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Solar bursts with fine temporal structure

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Abstract. This paper summarized the talk presented at XI Symposium and IX Congress of the Cuban Physical Society, were the main results obtained in the Solar Astrophysics group (Institute of Geophysics and Astronomy in Havana, Cuba) were presented. Solar bursts with fine temporal structure (characteristic time less than 1 s) are explained as a fragmentation in the energy release process.

Sumario. Este trabajo resume la conferencia impartida en el XI Simposio y IX Congreso de la Sociedad Cubana de Física donde los principales resultados del grupo de Astrofísica Solar del Instituto de Geofísica y Astronomía fueron presentados. Las explosiones solares en ondas de radio (*bursts* en inglés) con una estructura temporal fina (tiempo característico menor de 1 s) se explican como resultado de una fragmentación durante el proceso de liberación de la energía durante el destello.

Key words. Solar Physics 96.60_ j, Flares 96.60.qe, Magnetic reconnection 96.60.Iv.

1 Introduction

The solar corona is a high structured and dynamic plasma formed by dense tubes of solar plasma. There are many kinds of transients phenomena occurring on various time scales from hours to few tens of milliseconds associated to the evolution of these dense tubes of solar plasma. In particular, solar flares are one of the paradigmatic active phenomena where magnetic energy stored in these structures is transformed into kinetic energy of highly accelerated particles via magnetic reconnection.

One of the characteristic parameters of solar flares is its duration. Solar flares observed at radio frequencies (called bursts) with duration less than 1 s can be a key to understand the basic energy release process in flares. Observed from decameter wavelength range (~ 20 MHz) up to microwave wavelengths (near 10 GHz) these bursts with characteristic time less than 1 s include spikes, spike-like, very short period pulsations (regular or irregular), dips in radio emission, type I bursts, zebra-pattern structures, etc. which can be related with some kind of process of energy release fragmentation[1].

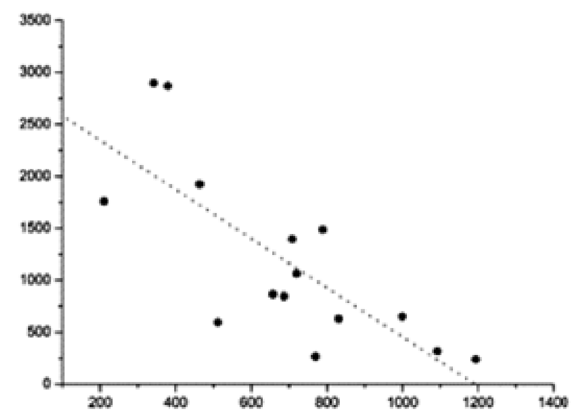

Figure 1. Relationship between intensities of spike-like events (y-axis) and intensity of associated background continuum (x-axis) observed at 327 MHz for July 9, 1982 solar flare. Axes in solar flux units ($10^{-32}Wm^{-2}Hz^{-1}$).

This fragmentation process might by produced by intrinsic properties of the radio emission mechanism itself during the primary energy release or as a result of local fragmented inhomogeneities of the source[2]. In [3, 4] a reviews on spatial fragmentation of radio emission sources are presented.

This paper resumes the talk gave at XI Symposium and IX Congress of the Cuban Society of Physics. The main results obtained by the Solar Astrophysics group (Institute of Geophysics and Astronomy in Havana, Cuba) are presented.

The used data is from Trieste Solar Radio System (INAF-Trieste Astronomical Observatory, Basovizza Observing Station, Italy) with high time resolution (from 10 to 1 ms) at metric-decimetric range (237, 327, 408, 610, 1420 and 2695 MHz).

2 Intensity of the bursts vs. background continuum

A crucial unsolved problem is the possible relationship between intensity of the solar burst with fine temporal structure and the associated background continuum. This subject would be directly related with mechanism of generation of burst and on the evolution of associated sources. Earlier works had focused mainly on the cluster or group of bursts not analyzing individual bursts.

In [5] this aspect is discussed analyzing selected study cases of spike-like bursts and type I bursts. In [5] the study case July 9, 1982 solar flare was analyzed and inverse linear relationship between intensities of spike-like bursts and intensities of the associated background continuum was found (Figure 1). We conclude if both mechanisms for spike-like bursts and background continuum are powered by the same primary energy source, and if spike-like burst generation mechanism has a growth index greater than the continuum one, early bursts could obtain much more energy than later one as background continuum mechanism extracts a significant part of the primary released energy. In this hypothetical description, these spike-like bursts cannot be used as a measure of primary energy source fragmentation. They would be the result of an emergence of new sources with a different generation mechanisms. However, analyzing another study case (September 8, 1999 flare) no relationship was found. So, at is point we conclude that no general rule is expected.

