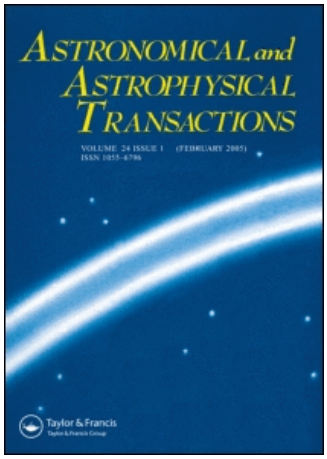

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O. V. Chumak [a]; Z. N. Chumak [a]
[a] Fesenkov Astrophysical Institute, National Academy of Sciences of Kazakhstan, Alma-Ata

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SUNSPOTS. THE MODEL OF "ELASTIC SCELETONS". ESTIMATION OF SUNSPOT UMBRA FRACTAL DIMENSION

O. V. CHUMAK and Z. N. CHUMAK

Fesenkov Astrophysical Institute, National Academy of Sciences of Kazakhstan, 480068, Alma-Ata

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On the basis of observational data, we estimated the fractal dimension of the solar spot umbras is made. The estimation is obtained using the method of "cross-section area – outline length" and it is equal to 1.35 ± 0.03. This value of the fractal dimension corresponds to turbulent structures of the "elastic sceletons" type.

KEY WORDS Sunspots, fractal dimensions

1 METHOD

There exist different methods for the evaluation of fractal dimensions of natural structures. One of them is an analysis of such ratios as surface-to-volume or cross-section area-to-outline length. This method has wide applications in various cases: for the study of laboratory turbulence, in the analysis of fractal structures of the storm clouds with strong convective fluxes, in the numerical simulation of clusters of correlated magnetic moments in the Ising model, and others (Proc. Sympos., 1986).

In this article the relation connecting the area of spot umbras S with its outline length L is analized:

$$S \sim L^q. \tag{1}$$

In the area of the spot umbra is fractally dependent on the outline length, than the index q is connected with fractal dimension of this structure d, with the relation:

$$q = \frac{2}{d}. \tag{2}$$

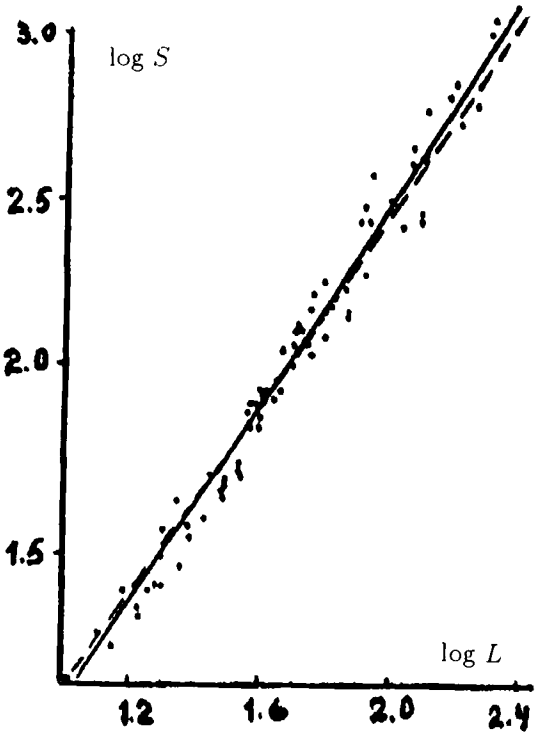

Figure 1

2 THE OBSERVATIONAL DATA AND THE RESULTS

The measurements areas and outline length of 79 spot umbras of different sizes are the basis of this study. The large-scale photographs of spots with high spatial resolution were obtained using the photoheliograph in the Astrophysical Institute of the Kazakh Academy of Sciences. The characteristics of the instrument were described by Minasiants *et al.*, 1993; Chumak *et al.*, 1993. The photographs were selected for the measurements according to two criteria: 1. Sunspots must be located near the central meridian, to make it possible to neglect geometric distortions. 2. The contrast of details should be as high as possible.

