SPECTRAL STUDY OF SOLAR TYPE III DECAMETRIC BURSTS

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Abstract

We investigate the spectral features of Type III Solar bursts observed at the Lustbühel radio station (Graz, Austria) in the frequency range from 29 MHz to 42 MHz. These radio decametric bursts were recorded by a digital spectro-polarimeter receiver with time and frequency resolutions of about 50 milliseconds and 12.5 kHz, respectively. A spectral method is described and used to proceed to a quantitative analysis of observational parameters and in particular the Type III burst spectral shape. A statistical approach gives common features of the Solar Type III bursts and a way to estimate their corresponding observational parameters. We discuss the advantage to use the spectral method which leads to investigate the shape of the Solar burst. This shape, and the corresponding observational parameters, should provide more knowledge about the emission beam associated to the bunch of electrons at the origin of the Solar Type III burst.

1 Solar Type III bursts

The study of Solar radio emissions of Type III is a powerful tool to explore the structure of the corona. These bursts are one of the earliest discovered forms of Solar radio emissions [Wild and McCready, 1950]. In general, the measured Solar radio emission properties are: the flux density at various single frequencies, the frequency spectrum and the polarization. These radio bursts (Fig.1) are produced by beams of energetic electrons ejected from the Sun travelling outward along open magnetic field lines through the corona and the interplanetary space. Along their path they generate, at each level, Langmuir waves at the local plasma frequency:

$$f_p\,(kHz) \;=\; (2\pi)^{-1}\,\sqrt{ne^2/m\varepsilon_0} \approx\; 8.98\,\sqrt{n_e} \tag{1}$$

where n_e is in [cm^{-3}]. Part of the energy of the Langmuir waves is converted into electromagnetic radiation [McLean, 1985].

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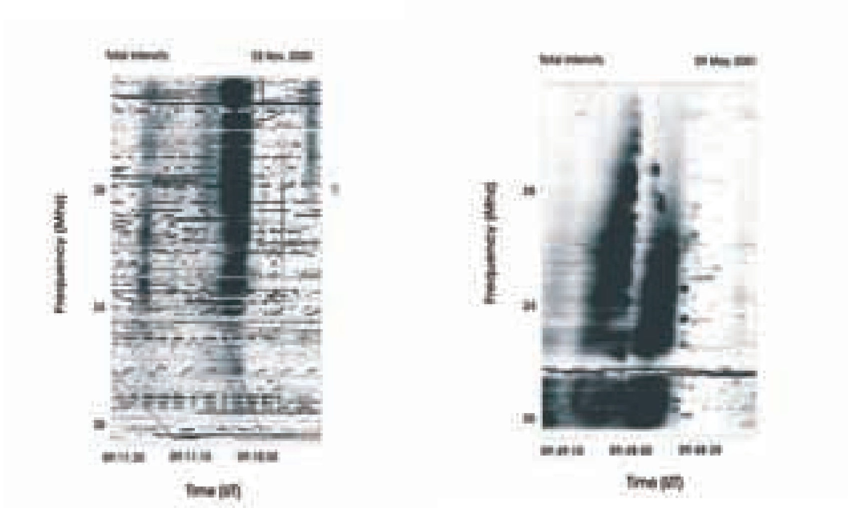

Figure 1: Solar Decametric Type III radio bursts observed at the Lustbühel radio station (Austria, left panel)and Kharkov Radiotelescope (Ukraine, right panel).

The observations of these features were made possible by the use of the spectro-analyser and the spectro-polarimeter which continue to be valuable tools. On the dynamic spectrum the Type III appears as an intense band of emission drifting rapidly with $df/dt \sim$ 100 MHz s^{-1} from high to low frequencies. Using the drift rate (hereafter DR) measurements reported by various authors, Alvarez and Haddock [1973] gave a relationship between the drift rate and the observed frequency:

$$\frac{df}{dt}(MHz/s) \; = \; -0.01\, f^{1.84} \tag{2}$$

in the frequency range from 550 MHz to 74 kHz. The flux density is found to be in the order of $10^{-19.0}$ W m^{-2} Hz^{-1} and $10^{-18.5}$ W m^{-2} Hz^{-1} at 80 MHz and 43 MHz, respectively [Dulk and Suzuki, 1980].

