SOLAR FIBER BURSTS DYNAMIC: REGULAR, DETERMINISTIC CHAOS OR STOCHASTIC

DINÁMICA DE EXPLOSIONES SOLARES FIBER: REGULAR, CAOS DETERMINÍSTICO O ESTOCÁSTICA

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The dynamic characteristics of solar fiber metric radio bursts as they evolve at fixed frequency are examined. Fiber bursts appear as highly structured in time series of emission and absorption with respect to the underlying continuum. The aim of this work is to determine if the primary process generating fiber bursts can be described as a deterministic chaos.

We use the data recorded by the radiopolarimeter of the Trieste Solar Radio System (INAF, Trieste Astronomical Observatory) at 327 MHz from 09:42:51 to 09:44:11 UT when a well-defined cluster of fiber bursts is present. The time resolution of the data is 10 ms.

We apply the time series analysis developed in the theory of non-linear dynamics systems in order to find out if the time series of solar fiber bursts is regular, deterministic chaos or stochastic. From the Takens embedding theorem [1], a single time series contains information on the entire system it originates from. According to that, the dynamics of such system can be reconstructed in its state-space through the ϵ-dimensional vector $\mathbf{X_t}$ as

$$\mathbf{X_t} = (x_t, x_{t+\tau}, ..., x_{t+\tau(\epsilon-1)}), \quad (1)$$

where t represents the time and x_t is the measured value at time t, τ represents the time delay (any multiple of time resolution), and ϵ is the embedding dimension of the system.

The mutual information was used to find the proper time delay in order to reconstruct the state-space [2]. Figure 1 shows the reconstructed 2-dimensional state-space with a time delay of 40 data points as suggested by the first minimum of average mutual information. From the limit asymptotic sets of trajectories the presence of attractor can be inferred.

The strangeness of the attractor can be measured through correlation dimension $D^{(2)}$ which is a suitable parameter to explore how deterministic a process is [3]. The Grassberger-Procaccia algorithm is an useful tool to find out $D^{(2)}$ via the correlation integral, $Cd(2)(r)$, where $D^{(2)}$ is defined as $Cd^{(2)}(r)\ rD^{(2)}$ and can be estimated as the slope in the linear scaling region independent of the embedding dimension ϵ in the $\log[Cd^{(2)}(r)]$ vs. $\log[r]$ plot [4].

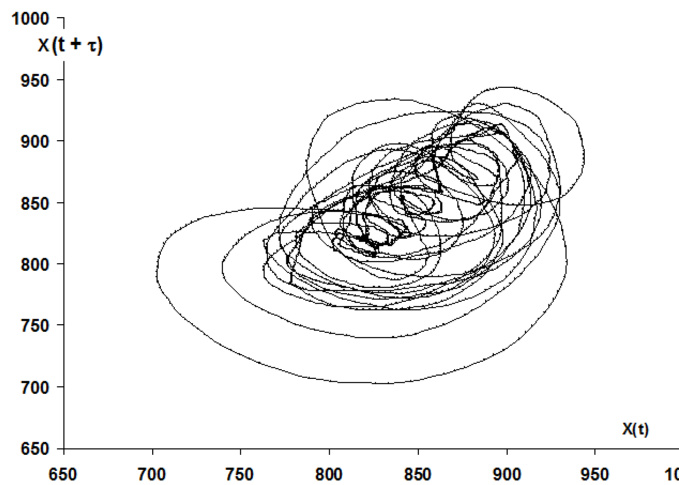

Figure 1. Reconstructed state-space of the analyzed series of fiber bursts.

Figure 2 shows the plots of $\log[Cd^{(2)}(r)]$ vs. $\log[r]$ for embedding dimension e from 2 to 15 for the time series corresponding to state-space of Figure 1. A linear scaling region independent of the embedding dimension can be noticed for $7 \leq e \leq 15$ in the range $-1.4 \leq \log[r] \leq -0.8$. The slope in this linear scaling region indicates $D^{(2)} = 1.2 \pm 0.2$.

The value for $D^{(2)} = 1.2$ indicates a process for solar fiber bursts characterized by a low-dimensional deterministic chaos. This value for $D^{(2)}$ is similar to some of the well-know attractors, e.g., Henon and Rssler models.

The dynamics in the generation of solar fiber bursts studied in this paper can be characterized by a low dimensional chaotic process. It means a non-periodic behavior with sensitive dependence on initial conditions. This non-periodic chaotic behavior is in contrast with a developed model suggesting an oscillatory cuasi-periodic process acting as fiber bursts source [5].

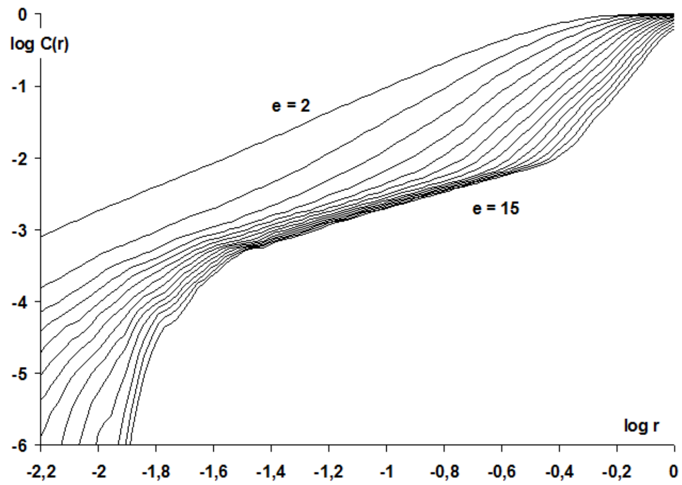

Figure 2. Plots of $\log[Cd^{(2)}(r)]$ vs. $\log[r]$ for embedding dimension e from 2 to 15 for the time series corresponding to state-space plotted in Figure 1.

The value for $D^{(2)} = 1.2$ indicates a low degree of freedom sufficient to describe the dynamics of the system and consequently the number of independent non-linear equations needed to specify its evolution is rather low. At least 2 non-linear equations are necessary to describe the process generating the cluster of fiber bursts considered in this paper.

The found value for $D^{(2)} = 1.2$ is quiet different and significantly low respect to the value found for other types of highly structured in time series of solar bursts like pulsations, Type I bursts, and millisecond spikes for which were found $D^{(2)} \geq 5$ [6,7] meaning, in contrast, a high dimension chaos.

This difference in the value for $D^{(2)}$ between fibers and other types of solar bursts highly structured in time suggest that the nature of fragmentation in the source of radio emission can be completely different from one type to another, making a differentiation between fibers and the others mentioned type of bursts. This could be an important feature to take into account for theoreticians constructing models explaining the fiber bursts and the nature of the fragmented radio emission.

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