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Solar activity waiting time distribution function for different spatial and temporal scales phenomena

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Sumario: En este trabajo investigamos la función de distribución del tiempo de espera de dos tipos de eventos solares, ambos caracterizados por su diferente tiempo característico: los *spikes* en ondas de radio y las expulsiones de masa coronal con emisiones sucesivas. Encontramos en ambos casos que la distribución parece seguir una ley de potencia. Este artículo resume los trabajos presentados en el evento Complejidad 2006 referidos a física solar.

Abstract: In this work we search for waiting time distribution function of two kind of solar transient events characterized both by its different spatial and temporal scales: solar radio spikes and coronal mass ejections with two emissions. We found that in both the distribution seems to follow a power-law. This paper summarizes the works presented in the workshop Complexity 2006 in Havana Cuba, referred to solar physics.

Keywords: solar activity 96.60.Q-, radiowaves 41.20.Jb, 84.40.-x, solar bursts 96.60.Rd

1 Introduction

There are many papers devoted to searching self-organized criticality in solar physics process (e.g. refs. [1, 2, 3]). In ref. [4] the authors interpret solar granulation on all scales and the formation and evolution of some structures in solar active regions to be the result of self-organization processes occurring in a turbulent medium. On the other hand, solar coronal magnetic field in a self-organized critical state is proposed to explain as avalanches of many small reconnection events the power-law dependence of solar flare occurrence rate founded[5], analogous to avalanches in a sand pile[6]. A power-law distribution function of waiting times is an indicator of self-organized criticality.

In nature, there are many intermittent phenomena that exhibit power-law statistics for the distribution of quiescent times between events: earthquakes[7], geomagnetic bursty events[8], etc. Likewise some solar transient events exhibit power-law statistics for the waiting time distribution function between events: Hα and X-ray flares[9,10], coronal mass ejections[11], etc. The waiting time is given by the time that passes between two consecutive intermittent events. The power law statistics for the waiting times in a given system implies that successive events are correlated with each other, in other words the system has memory.

In this paper we present the results for searching waiting time distribution in two different solar activity events characterized by its different spatial and temporal scales: solar radio spikes and coronal mass ejections with two emissions.

Waiting time distribution function in solar radio spikes. Known as a special astrophysical object and described mainly by its short duration (less than 0.1 sec) and exceptionally high brightness temperature ($T_B \approx 10^{15}$ K), as described in many reviews (e.g. refs. [12, 13, 14]) millisecond events (spikes) lag from a generally accepted model. The very short duration of spikes leds to the interpretation of a single spike as a microflare, and the presence of a large number of spikes during the flare led to the idea of energy release fragmentation[14]. Related to this, in previous paper[15], the coronal heating is explained by collective energy released by the ensemble of nanoflares (flares with energy about nine orders of magnitude smaller than a typical large solar flare) continuously occurring throughout the magnetized corona.

Spikes data. The radio observations were done by the Trieste Astronomical Observatory –Basovizza Station- in the 2695, 1420, 610, 408, 327, and 237 MHz in both left and right hand circular polarized components with a temporal resolution of 0.01 sec. We selected the spike activity associated to the July 14, 2000 flare. Once the data was explored and intervals of interest selected, their characteristics were determined in all frequencies. We selected those spike peaks with intensity greater than 10 solar flux units (1 solar flux unit = 10^{-22} $Wm^{-2}Hz^{-1}$) in a 50 millisecond temporal window. The peaks were selected independently for left, right polarized components, and "un-polarized" ones.

Waiting time distribution function analysis results in solar radio spikes. We found that in each interval studied, the waiting time distribution function of spikes adjust to a power-law function of the type $P(\tau) \propto \tau^{-\alpha}$. This behavior is observed in both polarized component left and right hand (Fig. 1). In some cases, the "un-polarized" spikes seem to follow power-law distribution too although its power-law index seems to be quiet different (Fig.1).

The power-law index (α) and the coefficient (A) were calculated for each waiting time distribution function, and we found they are related as $A = 9.8552\, e^{4.862\, \alpha}$. We have not an explanation for that behavior but it seams to be related not to the intervals of observation, but to the nature of the system.

