MORPHOLOGY AND POLARIZATION OF METRIC AND DECIMETRIC SOLAR RADIO PULSATIONS: A STATISTICAL APPROACH

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ABSTRACT

We analyzed a large data set of fine structures observed during type IV solar radio events recorded with high time resolution at single frequencies in the metric and decimetric bands by the Trieste Solar Radio System. Varieties of fine structures with periodical behavior but different temporal morphologies and polarization characteristics were identified. For selected events general statistics was derived in order to describe the evolution in time and at different observing frequencies, i.e., to infer the evolution of the related coronal plasma disturbances in time and height. To better characterize the observed radio pulsations in the framework of the flaring process, we derived the positions of the associated active regions, and studied the timing of such radio phenomena with respect to the associated SXR flares.

Key words: solar radio bursts; solar radio fine structures; radio pulsations; solar flares.

1. INTRODUCTION

Over the past few decades considerable attention has been given to solar radio fine structures including a wide range of phenomena, from sinusoidal oscillations to quasi-periodical structures, observed in the radio, microwave, and X-ray frequency bands. Based on phenomenological arguments, classifications of fine structures in the radio spectrum have been proposed (Bernold T., 1980; Güdel & Benz, 1988; Isliker & Benz, 1994; Jiřička et al. 2001, and references therein). The richness in morphological details observed in fine structures resulted in a variety of approaches and theoretical models, and it is still an open question which pulsation mechanisms are relevant for the interpretation of the observed events.

We analyzed a large set of fine structures during type IV solar radio bursts recorded at single frequencies in the metric and decimetric bands. Varieties of fine structures were identified which apparently exhibit similar periodical characteristics but different temporal morphologies and polarization characteristics. Common properties of fine structures can be indicative of their possible origin and/or radiation mechanism, so that a general statistical analysis can contribute to the identification of a consistent model. In this paper several significant parameters of periodical fine structures (PFS) are investigated and preliminary statistical results are discussed.

2. OBSERVATIONS

We analyzed the radiopolarimetric data recorded by the Trieste Solar Radio System (TSRS) with high time resolution (10 and 1 ms) at single frequencies in the metric and decimetric bands. A large set of fine structures in the time span 15 October 1997 - 10 July 2000 was inspected. Superimposed on the continuum of type IV bursts we identified 735 samples of fine structures, among which 511 events were classified as quasi-periodical or periodical fine structures. For each selected event we evaluated: a) period \( \tau \) (seconds); b) polarization \( P \) (percentage); c) flux density \( \mathcal{S} \) (solar flux units); d) duration \( \Delta t \) (seconds).

The selected events were showing a variety of intensity and structural characteristics, in time and frequency. However, in this stage of the analysis only general properties of PFSs and their relation to flares were considered, and we did not consider any detailed classification based on the morphology.

The events were selected according to the following criteria: a) presence during type IV bursts; b) quasi-periodical or periodical temporal profile; c) gradual changes in the intensity amplitude; d) duration of the individual event of at least 1 second. Flux density and polarization were calculated from the amplitude of the second largest pulse in the chosen interval (Figure 1a). When the time profiles in the left and right circular polarization channels (LCP and RCP, respectively) were showing a similar form, the flux...
Figure 1. An example of complementary data: a) single frequency LCP and RCP time profiles at 237 MHz with time resolution of 10 ms (upper panels); b) the correspondent dynamic radio spectrum (lower panel; courtesy of Henry Aurass, AIP)
density was computed as the sum of LCP and RCP signals, and the polarization was derived according to the usual formula \( P = 100 \times (L - R)/(L + R) \). If the profiles did not show similarities, only the channel with regular structures was considered and the event was attributed as totally polarized. Due to the absence of spectral information only PFSs present on at least two of our observing frequencies and showing the same time profile were considered as broad-band. In this respect a detailed complementary analysis of dynamic spectra would be needed, since single frequency data gave us only a lower limit (27\%) of the possible broad-band structures. An example of complementary data is shown in Figure 1 which depicts a TSRS single frequency recording and the correspondent dynamic radio spectrum by the Astrophysikalisches Institut Potsdam.