Since June 2000, two different broadband polarized log-periodic antennas have been deployed at the Lustbühel Observatory. This site is located at the eastern part of Graz, with the following geographical components: 15° E and 47° N. The Kharkov radiotelescope (37° E, 49° N) is composed of two rectangular arrays consisting of wideband horizontal dipoles positioned in the form of the letter "T". The telescope operates over the frequency range 10-26 MHz and the maximum effective area of each of the arrays is about 140 000 m^2 which makes it the biggest radio telescope at decameter wavelengths in the world. The digital spectro-polarimeter (hereafter DSP)receiver is a new generation of spectrum analyzers with the following key characteristics: (a) wide band spectral analysis over an instantaneous bandwidth of about 12.5 MHz, (b) great number of frequency channels, more than 1000, (c) capability of very high time resolution (approximately one millisecond), and (d) very high sensitivity in order to detect weaker emissions [Kleewein, 1997]. According to Lecacheux (2000), the DSP linear dynamic range for broadband noise is higher than 60 dB. Solar Type III bursts as shown in Fig.1 were recorded by the digital spectro-polarimeter at Lustbühel Observatory (Austria) and, later on, at the Kharkov radiotelescope (Ukraine), respectively.

2 Spectral analysis of Solar Type III bursts

In Fig.2, we show how a Type III burst (central panel) is "scanned" in the case of the classic (left panel) and the spectral method (right panel). The development in the radio instrument technology (in particular in the digital signal processing) leads to increase the time and the frequency resolutions of the receiver. As shown in Fig.2, the time resolutions for the classic and the spectral methods are of the order of about 300 milliseconds and 5 milliseconds, respectively. Also about two orders of magnitude separate the frequency resolution (the step from one channel to another) associated to each method. The spectral method has the advantage to precisely depict the shape of the Solar burst, and the corresponding observational parameters.

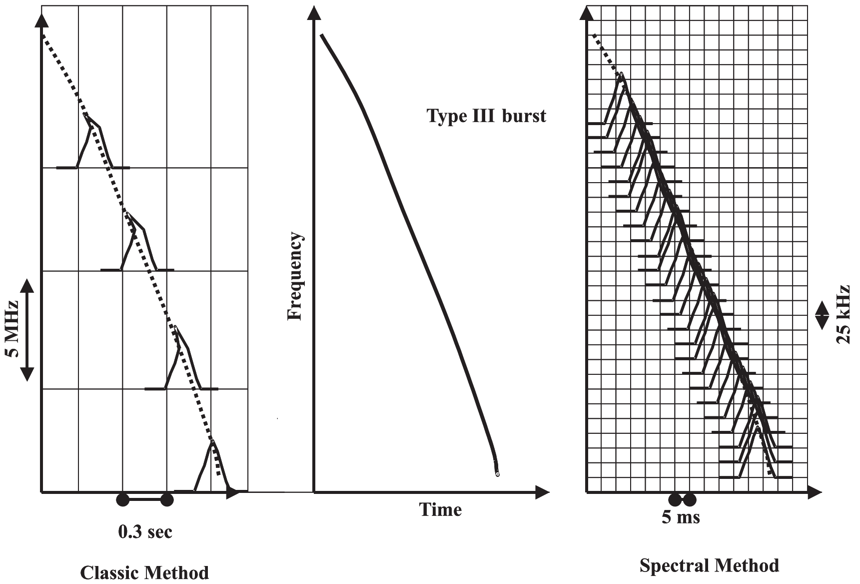

Figure 2: Classic and spectral methods applied to the same Type III burst. It is essential to note the fine resolution of the pixel in the case of the spectral method which leads to follow the exact shape of the Solar Type III burst.

Fig.3 displays the main spectral parameters which one can derive from a given Type III burst [Stangl, 2004]: ΔT is the time duration (sec), ΔF is the frequency bandwidth (MHz), $\frac{\Delta F}{\Delta T}$ is the drift rate (MHz/sec) , Δt_i is the fixed frequency duration (sec), and Δf_i is the instantaneous bandwidth (MHz). Using the PC's mouse, it is possible to follow in first the burst contour and automatically save three components, i.e. the relative intensity, and the corresponding time and frequency. The second step consists to measure the instantaneous time duration for several given frequencies with an interval from one frequency to another of about few dozen of kilohertz . Subsequently one can determine the instantaneous frequency duration for several given times.

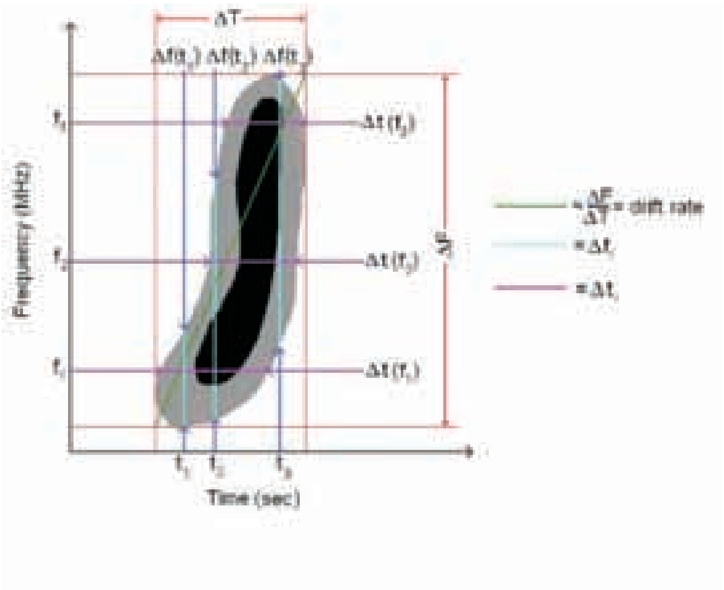

Figure 3: The observational parameters as estimated from the shape of a Type III burst.

