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SUPERGRANULATION – A CHAOTIC PHENOMENON

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ABSTRACT
The complexity of supergranular cells is studied by using intensity patterns from Kodaikanal solar observatory. The turbulence of the solar supergranulation can be studied by examining the interrelationships amongst the parameters characterizing supergranular cells namely size, horizontal flow field, lifetime, area, perimeter and its fractal dimension. The Data consist of visually identified supergranular cells, from which a fractal dimension ' D' for supergranulation is obtained according to the relation $P \propto A^{D/2}$ where A is the area and P is the perimeter of the supergranular cells. I find a fractal dimension close to about 1.3 which is consistent with that for isobars and suggests a possible turbulent origin. The findings are supportive of Kolmogorov's theory of turbulence. A dependence of the area of supergranular cells with respect to the Latitude is also studied and it is found that the cells are situated symmetrically about the 25^0 latitude. Fractal dimension of the supergranular cells also shows a latitudinal dependence, variation being in the range 1.7 -1.8 in the latitudinal limits of $\pm 30^0$ for solar min data and 1.15-1.2 for solar max data. Since supergranular cells are essentially a manifestation of convective phenomena, they can shed light on the physical conditions in the convection zone of the Sun. Moreover supergranules play a key role in the transport and dispersal of magnetic fields as it is an important step in our quest to understand the solar cycle.

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INTRODUCTION

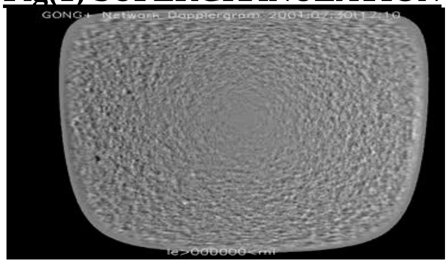
Heat flux transport is chiefly by convection rather than photon diffusion in the convection zone of all cool stars such as the Sun. The convective motions on the Sun are characterized by two by two prominent scales: the granulation with a most probable size of 1000 km and the supergranulation with a predominant size of 30000 km. The supergranules are characterized by horizontal outflow along the surface, Heat flux transport is chiefly by convection rather than photon diffusion in the convection zone of all cool stars such as the Sun. The convective motions on the Sun are characterized diverging from the cell centre and subsiding flow at the cell borders (Fig.1). Broadly speaking supergranules are characterized by the parameters namely the length scale L, lifetime T , horizontal flow velocity v_h , Area A and Perimeter P .

The interrelationships amongst these parameters can shed light on the underlying convective processes. (Paniveni et al, 2004, 2005, 2010).

SOURCE OF DATA

Ca II K intensity data obtained from Kodaikanal Solar Observatory in 1999 has been used. The Kodaikanal Intensitygram is obtained with a resolution of 2" which is twice the granular scale. Further, the data is time averaged over an interval of 10m which is twice the 5m period of oscillation. Thus the signal due to granular velocity is averaged out. Similarly, the contributions due to p-mode vibrations are reduced after time averaging. Accentuation of the supergranular cell is borne out by visual inspection. Corrections due to solar rotation are applied to the Dopplershifts. Well defined cells lying in between 15^0 and 60^0 angular distance limits are selected in order to discount weak granular flow signature and

Fig(1) SUPERGRANULATION



DATA PROCESSING

The profile of a visually identified cell was scanned as follows:
A fiducial y- direction was chosen on the cell and velocity profile scans were performed along the x-direction and this was done for all the pixel positions on the y-axis. The cell extent, in each scan, is considered as marked by the two adjacent crests separated by a trough expected in the Dopplergram. These data points were 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 (Krishan et al., 2002). The area and perimeter analysis was carried out for different cells at different latitudes. The latitudinal position of each one of the cells was noted. All these parameters are evaluated using IDL codes.

RESULTS AND DISCUSSION

There is an unsymmetrical variation of cell sizes with latitudes (Figure 2) when plotted using the solar maximum data. The plot shows approximately N-S symmetry with two minima at about 25^0 N and 25^0 S . For the solar maximum data, fractal dimensional variation with latitude is minimal with the variation being in the range 1.15-1.2 in the latitudinal limits of 30^0 N and 30^0 S (Figure 3). For the solar minimum data, fractal dimensional variation with latitude is low with the variation being in the range 1.7-1.8 in the latitudinal limits of 30^0 N and 30^0S (Figure 4).
Fractal dimension varies strongly with size. Variation is not consistent per different data sets. There is also an unsymmetrical variation of cell sizes with latitudes (Figure2). The plot shows approximately N-S symmetry with two minima at about 25^0 N and

