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DECAMETER TYPE IV BURST WITH UNUSUAL HIGH POLARIZATION

V. N. Melnik [1], A. I. Brazhenko [2], A.V. Frantsuzenko [2], V. V. Dorovskyy [1], M. V. Shevchuk [1]

[1] Institute of Radio Astronomy, Kharkov, Ukraine, melnik@rian.kharkov.ua

[2] Institute of Geophysics, Gravimetrical Observatory, Poltava, Ukraine

ABSTRACT. We present results of observations of Type IV burst with unusual high polarization equalled in maximum phase about 100%. This burst was registered both by URAN-2 and NDA radio telescopes on 13 July 2022. It continued for about 5 hours and consisted of sub-bursts with high frequency drift rates and had short durations. We associate it with the weak CME, which propagated in the East direction in the form of thread-like structure. Theoretical description of sub-burst in the plasma mechanism of radio emission allow explaining their high polarization, high drift rates and short durations.

Keywords: Type IV bursts, CME, Sub-bursts, Frequency drift rates, Durations, Polarization, Plasma model of radio emission.

АНОТАЦІЯ. Ми обговорюємо результати спостережень сплеску IV типу з незвично великою поляризацією, яка досягає в максимальній фазі 100%. Цей сплеск було зареєстровано радіотелескопами УРАН-2 (Україна) та НДА (Франція) 13 липня 2022 року. Цей сплеск тривав біля 5 годин і мав тонку структуру у вигляді суб-сплесків з великою швидкістю дрейфу та малою тривалістю. Ми пов’язуємо цей сплеск з корональним викидом мас (CME), який розповсюджувався практично в східному напрямку у вигляді ниткоподібної структури. Теоретичний розгляд властивостей суб-сплесків за допомогою плазмового механізму радіовипромінювання дозволяє пояснити їх високу поляризацію, великі швидкості дрейфу та малу тривалість в рамках єдиного підходу.

Ключові слова: Сплески IV типу, сплеск з корональним викидом мас (CME), субсплески, частота швидкості дрейфу, тривалість, поляризація, плазмова модель радіовипромінювання.

1. Introduction

Type IV bursts were identified as a separate group of solar bursts by Boischot in 1957 (Boischot, 1957). At first they were observed at frequencies of meter and decimetre ranges (Stewart, 1985) and later in the decametre range (Gergely & Kundu, 1974). In the decametre range Type IV bursts continued from tens of minutes to some hours. They have fine structure in the form of sub-bursts similar to usual Type III bursts with smaller frequency drift rates (Mel'nik et al., 2008a; Melnik et al., 2010; Antonov et al., 2014; Bouratzis et al., 2015) and sometimes larger drift rates (Dididze et al., 2019). Durations of these sub-bursts can be both smaller (Melnik et al., 2010; Dididze et al., 2019) and larger (Mel'Nik et al., 2008a) than that for usual Type III bursts. In the meter range Type IV bursts also have similar sub-bursts (Bouratzis et al., 2015; Alissandrakis et al., 2019; Bouratzis et al., 2019) so-called fiber-bursts. Radio fluxes of decametre Type IV bursts do not exceed 1000 s.f.u. as a rule and their polarization is about 40% (Mel'nik et al., 2008a). At the same time observations of meter Type IV bursts showed that polarization could be frequently more than 85% (Smerd & Dulk, 1971) and even up to 100% (Liu et al., 2018). Historically at first a synchrotron mechanism of radio emission (Boischot, 1957) was proposed for an explanation of Type IV burst properties. Later preference was given to gyro synchrotron mechanism (Kai, 1969; Dulk, 1970) and finally to plasma mechanism offered in 1981 (Duncan, 1981).

