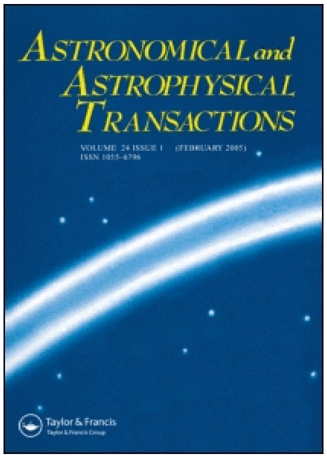

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Solar sporadic radio emission in the decametre waveband

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The first results of observations of solar sporadic radio emission with the UTR-2 radio telescope in 2001–2003 are reported in this paper. Using new back-end facilities, the digital spectro-polarimeter and 60-channel spectrometer allowed us to obtain data with a time resolution up to 2 ms and a frequency resolution of 12 kHz in a continuous frequency band of 12 MHz. The usual type III bursts, type IIIb bursts, U and J bursts, spikes and unusual bursts in the decametre wavelength band are discussed in this paper. Special attention is paid to the detection and analysis of type II bursts and their properties, the fine structure of type III bursts, the new observational features of drift pair bursts, 'absorption' bursts and the statistical analysis of solar radio bursts.

Keywords: Solar radio emission; Type II bursts; Type III bursts

1. Introduction

The radio telescope UTR-2 (Kharkov, Ukraine) is at present the world's largest radio telescope operating in the decametre wavelength band [1]. It has been involved in solar observations since the beginning of the 1970s. Usually the observations were carried out using filter bank spectrometers with only six or eight channels. This limitation did not allow us to investigate various components of solar sporadic radio emission. By the end of the 1990s our research activity was limited to the investigation of type III and IIIb bursts, drift pairs and the quiet Sun.

The collaboration of Austrian, French and Ukrainian scientists resulted in the creation of a new-generation spectrometer, namely a digital spectro-polarimeter (DSP) [2]. The DSP provided observations with high time and frequency resolutions in rather a wide frequency band of 12 MHz (or 50% of the working frequency). The DSP observations were supplemented by a 60-channel filter bank spectrometer, which increased even more the capability of solar radio emission investigations. The present paper introduces the first results of solar sporadic

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radio emission observations obtained with the new back-end facilities as well as analysis of the obtained results.

2. Radio telescope and associated equipment

The broadband T-shaped radio telescope UTR-2 consists of two antenna arrays: 'north–south' (1800 m along the north–south direction) and 'east–west' (900 m along the east–west direction). The 'north–south' antenna is in turn divided into two separate arrays, each of which includes 720 broadband dipoles (six rows by 120 dipoles). The 'east–west' antenna consists of six rows by 100 dipoles. The discrete phasing system allows us to cover the sector ±50° in the right ascension plane and ±80° in the declination plane. The effective area of the 'north–south' antenna equals 100 000 m^2 and that of the 'east–west' antenna equals 40 000 m^2 when pointed at the zenith. The telescope beam could be as narrow as 25′ at 25 MHz. The wide dynamic range and linearity of the amplifiers as well as their optimal distribution almost exclude intermodulation interference.

At the end of the 1990s a new 60-channel filter bank spectrometer was created. It has 60 identical channels with a selectable bandwidth from 3 to 10 kHz. The central frequency of each channel can be chosen in the range 10–30 MHz depending on the observational programme. The spectrometer has a variable time resolution from 20 ms to several minutes with data accumulation and averaging. The dynamic range is 40 dB with a sensitivity of about 10^{-25} W m^{-2} Hz^{-1}.

In 1999–2002, joint observations of the solar sporadic radio emission were carried out at the UTR-2 radio telescope with the assistance of scientists from the Space Research Institute (Graz, Austria), Paris-Meudon Observatory (Paris, France) and Institute of Radio Astronomy (Kharkov, Ukraine). During these observations the DSP was used as the back-end facility.

3. Observations

Observations with the new recording devices were started in 2001 [3]. During this period we have observed not only well-known events in the decametre band events, such as type III and IIIb bursts and drift pairs, but also bursts which have not been observed before in this frequency range: type II bursts, U, J and S bursts, decametric spikes and absorption bursts. Moreover we have obtained new information about well-known events and, in particular, we have found the fine structures of type III, type II bursts and drift pairs. Let us briefly describe the main properties of these events.

3.1 *Type III bursts*

Type III bursts in the decametre band have drift rates of about -3 MHz s^{-1} and durations close to 10 s. Their time profiles are smooth, which apparently indicates the uniformity of the electron beams generating these bursts. Type IIIb bursts are shorter (3 s) and drift a little more quickly (-4 MHz s^{-1}). Usually they are slightly brighter. Together with the ordinary bursts, we have also observed type III bursts with a fine structure [4]. During observations in 2001–2002, more than 50 such bursts were recorded. Usually the fine structure has the form of short narrowband subbursts with their own drift rates.

