OBSERVATIONS OF SOLAR S-BURSTS AT THE DECAMETER WAVELENGTHS

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Abstract

The results of observations of solar S–bursts at frequencies between 18 and 30 MHz carried out with the UTR–2 radio telescope are presented. These are the first observations of solar S-bursts at such a low frequency. The observations were performed within four different days during three different solar noise storms: 24 and 25 May 2001, 13 July 2002 and 29 July 2002. The UTR–2 radio telescope was equipped with highly effective back–end facilities, having high time and frequency resolution, what is important for investigation of such kind of solar sporadic radio emission. More than 200 bursts, about 50 for each day, were processed. Main parameters of the S-bursts, such as duration at fixed frequency and drift rate were found to be very stable during one selected storm. Nevertheless their parameters varied substantially from storm to storm. The empirical dependencies "drift rate vs. frequency" were derived for each day of observations separately. In average they were found to be in agreement with the dependence given by McConnell[1982]. Also two S–bursts with fine structure were observed.

1 Introduction

Solar S-bursts were firstly observed by Ellis[1969]. He classified them as Fast Drift Storm (FDS) bursts by analogy with Type I(fd) bursts. Then McConnell [1980] proposed these bursts to be reffered to as solar S–bursts by analogy to Jovian S–bursts. More deep and systematic study of the S–bursts phenomena was made by McConnell [1980, 1982], McConnell and Ellis [1981]. The dynamic spectrum of S–burst has an appearance of thin trace drifting from higher to lower frequency with average rate of about 1–2 MHz/s. The drift rate noticeably increases with frequency increasing. These bursts are closely associated with Type III as well as with drift pairs [McConnell, 1982] and use to appear in groups up to several tens in the frequency range from 25 to 70 MHz. S-bursts use

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to extend over wider frequency range about 5 MHz according to McConnell[1982]. The average duration at fixed frequency equals 0.7 s according to Ellis [1969] and 60 ms as was reported by McConnell [1980, 1982]. Instantaneous bandwidth usually lays between 30 kHz and 200 kHz.

McConnell [1980] supposed that the sources of S-bursts move through the corona at the constant speed of about 0.1 c and radiate at the fundamental or a harmonic of the local plasma frequency.

2 Observations

We used the data obtained at the UTR–2 radio telescope during observational campaigns in 2001 and 2002. For analysis we have chosen data of four days: 24 and 25 May 2001, 13 July 2002 and 29 July 2002. This set of days allowed us to obtain three different time intervals to estimate short term and long term variations of the S-bursts parameters. Thus we had one day interval between the neighboring days within the same storm (24–25 May 2001), then two weeks interval between two neighboring storms (13–29 July 2002) and finally one year interval (May 2001 – July 2002). Three sections of North-South antenna of the UTR–2 radio telescope provided the radiation pattern 13° in right ascension plane and 1° in the declination plane. The Digital Spectro–Polarimeter (DSP) [Kleewein, et al., 1997] was used for recording the data. DSP operated in one-channel mode covering the frequency band of 12 MHz with fixed frequency resolution 12 kHz. The time resolutions were 100 ms on 24 May, 2001 and on 25 May 2001 before 11:30 UT, 200 ms on 25 May, 2001 after 11:30 UT and 50ms on July 13 and 29, 2002. In observations of 2001 the working frequency band was from 20 to 32 MHz, and one year later it was from 18 to 30 MHz. Daily observations were carried out from 6:00 UT to 12:00 UT. It was the first time when solar S–bursts were observed at the frequencies below 30 MHz. For each of chosen days about 50 bursts were processed. In aggregate for four days it amounted of 210 bursts.

2.1 Associated active regions

As was noted before we have analyzed S–bursts within three different solar radio storms. By now there is no possibility still to locate the position of the S–bursts sources with existing heliographic system due to rather short burst duration in comparison with the acquisition period of the heliograph. During the first storm on 24–25 May 2001 there were two active regions that could be associated with this storm — AR9468 located at 35° East from the meridian, and AR9463 centered at the meridian on May 24. Since no heliographic measurements have been made we could not definitely associate this storm with one of these regions. Comparing these active regions in two neighboring days 24 and 25 May 2001 we noted that the active region AR9468 became weaker while the central spot group AR9463 did not change. This may probably point that the observed solar storm was associated with the central active region. The storm observed on 13 July 2002 was accompanied by single active region AR0030 located between 30° and 50° to the East.

