STATISTICAL ANALYSIS OF PULSATIONS AND PULSATIONS WITH FIBERS IN THE RANGE 800−2000 MHZ

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ABSTRACT

The July 14, 2000, April 12, 2001, April 15, 2001, July 19, 2001 and September 28, 2001 radio events with fine structures observed by the 800−2000 MHz Ondřejov radiospectrograph (time resolution 0.1 s) are studied. We realized that in the range 800−2000 MHz these events are strong (10^3 SFU) and that show phenomena with long periodicity ≥60 s. Five groups of pulsations alone and ten groups of pulsations together with fibers (observed by the Trieste radiopolarimeter at 1420 MHz with time resolution 1 ms) were studied in detail using linear and nonlinear methods in both L- and R-handed circular polarizations. In these selected intervals we found milisecond quasi-periodic structures and absorptions. The periods, duration, polarization and some other parameters are discussed.

Key words: solar radio emission; pulsations and fibers.

1. INTRODUCTION

The physical mechanism producing quasi-periodic pulsations have been grouped into three categories (see Aschwanden 1987): MHD oscillations of coronal loops, nonlinear wave−particle and wave−wave interactions and modulation of acceleration (e.g. Karlický et al. 2005). Pulsations are usually accompanied by fibers bursts and zebras (e.g. Chernov 2005). Characteristic parameters of fine structures and long periods during selected events in the frequency range 800−2000 MHz (Section 2) were found using spectral data. Detailed studies were performed during selected shorter time intervals at 1420 MHz (Section 3).

2. STUDY OF SELECTED RADIO EVENTS IN RANGE 800−2000 MHZ

For our study we selected the July 14, 2000, April 12, 2001, April 15, 2001, July 19, 2001 and September 28, 2001 radio events (see Table 1) recorded by the 800−2000 MHz Ondřejov radiospectrograph. The presence of pulsations independently, and pulsations with fibers is the common property of these events (see Table 2 as example for the April 12, 2001 event). In some cases also zebras or zebras superimposed on fibers (in about 1 s lasting intervals) are found. These strong intensity (10^3 SFU) dm-radio bursts are with high quality factor Q=πn=10^2 (n = number of pulses) at almost all frequencies in all selected events. The most frequent fine structures (pulsations, fibers) can be found in the whole frequency range 800−2000 MHz. The majority of pulsations were broadband (up to about 1000 SFU) with frequency drift that is not measurable in spectra with time resolution 0.1 s. However, in some individ-

Table 1. Selected dm-radio events, corresponding X−ray & optical flare importance and position.

event time interval [UT]	X-ray import.	optical import.	position
14 Jul 2000 10:03−11:31	X5.7	3B	N22W07
12 Apr 2001 10:13−11:01	X2.0	2B	S19W43
15 Apr 2001 13:31−16:21	X14.4	2B	S20W85
19 Jul 2001 09:54−10:43	M1.8	1B	S08W62
28 Sep 2001 09:31−10:28	M2.4	1N	S18W36

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Table 2. Fine structures during the April 12, 2001 event in the frequency range 800−2000 MHz. Pulsations and fibers are the most frequent fine structures during the whole event.

time interval [UT]	frequency [MHz]	fine structures
10:13:50-10:14:45	800-1700	spikes
10:14:30-10:16:40	1000-1900	pulsations & fibers
10:16:40-10:17:30	1700-2000	pulsations
10:17:30-10:20:20	1000-2000	pulsations
10:18:05-10:18:58	950-1648	zebra
10:30:25-10:37:10	800-1800	pulsations
10:33:08-10:33:14	1400-1700	zebra
10:37:55-10:39:25	900-1300	fibers
10:39:59-10:41:30	800-1500	pulsations
10:41:30-10:43:20	800-1500	pulsations & fibers
10:43:20-10:45:40	800-1300	pulsations
10:45:40-10:56:55	800-1100	fibers
10:14:18-10:59:42	800-2000	continuum

ual cases the measured frequency drift of pulsations is 600−1800 MHz s^{-1}. The frequency drift of fibers varies from -40 to -200 MHz s^{-1}, and their bandwidth is about 400 MHz.