The subbursts can be classified by their drift rates into four groups:

(i) subbursts drifting more rapidly than the host burst (the highest observed drift rate was about 12 MHz s^{-1}) (figure 1);

(ii) subbursts with drift rates of around $1\,\mathrm{MHz\,s^{-1}}$;
(iii) subbursts drifting more slowly than $100\,\mathrm{kHz\,s^{-1}}$ (figure 2(a));
(iv) a combination of subbursts with positive and negative drifts (figure (2b)).

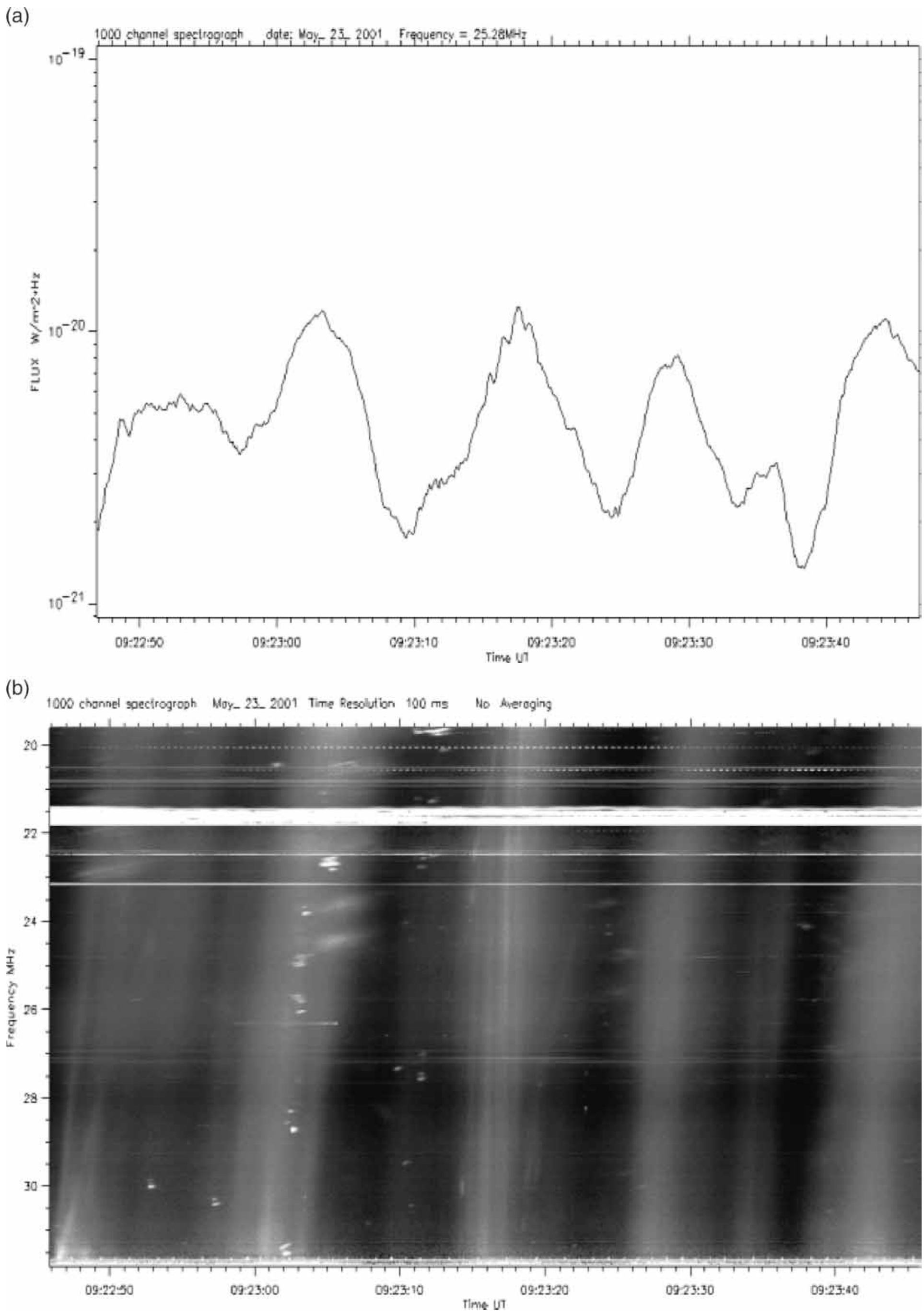

Figure 1. Type III burst with a fine structure: (a) profile; (b) dynamic spectrum.

