The decameter spikes as a tool for the coronal plasma parameters determination

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Abstract

The paper is devoted to the analysis of the unusual event observed on 14 June 2012 in the frequency range 8 - 42 MHz. During this event the radiation flux changed stepwise two times. Assuming that these changes of radiation flux could be associated with the changes of the coronal plasma parameters (temperature, magnetic field) and using spikes as a tool for the determination of those parameters we traced how the temperature and magnetic field varied during the time of observations. According to the model proposed in the paper the magnetic field was about 1.9 G and the temperature varied in the range of 0.1 - 0.6 × 10^6 K at the heights 1.6 −3.3 solar radii.

1. Introduction

Spikes are solar radio bursts which are usually observed during high solar activity in the wide frequency band from 8 GHz down to some MHz [1, 2, 3, 4, 5, 6, 7]. Independently from the frequency band in which they are observed they have short durations (≤ 1 s) and narrow frequency bandwidths (0.2 - 3% of the observational frequency) when compared with other solar radio bursts.Such morphological properties of the spikes make their identification simple and confident. By analyzing all results of spike observations reported by different authors it was established that spikes durations decrease and bandwidths increase withobserving frequency. The polarization of spikes is circular with the average value of about 25 %. The brightness temperature of the spikes is in the range $10^9 - 10^{15}$ K [3, 8].
In this paper the unusual event observed on 14 June 2012 with the radio telescopes UTR-2 (Kharkov, Ukraine), URAN-2 (Poltava, Ukraine) and NDA (Nancay, France) in the frequency band 8 - 42 MHz is analyzed. During that particular day of observations the storm of spikes observed simultaneously with the storm of type III bursts and type IV burst. The spikes durations, bandwidths, fluxes and polarization degrees were measured. Assuming that spikes durations and bandwidths are defined by the coronal plasma temperature and magnetic field respectively [7], we traced how these coronal parameters changed during the day of observations.

2. Equipment and observations

Three radio telescopes UTR-2 (Kharkov, Ukraine), URAN-2 (Poltava, Ukraine) and NDA (Nancay, France), were used simultaneously on 14 June 2012. The radio telescopes UTR-2 and URAN-2 were equipped with a two-channel digital receiver of new generation DSP-Z (Digital Spectra Polarimeter of Z modification) [9]. The observations were performed with 100 ms time and 4 kHz frequency resolutions in the frequency band 8 - 32 MHz. At the radio telescope NDA the spectrometer ROBIN (ROBust receiver) was used [10]. The registration was carried out in the frequency band 28 - 42 MHz with time and frequency resolutions of 37 ms and 12 kHz respectively. The joint use of these radio telescopes allowed us to carry out the observations in the frequency band 8 - 42 MHz (Figure 1).

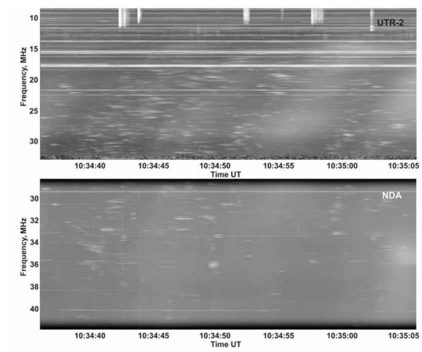


Figure 1. The dynamic spectrum in the frequency range 8 – 42 MHz. The upper panel corresponds to the data obtained with UTR-2 radio telescope and bottom one to the data obtained with NDA radio telescope.

The analyzed event was recorded in the time interval 04:45 - 16:00 UT on June 14, 2012. A storm of spikes was observed simultaneously with the storm of type III bursts and a type IV continuum. Such a high activity in the radio band is probably related to the large group of sunspots observed in that particular day.

During the observations the average radio emission flux changed stepwise two times from approximately 80 s.f.u. up to 20 s.f.u. in the time interval from 4:45 till 9:45 UT, and from 20 s.f.u. up to 1000 s.f.u. from 9:45 till 13:30 UT (Figure 2) (s.f.u. = $10^{-22}\,\mathrm{W/m^2Hz}$).

