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The multiscale nature of magnetic pattern on the solar surface

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Abstract. Multiscale magnetic underdense regions (voids) appear in high resolution magnetograms of quiet solar surface. These regions may be considered a signature of the underlying convective structure. The study of the associated pattern paves the way for the study of turbulent convective scales from granular to global. In order to address the question of magnetic pattern driven by turbulent convection we used a novel automatic void detection method to calculate void distributions. The absence of preferred scales of organization in the calculated distributions supports the multiscale nature of flows on the solar surface and the absence of preferred convective scales.

Key words. Sun:granulation, mesogranulation, supergranulation – Sun: magnetic fields – Sun: photosphere

1. Introduction

There is an ongoing debate on whether there is a continuum of sizes of the convection cells on scales above granular one, or mesogranular and supergranular scales are just the result of a collective interaction between families of granules (Nordlund et al. 2009).

Assuming that magnetic elements pattern on the solar surface reflects sub-photosperic turbulent convection, the magnetic field can be used as a proxy for the exploration of driving convective patterns (Yelles Chaouche et al. 2011). Indeed spectro-polarimetric observations, from space and ground-based telescopes, reveal the presence of *multiscale underdense magnetic regions*, commonly called *voids*, (Lites et al. 2008), which in full disk images appear a rather organized and reticulated pattern. Such network changes its characteristic when the magnetic field signal is observed at an higher resolution (e.g. figure 1, top) and the continuous cellular pattern is substituted by a collection of tiny aligned or clumped magnetic elements which produces highly branched and fractal-like patterns embodying isolated magnetic features.

Our work focuses on the question about if such low resolution network keeps its character also when observed at very high resolution and if the same underdense magnetic regions are organized on the solar ordinary scales (e.g., granulation, meso-granulation, supergranulation) when observed in detail. We seek the answer to this question by analyz-

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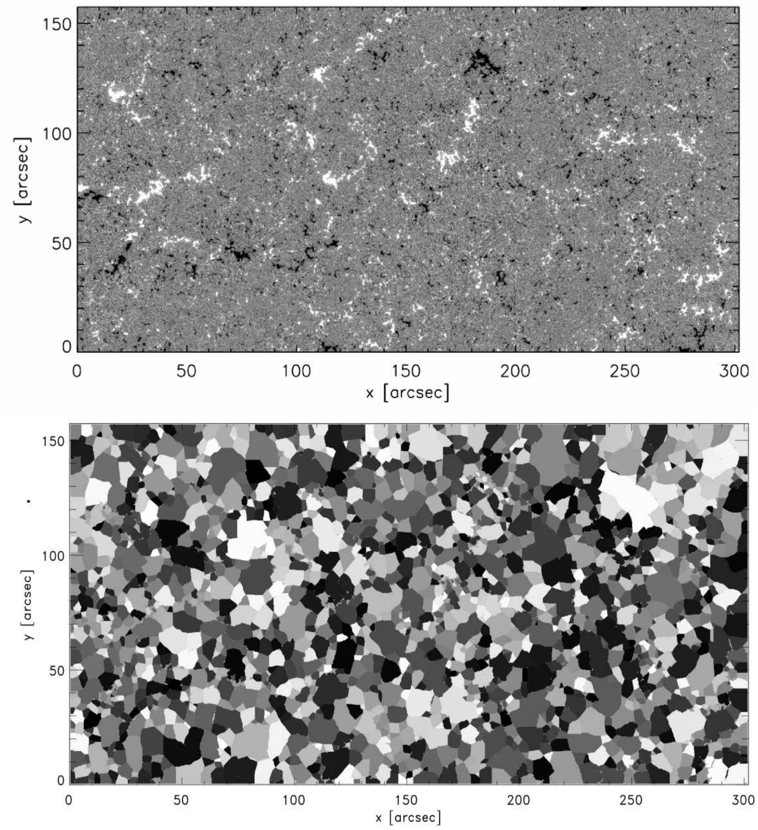


Fig. 1. Hinode SP line-of-sight high resolution magnetogram (top panel), voids pattern (bottom panel).

ing statistical properties of voids characteristic sizes.

2. Data and analysis

Void searching and analysis algorithms are largely used in cosmology to study the distribution of galaxies and cluster of galaxies in the Universe. Our goal is to identify voids in magnetic field of solar photosphere and compute their properties in an automated and objective manner, not biased by the human eye. To address the above question we employ the Void Probability Distribution (VPD). We define the *equivalent void diameter* as the diameter of the circle with the same area of the void, and the VPD the probability estimated by the frequency of voids equivalent diameters.

We analyzed first a high resolution magnetogram based on the spectropolarimetric measurements taken by the Solar Optical Telescope SOT/SP instrument aboard HINODE (Tsuneta et al. 2008; Viticchié et al. 2011) and already used in (Berrilli et al. 2013, henceforth BSG13). The image cover a 302×162 $arcsec^2$ portion of the solar photosphere observed at disk center on 10 March 2007, and with a plate scale of 0.1476 $arcsec\ pix^{-1}$ and 0.1585 $arcsec\ px^{-1}$.

On this image we used a two-dimension version of the void searching algorithm developed by Aikio and Mahonen (Aikio & Maehoenen 1998, henceforth AM98) on the Hinode SP line-of-sight high resolution magnetogram of figure 1. First we *binarized* the imagine by means of a given threshold and we get a sparse distribution of magnetic structures on the considered solar surface. In the binarized image we define a scalar field, called distance field (DF), as the distance of a given point to the nearest particle and look for all the local maxima of such field. Trivially we assumed that each voids encompasses several local maxima and apply the joining criterion described in AM98 and BSG13 to connect local maxima neighbor areas (subvoids) into a single void. The detected voids pattern is shown in bottom of Figure 1 and the resulting VPD is shown in figure 2 (top).