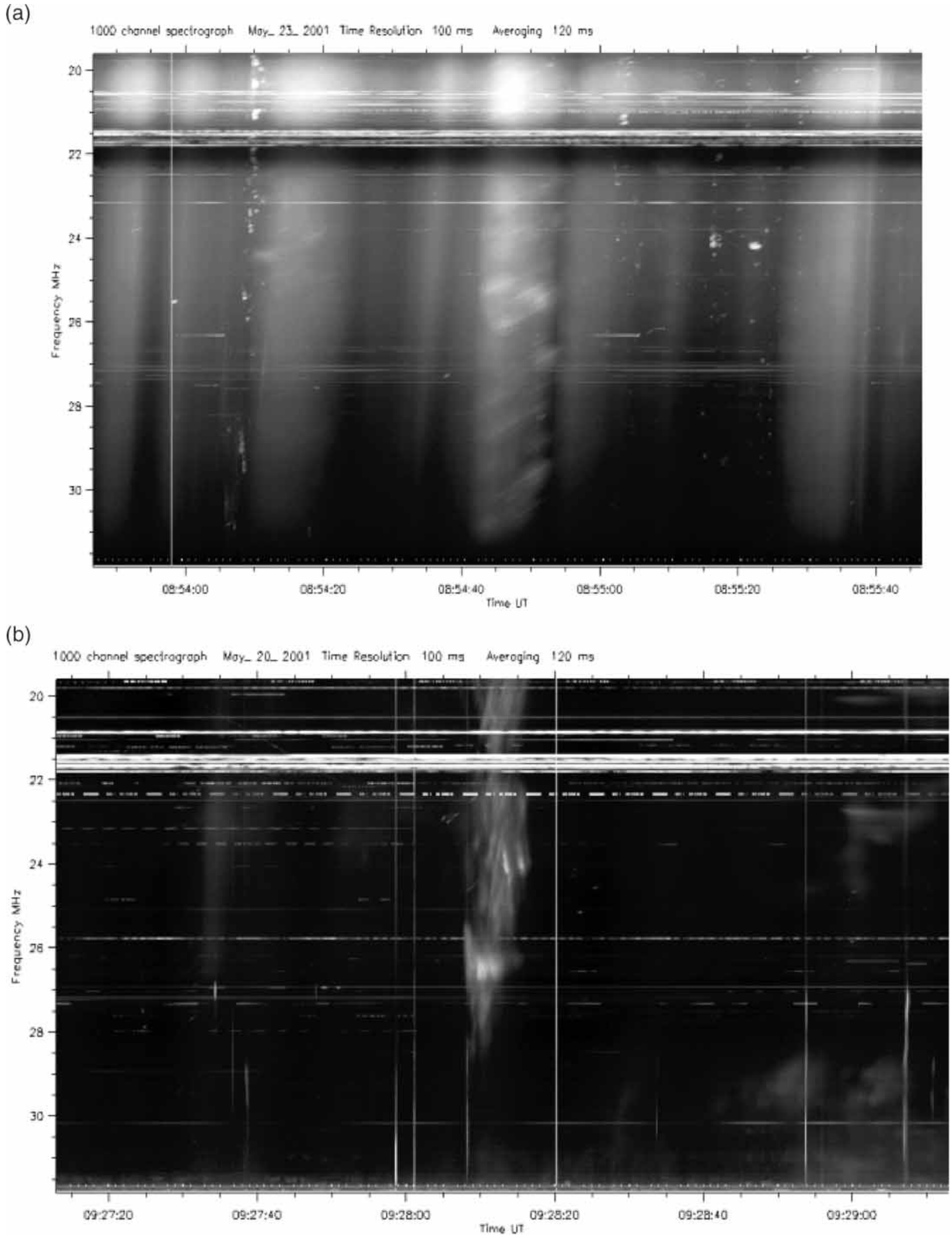

Figure 2. Type III bursts with subbursts (a) drifting more slowly than the host burst and (b) drifting in both directions.

Also in group (ii) we can include the cases when drift pairs and solar S bursts were observed just on the background of the type III burst. Apparently, this is not a simple superposition of different bursts emitted from different sources in the corona since both the drift pairs and the S bursts are sharply bounded by the host type III body. The duration of the subbursts belonging to the host burst usually equals approximately 1 s. In our opinion, the fine structure is a manifestation of some other particle beams with parameters (density and/or velocity) that are different from the parameters of the host type III electrons.