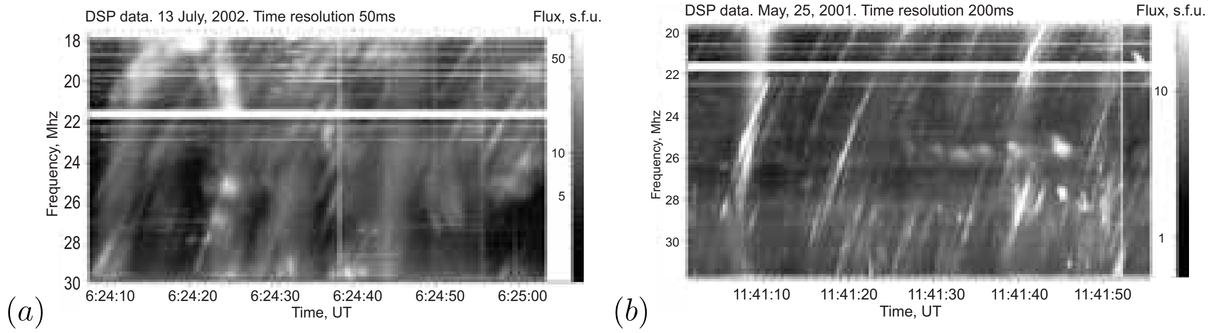


Figure 1: Dynamic spectra of S-bursts storms on 13 July 2002 (a) and 25 May 2001 (b)

Finally the storm on 29 July 2002 was associated with complex extended active region AR0039 which was also near the meridian that day.

