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Variations in Fractal Characteristics of Active Regions and Flares

A. A. Golovko and I. I. Salakhutdinova

Institute of Solar–Terrestrial Physics, Russian Academy of Sciences, Siberian Branch, P.O. Box 4026, Irkutsk, 664033 Russia

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Abstract—A multifractal analysis of the Hα images for an active region has been performed; the singularity spectra and segmented images for a narrow range of fractal dimensions have been computed for them. The segmented images show the presence of singular areas where the singularity index takes on maximum values. These areas mark the active sites of flares.

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The influx of new data on the dynamics of the solar atmosphere, primarily narrow-band images in various spectral bands and lines, requires invoking new methods of analysis. In recent years, methods of nonlinear dynamics and, in particular, fractal analysis have been used intensively. This is because a developed turbulence exists in the solar atmosphere.

In contrast to mathematical fractals, whose structure is retained on any scales of its consideration, all natural quasi-fractal structures are the product of

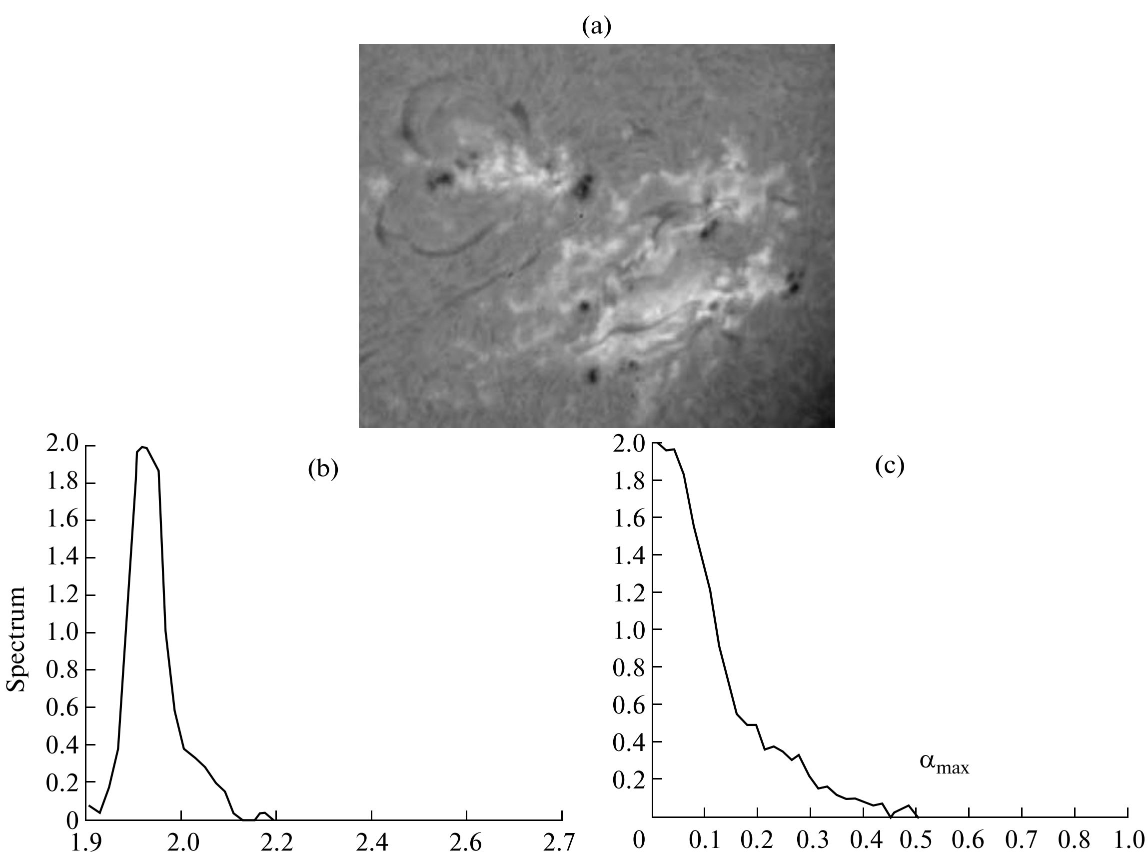

Fig. 1. (a) Filtergram of the activity complex on July 31, 2002 and multifractal spectra of this image for (b) μ_{sum} and (c) μ_{max}.