From (1), we have: $\log S \sim q \cdot \log L$. The correlation between $\log S$ and $\log L$ is shown in Figure 1. The solid line passing through the cloud of points was obtained using a east-squares solution. Thus, $q = 1.56 \pm 0.09$, and, from (2), $d = 1.28 \pm 0.08$.

It should be noted that atmospheric distortion of the picture, which one can see in many photographs, has an influence of different kinds on the measured values of areas and outline lengths of spot umbras: for the areas the distortion leads to increasing absolute and relative errors of measurements; for the outline lengths, besides, it leads to decreasing the values of L, because of "smoothing" the thin,

indented structure at the boundary between umbra and penumbra. This effect increases the value of q and, in such a way, leads to decreasing d.

For the estimation of the influence of the atmospheric distortion effect on the value of d, we selected the photographs in which, according to visual evaluations, the distortion was minimal. The number of such photos appeared to be 23. The line obtained using a east squares solution is shown in Figure 1 as a dashed line. In this case $q = 1.48$ and $d = 1.35 \pm 0.03$, that is possibly closer to reality than the previous value.

3 DISCUSSION

The obtained value of the fractal dimension is interesting in the sense that it corresponds to the structures known in the percolation theory under the name "elastic skeleton" (or frame-work). Such structures can appear in a wide range of scales: in the laboratory turbulence, at scales of the order of 10 m; in clusters of galaxies the scales are about 10 Mpc (Bershadskij, 1990).

The magnetic flux observed in the solar photosphere is probably generated by the dynamo process during nonstationary convection of the solar plasma (Priest, 1982). Moreover, significant part of the magnetic field having an accidentally distributed vector, which is connected with irregular microturbulent motions. However, the major part of the flux, as observations shown (Obridko, 1985), is concentrated in magneto-flux tubes having a large range of cross sections and, approximately, the identical density of the magnetic flux (Proc. Symp., 1987). The sunspots are the most developed representatives of such regular structures. However, there is a critical concentration for numerous clusters to appear from turbulized cells (Bershadskij, 1990). The magnetic moments in such a cluster can be regulared, approximately so as it is realized in the Ising model.

A correlation of the magnetic moments will lead to increasing magnetic flux density in such aggregates like it takes place when separate current coils are united into a bobbin. So, the initial weak chaotic field in such structures can be sharply enhanced.

From the point of view of energy transfer when the penetrating clusters appear, the situation also sharply changes: if earlier the energy coming from the central regions of the Sun into the convection zone was expended increasing the number of turbulized cells and the subsequent dissipation of them, then after the penetrating clusters appearance the energy can be transferred along these cells from the region of the turbulent motion to "infinity" (Bershadskij, 1990). In other words, in our case, it is transferred through the convection zone into the photosphere. The process of enhanced energy transfer in active regions, as known, is registered by observations. The essential stability of sunspots finds a natural explanation.

It is known that in the presence of clusters the concentration of turbulized cells can increase because damping under the influence of viscosity gets the chance to be compensated by the incoming energy flux. So, the nonequilibrium structure becomes self-sustaining.

It is natural that only such cells will be in the turbulized state, which are provided with a constant energy inflow, namely, the cells located on the dead-end branches of the cluster. The cells located on the dead-end branches will damp.

The whole complex of penetrating branches of the cluster is named sceleton (frame-work). Sceletons are stable structures in percolating media. The sceletons are fractal objects. The value of fractal dimension equal to 4/3, corresponds to "elastic sceletons", i.e. ones in which the shortest routes connect the most distant points (Bershadskij, 1990). The value we obtained, corresponds, rather exactly to the "elastic sceletons".

It should be noted, in conclusion that appearance of penetrating clusters is a critical phenomenon and may be connected with phase transitions. The simple model, which shows such transitions is proposed by one of the authors (Chumak, 1989a; Chumak, 1992).

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