SPORADIC SOLAR RADIO EMISSION AT DECAMETER WAVELENGTHS

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Results of observations of the solar sporadic radio emission in decameter range are presented. These observations were carried out at UTR-2 radio telescope with 60-channel spectrometer and DSP (Digital Spectral Polarimeter) last years. Particular attention is devoted to such components of sporadic radio emission as Type III bursts, Type II bursts, "drift pair" bursts. New properties of these bursts, which distinguished for decameter band, are noted. They are as follows:
– fine structure of Type III bursts unobserved before at other frequencies;
– first discovered fine structure of Type II bursts in the form of small duration sub bursts with positive and negative frequency drift;
– wavelike movement of Type II burst backbone with herringbone structure;
– difference of frequency drift rates of "drift pair" bursts with positive and negative rates.

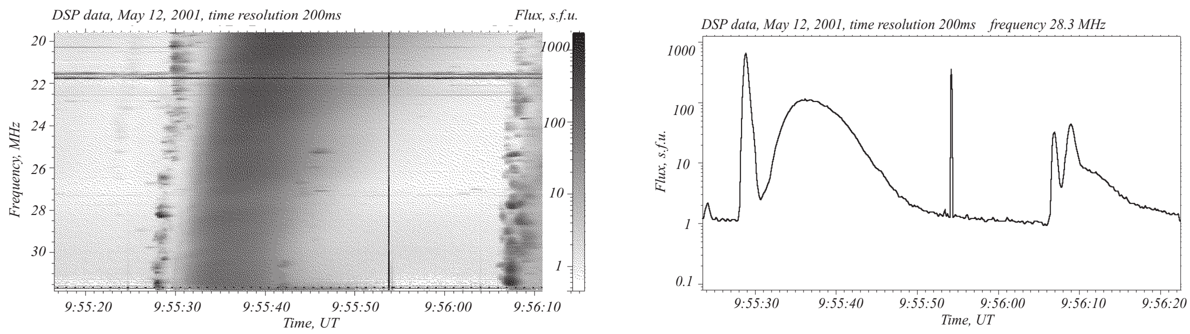
INTRODUCTION

Observations of solar sporadic radio emission are carried out at the Institute of Radio Astronomy of the National Academy of Sciences of Ukraine with the world largest decameter radio telescope UTR-2 since the end of the 1960s. On account of lack of frequency channels the main attention was focused on the Type III bursts investigation. Our observational programs were considerably extended lately. The 30-channel and 60-channel spectrometers and the Digital Spectral Polarimeter (DSP, created by our French and Austrian colleagues) have been put into operation by the end of the 1990s. In this paper we report about the results of solar radio emission observations carried out in 2001–2002. We concentrate our efforts especially on investigation of Type II bursts, Type III bursts with fine structures and "drift pair" bursts at the decameter wavelengths.

TYPE III BURSTS WITH FINE STRUCTURE

Type III bursts drift from high frequencies (approximately 1 GHz) down to lower ones (till 10 kHz), that corresponds to the exciter (electron flows) movement from the solar surface outward in the corona for long distances. It was currently known that Type III bursts had no fine structure. Typical dynamic of Type III burst spectrum is shown in Fig. 1a.

Time profile of the "classic" Type III bursts is smooth with fast rise and respectively slow fall (Fig. 1b). Their drift rate depends on frequency according to the empirical law $\propto f^{1.84}$, while the duration is inversely proportional to frequency. Observations at the decameter wavelengths show the drift rate from 3 to 6 MHz/s and burst duration ranges from 4 to 8 s. The fluxes are rather high and reach of 10^5–10^6 s.f.u. (1 s.f.u. $= 10^{-22}$ W m^{-2} Hz^{-1}). The Type III burst in Fig. 1 is preceded by Type IIIb burst. Well known Type IIIb bursts are the variants of Type III with fine frequency structure. They have slightly faster drift rates and shorter durations. The fine structure, or stria-bursts use to have doublet or triplet appearance that is apparently connected with magnetic field existence in the emission region. Pick *et al.* [6] and Benz *et al.* [1] noted the possibility of existence of Type III bursts with fine time structure at the high frequency side of the band (100–200 MHz). So, Pick *et al.* [6] discussed complex structure of Type III bursts in the form of several components. Benz *et al.* [1] informed that at high frequencies the Type III bursts followed the narrowband spikes with a fine temporal structure. Due to the fact of using new back-end facilities, first of all DSP with 12 MHz frequency band and time resolution up to 2 ms in combination with highly sensitive UTR-2 radio telescope we succeeded in observing of more than 50 Type III bursts with fine time structure. Figures 2 and 3 illustrate



a) b)

