

RADIO PULSATIONS IN THE m–dm BAND: CASE STUDIES

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Abstract

Radio pulsations are observed during several type IV bursts in the metric and decimetric band. A great variety of morphological and evolutionary features characterizes such events. Radio pulsations should carry information about the magnetic topology of the corona, the local particle density distribution, and about magnetic reconnection and particle acceleration processes at or near the radio source; the polarization degree should bring important clues about emission mode and propagation effects in the source and outside it. In this frame, we selected a representative set of radio pulsations, observed with high time resolution by the Trieste Solar Radio System in the meter–decimeter (m–dm) wavelength band, and performed a detailed morphological and spectral analysis to identify possible similarities in the descriptors relevant to different categories of events. Both classical and nonlinear techniques were applied in the attempt to investigate more deeply the physical nature of the emission process. The obtained results give the trend how the ratio magnetic field – characteristic dimension of the source increases at higher observing frequencies. A sudden rise of this ratio across the m–dm range was derived, indicating a different nature of pulsations in the two ranges.

1 Introduction

Radio pulsations are often observed during the evolution of type IV bursts in the metric and decimetric band and can exhibit a great variety of morphological and evolutionary features as fine structures of the same parent radio event. Their origin can be ascribed [Aschwanden, 1987] to: (a) MHD oscillations modulating the radio emissivity; (b) an oscillatory nonlinear regime of the originating kinetic plasma instability; (c) a modulation of particle acceleration, i.e., of wave energy. In particular, a recent study [Kliem et al., 2000] pointed out that non-stationary magnetic reconnection can account for the generation of decimetric radio pulsations observed during the flare impulsive phase. Hence, upon suitable physical hypotheses, radio pulsations carry information on the time evolution of the

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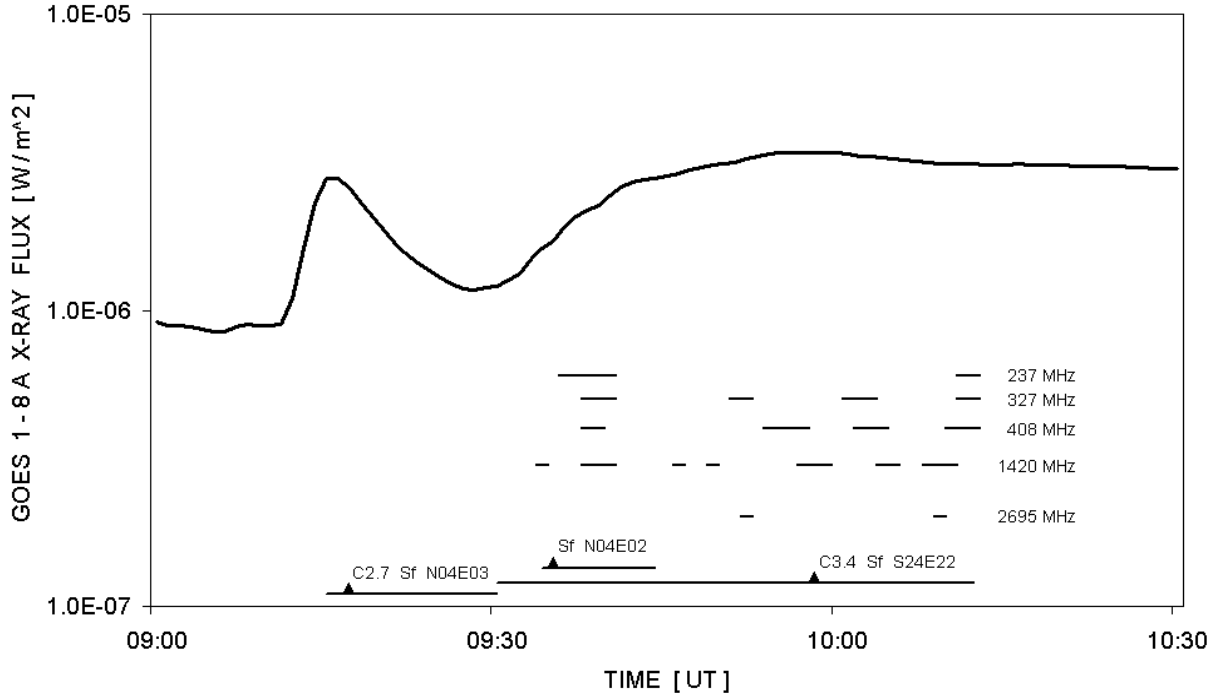