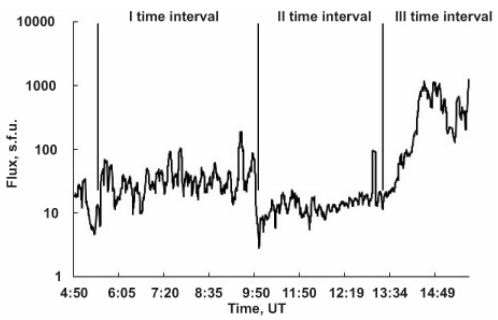


Figure 2. The time profile of whole day of observations at frequency 28 MHz obtained with URAN-2.

We assumed that such variation of the flux can be related to the changes of the coronal plasma parameters. In the frame of the hypotheses that the spikes durations and bandwidths are determined by the temperature and magnetic field of the ambient plasma correspondingly [7], we checked whether and how the plasma parameters varied during the observation day. Clearly, we would like to understand the nature of these variations. Hence, the observations were divided into three time intervals (Figure 2).

During the first time interval, which lasted from approximately 4:45 till 9:45 UT, the storm of spikes was observed simultaneously with the storm of type III bursts (eleven bursts per minute). At the same time five flares of C1.3 – 1.7 were registered. In this time interval the average flux was about 80 s.f.u.

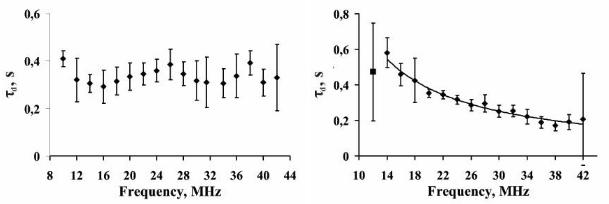
Approximately from 9:45 till 13:30 UT (the second time interval) the flux decreased to approximately 20 s.f.u. The number of type III bursts decreases to five bursts per minute. During this time interval two flares of C2.5 – C5.0 were observed. The storm of spikes continued.

The third time interval started at 13:30 UT with an increase of the flux to a thousand of s.f.u. This flux increase on the dynamical spectrum shows up as a type IV burst associated with the M1.9 flare (starting at 12:52 UT and peaking at 14:45 UT) and CME first seen in the SOHO LASCO C2 field of view at about 14:12 UT. The start time of the type IV continuum practically coincides with the start time of the CME that has been observed on this day. The storm of spikes ended in half an hour after the type IV burst has started. The type IV burst itself lasted approximately for about two hours.

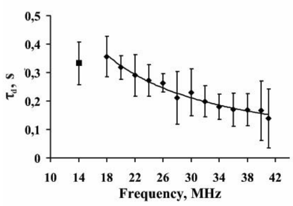
For each time interval we analyzed a large number of spikes. Thus for the first, second and third time intervals more than 500, 800 and 300 spikes we analyzed correspondingly. The spike parameters were measured manually at half maximum flux level using time and frequency profiles of the bursts.

3. Data analysis

In the majority of cases the time profiles of spikes are not symmetrical. In most cases (80%) the decay phase of the burst is a somewhat longer than the rise phase. On such asymmetric profiles at half maximum flux the total duration (d), the rise time (τ_r) and the decay time (τ_d) were measured. The majority of spikes have durations of 0.4 – 1 s. The spikes durations decrease with the frequencyand as a consequence also the rise and decay times, decreasedduring the day. The dependences of the spikes decay time on the frequency, for all three time intervals are presented in Figure 3.



a) b)



c)

Figure 3. The dependencies of average values τ_d on frequency for the first (a), second (b), and third (c) time intervals.