The study was extended to type I burst and some preliminary results were obtained. In three quiet different solar Noise Storms, a typical solar phenomenon containing type I burst, no clear relationship between intensities of type I bursts and the background continuum emission was found. However, it can be notice a group of bursts that seems to follow a positive linear dependence (Figure 2). These separated bursts would be represents some kind of different class of type I bursts in the evolution of the noise storm. Some detailed study must be do it in this respect; we do not know any report in the literature regarding distinctive classes of type I bursts.

3 Waiting time and energy distribution

There are many papers devoted to examine the waiting time distribution between individual solar events [i.e. 6-8] and a clear power-law is obtained implying that successive events are strongly correlated and there is not an characteristic value of waiting time.

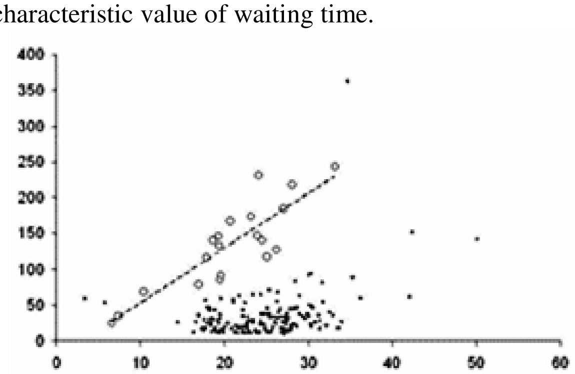

Figure 2. Relationship between intensities of type I bursts (y-axis) and background continuum (x-axis) for November 18, 2005 solar noise storm. It can be notice a group of bursts (marked with open circles) that seems to follow a positive linear dependence. Axes in solar flux units.

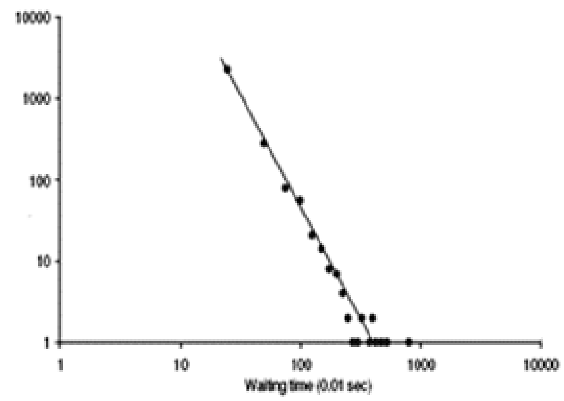

Figure 3. Log-log of waiting time distribution for spike-like bursts associated to large flare of July 14, 2000.

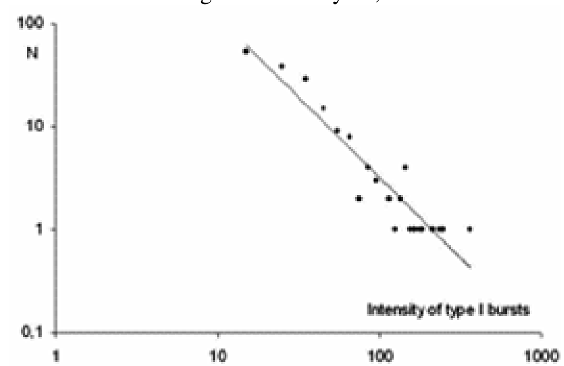

Figure 4. Log-log of energy distribution for type I bursts associated to Noise Storm of November 18, 2005.

We examined the waiting time and energy distribution of spike-like and type I bursts[9]. The waiting time distribution was examined in spike-like bursts associated to the large flare of July 14, 2000 and in the type I bursts associated to the three Noise Storms before mentioned. The energy distribution was analyzed in the spike-like bursts associated to the large flare of September 8, 1999 and in the same type I bursts.

In all examined cases, both waiting time and energy distribution of bursts seems to follow a power-law distribution (Figures 3 and 4).

These results point to waiting time and energy of all sizes is expected in these events. This could be related to some process fragmenting the source in all sizes in an avalanche of successive magnetic reconnections. The possibility of a self-organized criticality behavior must be analyzed in the future.

4 Dips in radio emission

Dips in radio emission are not common events and they are associated with the evolution of large flares. There is not an abundant literature on this subject. Dips are sudden reduction in the radio emission intensity lasting less than 1 s. Some authors refer dips events as anti-spike bursts.