The connection of decametre Type IV bursts with CME was studied in (Mel'nik et al., 2008a). It was found that among 13 Type IV bursts observed by radio telescope UTR-2 in frequency band 10-30 MHz for the period 2003-2006 12 of them were accompanied by CMEs. Later Hillaris et al. (2016) showed that 45 out of 48 decametre Type IV bursts observed with WIND/Waves at frequencies <14 MHz during 1998 – 2012. So we can conclude that decametre Type IV bursts and CMEs are connected with each other very closely. Moreover, it was shown (Melnik et al., 2018a; Melnik et al., 2020) that the sources of meter-decameter Type IV bursts observed on 2013 November 7 and 2017 September 6 were CME’s cores.

In this paper properties of Type IV burst in the frequency band of 26 – 70 MHz with high polarization of up to 100% are discussed. We suppose that this burst can be associated not with a bright CME but with very weak CME. Besides this burst consists of sub-bursts with high frequency drift rates and small durations. Model, which agrees with the unusual properties of this Type IV burst, is discussed in the frame of radio emission plasma mechanism.

2. Observations

The radio telescope URAN-2 (Poltava, Ukraine) observed the solar radio emission from 4:50 UT to 16:50 UT on 13 July 2022. This radio telescope (Brazhenko et al., 2005) is a rectangular array with an effective area of

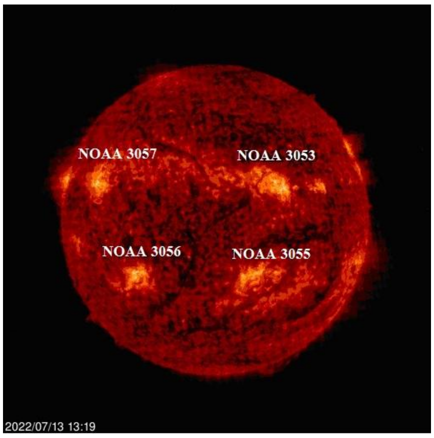


Figure 1: Solar disk on 13 July 2022 according to SOHO with active regions NOAA 3053, 3057, 3055 and 3056.

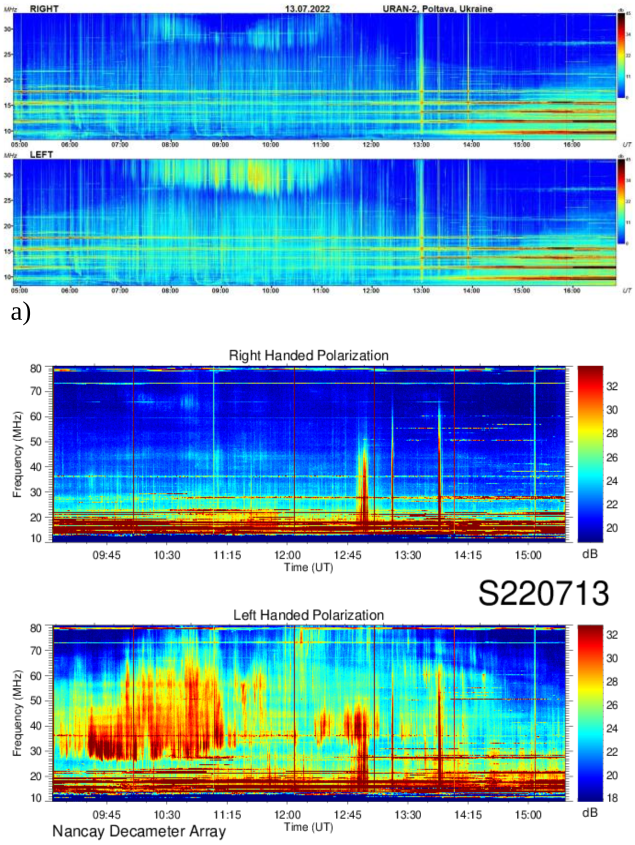
$28000 m^2$ operated in the frequency band of 8 – 33 MHz. This antenna array has a size of $238m$ in East–West direction and $118m$ in North–South direction and a beam size of 3.5◦ × 7◦ at a frequency of 20 MHz. The signals were recorded with a digital spectrum analyzer (DSPz) (Ryabov et al., 2010; Zakharenko et al., 2016), which allows us to carry out observations with frequency-time resolution of 4 kHz – 100 ms, and dynamic range of 90 dB in the working frequency band. This radio telescope can also measure polarization of solar radio emission in the frequency band of 8-33 MHz.