For searching characteristic long periods $\geq$ 60 s we studied radio data at 13 selected frequencies (outside data saturation) in the range 800−2000 MHz with 1.0 s time resolution. We used both the Fourier and the Morlet wavelet analysis. Among all, more or less likelihood periods, we have selected only the dominant ones. They can be found under rather restrictive conditions for both: the Fourier analysis (with probability $\geq$75%) and the Morlet wavelet method with significant periods aside from cone of incidence (COI, cross-hatched regions in Figs.1−3) and with respect to white (99% significant level) as well as red noise (80% significant level). The most frequent periods are in the range 60-180 s (see example in Fig.1 and Table 3) for all the events and most of the frequencies. Periods of about 300 s were also very frequent for most of the selected frequencies of events (except for the July 19, 2001 event). For the different frequencies we did not found distinctive differences among periods.

3. DETAILED STUDY OF SELECTED INTERVALS AT 1420 MHZ

For studying characteristic parameters of fine structures we selected *short time (20−210 s) intervals* at 1420 MHz (Trieste radiopolarimeter data) of pulsations alone (5 intervals) and pulsations with fibers (10 intervals). We studied them using both linear and nonlinear (surrogates) methods. The mean rate of pulses is derived from their power-law/exponential distributions. All pulses above the turnover of the distribution were included into this statistic. Statistical parameters of the pulsations alone are very similar. There are almost no differences among them: about 90% of these events show exponential distribution and all of them were L-handed polarized. The mean rate of pulsations was 46.1 pulses s^{-1}. On the other hand, the statistical parameters of pulsations with fibers reveal a rather broad dispersion of the values. They are observed with exponential (60%) and power-law (40%) distribution. Only 50% events are L-handed polarized. The mean rate of pulsations with fibers was lower, i.e. 36.1 pulses s^{-1}. All of the selected time series were tested with respect to nonlinearity. We found that most pulsations alone (90%) and pulsations with fibers (60%) show nonlinear signatures. They were also analyzed by both the Fourier and the Morlet wavelet methods searching for characteristic periods. We have found such periods in the range of 30−2 and 0.66−0.03 seconds. There is no significant difference between periods of intervals with pulsations alone and with pulsations with fibers.

We also studied selected *quasi-periodic structures lasting 2−7 s* with one dominant period of pulsations alone as well as pulsations with fibers using both the Fourier and the wavelet methods. Periods of quasi-periodic structures with pulsations alone during April 12, 2001 and July 19, 2001 events (for both L- and R-circular polarization) are shown in Table 4 where the most characteristic periods are marked in bold. As an example, the time series of pulsations alone on the July 19, 2001 event

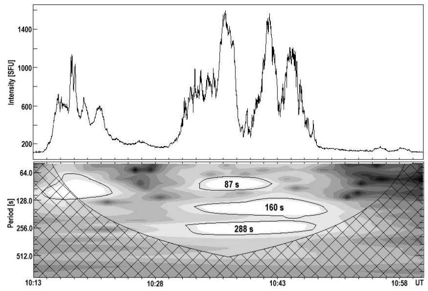

Figure 1. Trend of the April 12, 2001 event at 1100 MHz during 10:13−11:01 UT (top) and wavelet power spectrum with characteristic periods 288, 160 and 87 s (white color)(bottom). Cross-hatched region is the COI.

Table 3. Long periods ($\geq$ 60 s) of the April 12, 2001 event at 10 selected frequencies in the range 800−2000 MHz.

frequency [MHz]	periods [s]	frequency [MHz]	periods [s]
1020	320, 160, 76	1500	320
1100	288, 160, 87	1600	320, 160
1200	320, 160, 93	1700	-
1300	320, 160, 93, 78	1800	-
1400	320	1900	-

Table 4. Periods of quasi-periodic structures during selected intervals of pulsations at 1420 MHz. The most characteristic ones are marked in bold (L and R mean left and right circular polarization respectively).

