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Determination of the CME Core Parameters by Means of the Associated Spikes

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Abstract

The paper presents the analysis of the event observed on August 22, 2015 with UTR-2 and NDA radio telescopes. The main attention is paid to the study of the Type IV burst and spikes which were observed against its background. We assume that the emissions of Type IV burst and spikes escape from the CME core. Thus using the duration of spikes we reconstruct the profiles of the temperature and the magnetic field from the core center to its periphery.

Introduction

Simultaneous occurrence of Type IV bursts and spikes on the dynamic spectrum are rare events, especially when spikes are the fine structure of a Type IV burst [*Messerotti et al.*, 1985, *Nonino et al.*, 1986]. According to [*Ninino et al.*, 1986] in 120 Type IV bursts observed between 1972 and 1984 there were only 15 time intervals with spikes. The authors concluded that about 20% of all Type IV bursts might contain spikes as the intrinsic fine structure. In the meter wavelengths band the average duration of such spikes were about 100 ms with relative frequency width $\Delta f / f \approx 0.02$ [*Malville et al.*, 1967, *Bernold*, 1979, *Nonino et al.*, 1986, *Bouratzis et al.*, 2014, 2016]. Malville [*Malville et al.*, 1967] and Messerotti [*Messerotti et al.*, 1985] found that the spikes polarization degree varied from 0 to 100% and the sign of polarization coincided with that of the associated Type IV burst. Comparing the spikes parameters given in the literature we may conclude that spikes associated with Type III bursts and Type IV bursts practically do not differ from each other. It is in particular follows from the paper [*Bouratzis et al.*, 2016] who compared the parameters of different spikes in different frequency bands.

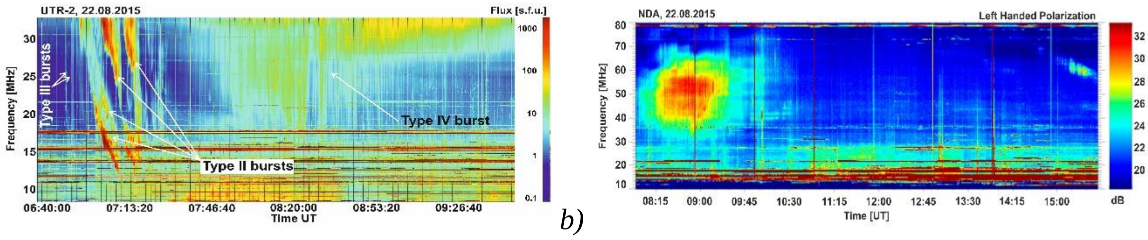
In this work, for the first time, we used spikes as a kind of "diagnostic tool" for remote determination of the temperature and the magnetic field in the CME core.

Observations

The analyzed event was observed on August 22, 2015 in the frequency band 8-80 MHz with the radio telescopes UTR-2 and NDA. This day the active region AR2403 exhibited enhanced activity resulted in 15 flares of C and M classes (https://tesis.lebedev.ru/). The AR was located near the center of the solar disk with the coordinates S14E09. In meter and decameter wavelengths bands this activity manifested itself in the form of Type II, Type III and IIIb, Type IV bursts and spikes.

Based on the observational data we concluded that the observed radio bursts were associated with the M1.2 flare started at 6.39 UT. The flare onset time coincides with the beginning of radio bursts observed with the UTR-2 radio telescope (Figure 1a). First Type III bursts appeared on the dynamic spectrum at 6:47 UT. They were followed by the Type II bursts that lasted from 6:53 till 7:30 UT. The Type IV burst itself was registered by the UTR-2 radio telescope between 7:34 and 9:44 UT while NDA radio telescope observed this burst from 8:00 till 9:45 UT (Figure 1b) (https://realtime.obs-nancay.fr/#). Judging from the dynamic spectrum it was a moving Type IV burst with the leading edge drifting from 73 MHz to 16 MHz with the drift rate of about 5 MHz/s. The spikes appeared against the Type IV burst background approximately at 8:23 UT and lasted until the end of the Type IV burst and further. However, the spikes observed against the Type IV background were bounded in the frequency by the

Type IV burst borders while spikes observed after the Type IV burst end were observed in the whole frequency band from 8 to 32 MHz.