In [5] dips events of very short duration (duration ~ 0.2 s) associated to large flare on July 9, 1982 were reported less than 1 s after the maximum of the flare only at 408 MHz (Figure 5).

Sudden reductions in radio emission are explained by upward injected high energy electron beams filling the loss-cone of the coronal magnetic trap[10, 11]. From our point of view, we explain the observed dips, not by the proposed mechanism but due to the increase by two orders of magnitude in the value of the optical depth related to a substantial increase of the temperature during the large associated flare, reducing the radio emission by the opaque radio emission level (408 MHz).

5 Pulsations

On the continuum of the strongest and longest radio emission at radio wavelengths, quasi-periodic variations have been known for several decades ago[12, 13]. These kinds of phenomena, related to strong energy release processes, represent a useful diagnostic tool giving information about highly perturbed plasma and physical conditions of the source region. Typical periods of quasi-periodic pulsations at radio wavelengths are in the range from milliseconds to several minutes.

Many models have been proposed to explain the observed characteristics of the quasi-pulsating events: magnetohydrodynamic oscillations, periodic plasma instabilities, periodic injections of fast electrons are mainly candidates for the driving mechanisms responsible for the generation of such phenomena[14].

In [15] we describe a singular case of pulsations observed during September 9, 2001 solar flare only at 237 MHz. Two different types of pulsations that occur in about 4 minutes were identified. Not pulsations were found at 327, 408, 610, 1420, 2695 MHz.

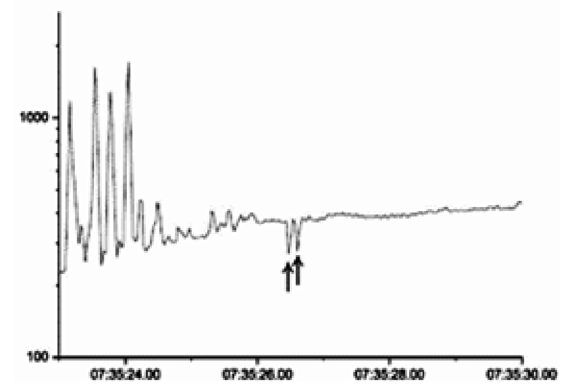

Figure 5. Segment of the profile of July 9, 1982 solar flare records at 408 MHz. The dips in radio emission intensity are marked with arrows. X-axis is referred to time (Universal Time). Y-axis is referred to logarithm of solar flux units.

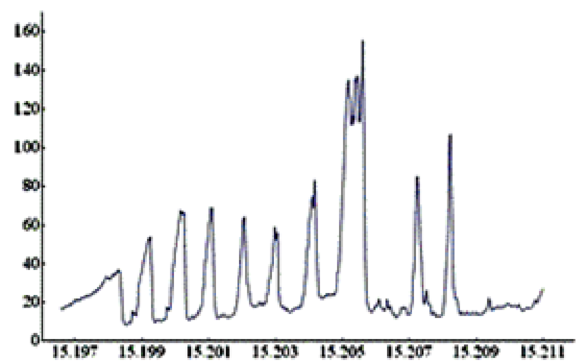

Figure 6. "Saw tooth-like" structure of the quasi-periodic pulsations observed at 237 MHz. X-axis is referred to time (Universal time) in hours and fraction of an hour. Y-axis is referred to solar flux units.

The first one shows a profile resembling a "saw tooth-like" structure with an increase continuum that is suddenly stopped and reduced it to a "forbidden" continuum (Figure 6). The second interval less than 4 minutes later represents a well "sinusoidal-like" structure.

Both pulsating structures were interpreted as magneto-acoustic oscillations of plasma dense flux tubes with an estimated radius of 4.58 x 10^3 km, relatively small diameter for such structures. The "saw tooth-like" structure with process where the radio emission is abruptly diminished was explained qualitatively by magnetic quasi-periodic compression of the structure, contrary to [10, 11] where injection of particles have been proposed to explain the sudden diminution of radio emission. A scenario for such magnetic quasi-periodic compression of the structure evolving magnetic traps of electrons following the magnetic reconnection was proposed [15].

6 Conclusions

This paper summarizes the talk presented at XI Symposium and IX Congress of the Cuban Society of Physics. The main results obtained by the Solar Astrophysics group (Institute of Geophysics and Astronomy in Havana, Cuba) concerning solar bursts with fine temporal structures are presented. Spike-like and type I bursts were analyzed using data from Basovizza Observing Station of Trieste Astronomical Observatory with high temporal resolution.

Intensity of radio bursts vs. associated background continuum, waiting time and energy distribution, dips, and quasi-periodic pulsations are analyzed.

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