Figure 1: Timing of selected radio pulsation intervals recorded by the Trieste Solar Radio System on 14 December 2000 with respect to the observed $H\alpha$ and soft X-ray flares.

coronal magnetic topology, the local particle density distribution, the magnetic reconnection and the particle acceleration process; polarization values should carry information about emission mode and propagation effects in the source and outside it. Classical spectral estimators and nonlinear dynamics ones are complementary tools to investigate deeply the physical nature of the pulsating processes.

2 Data set characterization

On December 14, 2000, during the interval from 09:30 to 10:12 UT at the Trieste Solar Radio System (TSRS) [Messerotti et al., 2001] 29 samples of pulsations were recorded: 2 cases at 237 MHz, 4 cases at 327 MHz, 7 cases at 408 MHz, 2 cases at 610 MHz, 12 cases at 1420 MHz and 2 cases at 2695 MHz. As the pulsations at 610 MHz were rather irregular and strongly affected by interferences, they were dropped from the analysis. The most distinct and numerous pulsations were recorded at 408 and 1420 MHz. The mean duration of pulsation samples was about 1 minute, two samples were longer than 2 minutes and only one was shorter than 10 seconds. The sampling rate of the acquisition system was 1000 Hz, which allows to perform a detailed analysis of short time scale structures.

During a time interval of 42 minutes pulsations were present in all the observing channels of the TSRS. Such an occasion is very rare as normally such an activity, when present, is seen at maximum in three channels contemporaneously. The rather short interval of 42 minutes indicates that probably only one or two active regions (AR) generated the observed pulsations. That is also confirmed by complementary soft X-ray and $H\alpha$ data