We did not find any specific dependence of the decay time on frequency for the first time interval (Figure 3a). At the same time the dependencies for the second and third intervals (Figure 3b, c) can be approximated by a power-law in the form of $\tau_d \sim f^p$ using the least-squares method. The power-law indices p are close to -1, having values of -1.01 and -1.05 for the second and third time interval, respectively. For comparison of dependencies and for further calculations we use the approximation $\tau_d = bf^{-1}$. The coefficient b for the second temporal interval is about 7.6 and for the third interval is approximately 6.4.

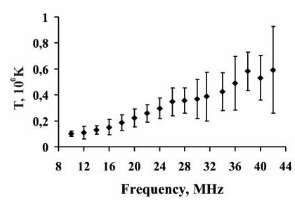
In the present study we focused on the decay time (τ_d) of the spikes. Since the plasma mechanism of generation is considered as a possible mechanism of the spikes generation it is reasonable to assume that the decay time of spikes is defined by the life time of the Langmuir waves in the plasma i.e. by the particle collision time (τ_{coll}) [3, 11]. The latter is determined by the temperature of the ambient plasma:

$$\tau_{coll} = \frac{k_B^{3/2}}{\pi^2 e^2 m^{1/2} \lambda} \frac{T^{3/2}}{f^2} \quad (1),$$

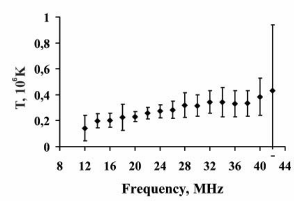
where λ is the Coulomb logarithm, e is the electron charge, m is the electron mass, T is the temperature, and f is thefrequency.
If we assume that the $\tau_d \approx \tau_{coll}$, then, knowing the spike decay time we can estimate the temperature of the coronal plasma:

$$T = 8 \times 10^3 f^{4/3} \tau_d^{2/3} \quad (2).$$

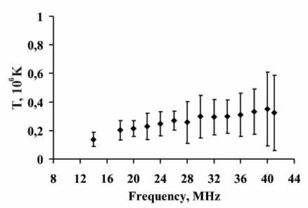
The obtained values of the temperature and their dependencies on frequency for all temporal intervals are presented in Figure 4.



a)



b)

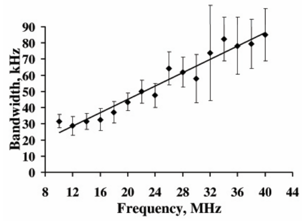


c)

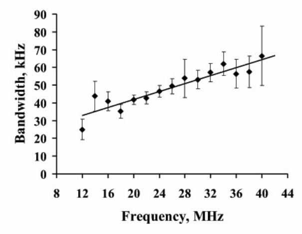
Figure 4. The dependencies of the temperature on frequency for all time intervals.

It can be seen that the temperature T increases with the frequency, as can be expected. During the first time interval the calculated coronal temperature was $\approx 0.1 - 0.6 \times 10^6$ K. During the second and third time intervals the temperature was found to be $\approx 0.2 - 0.43 \times 10^6$ K and $\approx 0.13 - 0.32 \times 10^6$ K respectively. However, it must be noted that the obtained temperatures T are considerably smaller than the usually considered coronal plasma temperature.
We inspected the correspondence of the coronal temperatures obtained with the high-frequency spikes (362 – 1010 MHz) [4] and the low frequency spikes (8 – 42 MHz). It was found that the temperatures obtained in the present paper are in good agreement with the temperatures found in [4]. Hence, we conclude that if the decay time is defined by the particle collision time, then knowing the durations of the spikes at different frequencies we can reconstruct the profile of the coronal temperature versus height above the solar surface.
In contrast to the temporal profile, the frequency profile of spikes is symmetrical. The instantaneous bandwidth of the decameter spike at the half maximum flux varies from 25±5.8 kHz at frequency 11 MHz to 80±17.2 kHz at frequency 40 MHz that is in average approximately 0.2% of the central frequency.We noticed that the spike bandwidth linearly increases with the observing frequency (see Figure 5):

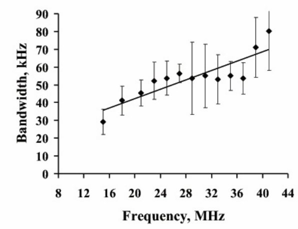
$$\Delta f \propto Af \quad (3).$$



a)



b)



c)

Figure 5. The dependencies of the spike bandwidth on the frequency for all three temporal intervals.