25^0 S. It was conjectured that this could possibly be due to the network field enhancements which closely follow the sunspot field (Harvey et al.,1994). Variation of Fractal dimension with latitude is minimal with the variation being in the range 1.15-1.2 for solar maximum data and 1.7 -1.8 for solar minimum data, both in the latitudinal limits of 30^0 N and 30^0 S (Fig (3)). For this data, the average area a = 209.5 Mm^2 with variance = 12188.4 (σ = 110.401).
Similar work is done by Raju K.P. et. al.(1998) .They have used CaK line spectroheliograms obtained during the solar minimum phases at Kodaikanal between 1913 and 1974 to study the network cell sizes. They have calculated the AC for 2D strips for 5 deg interval upto ± 50 deg Latitude. But their symmetrical pattern shows minima at 20^0 N and 20^0 S . They have adopted the autocorrelation technique and the curves are obtained by sliding the image in a direction parallel to the solar equator. The small variation could be due to the change in the phase of the solar cycle. So, it appears that while most authors agree that the supergranular sizes decrease from the equator to poles, the question of the dependence of cell length scales on the solar activity is yet to be ascertained. The decrease of supergranular sizes towards higher latitudes is in accordance with the latitudinal variation of convective flux as predicted from models (Gilman, 1981). The network field enhancements result in the minimum supergranular sizes because there is a theoretical calculation which indicates that the enhanced fields will lessen the supergranular cell sizes (Chandrasekhar, 1961). Another strengthening factor is that supergranular cells show a dependence on the solar cycle with a reduction of sizes at the solar maximum phase (Singh and Bappu, 1981; Ermolli et al.1998) and hence the fractal dimension.

CONCLUSION

There is an unsymmetrical variation of cell sizes with latitudes. Again, fractal dimension varies strongly with size. Also there is a non-monotonous variation of the fractal dimension with area. Variation of fractal dimension with solar cycle is one of the most important results and models should be able to reproduce this type of results to be realistic.

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Fig (2) AREA VS LATITUDE

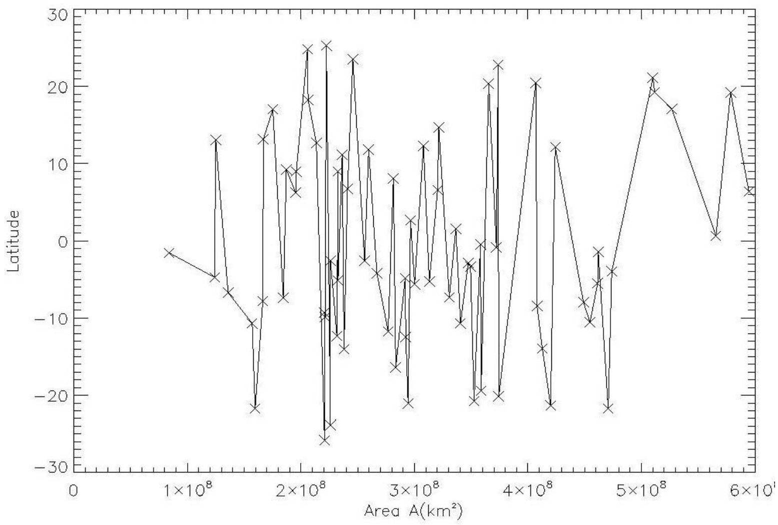

Fig (3): FRACTAL DIMENSION Vs AREA (Solar maximum)

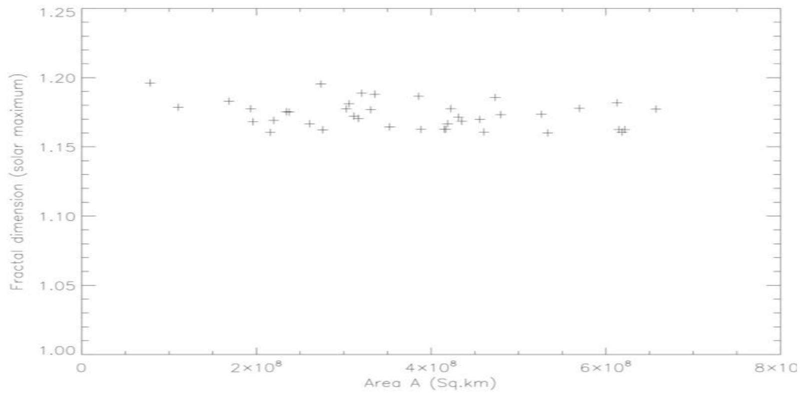

Fig (4): FRACTAL DIMENSION VS AREA (solar minimum)