2 Waiting time distribution function in complex coronal mass ejections

Coronal mass ejections (CMEs) are events with a complex morphology and temporal evolution. CMEs generated in the same location and temporally close can be considered as several emissions of a unique event with several components. In this sense, ref. 16] propose a CMEs classification that involves great scales structures, where they also present several emissions cases that would be related physically. This type of emissions of coronal plasma could be related with great scale restructuring processes of the solar magnetosphere topology[17].

Forecasting of solar activity impact on Earth needs to consider CMEs generated interplanetary disturbances and interactions (CME cannibalism[18]) and the CMEs with several emissions should be studied as key elements to understand these processes.

In our approach, we consider the possible evolution of solar magnetic structures to a stable state by several emissions ejection process. Few authors had examined flare or CME waiting time distribution in individual active regions. To analyze the behavior of the relaxation times on solar magnetic structures associated to CMEs, we studied the waiting time between emissions of complex CMEs. We define the waiting time (τ) as the time interval between the commencement of an emission and the commencement of the next emission considered as parts of a unique CME.

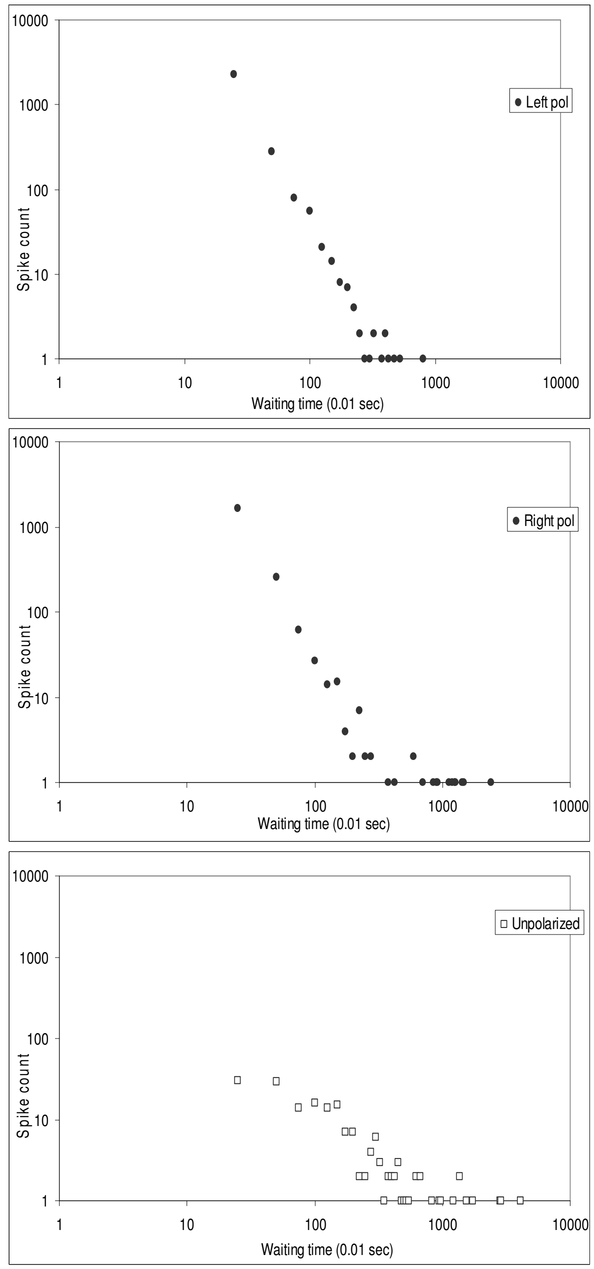

Figure 1. Waiting time distribution function in the 10:20-10:30 UT interval for left hand (a) and right hand (b) polarized, and unpolarized (c) spikes events in 237 MHz.

