. (2008) developed a theoretical model of the spikes as being produced by the ECM mechanism in numerous local sources with random magnetic inhomogeneities (local-trap model).

But if we turn to the known and widely utilized model representations of the distribution of concentration and magnetic field with the height into the corona, they give the inverse relationship of the frequencies. According to figure 5.21 in Chernov (2011), calculated using the dependence of plasma frequency on the barometric law and the empirical model of magnetic field of Dulk & McLean (1978) derived on the basis of numerous radio data, the relation of frequencies $\omega_{Pe}/\omega_{Be} \approx 10$ at the height of 1 5000 km (see also in Aschwanden 2004 figs. 1.15, 1.16 and 5.29).

In their figure 1, Dulk & McLean (1978) summarized the basic results of the calculations of the magnetic field extrapolated into the corona using the dipole approximation, beginning from the work of Kakinuma & Swarup (1962) and Ramaty & Petrosian (1972) et al. According to results of Kakinuma & Swarup (1962), the maximum values of the magnetic field strength were ~ 600 G at altitudes of $\sim 20\,000$ km. More advanced and recent calculations do not give higher values. Yasnov et al. (2011a) compare magnetic field strengths, obtained using the multifrequency observations of the polarized microwave radio emission at RATAN 600, with extrapolated data of photosphere values. Their maximum values of $\sim$ 1000 G at heights of $\sim$ 14 000 km slightly exceed the extrapolated values (such values of 1000 G were related to heights of $\sim$ 7000 km).

In this relationship, let us note two important factors. The values of the magnetic field on the basis of multifrequency observations with RATAN 600 can be overestimated, because they rely on the assumption that all the emission of the low-frequency maximum of polarized radiation is related to emission mainly at the third harmonic of the gyrofrequency. On the other hand, the extrapolated data can give underestimated values if the magnetic field does not arise from a potential and is not force-free. Such assumptions are used in many calculations. For instance, Sheiner & Zlotnik (1994) calculated the longitudinal magnetic field $B_{\|}$ with the dipole approximation in the following way: $B_{\|}(h) = B_{\rm ph}/(1 + h/hd)^3$, where $B_{\rm ph}$ is the magnetic field in the photosphere, and hd is the depth of the origin of the dipole under the photosphere. According to this formula (using hd =15 000 km and $B_{\rm ph}$ = 1200 G) for calculating the thermal cyclotron radiation of hot loops, Sheiner & Zlotnik

(1994) used $B_{\|}$ = 357 G for a source radiating at frequency 4 GHz and which is located in the interval of heights 8000–10 000 km. In such a case, the radio emission is connected with the fourth harmonic of gyrofrequency.

The magnetic field can be more complicated, in particular, it can contain the current's poloidal component (as Sheiner & Zlotnik 1994 showed). However, Yasnov et al. (2011b) showed that for several observed ARs, the measured values of the magnetic field strength with RATAN 600 coincided with the extrapolated data: $B = 500$ G for frequency 5 GHz (the third harmonic of gyrofrequency).

Thus, all known observational data and model results demonstrate the significant extent to which plasma frequency exceeds the gyrofrequency. Therefore, it is necessary to search for evidence showing the possibility of an inverse relationship between frequencies.

In the event under discussion (2005 September 16 in AR 10808) the photospheric magnetic field was 2000 G. The dipole's extrapolated value for the height of 15 000 km is $B \sim 250$ G, and for the dependence of plasma frequency according to the barometric law, we derive $\omega_{Pe}/\omega_{Be} \approx 5.7$.

Still, it is important to note that the harmonic relationship of the frequencies (far from the ratio 2:1) of the clusters of spikes was only observed in a few events in the decimeter range (Benz & Guedel 1987; Guedel 1990; Krucker & Benz 1994). In the majority of events, the harmonic relationships were not discovered, both in the meter and microwave ranges.

Thus, the ECM mechanism has encountered serious problems in the interpretation of microwave spikes, though authors often overlook this in their conclusions (Fleishman & Mel'Nikov 1998). The main obstacles are the high values of the magnetic field strength in a source, at times exceeding those in the photosphere. To avoid some difficulties, Wang & Li (1991) proposed a model with nonlinear parametric instability for millisecond spikes. But except for difficulties with the process of matching conditions for the coupling process of two electromagnetic waves with a whistler wave, the pump that affects an electromagnetic wave must be strong for nonlinear parametric instability to occur. It should be possible to propose enough conditions for the high region of the solar corona for whistler instability to happen with very small whistler wave numbers ($k_{\omega} \ll \omega_{Pe}/c$). It should be noted that such a model can explain only periodic spikes.

The solution of the nonlinear Schrödinger equation for the pumped wave in Wang & Li (1991), considering the Miller force (ponderomotive force in the equation of the electron motion), contradicts the conclusion of Wentzel & Aschwanden (1991): the maximum energy density inferred from the spike emission by the ECM mechanism is at least two orders of magnitude less than the energy density at which electron entrainment occurs. Thus we so far do not have a well accepted emission mechanism to explain the main spike parameters in microwaves. Although there is a general agreement that the emission mechanism has to be coherent, it is unclear whether it is by gyroemission or plasma emission like the one proposed in Altyntsev et al. (1998). Chernov et al. (2001) proposed that the propagation of fast shock fronts through the microwave source could generate fast bursts of spikes. They discuss the model of spike emission due to the coalescence of Langmuir waves with ion-sound waves.

