INTERACTION OF GRANULATION WITH THE 5-MIN PHOTOSPHERIC OSCILLATIONS

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ABSTRACT

We discuss the links between the photospheric 5-min oscillations and granulation patterns using a 30-min time series of CCD spectral images of solar granulation recorded with high spatial (0\textdegree 5) and temporal (9.3 s) resolution. The observations were carried out by one of us (Shchukina) at the Vacuum Tower Telescope in the Observatorio del Teide on Tenerife on August, 1996. The images contained Fe i 5324 Å line with good height coverage from the temperature minimum region up to the low photosphere. Our results confirm that strong oscillations are well separated temporally and spatially. We show that a response of the line intensity oscillations and a response of the velocity oscillations to the fine structure of the lower photosphere is clearly different. Amplitudes of the intensity oscillations above intergranular lanes are nearly two times larger than over granules. Amplitudes of the oscillations of velocity over granules and intergranules of the same brightness contrast are in fact equal. The intensity oscillations are dominated by higher frequency power while the velocity ones gain power in the lower band. The most energetic velocity oscillations turn out to occur over areas where the largest convective velocities are observed.

Key words: Sun; photosphere; granulation; oscillations.

1. INTRODUCTION

At the moment the solar local five-minute oscillations are widely believed to gain their energy from stochastic processes resulting from the turbulent convection just beneath the photosphere (Goldreich & Keeley 1977, Goldreich & P.Kumar 1988, Kumar & Goldreich 1989 and Goldreich et al. 1994). Moreover, Brown (1991) predicted that most of the acoustic emission could come from rare localized events, where convective velocities are the highest. Goode et al. (1992) associate these localized events with expanding overshoot granules. The latter authors interpreted observations of the solar velocity field made by Stebbins & Goode (1987) as consistent with their numerical simulations. Recent observations fulfilled by Espagnet et al. (1996) confirms that strong oscillations are well separated temporally and spatially. However, the most energetic oscillations turn out to occur only in expanding intergranular spaces with strong downflows. Rimmele et al. (1995) also located the aforementioned acoustic events in such intergranular spaces. On the other hand, analysing G-band granulation filtergrams Hoeksema et al. (1998b), Hoeksema & Rutten (1998) and Hoeksema et al. (1998a) have deduced “that the photospheric five-minute oscillations are primarily global and rather insensitive to the local fine structure”. We conclude that the issue of the links between Rimmele et al. (1998) also located the aforementioned acoustic events in such intergranular spaces. On the other hand, analysing G-band granulation filtergrams Hoeksema et al. (1998b), Hoeksema & Rutten (1998) and Hoeksema et al. (1998a) have deduced “that the photospheric five-minute oscillations are primarily global and rather insensitive to the local fine structure”. We conclude that the issue of the links between the local five-minute oscillations and granulation remains open. Here we tackle this issue once more using observations of spectral lines obtained with...
2. OBSERVATIONS AND REDUCTION

The observations were made by one of us (NGS) in August 1996 at the 70-cm German Vacuum Tower Telescope (VTT) at the Observatorio del Teide of the Instituto de Astrofísica de Canarias. We used CCD camera, which had 1024×1024 pixels, in 2×2 binning mode. The size of one binary pixel corresponded to 0.174 arcsec on the solar surface. The CCD images contained the Fe I 5324.185 Å line with good height coverage from the temperature minimum region up to the low photosphere (Shchukina & Trujillo Bueno 1998, Shchukina 1998). The spectral area recorded was 2 Å. The line was observed near the solar disk centre. Each overall image corresponded to an area on the solar surface about 0.38×0.89 arcsec². The spectrograms were taken every 0.3 s with integration time 5.7 s. The time series covered about 31 minutes and included 200 images in total. All 200 images were corrected for flatfield and dark current. For every spectral pixel row i (i = 1÷512) of every image j/j (j = 1÷200) we employed three line parameters. They are:

- a pixel position (wavelength) of the line core minimum $P(i,j)$;
- a line centre residual intensity $I_0(i,j)$;
- a continuum intensity $I_c(i,j)$.

The variations in $P(i,j)$ were transformed to the velocity variations $\delta V(i,j)$ with respect to the intensity minimum position in the time/space-average spectrum of the image. Please note, that everywhere in our study positive $\delta V$ values correspond to blue shifts of the line core (upward velocities). The intensity variations $\delta I_0(i,j)$ at the line center and at the continuum $\delta I_c(i,j)$ were also measured with respect to the time/space-average values. It was found that the velocity fluctuations $\delta V(i,j)$ in the Fe I 5324.185 line could be as large as 1 km/s and continuum and line center intensities fluctuate in the range 10 and 4 percent, respectively.

3. SEPARATION OF THE GRANULAR AND OSCILLATORY COMPONENTS

To separate the granulation and oscillatory components of velocity field, we plotted the velocity variations as a function of the temporal frequency $\omega$ and the spatial frequency $k$ (Fig. 1). Oscillations and convective motions

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Figure 4. 3D time evolution of the granulation brightness component $B = \delta I_c$ along the slit shown simultaneously with time variation of the square of the intensity oscillatory component $\delta I_o^2$. Light areas are granules, dark areas are intergranular lanes. The $\delta I_o^2$ isolines are 0.1, 0.2, 0.3, 0.5, and 1.0 in units of their maximum values. We define the granulation pattern as a granule if the value $\delta I_c$ is above the average value.

are clearly separated in the $k - \omega$ diagram by a minimum near $\omega = 1.9$ mHz (the period $T = 530$ s). We restricted the wave motions $\delta V_o$ by the frequency range $\omega = 1.8-5.7$ mHz (period $T = 120-560$ s) and the convective (granular) motions $\delta V_g$ by frequencies below 2.2 mHz ($T > 450$ s). The oscillatory and granular (convective) intensity components, $\delta I_o$ and $\delta I_g$, were separated in a similar manner.