	time interval [UT]	periods [s]
	April 12, 2001	
L	10:40:36−10:40:40	0.09,0.08,**0.06**,0.03
R	10:40:36−10:40:40	0.09,0.08,**0.06**,0.05,0.03
L	10:40:46−10:40:48.6	0.07,**0.06**,0.05,0.03
R	10:40:46−10:40:48.6	0.07,**0.06**,0.04,0.03
	July 19, 2001	
L,R	10:21:35−10:21:40	0.06,**0.04**,0.03
L,R	10:21:46−10:21:48	**0.04**,0.03
L,R	10:21:53−10:21:55	0.13,**0.03**
L	10:21:57−10:21:59	0.17,0.07,0.04,**0.03**
R	10:21:57−10:21:59	0.06,0.04,**0.03**

Table 5. Periods of quasi-periodic structures of pulsations with fibers at 1420 MHz. The most characteristic periods are marked in bold.

	time interval [UT]	periods [s]
	July 14, 2000	
R	10:49:03−10:49:05.5	**0.06**,0.04,0.03
	April 12, 2001	
L	10:16:00−10:16:07	**0.29**,0.12,0.10,0.09
R	10:16:00−10:16:07	**0.29**,0.12,0.10,0.08

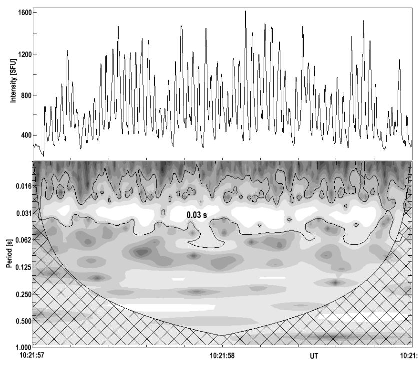

Figure 2. Pulsations during the July 19, 2001 event at 1420 MHz; R-polarized signal during time interval 10:21:57−10:21:59 UT (top) and the wavelet power spectrum (bottom) where the most characteristic period results 0.03 s (white color).

(R-polarization at 1420 MHz) during 10:21:57−10:21:59 and the wavelet power spectrum, are shown in Fig.2 with the most prominent period: 0.03 s. Periods of 0.3 s and 0.4 s were also present but their probability were lower than 75% in the Fourier analysis and with smaller significant level under the COI in the wavelet power spectrum. Periods of regular quasi-periodic structures of pulsations with fibers during the July 14, 2000 and the April 12, 2001 events for both L- and R-circular polarization are presented in Table 5. Fig.3 is showing the time series of pulsations/absorptions with fibers of the April 12, 2001 event (R-polarization) during 10:16:00−10:16:07, and the wavelet power spectrum with the most characteristic period of 0.29 s.

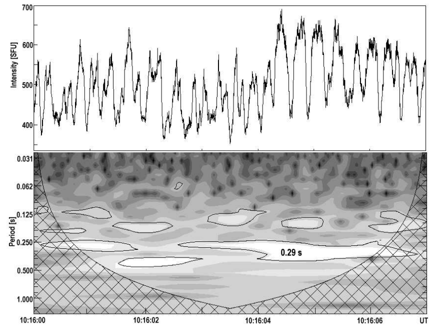

Figure 3. Pulsations and absorptions (in the late part of this interval) together with fibers during the of April 12, 2001 event at 1420 MHz; R-polarized signal during 10:16:00−10:16:07 UT (top). The wavelet power spectrum (bottom) shows the most characteristic period: 0.29 s (white color).

We selected 4 time intervals in different parts of the type IV enhancements, at 1420 MHz, and analyzed more than 750 *single pulsations/absorptions* (further on A/P) recorded during the April 15, 2001 event. It is very probable that the two types of activity are related, since it is possible to see the evolution from one type of activity to another. Characteristic parameters of the A/P are: intensity, half power duration, decay and rise time, polarization and possible time shift between the L- and R-components. It seems that the values of the characteristic parameters are different for the different intervals (Table 6). Generally the duration of the A/P changes in time rather gradually, but the difference between subsequent bursts can be very large. In particular, during shorter time interval, the duration can be rather homogeneous, as we found for the interval 14:05:12−14:06:00 where the duration was in the range 40−60 ms (Table 6). But sometimes, the range of measured values of durations can be also broader, for example 20−120 ms, as it was found for the time interval 14:33:35−14:34:22. In the Fig. 4 (left) we show the temporal evolution of the duration for the selected A/P for two time intervals. The first interval (14:01:00−14:03:00) was recorded during the ascending part of the type IV enhancement, and the second one (14:05:12−14:06:00) in the descending phase. The number of the selected A/P was larger during the first longer interval where the average duration decreased gradually from about 45 ms to 18 ms (up to about 14:02:30), afterwards it remained approximately constant at about 18 ms. In the second interval, where the absorptions were more regular, the duration appears rather constant and longer