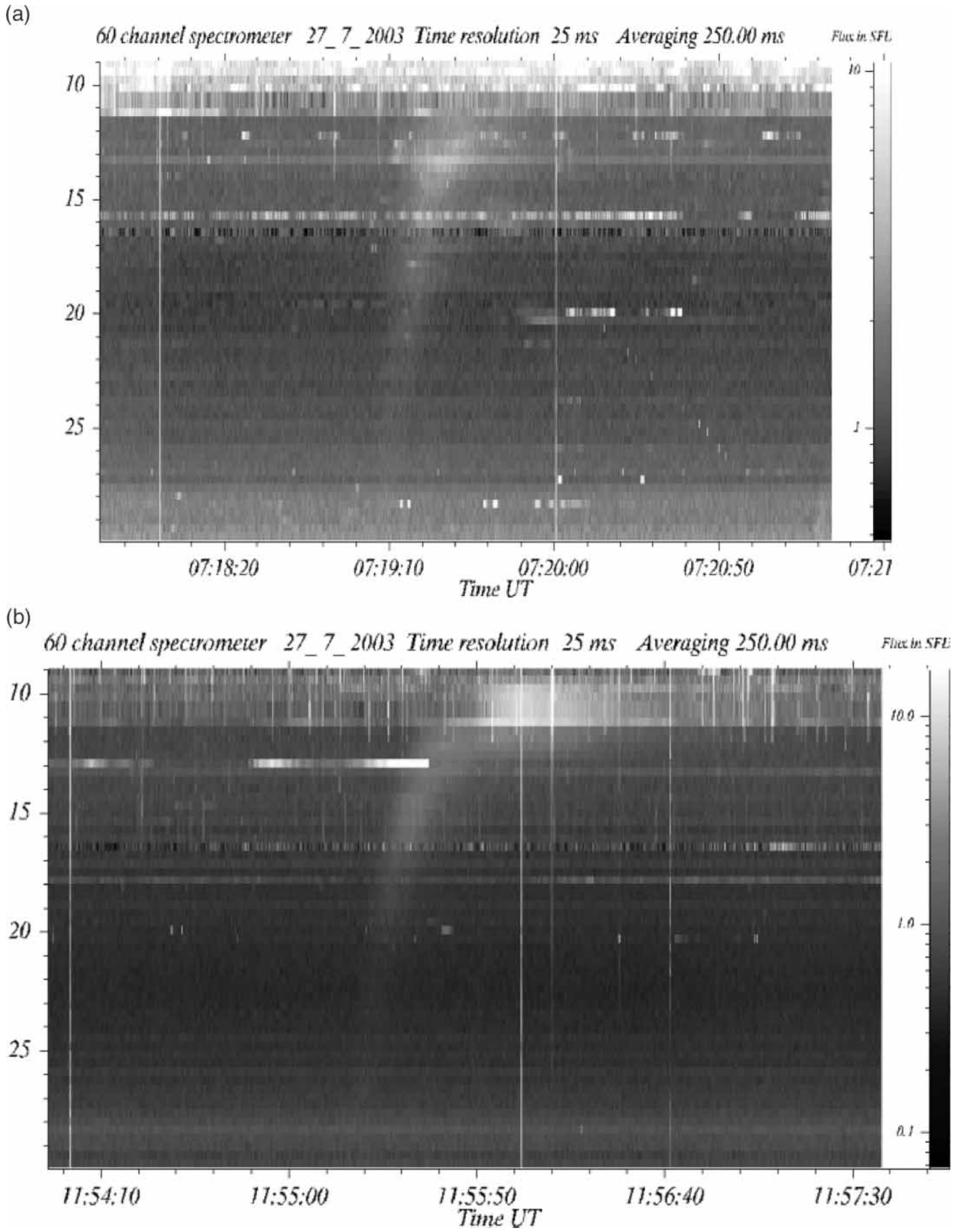

Figure 3. (a) U-type and (b) J-type bursts with the reverse point at 10 MHz.

Inverted U and J bursts are also included in the class of type III bursts. Examples of such bursts observed on 27 July 2003 are shown in figure 3. The return points of these bursts were at the lowest frequencies ever observed, namely 10 MHz. Thus, if we believe that these bursts are generated by the electrons moving along the closed magnetic loops, then it means that the heights of these loops exceed $R_{\odot}$.