3. RESULTS

Due to the absence of spectral information and to the fact that subclasses were not considered separately, this analysis is mainly based on phenomenological arguments. Hence no definite conclusions on the physical mechanisms responsible for the development of the PFS could be drawn. In the following we report the preliminary outcome of the analysis.

3.1. Period

There are several driving mechanisms which may be responsible for the generation of periodical radio structures, such as MHD oscillations, periodic plasma instabilities and modulations of acceleration (Aschwanden, 1987). The most representative parameter for the PFS is the period, which sets a limit on the source size. In fact, it must be smaller than that given by the velocity of light times the period, irrespectively of the generating mechanism (Elgaröy, 1986). By analyzing the PFS periods some driving mechanisms can be excluded. For example, in the case of MHD driver the Alf\'ven velocity should be used to determine the source size (at our observing frequencies in the range 1500 - 500 km s\(^{-1}\); Vršnak et al., 2002). The periods we found can rule out the MHD oscillations, as very small dimensions of the magnetic flux tube would be required.

For each observing frequency (237, 327, 408, 610, 1420 and 2695 MHz) average values of periods and their standard deviations were calculated (Figure 2). In order to point out possible differences between events during a single long lasting (several hours) type IV burst in a broad band frequency range and sporadic events occurring only at a single frequency at the time, a separate analysis was performed on a subset pertinent to the large type IV burst observed on 28 July 1999, characterized by one hundred individual pulsation intervals. The behavior of periods in the considered frequency domain derived for this event is typical of the whole data set (Figure 2).

![Figure 2. Average values of PFS periods vs observing frequency. Upper panel: periods derived for PFS observed during a single long lasting type IV burst occurred on 28 July 1999 (triangles), and for the whole data set (squares). Lower panel: PFS periods relevant to the metric band (triangles) and to both the metric and the decimetric ones (squares).](image)

PFS analyzed at the two highest observing frequencies generally show different morphological structures and the derived periods are similar to those given by Güdel & Benz (1990) for spikes which are generally assumed as non-periodic. An additional analysis was done accordingly. The results obtained for lower frequencies only (Figure 2) are showing similar trend as the whole data set. Distributions derived for each frequency separately (Figure 3) show the existence of at least two classes of PFSs. That is in agreement with the already reported significant differences between metric and low decimetric pulsations (Güdel & Benz, 1988).

3.2. Polarization

Most of the analyzed events show an almost constant polarization during their lifetime, which suggests that the emitting source is unique and not very extended (Zlobec et al., 1987). By examining the polarization of the whole data set, we found that 52\% of events were highly polarized, 35 \% had middle and 12\% very low or zero polarization (Figure 4 - left). Thus, most common are totally polarized events, while lower polarizations are less and less probable except for the (nearly) unpolarized cases.

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3.3. Association with SXR flares and their position on the solar disk

Comparing the PFS timing with the SXR flares presence (GOES data), we found that more than 95% of PFSs is related with flares. The PFSs typically occur during enhancements in type IV bursts. We evaluated the timing of individual PFS with respect to the evolution (rising or decay phase) of the SXR flare. A delay parameter $d$ is defined as:

$$d = \frac{t_{\text{puls}} - t_{\text{SXR}}}{t_{\text{SXR}} - t_{\text{SXR}}}$$

The delay $d = 0$ indicates the coincidence with the start of the SXR flare, and $d = 1$ with the SXR flare maximum. Figure 5 is showing two large classes of events, the first one is related to the rising phase of a flare ($d \leq 1$) and the second one to the decay phase ($d > 1$). The second class could be due to the fact that almost 40% of flares with PFSs was characterized by a prolonged decay phase during which repeated occurrences of enhancement in radio emission are frequently observed. SXR flares related to PFSs do not show any peculiarities as regards their importance classes and their position on the solar disk (Figure 4 - right).

4. CONCLUSIONS

This analysis of a rather large data set (511 events) is showing some new results which can be summarized as follows: a) The period and its range are decreasing with the observing frequency. b) The behavior in the frequency domain of the average periods during a single type IV burst is representative of the behavior of the average period derived for the whole data set which consists of PFSs present in different type IV bursts. c) More than 95% of analyzed PFSs are associated with SXR flares.

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REFERENCES

Aschwanden, M. J., 1987, Solar Phys. 111, 113