3 Statistical Analysis of Type III bursts

3.1 Relative intensity

Solar decametric events were recorded from October 2000 to January 2001 at the Lustbühel radio station. Several hundreds of Type III solar bursts were selected and analysed. Fig.4 (left panel) shows the occurrence of the relative intensity (in dB). The solar component ranges between –70 and –50 dB with an average value around –65 dB. On Nov. 24th, 2000, more than 50 bursts were recorded during a time period of few hours. In Fig.4 (right panel), one can see the variation of the level of intensity versus the frequency for the corresponding bursts. It appears that the level of intensities increases from high to low frequencies. The increase of the background level is due to antenna beam and the observatory environment. Also two interferences at about 30.8 MHz and 33.7 MHz are clearly seen at low frequencies.

3.2 Frequency drift rate

The quantitative analysis also leads to derive the drift rate of the Type III burst. Fig.5 shows the variation of the Type III drift rate versus the frequency. For the Lustbühel observations (symbol $*$), the averaged values are found to be $\sim$ 8 MHz/s with a standard deviation of about 7 MHz/s. Three empirical models of Type III drift rate were proposed to explain the dependence of the DR versus the frequency. These three models are shown in Fig.5: (a) the model of Wild [1950] in dashed line, (b) the Alvarez and Haddock model [1973] in dotted and full lines, and (c) the Mann et al. model [1999] in dotted-dashed line. On the same figure, we display the drift-rates of the Solar decametric Type III bursts observed by: Boischot [1967] (symbol $\diamond$) and Riihimaa [1963] (symbol $+$). The Alvarez-

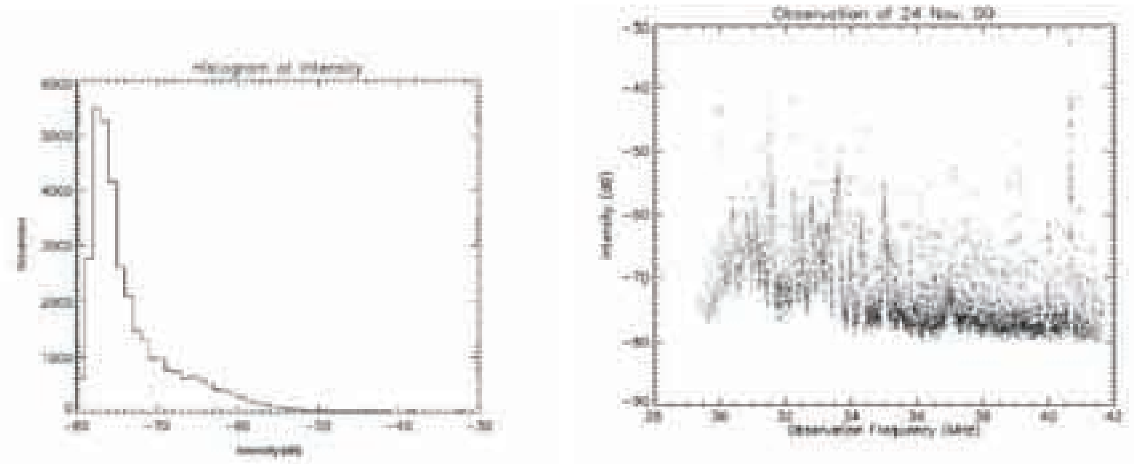

Figure 4: Relative intensity (in dB) of Type III bursts observed on Nov., 24th, 2000. The histogram occurrence and the frequency dependence are displayed in the left and right panels, respectively.

Haddock model is mainly based on space observations of OGO-5 between 50 kHz and 3.5 MHz. At higher frequencies (f > 10 MHz), this model is derived from ground-based observations made during one complete 11-yr Solar cycle by several authors [Boischot, 1967, and reference therein]. The Mann et al. model [1999] is based on Solar Type III bursts recorded by space experiments, Ulysses/URAP, Wind/WAVES, and ground-based observations of the Astrophysikalisches Institut Potsdam. Wild and Alvarez and Haddock models are found to fit part of the observed data. The Mann et al. model [1999] can be considered as a lower limit to the drift rate measurements in the decametric range.

