TWO-DIMENSIONAL SPECTROSCOPIC TIME SERIES OF SOLAR GRANULATION:
EVOLUTION OF INDIVIDUAL GRANULES

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ABSTRACT

In this paper we investigate the dynamics of the solar granulation by analyzing time series of 2-D spatially highly resolved spectrograms. The high quality of the data permitted us to follow the evolution of individual granular and intergranular areas. We used scans over the solar surface in order to obtain a 2-D information. This has the advantage of achieving high spectral and spatial resolution, however one scan lasted for about 2 min.

Key words: Sun; granulation; evolution.

1. INTRODUCTION

The evolution of solar granulation is one of the key parameters to understand this phenomenon and one of the most critical properties that can be compared with theoretical models. It has been studied many times and the main motivation for these studies was to determine the lifetime of the granules.

Also morphological descriptions and studies of different birth and decay mechanisms were done. The values of the mean granular lifetime that can be found in the literature are quite diverging. For example Title et al. (1989) report about lifetimes between 6 and 8 min, Alissandrakis et al. (1987) found longer lifetimes of about 16 min when reanalysing previous data. Another important question concerns the evolution of the granules. Rösch (1962) found for the evolution of a typical granule the following: a granule increases in size until it reaches a typical diameter of about 2.0''. Then it starts to split into several fragments. Mehlbrecher (1978) found that granules can be found by fragmentation of preexisting granules whereas Dialetis et al. (1986) indicate that granules can also originate spontaneously from the intergranular background or can be produced by merging of preexisting granules.

Granules can be classified according to their evolution. Oda (1984) has classified granules into active granules (repeated splitting and merging processes, their sizes increase monotonically from one splitting to the next), quiet granules (they are stationary in size) and decaying granules (decreasing monotonically in size and finally disappear). Title et al. (1989) found a strong correspondence between exploding granules and mesogranules.

In a series of papers Hirzberger et al. (1999, references therein) used an 80 minutes time series of high spatial resolution white light images obtained with the Swedish Vacuum Solar Telescope at the Observatorio del Roque de Los Muchachos, La Palma.

The evolution of solar granules deduced from 2-D simulations was studied by Ploner et al. (1999). Their simulation covered 15 Mm on the solar surface and was run over 5 h of solar time. Thus a sample of about 400 granules could be followed over time. The authors distinguish between fragmenting and dissolving granules. Fragmentation occurs by buoyancy breaking. Exploding granules develop a dark center surrounded by a bright expanding ring that is rapidly expanding (Title et al. 1989, Rast, 1995). Kawaguchi (1980) found that granules with sizes below 1'' predominantly dissipate whereas granules with sizes above 2'' fragment. A similar result was obtained later by Karpinsky and Pravdijk (1998).

Our data set consists of 2-D maps of spectral line profiles which were obtained by scanning over a small photospheric region. Thus one has the advantage of 2-D information however it must be stressed that of course the maps of the resulting line parameters were not obtained simultaneously, i.e. the first exposure and the last exposure of one map are separated by about 2 minutes. Hirzberger et al. (1999) used the Göttingen Fabry Perot Interferometer (FPI) to obtain narrow band line profiles. In our case the advantage is a better spectral resolution.


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2. DATA

The data were taken with the 70 cm Vacuum Tower Telescope at the Observatorio del Teide in Izaña, Tenerife, on June 2, 1999. A more detailed description of this telescope can be found in Schröter et al. (1985).

We obtained during the observing campaign two dimensional spectral scans, where the spatial sampling interval was 0.4″ and the total number of slit positions was 50. The slit length was 12.8″ covered by 100 individual spectra and therefore a total area of 12.8″ × 20″ was scanned. In order to obtain similar step widths in the x- and y-direction, a resampling was done by interpolation in the x-direction to obtain a step width of ~ 0.1″. The time step between two successive slit positions was 2.5 s. Thus one 2-D scan lasted for slightly more than 125 s. Seven scans were obtained in total. The area observed was near the disk center. The spectrograms contained the two lines:

- Line I: FeI at 630.1508 nm of $W_\lambda = 127$ mÅ, $EP = 3.64$ eV and $g_{eff} = 1.6$, estimated line core formation height 375 km (Gadun et al., 2000),
- Line II: FeI at 630.2499 nm of $W_\lambda = 83$ mÅ, $EP = 3.69$ eV and $g_{eff} = 2.5$, estimated line core formation height 270 km (Gadun et al., 2000).

We have calculated the common spectral characteristics from all the spectra of both lines.

3. RESULTS

In Fig. 1 the continuum intensity is given for the first 2-D map of the time sequence of that parameter. From that map area 1 was selected.