According to observations discussed in Chernov et al. (2001), spatial and time coincidence of hard X-ray (HXR) and microwave sources demonstrates that the same fast particles are responsible for those emissions and a common acceleration source which is usually proposed for magnetic reconnection at middle heights in the corona ($\geq$ 10 000 km). Fast particles accelerated in such a region can propagate in the upward direction and cause meter radio bursts and in the downward direction and cause successive decimetric, microwave and HXR emissions. A similar scheme was proposed for spikes by Fu et al. (1990) at the wavelength = 21 cm.

According to well accepted ideas, shock fronts are the source of Langmuir, ion-sound and whistler instabilities. All these waves are usually observed by in situ observations in interplanetary shocks and at the front of the Earth's bow shock (Gurnett et al. 1979). According to conclusions from the observations of microwave spikes in Chernov et al. (2001), a mechanism of spike emission must operate in direct association with shock fronts, where Langmuir and ion-sound wave instabilities develop. Therefore the most probable mechanism of spike emission may be the interaction of plasma Langmuir waves with ion-sound waves ($l+s \rightarrow t$). This process is well studied by Tsytovich (1970), and for type I bursts by Melrose (1980) and Benz & Wentzel (1981); a direct connection with decimetric spikes was firstly proposed by Kaastra (1985).

As Benz & Wentzel (1981) proposed, ion-sound waves are generated by current driven instability in a current sheet in a small magnetic reconnection region. The waves generate an anomalous resistance and create the conditions for their existence with $T_e \gg T_i$. Melrose (1989) believed that the mechanism by which these waves are generated is not understood and there is no basis for expecting them to be present in the corona other than by analogy with the interplanetary medium (Gurnett et al. 1979). In such a case, ion-sound waves could only be present in the narrow shock fronts. At the same time, all energetic estimations of Benz & Wentzel (1981) for the coalescence $l + s \rightarrow t$ remain available for our consideration. The three wave matching conditions for this coalescence were strictly verified in Chernov et al. (2001).

The duration of a separate spike is not connected with the parameters of a beam of fast particles (as in the beam instability). It can be determined by the local very short time of recovery for the nonisothermicity of plasma (after a burst from the miniature region) and subsequent temperature balance. Specifically, this chaotic process of spike release from the turbulent plasma can explain the chaotic appearance of spikes in the clusters, which accounts for hundreds to thousands of bursts. However, this model can be plausible for strong events. It helps us to propose a new explanation of the observations of decimetric spikes at harmonics 's' = 2–6 (Guedel 1990). The relativistic ECM emission seems implausible in the decimeter range, where the mechanism of plasma emission usually plays a major role. As a detail, conformity of spikes at different harmonics was not observed. We may relate the emission of consecutive frequency bands of spikes in consecutive magnetic islands with X-point configurations along a vertical magnetic current sheet. Frequency bandwidths at each harmonic show the vertical size of a zone between two fast shock fronts propagating from one X-point, and the frequency separation between the centers of each spike band (or harmonic frequency) is determined by the size of magnetic islands between X-points. Multiple magnetic islands are usually supposed to exist during the restoration of the magnetic structure after the escape of coronal mass ejections and were obtained in multiple numerical modelings of magnetic reconnection.

4 CONCLUSIONS

In strong events, spikes in emission and absorption observed at the limit of instrumental resolution (in one pixel) are real solar bursts. Chen & Yan (2008) and Chernov et al. (2010) discussed a possible physical model to explain such spikes in absorption.

In some events, weak fast solar bursts (near the level of the quiet Sun) were observed in the background of numerous spikes in emission and absorption. In such a case, the background contains the noise signals of the receiver. In the events that occurred on 2005 September 16 and 2002 April 14, the solar origin of fast bursts was confirmed by simultaneous observation of the bursts at several different observatories. The noisy background pixels in emission and absorption can be excluded by a higher subtracted level of the continuum during construction of the spectra.

The wavelet spectrum, noisy profiles in different polarization channels and the spectrum with a greater level that subtracts zero from the continuum demonstrate noise is in the shortest pixels representing emission and absorption.

Thus, in each case, in order to judge the solar origin of all spikes, it is necessary to determine the level of continuum against the background at which the solar bursts are observed.

The ECM emission mechanism runs into serious problems with the interpretation of microwave millisecond spikes: the main obstacles are too high values of the magnetic field strength in the source ($\omega_{Pe} \leq \omega_{Be}$). The probable mechanism is the interaction of plasma Langmuir waves with ion-sound waves ($l + s \rightarrow t$) in a source related with shock fronts in the reconnection region. In such a case, the duration of a separate spike is not connected with the parameters of fast particles (as in the ECM mechanism). It can be determined by the local very short time of recovery of the nonisothermicity of plasma (after a burst from the miniature region) and subsequent temperature balance. Specifically, this chaotic process of spike release from the turbulent plasma can explain the chaotic appearance of spikes in the clusters.

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