Coronal mass ejections data. The study is based on the CMEs observed by the Solar Maximum Mission in 1980 and in the period between 1984 and 1989 taken from ref. [19]. Following the criteria in ref. [20] the 113 cases considered as CMEs with two emissions were selected. To avoid the calculations of the location from which the CMEs were originated, but keeping the idea of one unique source or multiple sources of related emissions in CMEs, we classified them as “close” and “separate” paying attention to the angular distance between the CME central angle reported in ref. [19]. If the central angles differ in more than 20 degrees the pair of emissions was classified as “separate”, if less or equal 20 degrees the pair of emissions was classified as “close”.

Waiting time distribution function analysis results in complex coronal mass ejections. In our approach, the Sun is not considered a system as a whole generating this type of events. When we consider successive emissions from the same source we are taking into account the evolution of the magnetic structures intrinsic physical condition.

The waiting time distribution function of the 113 CMEs with two emissions divided in “close” and “separate” pairs were analyzed. For the whole data (all 113 cases) the waiting time distribution function adjust to a power-law of the type $P(\tau) \propto \tau^{-\beta}$ with $\beta = 1.41 \pm 0.148$ (Fig.2). For events classified as “close” and “separate” a power-law was found with indexes 1.677 ± 0.334 and 1.116 ± 0.198 respectively.

3 Discussions and Conclusions

The waiting time distribution function for two solar events with different scales was examined. These events –spikes and coronal mass ejections- are characterized by its quiet different spatial and temporal scales. In both cases the waiting time distribution function adjusts to a power-law function. It could be considered an indicator of self-organized criticality behavior in both event types.

In case of solar radio spikes, the waiting time distribution function would be related with the spike generation mechanism and with the process of energy release fragmentation. Both unclear aspects of spike activity. Related to the possibility of a self-organized criticality spikes behaviour, there are many details to be taken into account to be sure about such a behaviour, but a relatively simple way to explore this possibility is to analyze the waiting time distribution function between successive individual spikes. We consider waiting time an index related to the intrinsic behaviour of the system to self-organized criticality: the storage and dissipation of energy.

In case of emissions in complex coronal mass ejections, the waiting time of the CMEs with several emissions is a basic parameter in the analysis of the reorganization of the associated magnetic structure in the process of the ejections. We interpret the difference observed in the values of the indexes of the waiting time distribution of the “close” and “separate” CME related with the magnetic topology of the structures involved in the process of the ejections. The waiting time distribution comparison between “close” and “separate” ejections shows their indexes are different. We expect greater waiting times for “separate” ones. Considering the waiting time τ is related with Λ (characteristic spatial length of the CME associated magnetic structure) as $\tau \propto (\Lambda / V_a)$, where V_a is the Alfven velocity, our results are in agreement with the interpretation of two different scenarios in which the CMEs with several emissions occur. CMEs with “close” and “separate” emissions are associated to scenarios with different characteristic spatial length Λ. CMEs with “separate” emissions have a larger Λ than those associated to CMEs with “close” emissions. Then, the relation between values of the power-law index for the waiting time for “separate” and “close” ($\gamma_{separate} < \gamma_{close}$) are in agreement with the relation between characteristic spatial length Λ for “separate” and “close”. This results support the hypothesis of the existence of complex, multiple emissions CMEs.

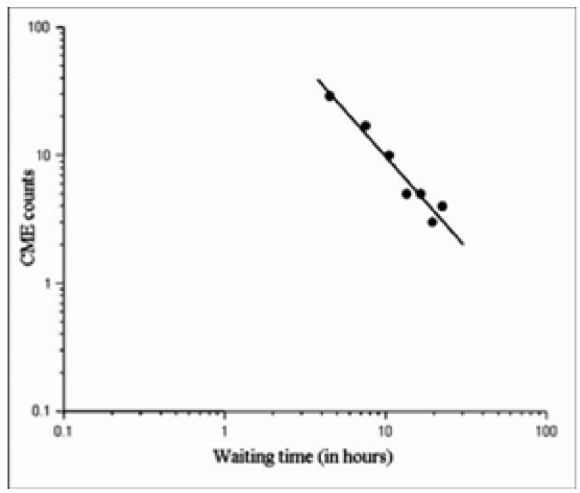

Figure 2. Waiting time distribution function of the all coronal mass ejections with two emissions examined, both “close” and “separate”.

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