The coefficient A equals to $2.1 \times 10^{-3}, 1.1 \times 10^{-3}$ and 1.3×10^{-3} for the first, second and third time intervals respectively.
Based on the ideas and assumptions proposed in [7] the magnetic field can be calculated:

$$B = \frac{\sqrt{2A}mc\omega_{pe}}{e\, sin\theta} \quad (4),$$

where m and e are the mass and the charge of the electron, c is the speed of light, $\omega_{pe} = \sqrt{4\pi e^2 n/m}$ is the plasma frequency, and θ is the angle in which the electron beam is confined.
If we suppose that the electron beam responsible for the generation of spikes is confined to some reasonable solid angle (θ= 15°) [7, 13], and knowing the coefficients A, we can determine the magnetic field B along the electron beam path. This yields that the magnetic field of the ambient plasma during the first, second, third time intervals amount about 2.2 G, 1.6 G, and 1.8 G correspondingly.
The decameter spike fluxes do not exceed 500 s.f.u. and in most cases they are even below 100 s.f.u. [7]. According to our analysis the majority of spikes reveal fluxes from 20 s.f.u. to 100 s.f.u. with the largest number of bursts occurring with fluxes of 20 – 40 s.f.u. The bursts with fluxes larger than 100 s.f.u. are rare. The maximum value of the flux registered on this day is 520 s.f.u. Such a high values of the flux lead to the high values of the brightness temperature T_b. According to [14] the angular sizes of the sources of striae bursts have apparent diameters between 20′ and 50′at the frequency 25 MHz. In the decameter range, the parameters of striae are practically the same as the parameters of spikes. The only

difference between these bursts is that striae are observed in the chains drifting from high frequencies toward the low thus forming type IIIb bursts while spikes are chaotically located on the dynamic spectrum. This circumstance is planned to be the subject of study in a future work. Hence, it is reasonable to assume that the sizes of their sources are also more or less the same. Thus we calculated the brightness temperatures of spikes which are in the range $10^9 - 10^{10}$ K. Such values of brightness temperatures can be understood in the frames of plasma generation mechanism.

The polarization of the decameter spikes is circular and varies from 20 % up to 100 % with an average value of about 60 %. The obtained values of the spikes polarization agrees well with the polarization obtained for the decameter type IIIb bursts [15]. This fact can be additional evidence that the mechanisms of both types of bursts most probably the same.

4. Conclusions

In the present paper we used decameter solar spikes as a tool for the determination of the coronal plasma parameters at heights 1.6 - 3.3 solar radii. We also traced the variation of the temperature T and magnetic field B in the course of the observation day. According to our analysis, the coronal temperature decreases during the day of observations. As a matter of fact, during the first, second and third time intervals the coronal temperatures were $\approx 0.1 - 0.6 \times 10^6$ K, $\approx 0.2 - 0.43 \times 10^6$ K and $\approx 0.13 - 0.32 \times 10^6$ K, respectively.

In this study we also found that the spike bandwidth linearly increases with the observational frequency. If we assume that the electron beam responsible for the generation of the spikes propagates within some average solid angle $\theta = 15^\circ$ (13), then the value of the magnetic field strength B varies in the range 1.6 – 2 G during the day. The magnetic field herein obtained is also in good agreement with the results obtained by other authors.

The comparison of temporal characteristics of decameter spikes studied herein with thosecharacteristics of the high-frequency spikes [4] indicates that we most likely are considering the same family of solar radio bursts.

5. Acknowledgements

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