ANALYSIS OF SOLAR SPIKE EVENTS BY MEANS OF
SYMBOLIC DYNAMICS METHODS

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Abstract. We have searched for interrelations of spikes emitted simultaneously at different frequencies during the impulsive phase of flare events (Fig.1). As the spikes are related to the flare energy release and are interpreted as emissions that originate at different sites having different magnetic field strengths, any relation in frequency is interpreted as a relation in space. Quantities of symbolic dynamics, such as mutual information, Shannon information and algorithmic complexity are appropriate to characterize such spatio-temporal patterns, whereas the popular estimate of fractal dimensions can be applied to low-dimensional systems only.

The goal is to decide between two possible types of fragmentation depending on the energy release and emission processes, which we call global and local organization. In the global organization the whole region becomes supercritical, and the energy is released in independent, small regions. The alternative local scenario requires a trigger that spreads from initial localized events and ignites nearby regions.

Mutual information which is a generalization of correlation indicates a relation in frequency beyond the bandwidth of individual spikes. The scans in the spectrograms with large mutual information also show a low level of Shannon information and algorithmic complexity, indicating that the simultaneous appearance of spikes at other frequencies is not a completely stochastic phenomenon (white noise). It may be caused by a nonlinear deterministic system or by a Markov process. By means of mutual information we find a memory over frequency intervals up to 60 MHz (Fig. 2). Shannon information and algorithmic complexity, however, describe spike events as a whole, i.e. a global source region. A global organization is also apparent in quasi-periodic changes of the Shannon information and algorithmic complexity in the range of 2 – 8 seconds (Fig. 3).

This finding is compatible with a scenario of local organization in which the information of one spike event spreads spatially and hence triggers further spike events at different places. The region is not an ensemble of independently flashing sources, each representing a system that cascades in energy after an initial trigger. On the contrary, there is a causal connection between the sources at any time.

The analysis of four spike events suggests that the simultaneous appearance of spikes is not stochastically independent but a process in which spikes at nearby locations are simultaneously triggered by a common exciter.

We have shown in the case of spikes that quantities from nonlinear dynamics used in this paper are helpful in detecting structural properties of complex spatio-temporal patterns. This approach seems to be promising also for several other astrophysical applications.

Key words: Radio radiation of the sun – Solar bursts – Data analysis

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Fig. 1. Dynamic spectrograms of millisecond spikes. The data was recorded by the frequency-agile solar radio spectrometer in ETH Zürich on 6 June, 1983 (Event 1: 389 channels, 740 scans, time resolution 0.2 sec). Low flux: bright. High flux: dark.

Fig. 2. Average of the 740 single mutual information estimates obtained from the symbol string pattern which is obtained from the solar data from event 1 (Fig. 1).

Fig. 3. Algorithmic complexity estimates obtained from the same symbol string pattern mentioned in Fig. 2