This day active regions NOAA 3053 and 3057 in the northern hemisphere and NOAA 3055 and 3056 in the southern hemisphere were present on the solar disk (Figure 1). Some weak flares were detected this day and three very weak CMEs at 4:24:05, 9:36:07 and 13:25:48 were marked as poor events by catalogue SOHO-LASCO (https://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL_ver1/2022_07/univ2022_07.html).

At the same time radio emissions in the decametre and meter ranges were strong enough. From the beginning of the observations with URAN-2 there was weak storm of Type III bursts with fluxes not higher than 10 s.f.u. with some single Type III bursts reaching up to 200 s.f.u. (Figure 2a).

The Type IV burst at the frequency range of 26 – 33 MHz began at 7:00 UT and lasted untill 12:00 UT approximately (Figure 2a). The radio telescope NDA (Nancy, France) also registered this burst in the frequency band of 26 – 70 MHz from the beginning of its observation this day (Figure 2b).

As for the standard decametre Type IV bursts (Mel'Nik et al., 2008a) the flux of this burst was increasing from the background level, which in this case was about 1-2 s.f.u., to the maximum value approximately equalled 100 s.f.u. in 1-2 hours (Figure 3a). After that starting from about 10:00 UT the flux was decreasing during 2 hours to the background level. The polarization of Type IV burst also uniformly increased from the beginning to approximately 8:40 UT. During about 1 hour, from 8:40 to 9:40 UT, maximum polarization was 100%. Then it uniformly decreased to the end of the burst. In spite of the observations by NDA were begun practically from the maximum phase of the burst Figure 2c showed that its polarization was mainly left handed and was practically 100%. Given Type IV burst has fine structure in the form of sub-bursts similar to standard Type III bursts as usual (Melnik et al., 2008a). Generally, such sub-bursts have higher and smaller frequency drift rates and durations compared with decametre Type III bursts for which standard values are –(2-4) MHz/s and 6-12 s correspondingly (Mel'nik, et al., 2005).



a)

b)

Figure 2: The dynamic spectra of solar radio emission on 13 July 2022 according to URAN-2 (a) and NDA (b). Both spectra show left handed polarization mainly and absence of right one.

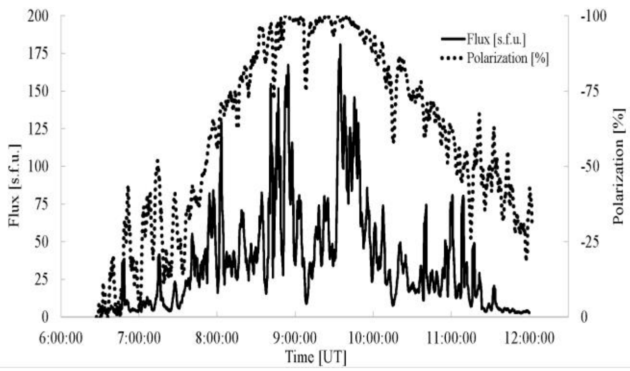


Figure 3: Flux and polarization in the form of a hump of the Type IV burst at frequency 32 MHz (URAN-2).

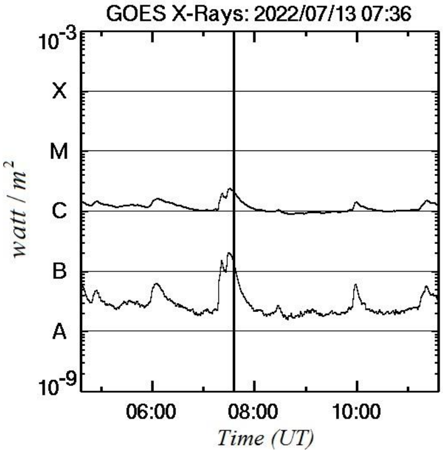


Figure 4: Flare in active region NOAA 3057 (N15 E52) in X-ray emission at 1-8A (upper curve) and at 0.5-4A (low curve) at 7:30 UT.