Figure 1. Dynamic spectrum (a) and time profile (b) of classic Type IIIb–III burst

different types of these fine structures. Figure 2 shows Type III burst with the fine structure in the form of narrow sub-bursts drifting slower than the envelope does. At the same time there were also cases when Type III bursts had sub-bursts with either lower or equal drift rates with respect to that of the envelope. Ones we observed an event where it is clearly seen the "drift pair" bursts just on the envelope of Type III burst. Judging from coincidence of the starting and ending times of both drifting pairs and Type III burst this effect cannot be considered as a simple superimposition of two bursts arrived from different locations in the corona. An interesting example of fine structure of Type III burst is shown in Fig. 3. The burst has appearance of a spindle with the sub-bursts having both negative and positive drift rates. The duration of all sub-bursts is about 1 s and absolute value of drift rate is 1 MHz/s. The last values can be considered as typical for the fine structure components of Type III bursts at the decameter wavelengths.

TYPE II BURSTS

Solar Type II bursts have their drift rates two orders less than those of Type III bursts at the same frequency band. These bursts are connected with shock waves [4], which propagate at the speed up to 1500 km/s. Often they move ahead of coronal mass ejections (CME) [2]. The electrons accelerated to the high energies at the shock front are considered to be a source of the Type II emission. Such emission was also observed by spacecrafts in the interplanetary space at the lower frequencies. At the decameter wavelengths the Type II bursts up to recent times were not observed basically due to absence of corresponding back-end facilities. The DSP and 60-channel spectrometer allowed us not only to observe the Type II emission, but also to obtain the new unique information about this type of solar radio emission.

Type II burst observed on May 11, 2001 is shown in Fig. 4a. One can clearly see that the burst has fine structure in the form of short sub-bursts and consists of two lanes of emission. Usually, it is thought that these two lanes represent the emission from two different sources located on both sides of the shock front. But our observations show that it doesn't seem to be correct. Indeed, we can see that Type II burst has fine time structure (this peculiarity was firstly observed by us) in the form of short sub-bursts which cross both lanes of the Type II. If the emission went from the both sides of the shock front the sub-bursts would change the drift rate due to sudden change of plasma density on the front. But the experiment shows no "jumps" in the sub-bursts drift rates, and it means that both lanes originate from one side of the shock. Moreover, the electrons move in both direction, *i.e.*, towards the front and away from it since there are sub-bursts with positive and negative drifts. On July 7, 2002 we observed the Type II burst with so-called "herringbone" structure, when on opposite sides of the "backbone" we could see the sub-bursts with the opposite signs drift (Fig. 4b). Currently, this phenomenon was explained as electron acceleration in two opposite direction from the shock front. We first found that the parameters of sub-bursts with positive and negative drifts are different. The negative drifting sub-bursts have shorter life time and slower drift rates in comparison with positive drifting ones. The drift rate of the Type II burst itself is almost zero that means the shock wave propagates parallel to the solar surface. Nevertheless, the "backbone" of the burst makes wavy movements that could mean the shock wave crosses of some coronal structures. It is possible to estimate the sizes of those structures as well as density variation along the shock wave propagation from our experimental data.

