PROPERTIES OF SOLAR GRANULATION CELLS IN QUIET REGIONS AS DERIVED FROM A TIME SERIES OF WHITE LIGHT IMAGES

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ABSTRACT. In this work we study the cellular pattern of granulation cells in quiet regions near the center of the Sun, using a time series of high spatial resolution white light images, obtained at the Vacuum Tower Telescope (VTT) at the NSO/SP in October 1996. As definition of boundaries of granulation cells we used the skeleton of dark intergranular lanes. We find a characteristic scale of granulation cells of 1.1 to 2.1 arcsec. The cells are regular in shape, slightly flat, and isotropically orientated on the Sun.

1. Introduction

Looking at the surface of the Sun we observe small scale motions, known as solar granulation, that produce a pattern of bright granules surrounded by dark intergranular lanes. These motions, deriving from the overshoot of convective elements produced in the convection zone, overturn in about 10 minutes and are roughly 1500 km across. Various, simplified models of turbulent compressible convection have been presented in the literature in the last few years (see, e.g., Brummel, Hurlburt and Toomre, 1996). Such models cannot yet take into account all the minuscule details observed on the solar surface but can, nevertheless, reproduce situations pertaining to the actual observations. A statistical approach to the definition of the geometrical properties of granulation, and to the characterization of associated velocity and intensity patterns, provides a useful tool to test the model results.

A statistical approach needs an automatic procedure to extract and characterize a high number of granulation cells and to remove possible “observer dependence” in their identification. Several numerical algorithms have been developed to define cells (Title et al., 1989, Schrijver, Hagnaan and Title, 1997; Hirzberger et al., 1997; Berrilli, Florio and Ermolli, 1998; Florio and Berrilli, 1998). In the following we will adopt the algorithm of Florio and Berrilli (1998) to define the boundaries of the granular cells. This algorithm
Fig. 1. Granulation sub-field (32″ × 32″) with superimposed the skeleton (light line) of intergranular dark lanes.

uses the skeleton of dark intergranular lanes, i.e. follows the minima of the intensity distribution, to derive the contour of a granular cell. Over 30,000 cells singled out from a sample of the original dataset will be used to study the photospheric convection pattern.

2. Observations and image-processing algorithms

A sequence of white light images (WL) was acquired at the VTT/NSO (Sacramento Peak), on October 16, 1996, from 14:30 UT to about 16:30 UT. Seeing conditions were excellent, and the use of the NSO/SP granulation tracker allowed a further improvement of the image stability. For a great part of the sequence, the images are nearly diffraction limited (0.19″, about 140 km on the Sun). A portion of the quiet Sun at disk center was imaged through an interference filter at 550 nm, with 10 nm FWHM. The images were recorded with a 8-bit camera, 1360 × 1036 pixels, equipped with an automatic frame selection system, and each image was acquired with an exposure time of 8 ms. The total interval between successive images was 4.7 s. A sub-portion of 1024 × 1024 pixels made up the final images; the image scale was set at 0.123 arcsec/pixel, for a total field of view of about 2×2 arcminutes. The sequence analyzed for the present work includes about 1300 images, for a total observing time of 1h 40 m. After the standard dark current and flat field corrections, we applied a destretching algorithm to remove the atmospheric distortions in the white light images.

As shown by e.g., Title et al. (1989), the 5-minute oscillations must be removed from the intensity images before analyzing the granulation pattern. We hence applied a 3-dimensional Fourier filter in the $k - \omega$ domain, that removed all Fourier components with $\omega/k > 4.7$ km s$^{-1}$. 
Fig. 2. Histograms show: a) the granular cell scales distribution, b) percentage of covered area by granulation cells as a function of their scale. The scale is defined as the square root of the area.

We analyzed the granulation properties over few selected images of the resulting sequence, taken approximately every 10 minutes. This temporal interval allows statistical independence of the granulation pattern in each image. The cell finding procedure extracted from these images the boundaries of over 30,000 cells, defining the skeleton of dark intergranular lanes. In Figure 1 we report an example of the correspondence of the cell boundaries, as extracted by the algorithm, and the intergranular lanes. We then measured different geometrical properties (i.e. area, perimeter, barycenter coordinates and orientation) of each identified cell. Furthermore, we proposed a multifractal analysis of these data. The aim of this approach is to reveal and characterize the disomogeneity of the temperature fluctuation field (data not shown here) as evaluated from the luminosity field. In particular the purpose of the multifractal analysis is to reveal the existence of a hierarchy of scaling indices due to the different local scaling properties of the data (Paladin and Vulpiani, 1987).

3. Discussion

From the analysis performed on more than 30,000 granulation cells we derived informations about the distribution of the granulation cells sizes and their orientation and shape.

The histogram of Fig. 2a, composed of 700 bins, shows the size distribution. We observe an increase in the number of cells towards a size of 1 arcsec and a drop at a value of about 2 arcsec, equivalent to a scale of 1.4 Mm. The shape of the curve is more gentle, with respect to that of Hirzberger et al. (1997), but the changes in slope are located at the same values. By using this distribution we evaluated the fractional contribution to
the whole area from cells of different size. The normalized histogram of Fig. 2b shows that the cells with scales ranging from 1.1 to 2.1 arcsec contribute to cover about 70% of the whole surface. This distribution is important to define a characteristic scale of granulation cells, since it implies that even if a number of small cells remain unresolved, their contribution to the total area is small.

Spherical shell global simulations of the convection zone (i.e. Gilman and Miller, 1986) predict "banana cells" oriented in the polar direction. To search for a possible anisotropy in the cell orientation we derived the cell dimensions in the four directions (polar, equatorial and diagonals). In Table 1 we report the arithmetic mean of cell size (first row) and the percentage of cells (second row) for different orientations. We found an upper limit of 2% for the anisotropy of the cell orientation.

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<th>Tab. 1 - Granular cell orientation</th>
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<td>size (arcsec)</td>
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Finally, we analyzed the cell shape using two different geometrical descriptors. The fractal dimension, derived from a perimeter versus area log-log plot, gives a value of 1.10. The ratio \( L_{\text{max}} / L_{\text{ortho}} \) between the longest dimension and its orthogonal dimension gives a value of 1.41. The values found imply that the granular cells are regular in shape, slightly flat and randomly orientated.

We started to expand our characterization of the granulation taking into account different types of scaling exponents such as multifractal exponents for temperature fluctuations. A first analysis seems to evidence that the temperature fluctuations in the solar photosphere have an intermittent character due to an inhomogeneous distribution of the temperature. In particular the existence of a non-trivial singularity spectrum, which reflects the existence of a hierarchy of dimensions, could be an indication for the occurrence of a turbulent convection in the solar photosphere.

References