But usually these differences are not large, up to ten percents. In this case properties of sub-bursts distinguished very importantly. We measured parameters of sub-bursts such as durations, drift rates, fluxes and polarization at the rise, maximum and fall phases of Type IV burst and found that durations, drift rates, fluxes and polarizations were 0.6–2.6 s, -6 – -21 MHz/s (and sometimes positive), 50–700 s.f.u. and 90–100% (at the maximum of Type IV burst) correspondingly. Such parameters especially durations and drift rates remind single fast decametre Type III bursts (Melnik et al., 2008b) whose frequency drift rates were essentially higher and their durations were noticeably shorter than those of standard decametre Type III bursts (2–4 MHz/s and 6–12 s correspondingly). Those decametre Type III bursts were continuation of high frequency fast Type III bursts (so called Type III-like bursts) (Young et al., 1961; Elgaroy, 1980).

As we noticed already earlier practically all decametre Type IV bursts were associated with bright coronal mass ejections (CME). Most of them have standard structures consisting of bright leading edge, a dark void and a bright core (Aschwanden, 2004). Moreover, we put arguments (Melnik et al., 2018a; Melnik et al., 2020) that in those cases the sources of Type IV bursts are CME cores.

This day, as we said above, there were only weak CMEs and only CME at 9:36:07 UT can be associated with the Type IV burst observed by URAN-2 and NDA. This CME could be initiated by the flare at 7:30 (Figure 4). It was not practically seen in the optical band it was not seen practically but the differential optical emission (Figure 5) showed a thread-like structure of this CME, which had the length more than 4Rs at 11:36:00 UT. In this case it is reasonable to suppose that electron beam responsible for fast sub-bursts propagate along this thread-like structure of the CME.

3. Discussion

The main property of the discussed Type IV burst is its high polarization with maximum value of 100%. In our point of view, it is connected with the fact that sub-bursts of this Type IV burst are fast Type III bursts.

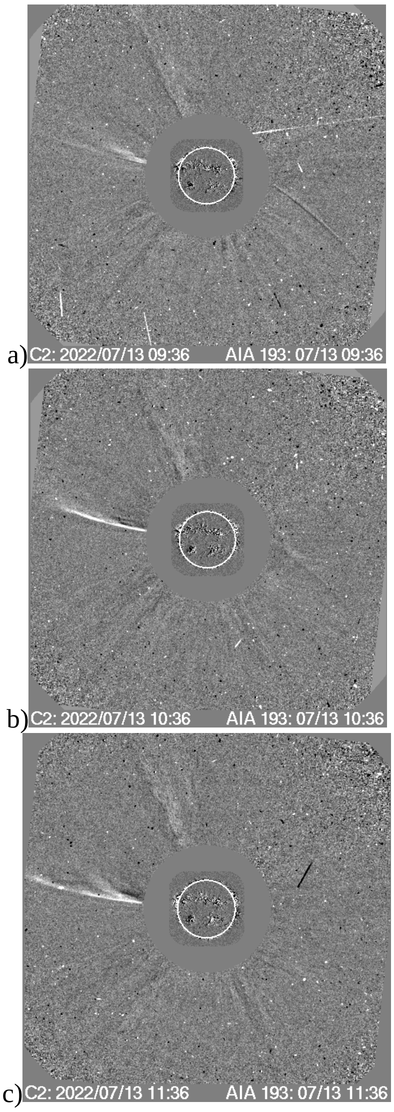


Figure 5: Differential optical radio emission according to SOHO at three different moments 9:36, 10:36 and 11:36 UT, which coincide with weak CME with velocity of 495 km/s and angular width of 12° (https://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL_ver1/2022_07/univ2022_07.html).