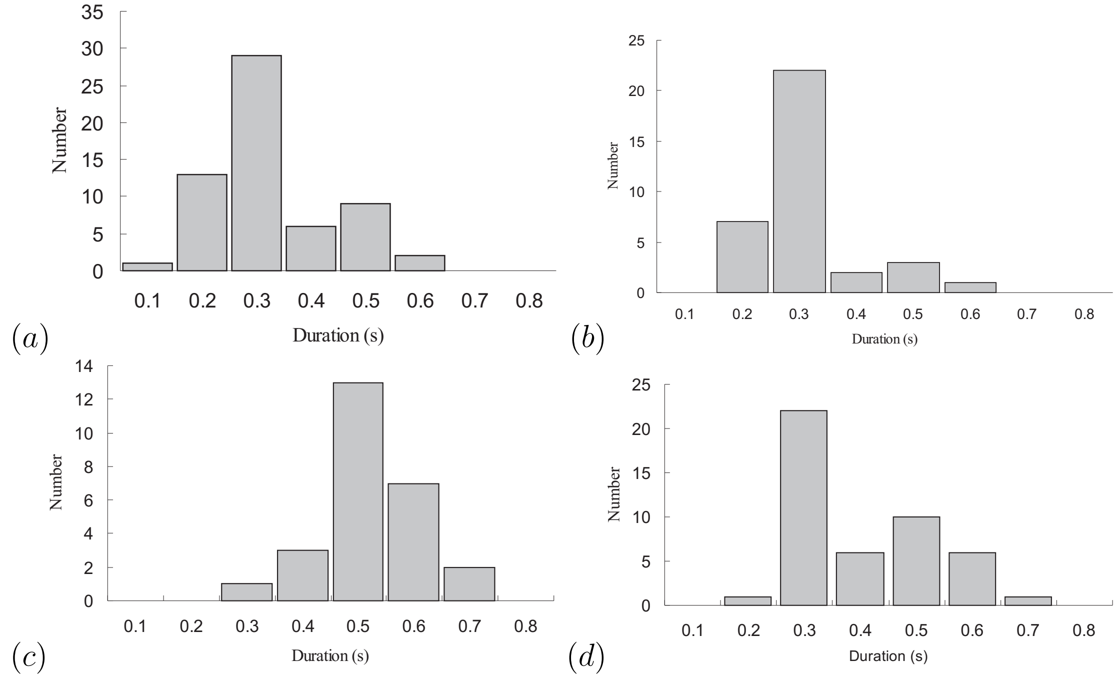
2.2 Appearance

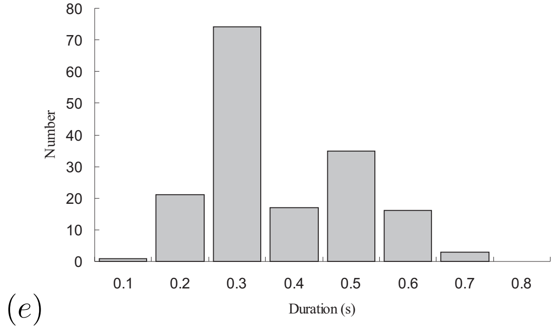
All mentioned Type III storms were characterized by high activity of solar S-bursts. The typical appearance of the radio storms with the S-bursts is shown in Figure 1. It is clearly seen that all of them look very similar to each other within the same storm by duration, flux density and the drift rate. At the same time from the comparison of the dynamic spectra in Figures 1a and 1b it is evident that the bursts from different storms are different. Taking into account that dynamic spectra in Figures 1a and 1b have the same time and frequency scales we can say that bursts observed on 25 May 2001 look noticeably shorter and drift faster than bursts from 13 July 2002.

2.3 Bursts duration

One of the specific characteristics of the S-bursts is their respectively short duration at fixed frequency. McConnell [1981] reported about rather wide distribution of this parameter between 5 and 160 ms in frequency range 30–82 MHz with mean value about 50 ms. We found that in frequency range 18–30 MHz this distribution was much narrower and shifted towards longer durations, as was shown in Figure 2. The difference could appear due to either diverse frequency ranges or dissimilar conditions in the corona.

The distributions of S–bursts durations for 24 and 25 May 2001 (Figures 2a, 2b) look similar. Both have the pronounced maximum at the 0.3 s and another much weaker maximum at 0.5 s. No bursts longer than 0.6 s and shorter than 0.1 s were observed on these days. The situation has changed a year later — on July 13 2002 (Figure 2c). The duration distribution remained narrow but the maximum in this case shifted to the value of 0.5 s. The fact that the main maximum of the distribution in Figure 2c coincides with the secondary maximum of the distribution in Figures 2a, 2b doesn't look occasional. This is proved by the last distribution from 29 July 2002 (Figure 2d) and total distribution from all 4 days (Figure 2e). Distribution in Figure 2d shows two noticeable maxima at 0.3 s





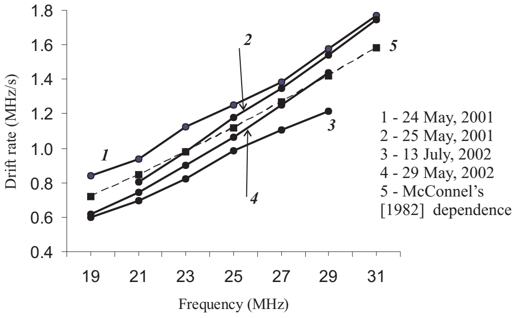


Figure 2: S–bursts durations distribution for 24 May 2001 (a), 25 May 2001 (b), 13 July 2002 (c), 29 July 2002 (d) and aggregate for all days (e)

Figure 3: (right-bottom) Dependence of drift rates vs. frequency for S–bursts observed on different days

and 0.5 s. These two specific maxima are seen also in the duration distribution obtained for all observed bursts (Figure 2e). We should add also that unlike the Type III bursts the duration of one separate S–burst doesn't show any substantial frequency dependence in frequency range from 18 to 32 MHz.

2.4 Drift rate

The observed drift rates varied from -0.5 to -2 MHz/s depending on frequency and the date of observations that was in good agreement with the current knowledge [Ellis, 1969; McConnell, 1980 and 1982]. These specific values differed considerably from Type III or Type II drift rates and were very close to that of forward drift pairs [Melrose, 1982]. This fact and also the fact that S–bursts were always associated with forward drift pairs [McConnell,1982] made us think that sources of these bursts could be connected with each other or dependent on each other. The dynamic spectra of the S–bursts showed noticeable dependence of the drift rate of separate burst on frequency (see Figure 1). We have analyzed this dependence separately for each of observational days. The results of the analysis is shown in Figure 3.