3.2 *Type II bursts*

In 2001–2002, we first observed type II bursts in the frequency range 10–30 MHz (figures 4 and 5) [4]. In the decametre wavelength band, the type II bursts drifted with rates of 30–70 kHz s^{-1}. Their instantaneous bandwidth was 1–3 MHz. They often consisted of lines in

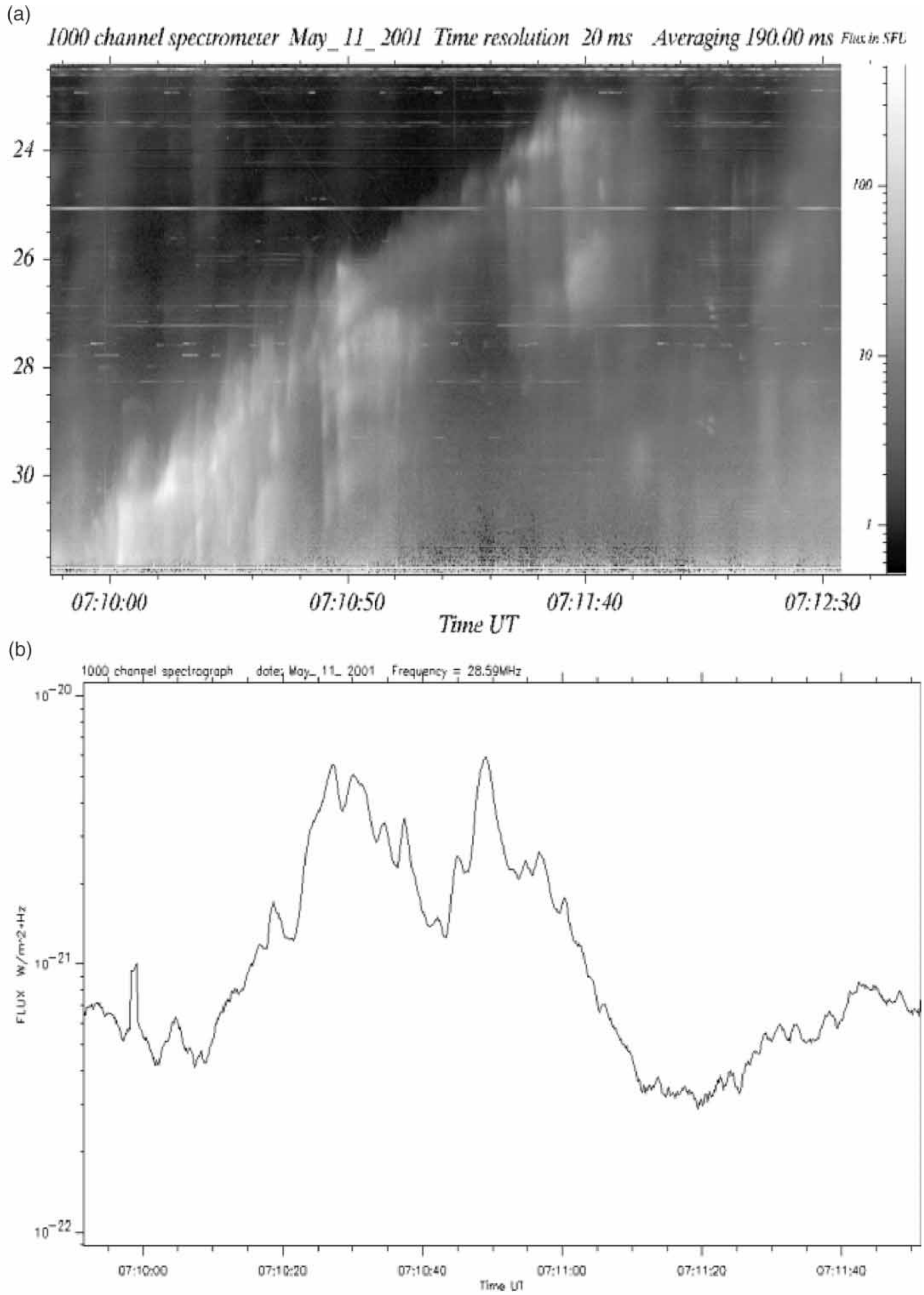

Figure 4. Type II burst: (a) dynamic spectrum; (b) time profile.