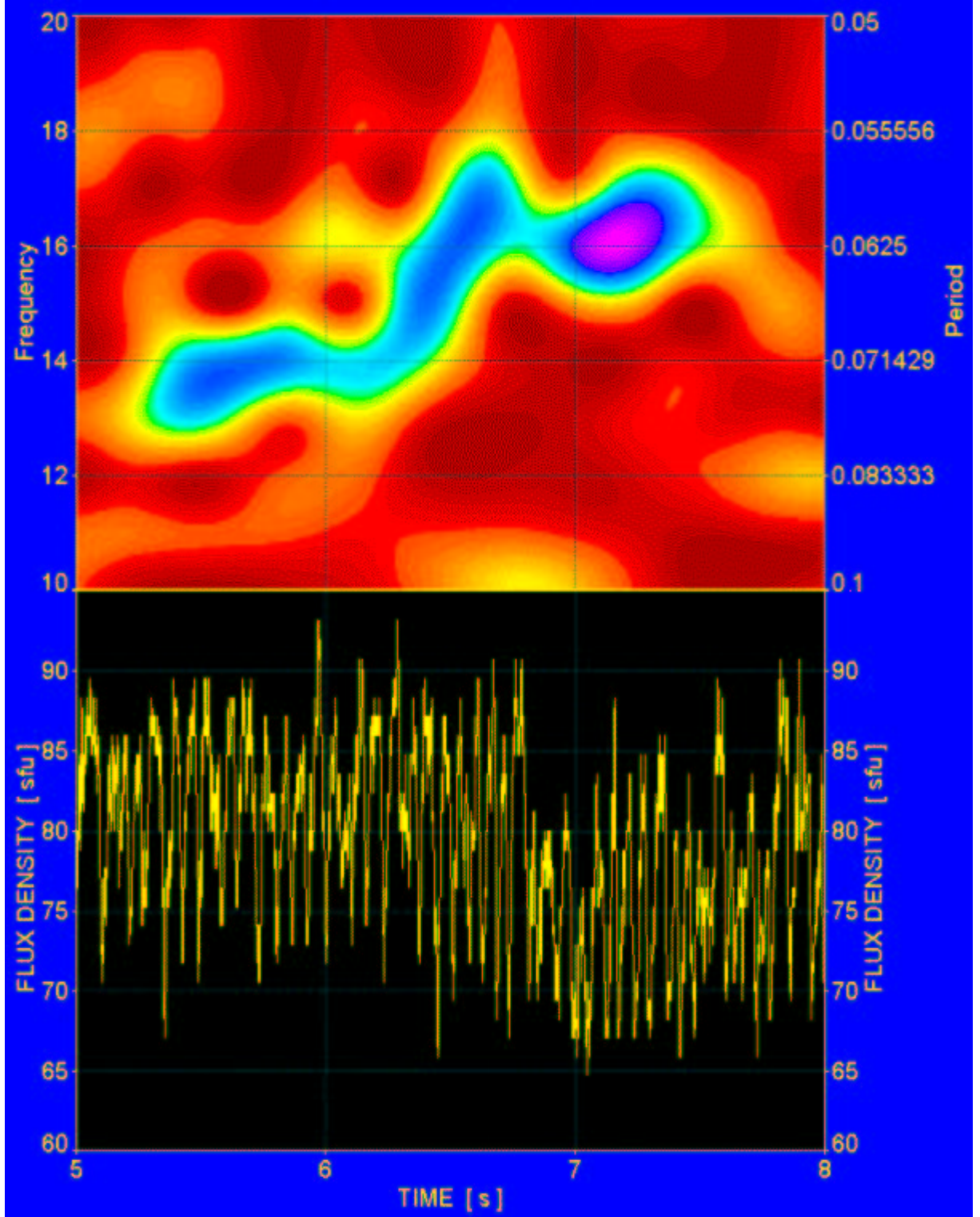


Figure 2: A shift in the dominant pulsation frequency (period), observed at 1420 MHz (start at 09:48:58 UT, duration 3 s): time series (lower panel); related continuous wavelet transform spectrum (upper panel).

(see Figure 1). During the time of the radio pulsations, two subflares appeared in two different active regions: AR 9267 in the Northern hemisphere and AR 9264 in the Southern hemisphere. The pulsations in the channels at 237, 327 and 408 MHz were unpolarized, only the last samples were generally R-handed polarized. At 1420 MHz the polarization was totally R-handed up to 9:52 UT, afterwards it was totally L-handed. At 2695 MHz the polarization was in the opposite sense, i.e. in the first sample L-handed and in the second R-handed. Such rather complex polarization conditions indicate that probably both active regions were involved in the radio emission process.

3 Data analysis techniques

3.1 Wavelet transform

Like Fourier analysis, wavelet analysis provides a spectral decomposition of a time series. However, contrary to Fourier decomposition, wavelet analysis also locates the dominant spectral features in time, thus providing the time and frequency information simultaneously. Since wavelet transforms do not have a single set of basic functions like the Fourier transform, but an infinite set of possible basis functions, the wavelet analysis provides access to information that can be obscured by Fourier decomposition [e.g. Graps, 1995]. Therefore, the wavelet transform is more suitable to analyze periodic or quasi-periodic phenomena, which are characterized by oscillation frequencies variable in time, with respect to conventional Fourier analysis.

In the present analysis, continuous wavelet transform spectra are calculated. In order to obtain the maximum resolution in frequency, a Morlet mother wavelet with wavenumber 20 was used. Spectral peaks with significant power were automatically identified by a numerical search algorithm.

3.2 Recurrence plots and recurrence histograms

A recurrence plot displays the distances between points x_i and x_j of a time series [Eckmann et al., 1987]. For the construction of a recurrence plot, the observed one-dimensional time series is expanded into a higher-dimensional space by means of time delayed coordinates [Takens, 1981], in order to reconstruct the space of the underlying dynamical system. The recurrence histogram is calculated from all the distance values of the recurrence plot.