Here curves (1) and (2) correspond to 24 and 25 May 2001 belonging to one storm. One can see that these two lines almost coincide with each other and only below 25 MHz bursts from 24 May inhibit slightly faster drifts. Curve (3) represents the dependence of drift rate on frequency corresponding to the next storm on 13 July 2002. S–bursts in this day drifted about 25% slower than in previous case. Also the average inclination of the curve on drift rate/frequency plane is less. The last day of our analysis corresponding to the last solar storm on 29 July 2002 is represented by the curve (4). The dependence for this storm occupies an intermediate position between two previous, as it can be seen in the Figure 3. In general it has slightly faster drift rates and stronger frequency dependence in comparison with the preceding storm. McConnell [1982] has approximated the drift rate dependence on frequency according to his data in frequency range 30–70 MHz by the equation.

$$df/dt = -6.5 \cdot 10^{-3} \cdot f^{1.6}, \tag{1}$$

where df/dt is the drift rate in MHz/s, f is the frequency in MHz.

We have extrapolated his empirical dependence down to frequencies of 18 MHz and plotted it on our graph as curve (5) for comparison. Rather good agreement of the McConnell's dependence with ours is evident. Moreover we have approximated our observed dependences by the power law equation as follows:

$$df/dt = A \cdot \left(\frac{f}{f_0}\right)^B + C, \tag{2}$$

where df/dt is the drift rate in MHz/s, f is the frequency in MHz and f_0 is the normalization frequency equal in our case to 25 MHz. The values of the coefficients for different days are collected into the Table 1.

Table 1: Coefficients of the equation (2)

	A, MHz/s	B	C, MHz/s
24 May, 2001	−0.9	2	0.3
25 May, 2001	−1.8	1.3	0.6
13 July, 2002	−1.45	1.1	0.5
29 July, 2002	−0.98	2.2	0.1

We would like to emphasize the fact that dependences shown in Figure 3 in drift rate/frequency plane are almost "parallel" to each other and to that of well–known Type III bursts. The same property was illustrated by McConnell[1980]. The power–low approximation of the drift rate vs frequency dependence for the Type III bursts given by Alvarez and Haddock [1973] was characterized by the index 1.84. That is very close to the index

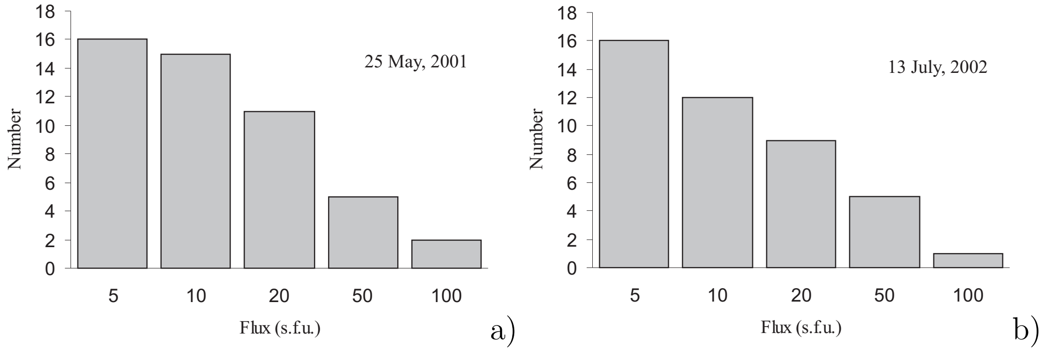


Figure 4: Distribution of S–bursts by their fluxes I for 25 May 2001 (a) and for 13 July 2002 (b)

obtained for the S–bursts both by McConnell[1980] (1.6) and by us (1.1 – 2.2). Type III bursts are considered to be connected with the fast electron beams moving along the open magnetic field lines through the corona. Hence the equality of the indexes of power for Type III and S–bursts may lead to the conclusion that S–bursts source (particle beam) moves through the same corona as Type III source, but several times slower.

2.5 Flux density

As was noted repeatedly by many authors [Ellis, 1969; McConnell, 1982; Melrose, 1982] the S–bursts are rare and weak phenomena. There were no exclusions from this rule in our observations. Figure 4 shows the distributions of S–bursts by their flux densities I for two different days. These distributions were very similar for different days and even for different storms and showed that the higher the flux density of the burst the lower the number of observed bursts. About 86% of all observed bursts had flux densities less than 20 s.f.u. (1 s.f.u.=$1 \cdot 10^{-22} W m^{-2} Hz^{-1}$). And only very few had fluxes of 100 s.f.u.