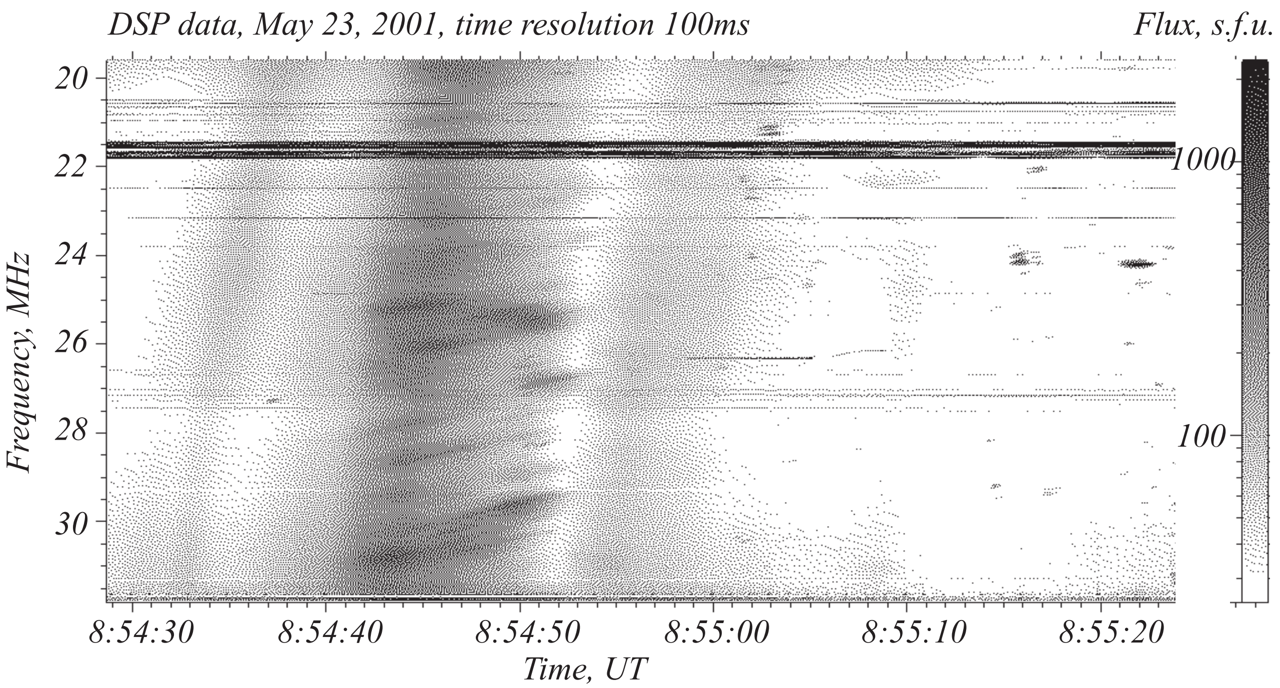


Figure 2. Type III burst with slower sub-bursts

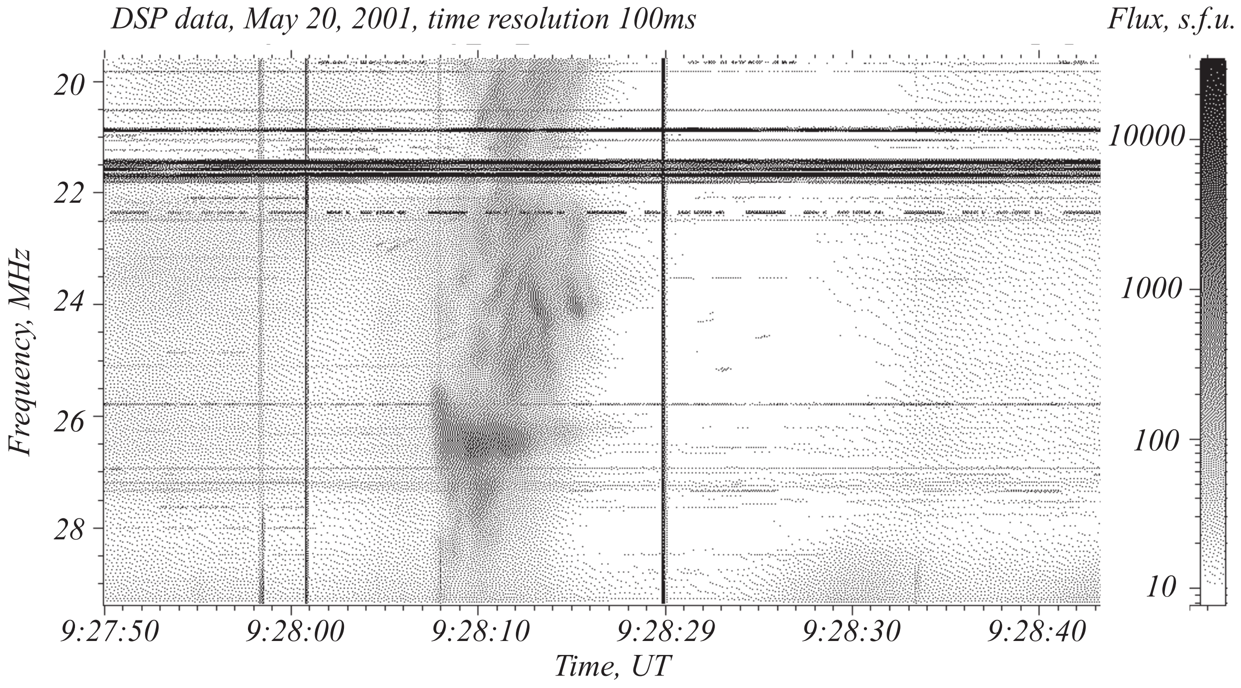
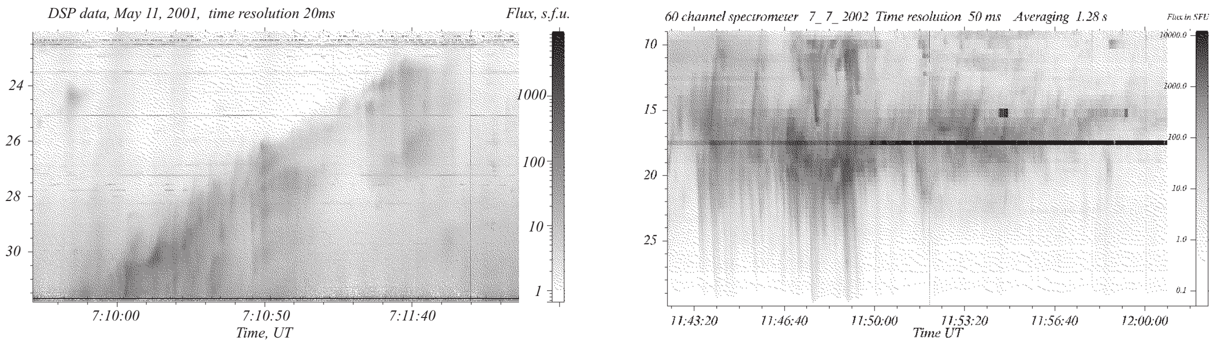


Figure 3. Type III burst in the form of "spindle"



a) splitted Type II with fine structure

b) Type II with "herringbone structure"

Figure 4. Type II bursts with fine structures

"DRIFT PAIR" BURSTS

"Drift pair" bursts or DP are usually observed during solar Type III storms (Fig. 5). The nature of the DP still remains unclear in spite of more than 50 years of investigation. These bursts appear at frequencies below 70 MHz with their number increasing at the lower frequencies. The DP consists of two similar components separated in time by 1.5–2.5 s and extended over the frequency range 0.5–2 MHz [3]. Both elements of DP have nearly the same duration, which lies between 1 s and 1.5 s. Their drift rates range from 1 to 8 MHz/s [3], and can be positive ("reverse" DP) or negative ("forward" DP). In each case drift rate is constant for one chosen DP. In 2002 we have observed several DP storms. Due to high sensitivity of the UTR-2 antenna and excellent frequency and time resolution of back-end facility we have observed and processed more than 700 DPs during the storm on July 11–21, 2002. In contrast to existing opinion about considerable quantitative prevalence of "reverse" DPs over "forward" ones [5] we found that correlation between them was not stable during the storm. On July 13 we observed 109 "forward" and 89 "reverse" DPs, on July 14 – 186 and 123 ones, on July 15 – 109 and 158, respectively. Our observations also showed that at the frequencies below 25 MHz "reverse" DPs were more rare than "forward" ones and almost disappeared at the frequencies below 15 MHz. According to our experimental data the values of drift rates and their dispersion are different for "forward" and "reverse" DPs. "Forward" DPs in majority have absolute value drift rates <1 MHz/s with maximum at 0.8 MHz/s and low dispersion, respectively. At the same time "reverse" DPs have wide drift distribution with maximum at +1.5 MHz/s. It is also necessary to note that the enormously high drift rates (more than 8 MHz/s) were detected only for "reverse" DPs. The empirical formula given below describes the dependence of the DP drift rate on frequency.