Recurrence plots and histograms contain time correlation information and allow, e.g., to detected local periodicities, similarities in patterns across the time series and global drifts. The present analysis intends to infer information upon local periodicities in the radio flux time series. In the recurrence plot local periodicities show up as lines parallel to the diagonal; in the recurrence histogram they appear as peaks at distances, which are equal to the dominant periods.

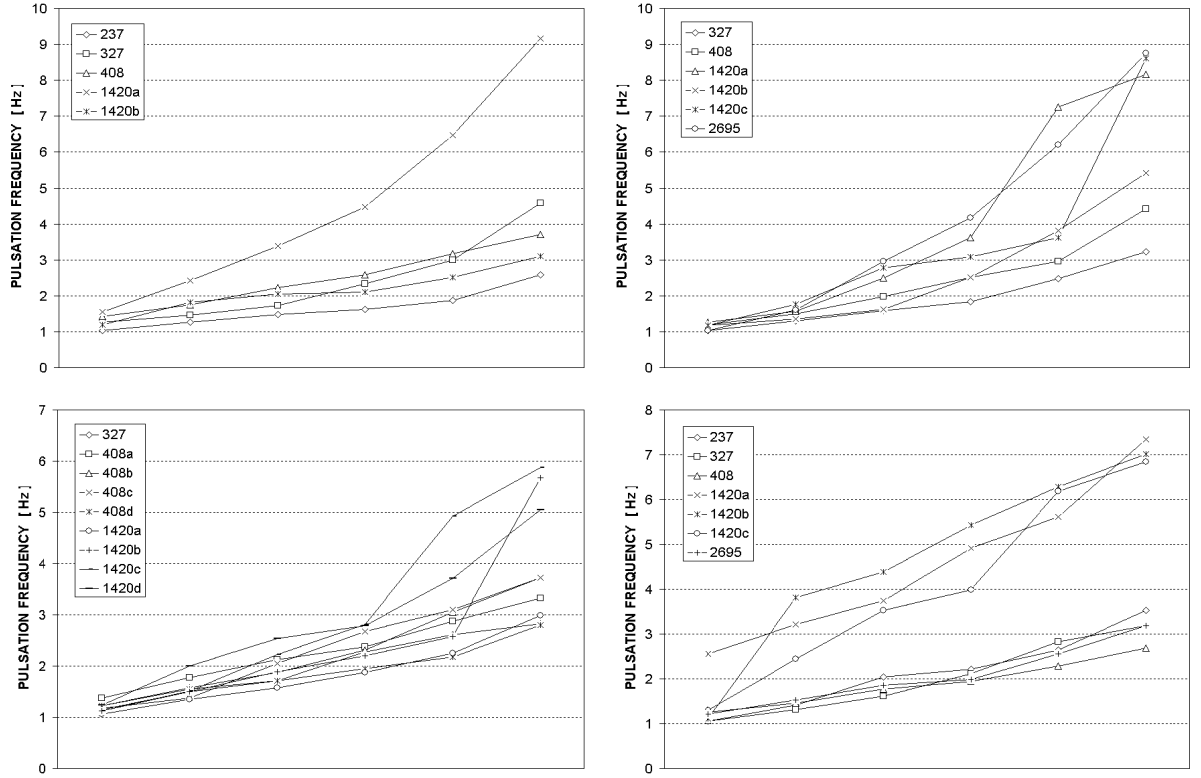


Figure 3: Frequencies of the strongest peaks in the 1–10 Hz spectral domain identified for each of the four considered sub-intervals (upper left, upper right, lower left and lower right panel respectively).

4 Data analysis

4.1 Spectral analysis

We divided the whole 42 minutes long interval into four parts in order to realize if during the whole interval the pulsation characteristics were changing. The first sub-interval lasted from 9:30 to 9:37 UT (no sample at 2695 MHz), the second from 9:45 to 9:59 UT (no sample at 237 MHz), the third from 10:01 to 10:05 UT (no sample at 237 and 2695 MHz) and the last one from 10:08 to 10:12 UT. The highest peaks in the spectral domain were found in the range 1–10 Hz. For the samples recorded at frequencies >1 GHz, the spectral components were also quite strong at frequencies higher than 10 Hz.