Table 6. Selected A/P during the April 15, 2001 event: the range of some characteristic parameters is given.

intensity [SFU]	polarization [%]	duration [ms]	decay/rise time [ms]
	time interval [UT]		
	14:01:00−14:03:00		
50−400	30−55 L	5−70	5−50/5−80
	14:05:12−14:06:00		
50−180	80−95 L	40−60	20−60/25−100
	14:33:35−14:34:22		
50−1100	15−35 L	15−140	5−80/5−130
	14:35:42−14:36:18		
200−1200	20−40 L	5−100	5−60/5−110

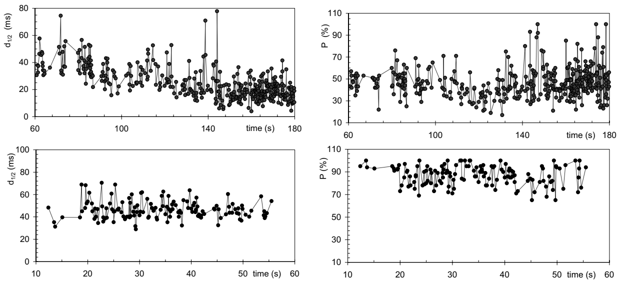

Figure 4. Temporal evolution of the duration (left) and the polarization (right) of the selected A/P at 1420 MHz during April 15, 2001; the starting time is 14:01:00 (top) and 14:05:00 (bottom).

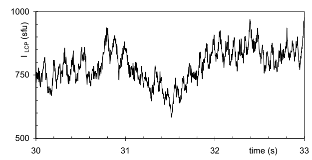

Figure 5. Time profile at 1420 MHz of a "depression" due to a fiber during the 14:04:30−14:04:33 interval.

(about 50 ms). The range of the duration can be also broader (for example 15−140 ms) (see Table 6). However, due to the significantly different length of the selected intervals no definite conclusion can be made except that the behavior of the duration trend looks similar (no larger "jumps") in the ascending and the descending phase of the type IV event. The polarization was intermediate L in the first interval and high L in the second one (Fig. 4 right). The A/P showed practically the same polarization degree as the contemporaneous continuum, that confirms what was previously stated at lower frequencies (Zlobec et al. 1987).

During the time interval 14:04:30−14:04:55, at 1420 MHz three weak fibers were also recorded (see Fig. 5). In the single frequency measurements they appear as rather long lasting "depressions" (without any emission phase) of the continuum. Their polarization was the same (about 66% L) as for the contemporaneous A/P. It seems that the characteristics of these "fast" structures were not modulated by the presence of fibers, what confirms the results of the previous analysis.

4. CONCLUSIONS

In this preliminary statistical study of dm fine structures of pulsations/absorptions and fibers we have found dominant periods of about 100 and 300 s in 800−2000 frequency range and, using better time resolution, 30−0.03 s at 1420 MHz. There is no significant difference between periods of pulsations alone and pulsations with fibers. Regular structures occur more frequently for pulsations alone than for pulsations with fibers. We found only one case of regular structure of both pulsations alone and pulsations with fibers (for the April 12, 2001 event). In this case we have found longer periods for pulsations with fibers. Rather small differences between them were found in their statistical parameters (rate, distribution type, nonlinear signatures). Therefore, for both pulsations and fibers, a common source mechanism is expected. The detailed study of single pulsations/absorptions during different intervals has shown very different results for the measured parameters as polarization, duration, rise and decay time. That means that such phenomena can be originated under rather broad plasma conditions. In future, comparing radio spectroscopic observations with X-ray/optical data of these flares, more detailed study of spectroscopic observations in broader radio frequency range and more detailed study of periods in seconds range as well as more detailed study of fine structures (fibers/zebras/zebras superimposed on fibers) are planned.

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