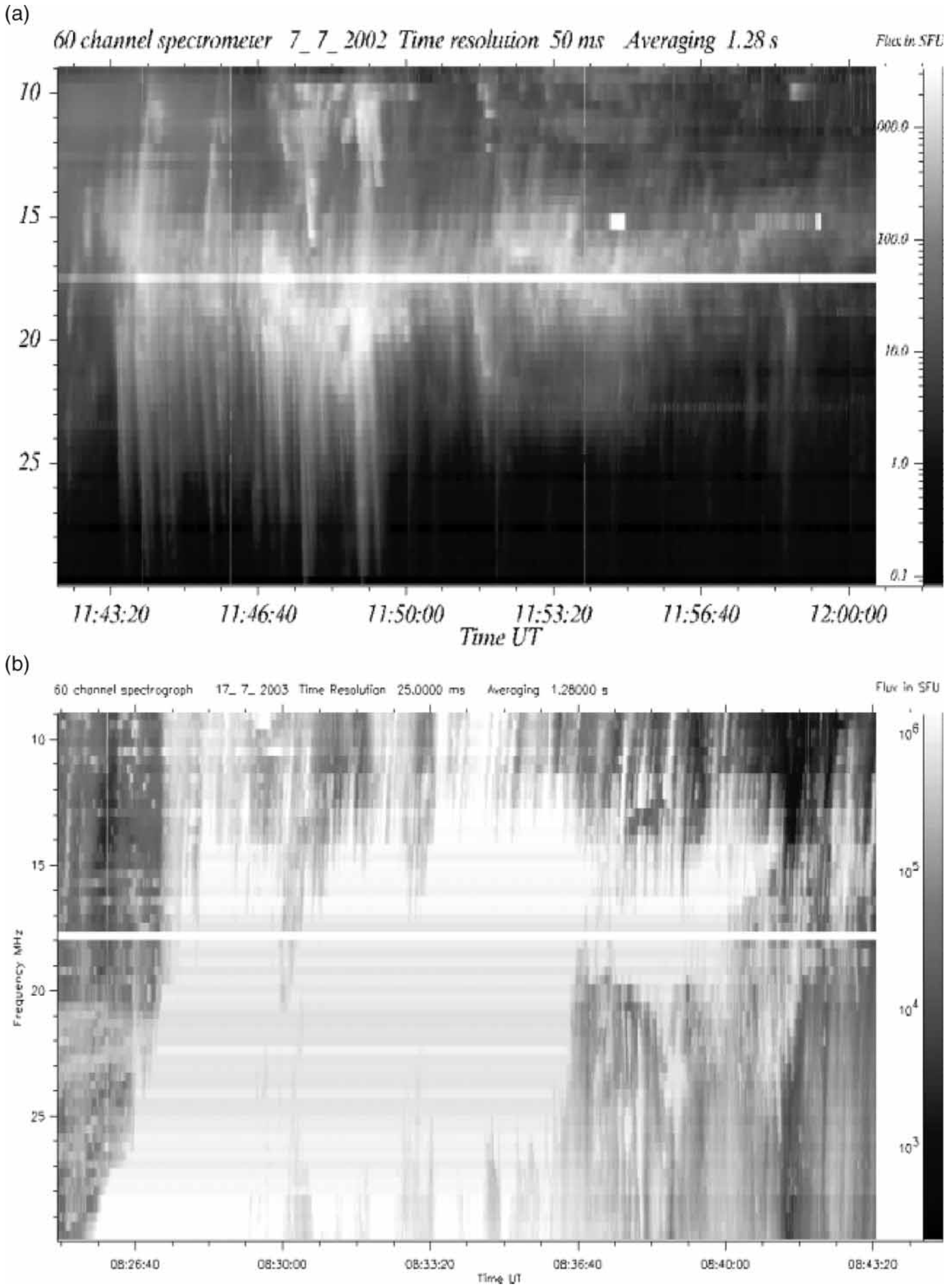

Figure 5. Type II bursts with a 'herringbone' structure and a wave-like 'backbone'.

the same way as occurred at higher frequencies. The most important feature was that the type II bursts had a fine structure in the form of subbursts drifting towards both lower and higher frequencies. This may mean that electrons were accelerated in opposite directions from the shock front, i.e., they moved towards and outwards from the Sun. The observed subburst drift rates were about 1–3 MHz s^{-1} while their duration was 1–2 s.

A type II burst with a herringbone structure was recorded on 7 July 2002 (figure 5(a)). Its drift rate was approximately equal to zero, which meant that the shock wave moved parallel to the solar surface. As can be seen from figure 5(a), the backbone had a wave-like shape. In our opinion this can take place when the shock wave intersects the coronal structures. The characteristic parameters of these structures could be estimated from the 'amplitude' and 'wavelength' of the backbone trace on the time–frequency plane. We recorded a very similar burst on 17 July 2003 (figure 5(b)). Its average drift rate was $25\,\mathrm{kHz\,s^{-1}}$ and it also had a wave-like backbone. The subbursts drifting towards higher frequencies had absolute drift rates several times higher than those drifting in the opposite direction. They also had longer lifetimes, which may be the result of different conditions for the propagation of accelerated electrons at the two sides of the shock wave.