In performing the analysis a clear example of shift in the dominant frequency (period) was identified: during an interval of about 2 s, the frequency varied from 13 to 17 Hz, i.e. the period from 77 to 59 ms. The shift occurred in the sample recorded at 1420 MHz at 9:48:58 UT (see Figure 2). Such fast pulsations with variable period have recently been reported by Xie and Wang [2000], observed at 2.84 GHz.

For each sub-interval we determined the pulsation frequencies of the strongest peaks in the frequency domain 1–10 Hz. The results for the four sub-intervals are reported in Figure 3. It is very evident that higher frequency peaks correspond to samples recorded

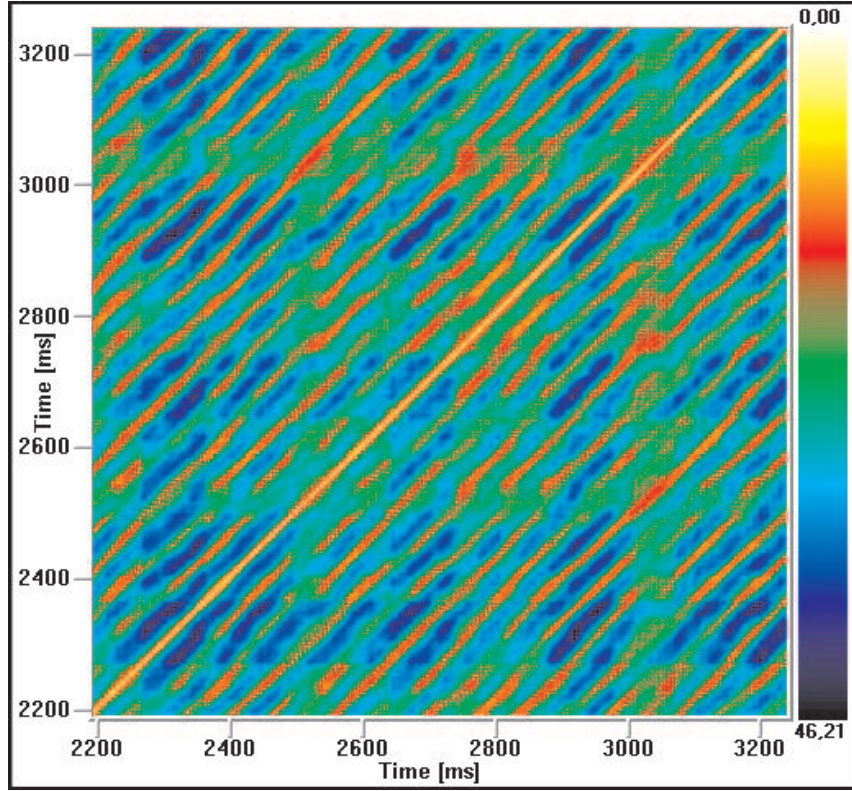


Figure 4: Recurrence plot of a 1 s sub-interval starting at 09:48:43 UT recorded at 1420 MHz.

