Time Series of Solar Photospheric Spectrograms
Bisector Analysis

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Abstract. Time series of spectrograms near solar disk center, obtained with the VTT telescope at the observatorio del Teide were analyzed. A 47 min time series was used to study the influence of oscillations on the behavior and variation of several line parameters, calculated from the line profiles.

1. Introduction

The convective overshoot of plasma flows from the solar convection zone into the photosphere produces to the well known phenomenon of solar granulation. Overviews about the properties of this phenomenon were given by Bray, Loughhead, & Durrant 1984, and Spruit, Nordlund, & Title 1990.

To study the evolution of the solar granulation time series of spectrograms or white light images are needed. However, it is very difficult to obtain long lasting high quality time series because of atmospheric seeing, image and telescopic motions etc. Since we want to study convective motions, oscillatory motions must be separated from convective overshooting. This is possible in the case of time series by applying a filter in the spatial-temporal domain (Title et al.1986). Furthermore, the use of a correlation tracker developed at the IAC (Instituto de Astrofísica de Canarias, La Laguna, Tenerife) guaranteed that always the same physical point on the sun was observed.

Parameters derived from such observations are needed for HD simulations. These can be divided into 2-D simulations (less accurate, however better spatial resolution, e.g. Nordlund (1976), Nelson (1978) (all are incompressible) and Steffen, Ludwig & Kruss 1989, Gadun (1995) (compressible)) and 3-D simulations (Nordlund (1982) (anelastic approximation in cont. equation), Stein and Nordlund (1989), Cattaneo, Hurlburt, & Toomre 1989, (fully compressible)).

2. Observations

We used a 1k×1k CCD to take solar photospheric line spectrograms at the 70 cm VTT (Schrötter, Soltau, & Wiehr 1985. The data consists of a 47 min time series the time interval between two successive spectrograms was about 20 s.
The entrance slit of the spectrograph covered a quiet region (this was checked by comparing with a $H - \alpha$ slit jaw), the spectrograph entrance slit width was set to 100$\mu$. The following lines were observed:

Table 1. Important parameters for the lines analyzed (Moore, Minnaert, & Houtgast 1966. 1966)

<table>
<thead>
<tr>
<th>Line</th>
<th>$\lambda$ [Å]</th>
<th>$W_\lambda$ [mA]</th>
<th>height [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>line I</td>
<td>6494.994</td>
<td>165</td>
<td>500</td>
</tr>
<tr>
<td>line III</td>
<td>6494.476</td>
<td>69</td>
<td>200</td>
</tr>
</tbody>
</table>

The pixel resolution was 0.11 arcsec in the spatial direction, the exposure time 1.5s. The image was stabilized using a correlation tracker (Bonet et al. 1994). Our data set consists of 501 points in the spatial direction and 141 points in the time direction.

Flat fields where obtained by drifting the telescope in the same spectral region. Transparency changes in the earth’s atmosphere were compensated by normalization of each spectrogram to its mean continuum intensity.

The line shifts were obtained from the profiles by a) finding the minimum using a 4th order polynomial fitting, b) reference to the positions of the terrestrial line.

Finally a 5 min oscillation filtering was applied (Title et al. 1989) using $\omega = 5k$. Such a filtering seems to be not correct from the mathematical point of view, since one needs a 2-D time series, which is not the case here. Our procedure was tested using a time series of 2-D images of solar granulation and applying the filter a) to the original 2-D time series and b) to successive 1-D rows of the time series and then reconstructing the image again. We found no remarkable difference between these two images (procedure a, b).

3. Results

If we average all bisectors over space and time and apply this process to the unfiltered and filtered data, we find no difference between the filtered and unfiltered mean bisector. This can be used as an indication that the process of oscillation filtering worked properly, since when averaging over time and space these oscillations should cancel. A similar result was obtained for the deeper originating line however, due its deeper formation height smaller asymmetries were observed.

Plotting the whole set of continuum fluctuations as a function of time and spatial coordinate we can see that there are regions where the continuum intensity was lower than the average (dark zones) and regions where the continuum intensity was higher than the average (bright zones).