Let us consider the evolution of these line parameters starting with the maps at the bottom which are the first in the time series. In the first map of continuum intensity of the time series (at bottom of Fig. 2) the most part is filled with larger values indicated by white, indicating high continuum intensity values > 110%. Near the center some small depression of the values can be recognized (the values are still slightly above the mean granular level) indicating a fragmentation of the granular structure which is well recognized in the next map of the series (map nr 2 from bottom of Fig. 2). Comparing these two maps one can estimate a horizontal expansion velocity for the maxima of the bright structures of about 1.7 km/s. The two resulting structures can be followed in the continuum maps until the last where only some small bright features remain. From map nr. 2 the bright structure at the right expands until map nr. 4 then seems to decay again. In maps 2 and 3 two bright structures are seen, the bright structure on the right hand side decays rapidly and vanishes in map 5. Thus the evolution could be followed over three maps corresponding to 6 min. In map 5 a new bright structure appears on the right side. A bright structure can be followed on the left side starting in map 2 and disappearing in map 7.

Comparing the evolution of the continuum maps with the residual intensity maps we can see some anticorrelation. In the first map of the time series the residual intensity is low (indicated by dark red and dark values) where the continuum intensity is high. However such anticorrelation seems to be valid only for moderate values. We can see e.g. in the 5th map that the smallest values of the residual intensity correlate with the smallest value of the continuum.

For the full width at half maximum this seems to be even more complex. In the third column of Fig. 2 the color coding is as follows: large values of the full width at half maximum are given by white and yellow, the smallest values by blue. The first map shows a correlation with the continuum intensity. The full width at half maximum is low where the continuum intensity is high and vice versa. In the second map the granule fragments as it was discussed above and the full width at half maximum is low at the lower right corner where the continuum intensity is high. In the third map this is preserved however at the left right where the continuum is high (indicating granular structure) the full width at half maximum is also high. In the third map one sees both a correlation and an anticorrelation between continuum and full width at half maximum. The smallest values of the full width at half maximum occur where the continuum is smallest. In map nr 5 of the time series we find that small full width at half maximum values are located in similar positions as small residual intensity values. In the left corner of map nr. 6 high full width at half maximum values coincide with high continuum intensity values. These examples clearly show that there is no correlation between continuum intensity and full width at half maximum.

Column nr 4 in Fig. 2 shows the evolution of the

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Figure 1. Location of the 3 selected areas in the map of continuum intensity (map nr. 1 of the time series).

In this section in the map of continuum intensities mainly granules are visible and therefore we speak of granular evolution.

The evolution of the line parameters is shown in Fig. 2 for line I (first 4 columns) and for line II (last 4 columns).
Figure 2. Evolution starting with a granular structure: 2-D maps of the continuum intensity, residual intensity, full width at half maximum and line center velocity evolution with time (vertical direction). The first 4 columns give the evolution for line I, the last 4 columns for line II. The units on both axis are 0.4 arcsec per pixel.
line center velocities for line I. The color coding is as follows: positive velocities, (upstreaming) are blue, negative velocities (downstreaming) red. Intermediate values are coded yellow. In the first map it is clearly seen that the largest upward motions occur in the center of the granular structure that starts to fragment in the middle. These upflows seem also be the driver for the large horizontal flows that can be estimated comparing maps 1 and 2. It is interesting to note that these upflows break down in map 2 to transforming into a strong downflow which occurs in the middle between the two bright structures. These velocities decline as it is seen in the next map. In map nr. 6 the downflows are connected to dark intergranular areas and the upflows to bright granular areas.

Let us compare the evolution of the line parameters for the two different lines I and II. The evolution of the line parameters of line II is given in the last 4 columns in Fig. 2. Please keep in mind that line 2 has a deeper formation height (270 km) than line I (378 km). Comparing the columns 1 and 5 we see that the continuum that was taken outside the line shows the same evolution as has to be expected. Columns 2 and 6 show that the evolution of the residual intensity is similar for the two lines but there occur also differences. For example in the first map of the residual intensity the lowest values (dark) occur at different positions. The second maps of the time series are quite similar. In the third map the highest values for the residual intensity of line 2 occur at the point of fragmentation.

Comparing the results of the full width at half maximum variation (columns 3 and 7) some similarities but also differences can be observed. For example in map nr. 5 of the full width at half maximum variations the lower values seem to be shifted to the left for line I with respect to line 2.

The differences between the evolution of the line center velocities for the two different lines seem to be less pronounced than for the other line parameters. The largest difference is found in map 4. In the case of line I downflows are restricted to an area below y=5, whereas in map 4 for line 2 there is a downflow area going through the whole vertical range of the area considered. Note also some small details such as the differences between the velocity maps nr 2 of line I and line II. For line II that is formed deeper the velocity map 2 seems to be better correlated with the corresponding temperature field than for line I.

Let us summarize the main results of the observed evolution of granular structures:

- a fragmentation of a granule was observed;
- this fragmentation is accompanied by a large downflow as it is seen in the map 2 of Fig. 2;
- in map nr. 4 a granulum is seen on the left half and an intergranular area on the right half of the continuum intensity map. Please note the strong difference between the line center velocity maps for the two lines there. In the deeper forming line II in the intergranular area a strong downflow occurs whereas there is no clear correlation for the velocities and continuum intensities for the higher forming line;
- large values of the full width at half maximum are not correlated with the continuum intensity. There seems to be a trend that higher values occur at higher continuum intensity values, i.e. enhanced full width at half maximum values seem to coincide with granular areas;
- Velocity and temperature fields are better correlated for the deeper originating line II than for line I.

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