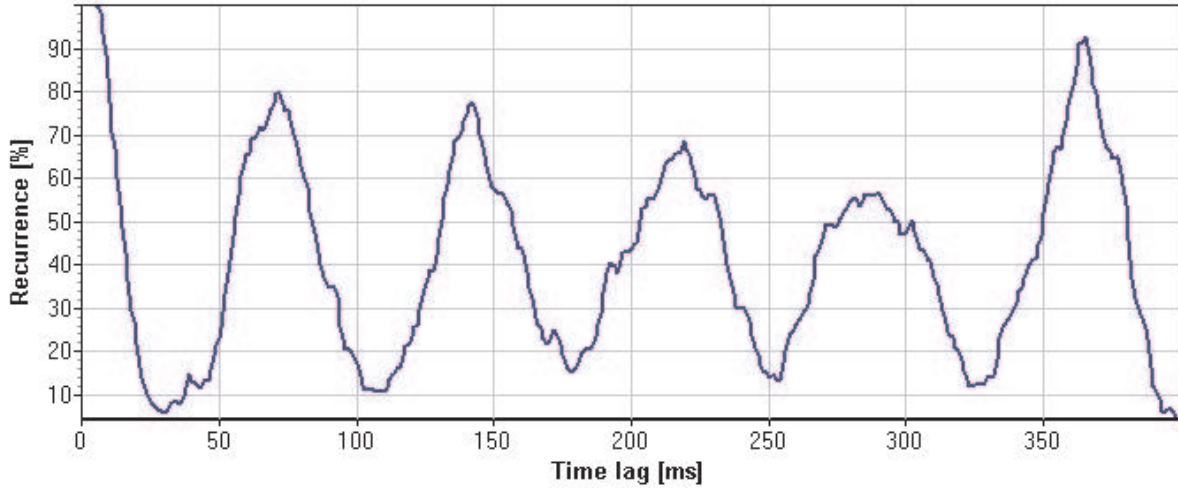


Figure 5: Recurrence histogram calculated from the recurrence plot shown in Figure 4.

at higher frequencies. The first three sub-intervals reveal a similar trend. However, the fourth sub-interval (lower right panel) shows a different behavior for the samples recorded at 1420 MHz, i.e. a stronger increase of the predominant pulsation frequency. This enhancement was probably induced by the presence of spikes (mean duration at half power ~ 7 ms).

Figure 4 shows a sample recurrence plot calculated from a 1 s sub-interval recorded at

1420 MHz (start 09:48:43 UT). The recurrence plot reveals several bright line segments parallel to the diagonal, which are indicative of local periodicities. The periodicities can be seen even clearer in the related recurrence histogram (Figure 5). The dominant period of ≈ 70 ms can be followed over several recurrences, indicating that the pulsation period stays roughly constant during consecutive pulsations.

4.2 Source parameters

Based on the fact that the trend of the frequencies of the strongest peaks in the frequency domain (see Figure 3) is well established, we considered as representative at each observing frequency the mean value of the sixth (i.e. highest) strongest peaks reported. In this way we minimized the influence (see last panel of Figure 3) of the spikes at 1420 MHz, as the six values are similar to the ones identified in the other sub-intervals.

Assuming that the pulsations were impulsively-generated, propagating MHD waves [Roberts et al., 1984], we can infer characteristics of the flux tube [Zlobec et al., 1992].

According to the selected model, the pulsation period is given by:

$$p \sim \frac{a}{v_A}, \quad (1)$$

where a is the radius of the oscillating flux tube and v_A is the Alfvén velocity inside the tube. The magnetic field strength inside the loop is therefore:

$$B \sim a \frac{n_e^{1/2}}{p}, \quad (2)$$

with n_e the local electron density, assuming plasma emission at the fundamental. The normalized flux tube parameter is therefore:

$$\frac{B}{a} \sim \frac{n_e^{1/2}}{p} = n_e^{1/2} \langle f_{\text{puls}} \rangle \quad (3)$$

where f_{puls} is the highest considered spectral peak.

Observing Frequency [MHz]	B/a Normalized to 237 MHz
237	1.00
327	1.52
408	1.86
1420	11.16
2695	28.24

Table 1: Ratio magnetic field – source dimension as function of the observing frequency.

The parameter given by the ratio magnetic field – dimensions of the source producing pulsations shows an enhancement for higher observing frequency (see Table 1). It is noteworthy to mention the sudden rise of this parameter across the m–dm observing range which should testify different characteristics of pulsations in the two ranges and therefore different physical conditions in the source.

5 Conclusions

Fast radio pulsations (<1 s) were recorded in the TSRS channels at 237, 327, 408, 1420 and 2695 MHz in a 42 minutes time interval. A detailed spectral analysis based on continuous wavelet transform spectra and recurrence plots pointed out evolving features in the time and frequency domains. Assuming a mechanism based on propagating MHD waves, the derived normalized flux tube parameter B/a results in an increase with the observing frequency. The sudden rise of this parameter across the m-dm observing range indicates different characteristics of pulsations in the two wavelength ranges.

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