3.3 *Drift pair bursts*

This kind of sporadic solar radio emission was observed mostly during type III storms and very often appeared as a storm of drift pair bursts [4, 5]. These events were rare and not every type III storm was accompanied by them. There were 'forward' (drifting from higher to lower frequencies) and 'reverse' (drifting in the opposite direction) drift pairs. According to our observations [4, 5], the numbers of these were approximately equal, but they occurred at different frequencies. The forward drift pairs occurred more or less uniformly in the frequency range down to 15 MHz, but the number of reverse drift pairs decreased sharply below 25 MHz. Drift pairs usually extend over a frequency band of 3–4 MHz. The forward drift pairs had absolute average drift rates of about $0.8\,\mathrm{MHz\,s^{-1}}$ and a corresponding narrow drift rate distribution. In contrast, the reverse pairs had a wider drift rate distribution with a maximum at approximately $1.6\,\mathrm{MHz\,s^{-1}}$. Also we should note that enormously high drift rates (more than $10\,\mathrm{MHz\,s^{-1}}$) were detected only for reverse drift pairs. At the same time, only forward bursts were observed with anomalous low drift rates (up to $0.3\,\mathrm{MHz\,s^{-1}}$). The average values of time delay between the components of the pair in all cases were almost equal: 1.7 s for forward drift pairs and 2 s for reverse drift pairs. The duration of each component was about 1 s again for both types of drift pair. The fluxes of the majority of drift pairs were between 5 and 100 solar flux units. Sometimes we observed 'diffuse' drift pairs with a duration of 2 s, drift pairs with a fine structure in the form of clouds or subbursts, as well as 'hook' bursts (the combination of reverse and forward drift pairs when the end of the first drift pair sharply coincided with the beginning of the second).

The preferred value of the drift rate may be explained by the fact that these bursts are generated by the excitation of fast magnetosonic waves having equal phase and group velocities. In this case, on the one hand, the Cherenkov resonance condition is satisfied ($v_{\mathrm{ph}} = v_{\mathrm{gr}}$, v_{ph} and v_{gr} are the phase and group velocities respectively of the fast magnetosonic wave). On the other hand, these waves propagating together with the particle beam at the same speed as the beam ($v_{\mathrm{gr}} = v_{\mathrm{b}}$, where v_{b} is the speed of the particles in the beam) could obtain energy from the particles for a long period of time. Further interaction of excited magnetosonic waves with existing Langmuir waves gives transverse waves, which were recorded as drift pair bursts. The limited frequency band in which drift pairs occur and the existence of the bursts with drift pairs of opposite signs may be connected with inhomogeneities in the coronal plasma, as was noted in [6].

3.4 *Solar S bursts*

Solar S bursts as well as drift pair bursts are observed mostly during type III storms and appeared in a group forming a kind of S-burst storm. The main properties of these bursts have been discussed in more detail in a separate paper. Here we would like to note that some of the parameters of S bursts are very close to those of drift pairs. First of all we consider the drift rate, which for S bursts equals 1 MHz s^{-1}. However, for drift pairs the drift rate remains constant along one separate burst, whereas for S bursts it noticeably decreases with decreasing frequency. Moreover, the dependence of the drift rate on the frequency is very similar to that of type III bursts. This apparently indicates that, in the same way as for type III bursts, the