5. "ARTIFICIAL" GRANULE

One of the ways to investigate the links between 5-min oscillations and granulation is to isolate an individual granule and intergranular lane and then to observe the evolution of oscillations above them. However, there are two problems:

- How to identify the same granulation structure during its lifetime lasting usually about two periods of 5-min oscillations?
- How to apply the methods of spectral analysis to such a short time series (~10 min)?

To overcome these problems we constructed an "artificial" spectrum of an granule and intergranular lane and followed its evolution in time. An important advantage of our approach as against deterministic one consists in avoiding all the problems of granule finding algorithm. In our case we tested spatially averaged oscillatory properties of the area of different brightness covered by the spectrograph slit on the solar surface. According our approach we splitted row spectra of each image into granular and intergranular ones using the spatially and temporally averaged continuum intensity as criterion. We assigned the rows to areas located above granules if its continuum were brighter than the mean one. We call them "bright" rows. The rows with negative granulation brightness were considered as spectra of areas located above intergranular lanes and were called correspondingly "dark". Finally, for each individual frame of the time series we averaged separately the bright and dark
Figure 6. Time evolution of the spatially averaged velocities measured in FeI 5254.185 Å line over areas located above bright (solid lines) and dark (dashed-dotted lines) continuum features with different brightness contrast $B$. Left panels: the oscillatory velocity component $\delta V_\nu$ (top) and the oscillatory intensity component $\delta I_\nu$ (bottom) per each contrast class. Right: the granular velocity component (top) and the granular intensity component (bottom). Numbers above curves indicate mean continuum brightness of contrast classes considered.

Row spectra, and found mean values of $\delta V_\nu$, $\delta I_\nu$, $\delta I_c$. The time evolution of these values above such "artificial" granules and intergranular spaces are plotted in Fig. 6. Following this way we introduced more refined classification of the brightness continuum differences. The bright and dark samples were splitted further into 6 brightness classes by combining the rows in the same class if an absolute value of their convective component of continuum intensity brightness (contrast) $B = \delta I_c$ exceeded some threshold. We have used thresholds for the bright rows in the range 1 - 5.5% and for the dark ones in the range from -1% to -5%.

Figure 6 shows that amplitudes of intensity and velocity oscillations increase with the absolute value of continuum brightness. Amplitudes of intensity oscillations over intergranular lanes are nearly two times larger than over granules of the same contrast $B$ while amplitudes of the velocity oscillations are in fact equal. We note that one of the disadvantages of our approach could be the change of angular degree $l$ with change of the contrast $B$ (Snider & Otten 1974, Tanenbaum et al. 1969). However, the more detailed study by Kostik & Shchukina (1999) shows that this is not the case.

Our results demonstrate that, on average, the bright continuum features cover a smaller fraction $S$ (47.8%) of the total area of the time series images in comparison with the dark ones. This result is in good agreement with recent studies of Hirschberger et al. (1997) and Hoeksema et al. (1998b). The higher the brightness of continuum features, the smaller is the area fraction $S$ covered by them. For the bright classes considered $S$ values range from 38.3% to 4.5%, while for the dark ones they decrease from 35.3% to 4.5%. Thus, the number of spectral rows per image in each class turns out to be sufficient for statistical analysis (Fig. 7).
Figure 7. $B - \omega$ diagram: the power of the velocity oscillatory component $\delta V_o$ (top) and intensity oscillatory component $\delta I_o$ (bottom) over "artificial" granules and intergranular lanes of different brightness. Right: for all frequencies. Left: for frequencies where the largest power is concentrated.
6. $B - \omega$ DIAGRAM

Figure 7 displays the B-w diagram for the “artificial” granular patterns. On the diagram power of oscillations are shown for different periods $T = 258$ s and $T = 312$ s. At the period $T = 312$ s (5-min oscillations) the power of velocity oscillations is distributed over the whole range of the granulation brightness; there is a little less power in the negative range. Around this period the power increases with absolute value of contrast: the velocity oscillations occur preferentially over bright areas of the granulation, especially over brightest parts, where the power is maximum. At $T = 258$ s there is much more power in the negative range than in the positive one. Unlike the velocity oscillations the most powerful intensity oscillations occur preferably over the darkest intergranular lanes for both periods.

7. CONCLUSIONS

We summarize our results as follows:

- The 5-min oscillations of the velocity and intensity near temperature minimum where the Fe I 5324.185 Å line is formed respond differently to the fine structure of the low photosphere.
- Amplitudes of 5-min velocity and intensity depend on brightness of granulation pattern. Large-amplitude intensity oscillations occur predominantly above dark intergranular lanes. The oscillations above granules are much weaker. Unlike the intensity oscillations, the velocity oscillations occur with equal probability above granules and dark lanes. The brighter or the darker the granulation pattern the larger are the velocity amplitudes.
- Oscillations above granules and intergranules occur with different periods. The power spectrum of intensity oscillations is dominated by higher-frequency oscillations while the velocity oscillations gain power in the lower-frequency band.

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