2.6 Unusual S-bursts

McConnell [1980] reported that about 1–2% of S–bursts had fine frequency structure, which he called “fringes”. Among the bursts we have chosen for analysis there was the only structured S-bursts found on 13 July 2002 at $6^h 58^m 40^s$ UT. Among all S-bursts observed during 2001–2002 there was only one more case of “fringes” in addition to the latter — on 8 August 2002 at $9^h 04^m 32^s$ UT. The dynamic spectra of these two bursts are shown in Figure 5.

The burst observed on 13 July 2002 had drift rate of -1 MHz/s and duration about 0.8 s. The fringes had the form of diffuse clouds with the frequency and time scales of 300 kHz and 0.8 s. These values were at least one order of magnitude larger than was reported by McConnell [1980]. In contrast to McConnell’s estimations the frequency spacing between neighboring fringes was not constant, varying from 400 to 600 kHz. The relative flux modulation $\Delta I/I$ along the burst trace did not exceed 10%. Second burst was recorded

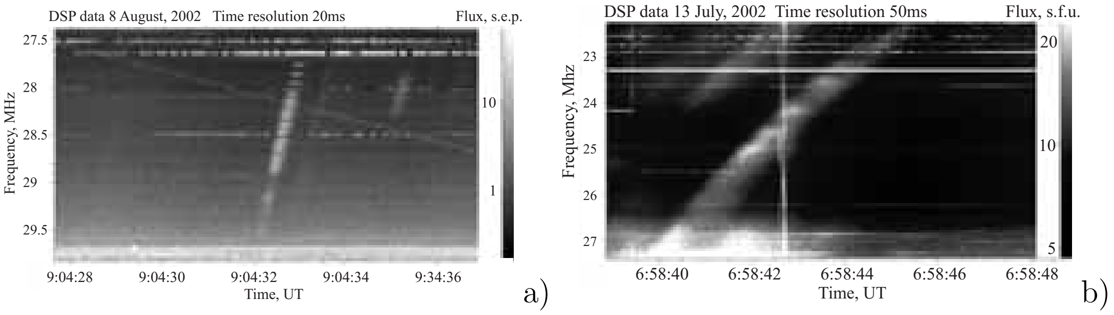


Figure 5: Dynamic spectra of S-bursts with fringes

on 8 August of the same year and had completely different characteristics. The drift rate was higher — about -2 MHz/s, the bandwidth of fringes was considerably shorter — only 30–40 kHz, the fringes were spaced by variable interval 50–100 kHz. These values were much closer to those reported by McConnell [1980]. And finally the relative flux modulation $\Delta I/I$ along the burst trace was about 100%.

3 Conclusions

The results of observations of solar S–bursts on four different days belonging to three different solar radio storms are introduced. In total more than 200 bursts were analyzed. We found that such determinant characteristics of S–bursts as drift rate and duration are very stable during one separate storm and may differ considerably from one storm to another. The observed duration appeared to have two characteristic values — 0.3 and 0.5 s, that in any case was much longer, then values reported by McConnell [1982]. These durations at the same time are shorter than that of drift pairs at the same frequency range [Mel'nik et al., 2005]. The observed drift rates varied from 0.5 to 2 MHz/s and showed noticeable dependence on frequency and date of observations. The drift rate dependence on frequency was approximated by power-law empirical equation. We found our dependence being in good agreement with the equation, given by McConnell [1982]. Comparing such an empirical equation for Type III bursts derived by Alvarez and Haddock [1973] we deduce, that the S-bursts just as the Type III bursts are connected with the particle beams moving outwards through the corona at the constant speed. Taking into account known values of Type III electron speeds of around $1 \cdot 10^{10}$ cm/s the apparent velocity of the S–bursts source was derived as $1 - 2 \cdot 10^{9}$ cm/s. This speed is very close to the estimated value for drift pairs [Mel'nik et al., 2005]. The fact that S–bursts on the one hand extend over much wider frequency range, are shorter and show noticeable dependence of their drift rate on frequency along one separate burst and on the other hand have very similar drift rate and occurrence allow us to attribute both S–bursts and drift pairs to the same emission mechanism, which is realized probably in different conditions.

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