Let us consider the possible connection of high polarization of sub-bursts with their large drift rates in the plasma mechanism of radio emission. In the plasma theory of Type III bursts the Langmuir waves (Z-mode in plasma with magnetic field), l, generated by fast electrons, are transformed into O- or X- modes of electromagnetic waves, t, in the processes of scattering on ions, i, $l + i = t + i$ (Ginzburg & Zhelezniakov, 1958). According to the conservation of energy in these processes the frequency of electromagnetic wave equals to frequency of Langmuir wave $\omega_t = \omega_l$. Then if the frequency of Langmuir wave ω_l is smaller than the frequency $\omega_{pe} + \omega_{Be} / 2$ ($\omega_{pe} = \sqrt{4\pi e^2 n / m}$ is the plasma frequency, $\omega_{Be} = eB / mc$

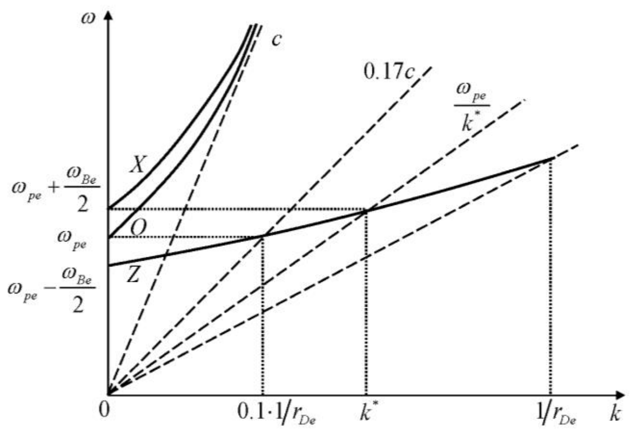


Figure 6: Dispersion curves for X-, O-, and Z-modes for plasma in a magnetic field (Achiezer et al., 1974).

is the electron cyclotron frequency) (Figure 5), Langmuir waves are transformed into O-mode only. At that the wave number of Langmuir wave k_l should be smaller than $k^* = \sqrt{\omega_{pe}\omega_{Be}/3}/v_{Te}$ (corresponding phase velocity is $v^* = \omega_{pe}/k^* = \sqrt{3\omega_{pe}/\omega_{Be}}\cdot v_{Te}$) (Melnik et al., 2018b). If the frequency of Langmuir wave ω_l is larger than $\omega_{pe} + \omega_{Be}/2$ then Langmuir waves can be transformed both into O- and X- modes. It is well known (see, for example, Zlotnik, 1981; Melrose, 1985) that the degree of the polarization is defined by the difference of X- and O-waves. In the first case electromagnetic waves have practically 100% O-polarization and in the second case the polarization is smaller.

As we said earlier sub-bursts of Type IV burst had high negative frequency drifts and even positive ones. As was shown in (Melnik et al., 2008b) large negative drifts and positive drifts (Melnik et al., 2015) of Type III-like bursts are explained by the approximate equality of velocity of electron beams responsible for these bursts and group velocity of electromagnetic waves generated by these beams. In the case of propagation of these electrons to the direction to the viewer this velocity is equal to $v_s = 5\cdot 10^9 cm/s = 0.17c$ ($c = 3\cdot 10^{10} cm/s$ is the speed of light) (Melnik et al., 2008b). If electrons move under the angle θ to the viewer then this velocity is $v_s = \frac{5\cdot 10^9}{\sqrt{\cos\theta}} cm/s$. Under supposition that electron beams propagate along thread-like structure of CME the angle θ was $\theta = 52^\circ$ the velocity v_s was $v_s = 6.4\cdot 10^9 cm/s$. If electron velocity is larger than these values then frequency drift rates of corresponding Type III bursts will be positive (Melnik et al., 2015). In the plasma mechanism of radio emission the fast electrons with velocity v_s generate Langmuir waves with wave numbers $k_s \approx \omega_{pe}/v_s$ mainly (Drummond & Pines, 1962; Vedenov et al., 1962). Interaction of these waves with beam electrons leads to the formation of a plateau on the electron distribution function from the maximum velocity v_s to some minimum velocity $v_{\min}$ during the time τ according to the equation (Vedenov & Ryutov, 1975)