$$\dot{f}(f) = A \cdot \left(\frac{f}{f_0}\right)^B + C, \tag{1}$$

where $\dot{f}(f)$ is the drift rate in MHz/s, f is the median frequency of the burst in MHz, f_0 (the normalization frequency) equals to 25 MHz (frequency of maximum drift pairs activity); $A = -0.5$, $B = 2.7$, $C = -0.4$ for "forward" DPs; $A = 2.3$, $B = 6.2$, $C = 1$ for "reverse" DPs.

Time delay between the DP elements does not show any substantial dependence on frequency and is slightly larger for "reverse" bursts. The dependence of the flux densities on frequency is also different for "reverse" and "forward" DPs. The fluxes of the first one do not change with frequency till 23 MHz, and then rapidly fall from 90 to 30 s.f.u. The fluxes of the second one decrease monotonously from 40 to 20 s.f.u. in all frequency band from 12 to 30 MHz. Thus, we first show that properties are differ for DPs with positive and negative drifts. We think this difference is connected with the different conditions in which bursts are generated. But coincidence of other important parameters, such as duration, time delay and frequency band, allows us to suggest that the emission mechanism for both "forward" and "reverse" DPs is the same.

During the DP storm we have also observed unusual variants of DPs, in particular, so-called "hook" bursts. This is such a combination of two DPs with opposite drifts when the end point of the first DP sharply coincide with the start point of the second one. The high frequency and time resolution also allowed us to detect fine structure of DP bursts. These fine structures have appearance of either the diffuse clouds (Fig. 6) or more short and narrow sub-bursts with their own drift rates (Fig. 7).

