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Supergranulation and its Activity Dependence

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Abstract. We study the complexity of supergranular cells using the intensity patterns obtained at the Kodaikanal solar observatory during the solar maximum. Our data consists of visually identified supergranular cells, from which a fractal dimension D is obtained according to the relation $P \propto A^{D/2}$ where A is the area and P is the perimeter of the cells. We find a difference in the fractal dimension between the active and the quiet region cells which is conjectured to be due to the magnetic activity level.

Keywords. Sun: granulation —-turbulence

1. Introduction

Heat flux transport is chiefly by convection rather than by photon diffusion in the convection zone of all cool stars such as the Sun, the thickness of convection zone being 30% of the solar radius below the photosphere (Noyes 1982). Convection is revealed predominantly on two scales– on the typical scale of 1″-2″ as granulation, and on the typical scale of 30″-40″ as supergranulation. The typical lifetime of supergranular cell is around 24 hours.The horizontal motions of the supergranular cells transport magnetic flux from the central upflow region in the cell to the edge, where the resultant production of excess heat at the chromospheric level traces out the supergranular network (Kosovichev 2007).Supergranules are characterized by typical horizontal speeds of $0.3 - 0.4$ km s^{-1}. Fractal analysis is a valuable mathematical tool to quantify the complexity of geometric structures and thus gain insight into the underlying dynamics. Fractal analysis was first adopted by Roudier and Muller (1986) to study the complexity of solar granulation. In the context of supergranulation, fractal analysis can shed light on the turbulence of magneto-convective processes that generate the magnetic structures (Stenflo and Holzreuter 2003;Lawrence,Ruzmaikin and Cadavid 1993). For our purpose, fractal dimension D is characterized by the area-perimeter relation of the structures (Mandelbrot 1977). Self-similarity, meaning the same degree of complexity regardless of the scale at which the structures are observed, is expressed by a linear relationship between $\log P$ and $\log A$ over some range of scales. A fractal analysis helps quantify the supergranular irregularity, which can shed light on the nature of solar turbulence (Paniveni *et al.* 2005).

2. Data Analysis

We analysed intensity data, consisting of Ca II K filtergrams (λ = 3934 Å) of the Sun, obtained between 16th May 2001 and 26th August 2001, during the solar maximum phase of the 23rd Solar cycle at the solar observatory, Kodaikanal. The images have

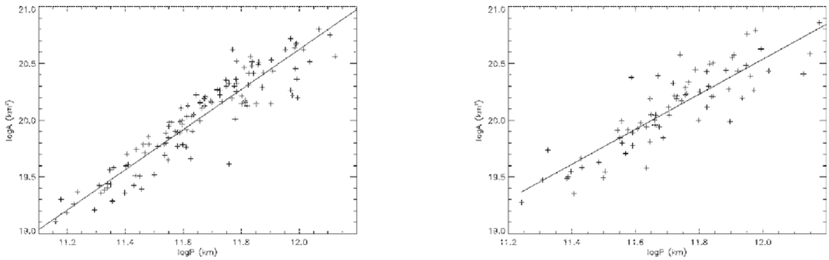

Figure 1. (a) Left : Plot of the natural logarithm of the supergranular area (in sq.km) against the natural logarithm of perimeter (km) in the Active Region (b) Right : Plot of the natural logarithm o the supergranular area (in sq.km) against the natural logarithm of perimeter (km) in the Quiet Region

a resolution of about $2''$, which is twice the granular scale. Only cells lying within $60°$ angular distance from the disc centre were selected in order to minimize projection effects. Cells close to the sunspot or plage region were identified as active region cells and cells away from these were noted as quiet region cells. We analysed 152 active region cells and 87 quiet region cells. We chose a fiducial y-direction on the cell and performed intensity profile scans along the x-direction for all the pixel positions on the y-axis. In each scan, the cell extent is taken to be marked by two juxtaposed 'crest'(separated by a 'trough') as expected in the intensitygrams. This set of data points was used to determine the area and perimeter of a given cell and of the spectrum of all selected supergranules. The area-perimeter relation is used to evaluate the fractal dimension.

3. Results and Discussion

The $\log(A)$ vs $\log(P)$ relation is linear as shown in the Figure1(a) for the active region. A correlation co-efficient of 0.94 indicates strong correlation. Fractal dimension D calculated as 2/slope is found to be 1.12 ± 0.07.The $\log(A)$ vs $\log(P)$ relation is linear as shown in the Figure1(b) in the quiet region. A correlation co-efficient of 0.88 indicates strong correlation. Fractal dimension D calculated as 2/slope is found to be 1.25 ± 0.14. The linear relations of both Figure1(a) and Figure1(b) suggest that supergranules are self-similar and can be regarded as fractal objects. According to Mandelbrot (1975), an isosurface has a fractal dimension given by $D_I =$ (Euclid dimension) - 1/2 (exponent of the variance). The pressure variance $\langle p^2 \rangle$ is proportional to the square of the velocity variance i.e. $\langle p^2 \rangle \propto r^{4/3}$ (Batchelor 1953).The fractal dimension of an isobar is found to be $D_p = 2 - (1/2 \times 4/3) = 1.33$. Our data furnishes an average fractal dimension of nearly $D = 1.21$ which indicates that the supergranular network is close to being an isobar.

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