In order to see if there is any difference between the influence of oscillations for bisectors arising mainly from bright granular areas and those arising mainly
from dark intergranular lanes during the time series, we depicted all bisectors arising from line profiles with a continuum intensity \( I > \bar{I} \), \( \bar{I} \) denoting the averaged continuum intensity, from the data set and call them granular bisectors and consequently all bisectors belonging to areas where \( I < \bar{I} \) as intergranular bisectors. The results can be seen in Fig. 1 for the higher originating line and Fig. 2 for the deeper forming line. In these plots we give also the results for the filtered data (dashed). It is clearly seen that the filtering has practically no influence on the "granular" bisectors, however, in the case of intergranular bisectors the asymmetries turn from red values (Fig. 1b, 2b full lines) for the unfiltered case to blue values for filtered data (Fig. 1b, 2b dashed lines). Thus the filtering process seems to influence only on the intergranular bisectors. In Figs. 1c, 2c we give also the so called mixed bisectors arising from zones where both higher and lower continuum intensities occurred.

In the following two figures we follow the evolution of a typical granulun and a typical intergranulum - again according to the above mentioned definition that in the case of a granulun the continuum intensity of the line profile must be greater than the average continuum intensity, \( I > \bar{I} \) and in the case of the intergranulum \( I < \bar{I} \). In order to show the variation of the individual bisectors, the bisectors were shifted by 2mÅ with respect to each other and numbered (only the even numbers are given here).
Figure 2. "Granular" bisector variations along a selected range from $\delta I$ fluctuations; a) line I, b) line I filtered, c) line III, d) line III filtered.

In Fig. 3 we give the bisector evolution for a typical granular evolution; as it can be seen these bisectors are from areas with enhanced $I$ values and have large blue asymmetries. Comparing the filtered bisectors with the unfiltered values the only difference is that in the cases for the filtered bisectors the arrangement seems to be better ordered and the bisector footpoints are stronger affected than the bisector endpoints. A similar trend but weaker can be observed for bisectors belonging to the weaker line III.

In Fig. 4 the bisector evolution is shown for a time interval during which the $I$ values are relatively small, that means we follow the bisector evolution over a dark region (intergranulum). For the unfiltered data, in both cases, line I and line III one clearly gets what can be called "intergranular bisectors" with relatively large red asymmetry values. However, one should note that after filtering these red asymmetries completely vanish and turn into a blue asymmetry again. By carefully comparing the plots for the unfiltered and the filtered bisectors it seems that one can obtain the unfiltered bisectors from the filtered ones by just shifting the endpoints to the read and the footpoints toward the blue.
Figure 3. "Intergranular" Bisector variations along a selected range from \( \delta I \) fluctuations; a) line I, b) line I filtered, c) line III, d) line III filtered.

Considering the absolute shifts we note that here the whole sample of filtered bisectors is shifted toward the blue with regard to the unfiltered bisectors. In the case of the example of bisectors given by Fig. 5 we notice a slight blueshift of the sample of filtered bisectors with regard to the sample of unfiltered bisectors. This trends are even more pronounced in the samples of the bisectors belonging to line III.

4. Discussion

Two important conclusions can be drawn from this paper: a) it is possible to use 1-D time series for appropriate filtering for oscillations and b) the influence of the filtering greatly affects line asymmetries of lines originating in the intergranular lanes whereas for lines that originate in the granulum the influence is very small. This can be regarded as a hint that oscillations are mostly concentrated in the
intergranulum, which was by different authors (e.g. see Goode et al. 1999 or
Rast, 1999).

The influence of convection on the p-modes was studied by many different
groups (e.g. Goldreich and Kumar, 1988) because it was found that convective
eddies may be the agent of oscillations. Bogdan (1989) gave a description of the
interaction of solar acoustic oscillations with convection from a theoretical point
of view and pointed out the interaction between sound and vorticity.

In the paper of Bonet et al. (1991) asymmetries and shifts of the solar KI
\(\lambda 7699\) Å line were studied. They found that a line profile calculated by granu-
lation models (using the code of Nelson,1978) does not match the observational
results and studied the influence of 8min period gravity waves on the line bi-
sectors. Introducing these oscillations into the calculation of the profiles they
found decreasing bisector asymmetries.

Rimmele et al. (1995) and Goode et al. (1998) report on seismic events that
are associated with the excitation of solar oscillations. They found that these
events are located in the dark intergranular lanes and that the seismic events
are preceeded by a further darkening of an already dark lane; on the temporal
end of the seismic event a still further darkening was also found.

In a theoretical study given by Rast (1999) the onset of instabilities in
downflowing intergranular areas are discussed. Such downflowing regions evolve
when a local heat reduction in vertical flows leads to net energy losses and two
kinds of instability occur: varicose and sinuous. The first one is compressive and
is caused by dynamic pressure fluctuations behind a plume leading to secondary
head formation. The second one results from shear instability of the stem flow.
Such formed pressure fluctuations are the cause of solar acoustic excitation.

Our results are in good agreement with these findings because we also found
that the oscillations are concentrated in the intergranulum.

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