To improve the statistics of voids distribution on the solar surface we studied an unusually extended series of magnetograms of the Solar Oscillations Investigation/Michelson Doppler Imager (SOI/MDI) instrument, on board of the SOHO spacecraft (Scherrer et al. 1995). The MDI 1024×1024 CCD camera was observing in two spatial resolution modes: full disk (FD) and high-resolution (HR) modes. HR images cover a field of view of 11'×11' with a plate scale of 0.625" per pixels and a diffraction-limited resolution of 1.25". The dataset we used spans from January of 2008 to June 2009 and covers with an almost daily cadence the last minimum of solar activity, with a total of 510 magnetograms.

The most time consuming part of the original AM98 method is the "climbing algorithm" which finds for each pixel of the image the DF local maximum it belongs to, and throughout this maximum it assigns the pixel to the relative void. Our new *bubble method* assigns bubbles of pixels to each void. Each bubble is designed as a circle centred in a local maximum of DF and with radius equal to the DF value. The creation of bubbles for each local maxima would generate a number of partially overlapping circles. To avoid the merging of such circles an iterative bubbles creation algorithm is used. Starting from a binary image a first bubble around an absolute maximum of the DF is created and all the pixels inside the bubble are labeled as magnetic. Then a new DF is created and a new absolute maximum is detected with the relative bubble. The new bubble diameter is lower (or equal) than the previous one. The bubble collection fills the space of non magnetic pixels. The procedure is iteratively repeated until a resolution parameter (minimum bubble diameter) is reached. Lastly the bubbles are merged in voids by adopting the same climbing algorithm to the bubble centers only. This new method perform the voids construction about 25 times faster than the previous one, allowing us the exploration of large magnetogram datasets.

3. Results

The distribution of voids length scale for the HINODE/SP high resolution magnetogram is shown in figure 2 (top). We used a threshold equal to 3σ of magnetic flux ($\sigma = 65$ $Gauss$) to get this voids pattern.

The calculated distribution of these 1951 voids shows an exponential decrease between 2 and 10 Mm with a decay constant equal to 2.2 0.2 Mm and a coefficient of determination R2 = 0.98. The magnitude of R2 indicates a very high degree of correlation.

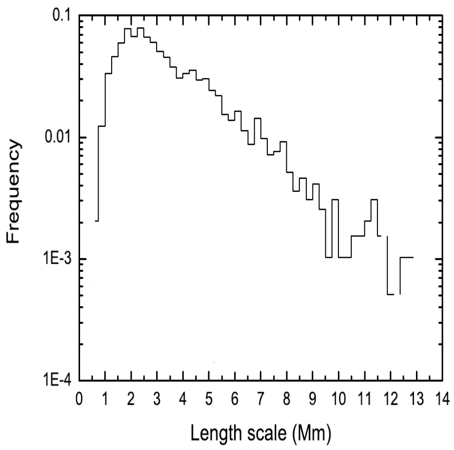
The absence of features at scales of 5-10 Mm indicates the lack of an intrinsic mesogranular scale likewise the results reported by Yelles Chaouche et al. (2011): it appears that mesogranulation is not among the primary energy-injection scales of solar convection.

With the large SOHO/MDI dataset, analyzed by our new voids detection method, we identified 252488 voids in the whole dataset, adopting a threshold of 45 Gauss (3σ). The mean voids length scale distribution is shown in figure 2 (bottom), together with a variability estimator evaluated through 1000 bootstrap sampling of the original images.

Again, the distribution shows an exponential low in the range 10-35 Mm and there is no evidence of intermediate scales.

4. Conclusions

We analized two ranges of scale of magnetic structure patterns on solar photosphere: the range 2-10 Mm from a single HINODE/SP magnetogram and the range 10-60 Mm from SOHO/MDI a magnetograms large dataset.



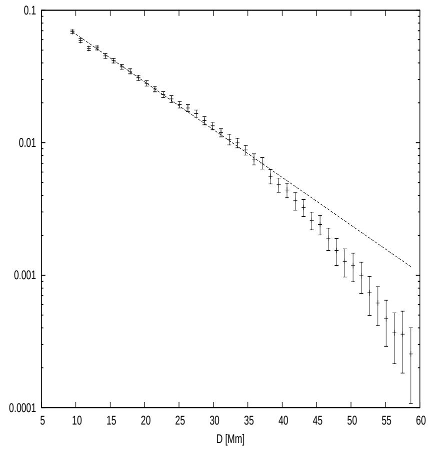


Fig. 2. Equivalent diameter distribution. Top: HINODE/SP 1951 voids. Bottom: SOHO/MDI 252488 voids.

In both the case we have no evidence of preferred organization scales on the considered intervals.

In particular, the HINODE/SP result shows an exponential decrease between 2 and 10 Mm with a constant decay scale. The absence of features at scales of 5-10 Mm suggests no evidence of preferred intermediate scale and the lack of an intrinsic mesogranular characteristic dimension of voids.

The unprecedented SOHO/MDI dataset extends the same conclusions up to a characteristic dimension of 35 Mm, where a faster decay rate in the distributions lets us suppose some change in magnetic organization dynamic. Because the less rich statistics over the 35 Mm edge, it is not clear if the decay keep being exponential or if it change its functional representation.

Unfortunately we can not just connect the HINODE/SP exponential to the SOHO/MDI one, because we suppose that different instrumental sensibilities and resolutions influence the decay rate in a non trivial way.

The issue of *the best* threshold in magnetogram binarization remains in debate and further efforts shall be spent to set up an acceptable instrument-independent segmentation criterion.

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