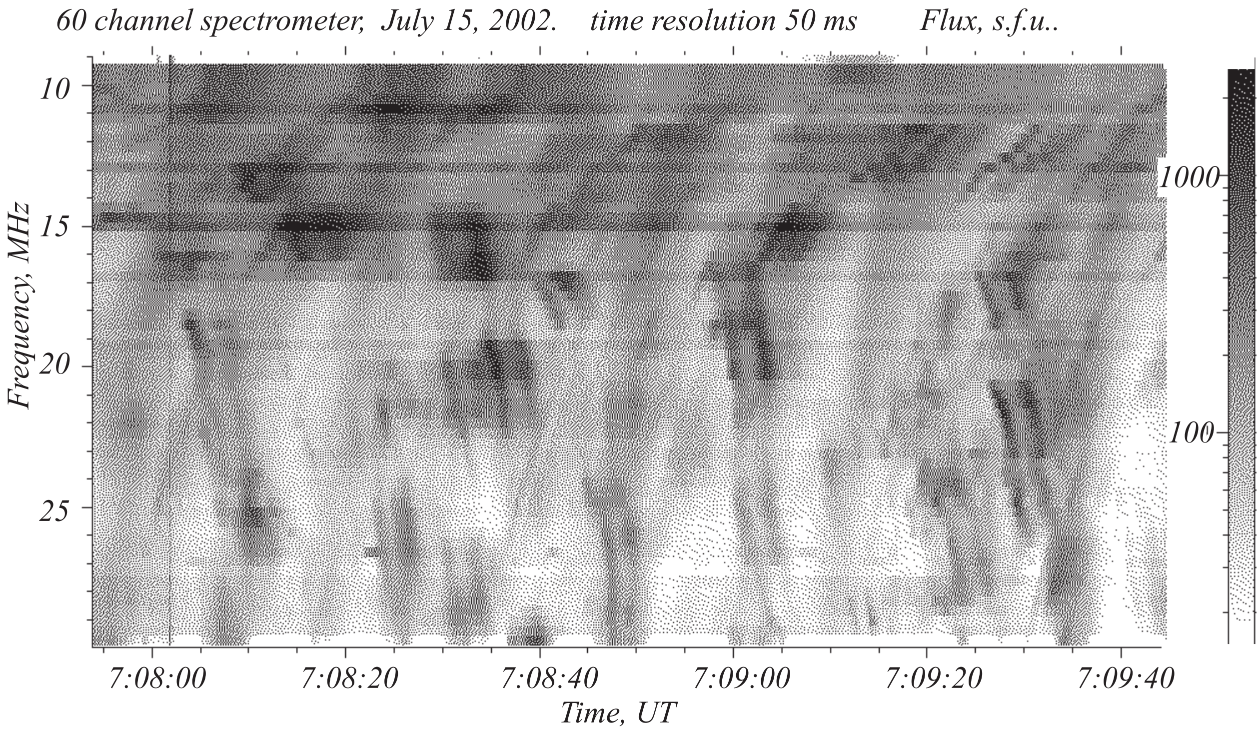


Figure 5. Fragment of the "drift pair" storm on July 15, 2002

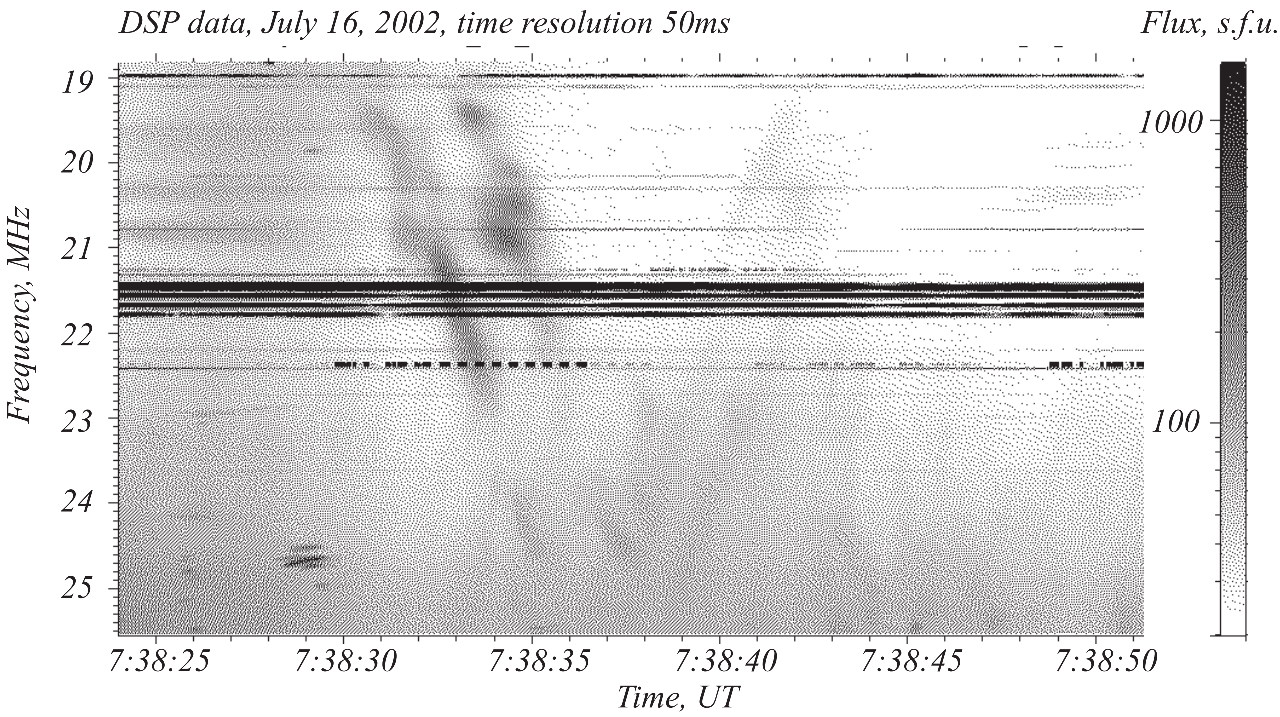


Figure 6. The "drift pair" burst with cloudy fine structure

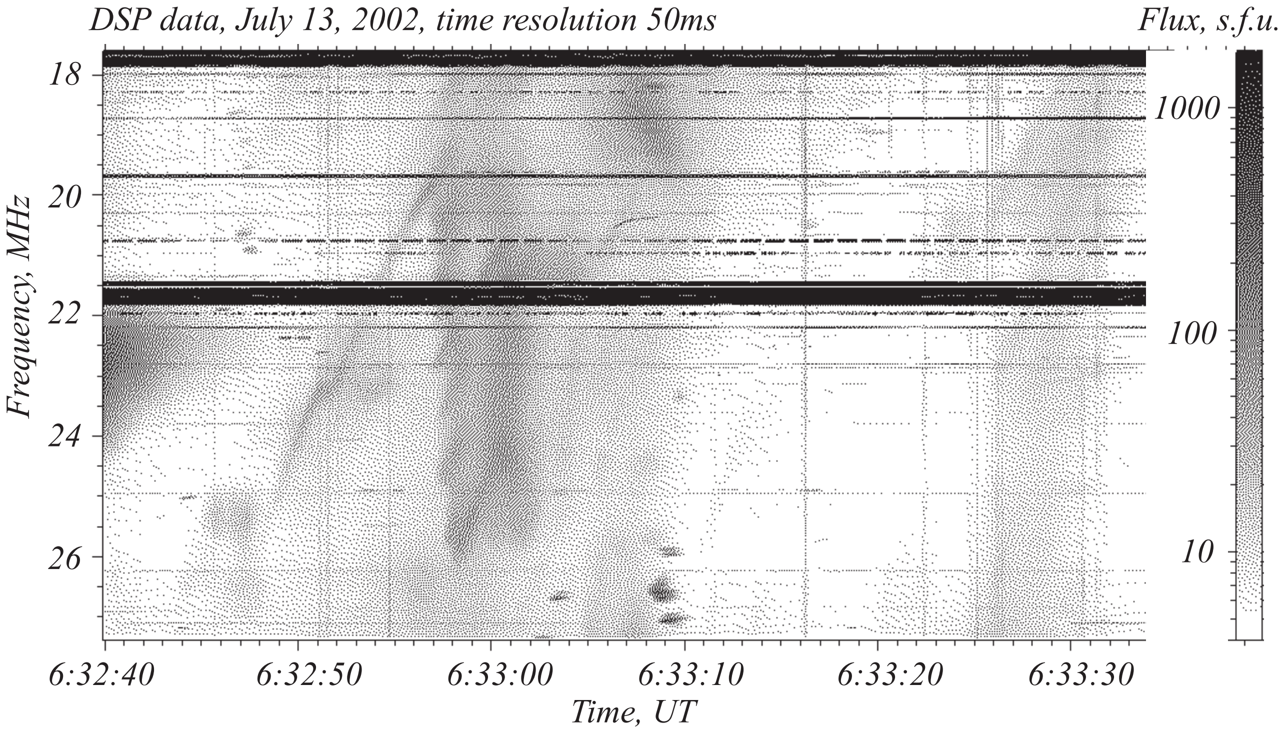


Figure 7. The "drift pair" burst with fine structure in the form of sub-bursts

CONCLUSION

The observations carried out using UTR-2 radio telescope equipped with powerful back-end facilities show that solar sporadic radio emission at the decameter wavelengths has substantial differences depending on the higher frequency radio emission. First of all because it has more rich and various fine structures both in time and frequency domains. The latter can be apparently explained by the fact that the decameter radio emission originates from substantially inhomogeneous regions, which in their turn, can be connected with both the plasma density distribution and the magnetic field effect. Therefore, the detailed study of the solar radio emission will allow us to understand not only the emission mechanisms but also to investigate the structure of the solar corona at heights of about one solar radius.

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