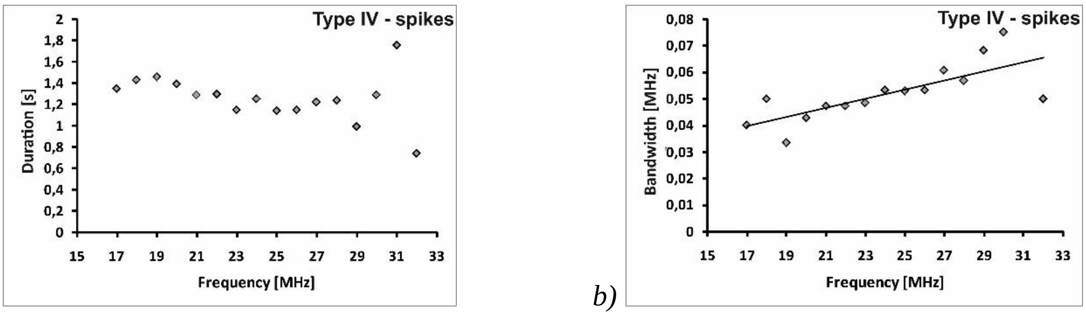
a) b)

Fig. 1 The event observed on August 22, 2015 with UTR-2 (a) and NDA (b) radio telescopes.

Analysis of the spikes parameters

For the analysis we chose spikes whose parameters could be reliably measured. It should be noted that their parameters were measured manually. More than 230 spikes against the Type IV burst background were processed. Statistical analysis shows that average duration and bandwidth of the spikes equal 1.2 s and 50 kHz respectively.

The dependences of average durations and bandwidths on frequency are presented on the Figure 2. Figure 2a shows that durations of spikes do not reveal regular dependence on frequency and lie within 1-1.5 s interval except a few cases. At the same time their bandwidth is proportional to frequency $\Delta f \approx Af$ (Figure 2b). The proportion coefficient A equals 1.7×10^{-3}. The same dependencies with slightly different A were also obtained in [*Melnik et al.*, 2014] and [*Shevchuk et al.*, 2016].



a) b)

Fig. 2 The dependencies of spikes average durations(a) and bandwidth (b) on frequency.

Determination of the CME parameters

The first determined parameter was density distribution across the CME core, which in turn allowed to estimate the CME mass. Since this CME moved toward Earth we couldn't obtain the exact size of its core. Nevertheless in the recent papers by [*Melnik et al.*, 2018, 2020] the sizes of two CMEs were determined as $1R_s$ and $2R_s$ respectively (R_s is the solar radius). Thus we determined the density distributions and masses for these two sizes. Similarly to [*Melnik et al.*, 2018] we assumed that the radio emission at the highest frequency $\approx 73MHz$ (Figures 1b) was radiated from the center of the core, while the lowest frequency emission $\approx 16MHz$ originated from the peripheral area (Figures 1a). Thus in the frames of plasma emission mechanism and supposing that the emission radiates at the first harmonic the densities at the center and borders of the CME core equal $n_c \approx 6.6\times10^{7}cm^{-3}$ and $n_p \approx 3.2\times10^{6}cm^{-3}$ respectively. If the density across the core follows the exponential law as [*Melnik et al.*, 2018]:

$$n(r) = n_c \exp(-\alpha r),$$

then we obtain $\alpha \approx 6/R_s$ for the core size of $1R_s$, and $\alpha \approx 3/R_s$ for the core size of $2R_s$. For both cases the peripheral density - $n_p \approx 3.2\times10^{6}cm^{-3}$. Obtained values allow us to estimate the CME mass as:

$$M_{CME} \approx 4\pi \int_0^r m_p n(r) r^2 dr .$$

The CME masses were approximately $10^{15} g$ and $10^{16} g$ for the core radiuses of $r = 0.5R_s$ and $r = 1R_s$ respectively. These values agree well with the data provided by SOHO/LASCO CME Catalog (https://cdaw.gsfc.nasa.gov/CME_list/) - $\approx 1.5\times10^{15} g$.