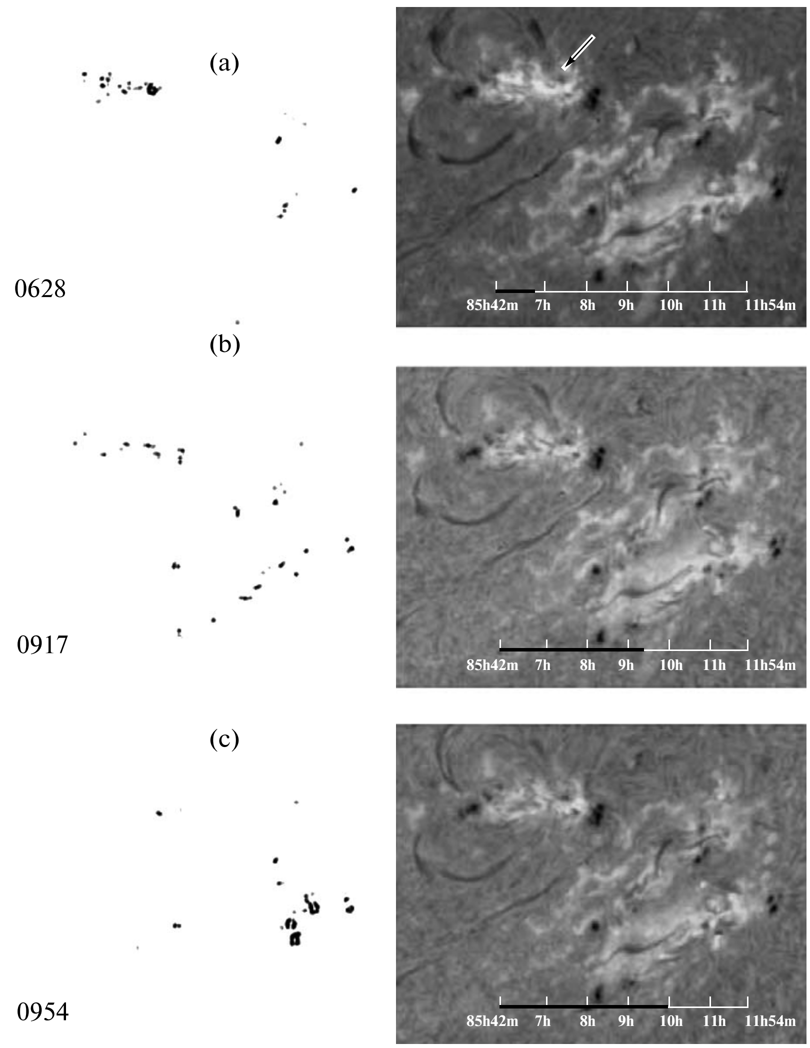

Fig. 2. Segmented images (left) and original filtergrams (right) for various times (a–c).

complex chaotic natural processes. Bak et al. [1988] suggested considering natural fractal structures as the instantaneous "cross sections" of self-organized critical processes (self-organized criticality—SOC) without any rigorous similarity.

In our previous papers [Salakhutdinova and Golovko, 2005; Golovko et al., 2006], we applied the method of structure functions to series of chromospheric line images. We investigated the variations in parameters of the structure functions at the preflare phase and found impulsive and quasi-periodic variations. These variations were revealed by simultaneously obtained Hα filtergrams and images obtained on the TRACE satellite in the FeXI 171 Å line of the transition zone, which proves their solar origin.

The fractal parameters estimated from the structure functions describe the object under study statistically as a whole and it remains unclear in which areas of the active region the changes associated with flares occur. To answer this question, here we apply different methods of analysis—the method of calculating the singularity spectra that was first used in heliophysics by Lawrence et al. [Laurence et al., 1993] and the microcanonical method of multifractal analysis developed in [Levi-Vehel and Vojak; Kruglun et al., 2007], which is consistent with it.

This paper is based on the July 31, 2002, observations with the Baikal Astrophysical Observatory chromospheric telescope in the Hα core.

Here, we use the microcanonical formalism based on the estimates of parameters in a close vicinity of the current image point. If the natural system under study is multifractal within the framework of the microcanonical formalism, it is such in accordance with the canonical approach [Kruglun et al., 2007].

In practical calculations, we used the Fraclab 1.1 package [http://www/irccyn.ec-nantes.fr/hebergement/FracLab/] to compute the multifractal spectra and segmented images.

Figure 1 shows the original image (a) and the Hausdorff multifractal spectra $f(\alpha)$ computed for the sum measure μ_{sum} (b) and Choquet capacity μ_{max} (c). The Choquet capacities are the simplest generalization of the measure and a multifractal analysis is applicable for them [Kruglun et al., 2007]. Here, α is the singularity index and f is the Hausdorff fractal dimension. The spectra at maximum reach the dimension of a plane figure ($f_{max} = 2$), i.e., the entire image. The spectrum for the sum measure has the typical shape of a bell. Its narrowness reflects a small range of contrasts of the original images. The spectrum for μ_{max} resembles a monotonically decreasing function—the right half of a Gaussian bell, although it approaches a straight line of the form $y = 2 - ax$, where $a > 2$, for some of the images in the series.

Although the spectrum $f(\alpha)$ is continuous, its different parts describe different structures in the original image. The region $f < 1$ describes discrete island structures that degenerate into dust when $f \longrightarrow 0$; the singularity index for them reaches its maximum value.

Since the upper boundary of the spectrum α exhibits temporal variations that almost coincide with those detected in [Salakhutdinova and Golovko, 2005], we chose the range $f = 0$–0.4 to construct the segmented, i.e., filtered out from the original image, distributions.

Figure 2 presents three segmented images (left panels) and the original Hα images (right panels). The activity complex under study consisted of an eastern component, the young AR 10050, and a western component, the close AR 10039 (left) and AR 10044 (right).

Only the black areas in which the singularity index is high are seen in the segmented images. These "singularity clusters" or "dust clusters" somehow mark the active sites of flare activity. As can be seen from Fig. 2, different parts of the complex are active at different times (indicated by the arrows). Bringing the segmented images into coincidence with the original filtergrams shows that the dust clusters are located near the kernels of flare emission. At the same time, there exist clusters located far from the emission features.

The above analysis led us to the following conclusion. The segmented images obtained by a multifractal analysis of the chromospheric images for an active region at minimum fractal dimensions reveal singular areas with a maximum singularity index (dust clusters) marking the active sites of flares.

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