$$v_s / v_{\min} + \ln(v_{\min}/v_s) = 1 + \frac{\pi}{\Lambda}\omega_{pe}\frac{n'}{n}\tau \qquad (1)$$

where n' and n are densities of fast electrons and background plasma and Λ is the Coulomb logarithm. In order to the generated Langmuir waves are transformed into O-mode it is necessary that $v_{\min}$ is greater than v^* (or $k_{\min} < k^*$, see Figure 5). For the very case when $v_{\min} = v^*$ ($k_{\min} = k^*$), the time τ of establishing plateau from v_s to $v_{\min}$ is equal approximately to sub-burst duration $\tau = 1s$ at frequency $f_{pe} = 30MHz$, magnetic field equal 2G we find from equation (1) that the density of fast electrons is about $n' = 0.2cm^{-3}$. So the beam of fast electrons with such density and the velocity a little smaller than $v_s = 6.4\cdot 10^9 cm/s = 0.21c$ is a source of electromagnetic waves with 100% O-mode and high frequency drift rate. If $k_{\min} > k^*$ some of Langmuir waves will be transformed into X-mode (see Figure 5) and polarization will be smaller. If the velocity of fast electrons will be larger than $v_s = 6.4\cdot 10^9 cm/s = 0.21c$ then corresponding sub-bursts will have positive drift rates and polarization will be also high.

In (Melnik et al., 2017) analysing interferometer observations of decametre Type III bursts we showed that sources sizes were approximately equal to $L \approx \tau\cdot v_b$, where τ is the Type III duration and v_b is the velocity of Type III electrons. Supposing that this estimate is true for the sub-bursts we can find brightness temperatures of sub-bursts radio emission

$$T_b = 5.5\cdot 10^{29}\frac{\lambda^2 S}{\Theta_p\Theta_t} \qquad (2)$$

where S is the flux [W/m^2Hz], Θ_p and Θ_t are source diameters [minutes] in equatorial and polar directions, and λ is the wavelength [m]. So we found brightness temperatures for the sub-bursts of Type IV burst, which are in the limits from $4\cdot 10^{10} K$ to $5\cdot 10^{12} K$ supposing that $\Theta_p \approx \Theta_t$. It means that in the plasma theory of radio emission such temperatures can be produced due to induced regime of transformation of Langmuir waves to electromagnetic ones (Melrose, 1985; Suzuki & Dulk, 1985; Mel'Nik & Kontar, 2003).

4. Conclusion

Type IV burst with high polarization up to 100% was observed by radio telescopes URAN-2 and NDA on 13 July 2022. Its duration was about 5 hours and frequency band was from 26 MHz to 50 MHz. Another peculiarity of this burst was fine structure in the form of sub-bursts with high negative and sometimes even positive drift rates. These sub-bursts were short and their durations were in the range from 1 to 2.6 s mainly. According to these parameters these sub-bursts are similar to decametre Type III-like bursts (Melnik et al., 2008b). Besides these sub-bursts have high polarization up to 100%. We propose the interpretation of these properties in the frame of plasma mechanism of radio emission in the processes of $l + i = t + i$ with the generation of O-mode of electromagnetic waves. It allows estimating the density of fast electrons, which are the sources of sub-bursts.

Interesting peculiarity of the discussed Type IV burst is the absence of bright coronal mass ejection, CME, which usually accompany decametre Type IV bursts. In this case only very weak optical CME in the form of thread-like structure accompanied this Type IV burst.

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