Another parameter is the CME core temperature and in particular its distribution across it. Similarly to [*Shevchuk et al.*, 2016] we estimated the temperature by the spikes decay time (τ_d). The dependence of τ_d on frequency is shown in Figure 3. Unlike the total durations of spikes their decay times decrease with frequency as $\tau_d \sim f^{-0.5}$.

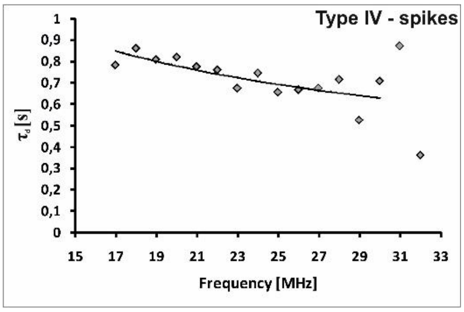


Fig. 3 . The dependence of the average decay times of spikes on frequency.

Based on the obtained observational dependency we got the relation for the temperature distribution on frequency:

$$T \approx 1.9\times10^4 f .$$

Figure 4 shows the obtained dependence for our particular case. This dependence essentially differs from the earlier obtained one by [*Shevchuk et al.*, 2016] for the storm of spikes observed before Type IV burst ($T \sim f^{2/3}$). The obtained temperature varied from 1.3 MK in the core center to 0.3 MK at its periphery.

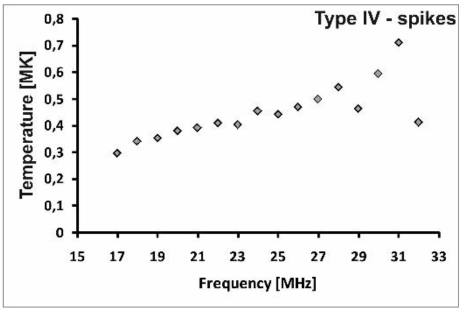


Fig. 4 The dependence of the temperature on frequency for the plasma inside the CME core.

Using the obtained dependence *T(f)* and following [*Melnik et al.*, 2018] we found the magnetic field distribution across the CME core. The gas-kinetic pressure $p = nkT$ (k is the Boltzmann constant) of the core should be compensated by the magnetic pressure $p = B^2/8\pi$. From the equality of these two pressures and obtained dependency *T(f)* we got an expression for the magnetic field:

$$B \approx 9\times10^{-4} f^{3/2} .$$

The obtained dependence is illustrated by Figure 5. One can see that the magnetic field decreases from $0.5G$ at the core center to $5\times10^{-2}G$ at its periphery. This result agrees well with the magnetic field value obtained in [*Melnik et al.*, 2018].

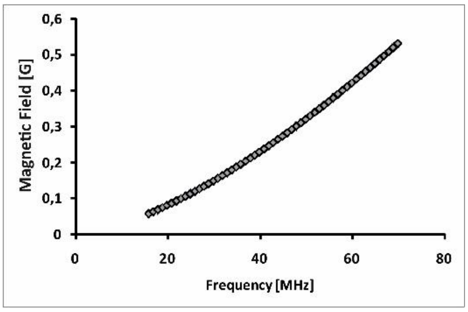


Fig. 5 The dependence of the magnetic field in the CME core.

Conclusion

In this article we analyzed the spikes observed against the Type IV burst background on August 22, 2015. It was shown that in this particular case the duration of spikes did not depend on the frequency, while their bandwidth revealed linear increase with frequency. Using spikes as a kind of "thermometer" we determined the temperature inside the CME core which appeared to change from 0.3 MK at the CME core periphery to 1.3 MK at its center. Also using the obtained dependence *T(f)* we got the value of the magnetic field and its profile across the CME core ($B \sim f^{3/2}$). The magnetic field varied from $5\times10^{-2}G$ at the core borders to $0.5G$ at its center.

Acknowledgements

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