4 Discussion and Conclusion

The study of Solar radio emissions of Type III bursts is a powerful tool to explore the structure of the corona. For instance, it is possible to estimate the coronal electron density by combining Eq.(1) and Eq.(2). Also both equations lead to an approximate formula for the electron density distribution models of the solar wind. Using the Solar decametric radio bursts one can derive the observational parameters which are directly linked to the physical conditions occurring in the Solar corona plasma.

Several previous studies reported on the Type III spectral features in the decametric range [Aubier and Boischot, 1972; Abranin et al., 1980; Dulk and Suzuki, 1980]. Their analysis method was mainly based on the study of the time profile for given frequencies. This method leads to essentially estimate the flux density, the time duration and some spectral features for a large frequency range. It is mainly the case of the Culgoora observations which were covering a frequency range from 8 MHz to 8 GHz using some specific receiver like the radiospectrograph (Nelson et al., 1985). Of course the advantage in this method

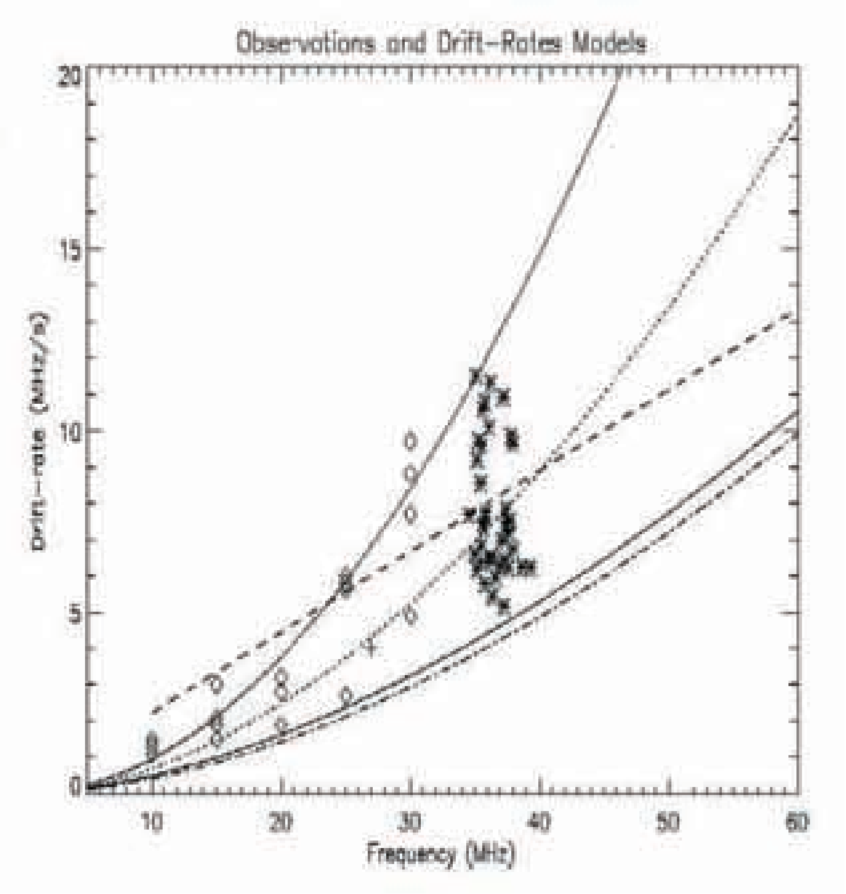

Figure 5: Observations and empirical models of Type III drift-rates. The symbols are associated to the DR reported by Boischot (symbol ♢), Riihimaa (symbol +), and our DR measurements (symbol ∗). The curves are related to the empirical DR models proposed by Wild (dashed line), Alvarez-Haddock (three curves for three exponent values: 1.84 (dotted line), 1.70 or 1.98, respectively (solid line)), and Mann-model (dotted-dashed line).

is to follow the evolution of the Solar bursts on a large frequency bandwidth. However the frequency gap from one channel to another could be very variable, from 0.3 MHz to several hundred of Megahertz. The metric and decametric frequencies (from ∼ 250 MHz to ∼ 30 MHz) correspond to a very large scale height of the Corona which is estimated to be in the order of one Solar radius. A stream of electrons at the origin of a Type III could travel this distance in 7 seconds at a speed of about $\frac{c}{3}$ where c is the light speed [McLean, 1985]. Because of the frequency gap several phenomena are totally missed along the Type III ray path in the Solar corona.

The spectral method described in our paper has the advantage to analyze the spectral evolution of the Solar burst within a limited frequency bandwidth (i.e. 12.5 MHz) but the gap from one channel to the next is only in the order of 15 kHz. Taking into consideration the previous ratio between one Solar radius and the corresponding covered frequency range, a frequency resolution of about 15 kHz represents a spatial resolution of about $R_\odot/10^3$. Such measurement technique could provide more knowledge about the "micro-scale" phenomena which are occurring in the Solar corona.

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