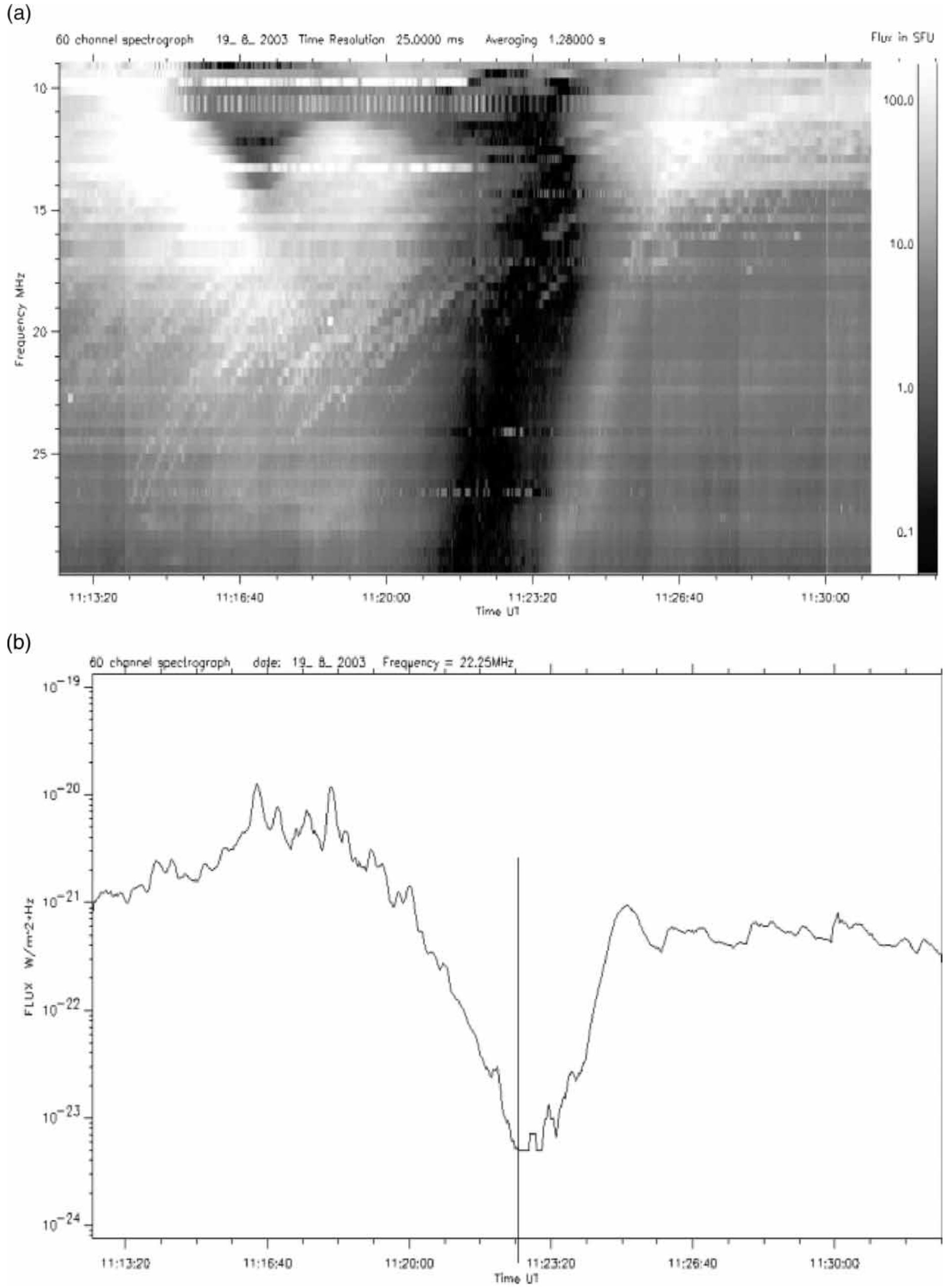

Figure 6. Absorption bursts: (a) dynamic spectrum; (b) time profile at a frequency of 22.25 MHz.

dependence of the S-burst drift rate on the frequency is the manifestation of the inhomogeneity in the average corona, i.e., we can assume that the source of the S bursts moves through the plasma of the average corona. S bursts have a negative drift rate and apparently do not form pairs with a definite time interval. Their duration in the decametre band (0.3 s) appeared to be larger than at frequencies greater than 40 MHz s^{-1} (about 0.1 s). This looks natural when it is taken into account that the durations of type III bursts also increase at lower frequencies. The emission mechanism of S bursts may be analogous to that of drift pairs, but it is realized in the conditions of a homogeneous average corona.

3.5 *Absorption bursts*

A number of papers [7, 8] have reported an absorption region in the background of the emission. This absorption region drifted rapidly towards lower frequencies. Such a phenomenonon was called an absorption burst or type III absorption burst [7]. All previous observations were carried out at frequencies greater than 34 MHz. On 19 August 2003 at 11 h 19 m 10 s to 11 h 25 m 00 s we recorded an absorption burst at lower frequencies (less than 30 MHz) (figure 6(a)) [9]. Also we observed its evolution in the frequency range 10–30 MHz. This burst drifted with a rate of about 120 kHz s^{-1} which corresponded to a linear velocity in the absorption region of more than 2000 km s^{-1}.

The type II burst on the background of which the absorption burst was seen drifted slowly, about 30 kHz s^{-1}. Approximately 4 min earlier (from 11 h 15 m 00 s to 11 h 18 m 20 s) there was another absorption region at frequencies of 10–14 MHz. It was difficult to estimate its drift rate. The time profile of the absorption burst (figure 6(b)) showed that the leading edge of the burst was flatter than the trailing edge ($\tau_l \approx 1.5\tau_t$, where τ_l is the emission decay time and τ_t is the emission rise time). In the literature, there was no definite point of view on the nature of this phenomenon. A fast drift rate only adds uncertainty, since it is to fast to transport a large amount of matter which could be considered as one possible absorbing object.

4. Conclusion

New back-end facilities installed at the world's largest decametre radio telescope UTR-2 allowed us to observe for the first time new phenomena in the frequency range 10–30 MHz, such as type II bursts at decametre wavelengths and the fine structure of type II and type III bursts. Also new information about the properties of type II and type III bursts, solar S bursts, drift pairs and absorption bursts were obtained. It is expected that the LOFAR radio telescope at present being built will give new information about solar sporadic radio emission.

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