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Evolution of temperature in granule and intergranular space

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Abstract. The temporal evolution of temperature in a dissolving granule and in an adjacent intergranular space is presented. The semi-empirical evolutionary models have been calculated using an inversion method applied to 4-min time series of Stokes I spectral line profiles. The models are presented in the form of the functional dependence of temperature $T(\log \tau_5, t)$ on optical depth τ_5 at 500 nm and time t. The observed disappearance of the granule is accompanied with overall cooling of the granular photosphere. Temperature changes greater than 100 K have been found in deeper $(\log \tau_5 \geq 0)$ and upper layers $(\log \tau_5 \leq -2)$ whereas the intermediate layers are thermally stable. The intergranular space, which is 2 arcsec off the granule, keeps the temperature structure of the layers from $\log \tau_5 = 0.5$ to $\log \tau_5 = -2$ without global evolutionary changes except short-term and spatially confined heating. Finally, the significant temperature changes in the upper layers $(\log \tau_5 \leq -2.5)$ observed during the time interval of 4 min are found to be typical for the granular and intergranular photosphere.

Key words: Sun:granulation – Sun:photosphere – stars:atmospheres

1. Introduction

Our empirical understanding of solar granulation stems from high resolution spectroscopy and imaging of the photosphere. On the other hand, hydrodynamical simulations succeeded to reproduce many details of granular structure demonstrating progress in our theoretical understanding of granulation (Spruit, Nordlund & Title 1990; Muller 1999). Inversion methods represent another tool for diagnostics of the solar atmosphere allowing straightforward interpretation of the observed spectra in terms of physical quantities. In this work, we present results of the application of the SIR inversion technique (Ruiz Cobo & del Toro Iniesta 1992; Borrero & Bellot Rubio 2002) to Stokes I spectral line profiles in order to study the temporal evolution and radial stratification of temperature in a disappearing granule and an adjacent intergranular space.

This study is linked with two previous papers dealing with the temporal evolution of physical parameters in a granule (Koza et al. 2002a, hereafter Paper I) and the evolution of the line-of-sight velocity in a disappearing granule (Koza et al. 2002b, hereafter Paper II).

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2. Observational data and investigated targets

The spectra obtained as time series with the Echelle spectrograph of the German VTT, Tenerife, are used as observational data. The series consists of 28 pairs of spectra of spectral regions around 522.5 nm and 557.6 nm. The intensity profiles

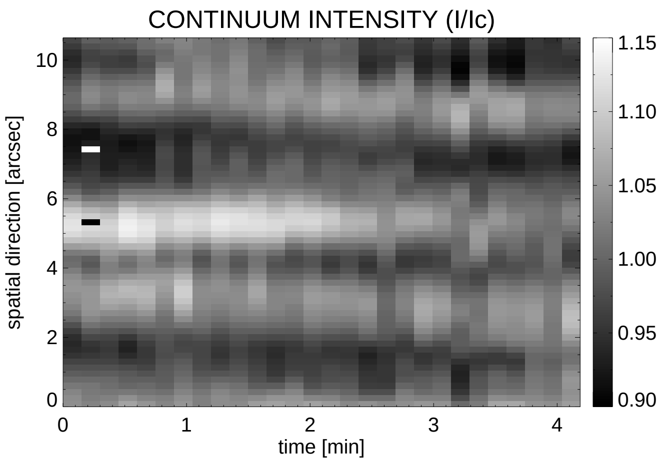

Fig. 1. Time-slice map of the continuum intensity demonstrating the evolution of the investigated granule and intergranular space which are indicated with black and white mark respectively.

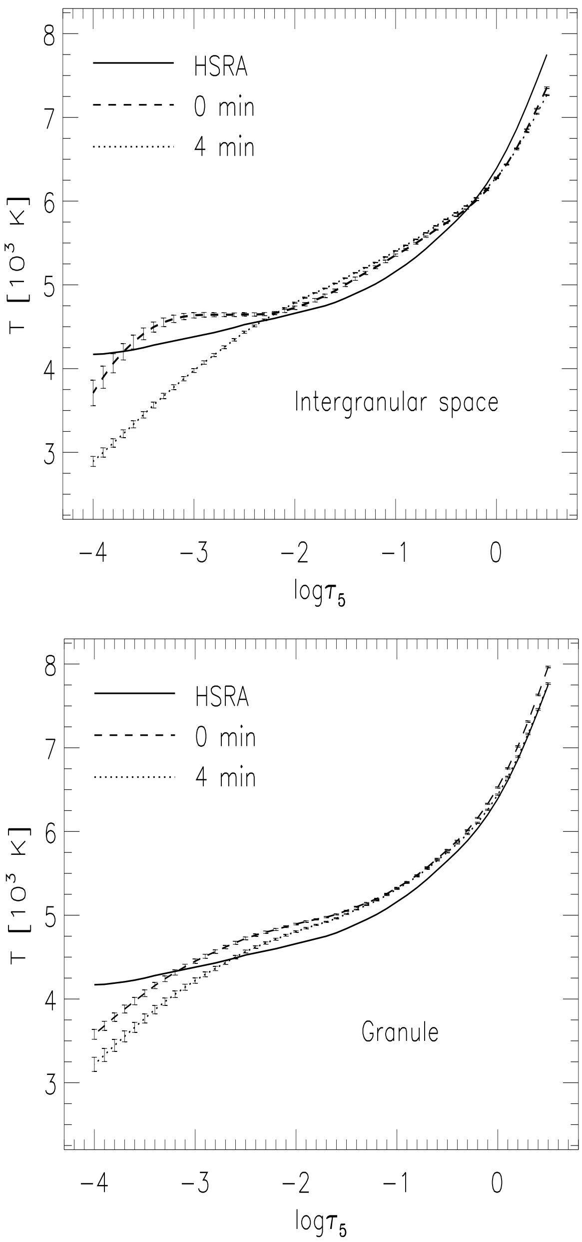

Fig. 2. The temperature stratifications of the intergranular and granular photosphere at $t = 0$ min (dashed) and $t = 4$ min (dotted). The HSRA model (solid line) is depicted without error bars.

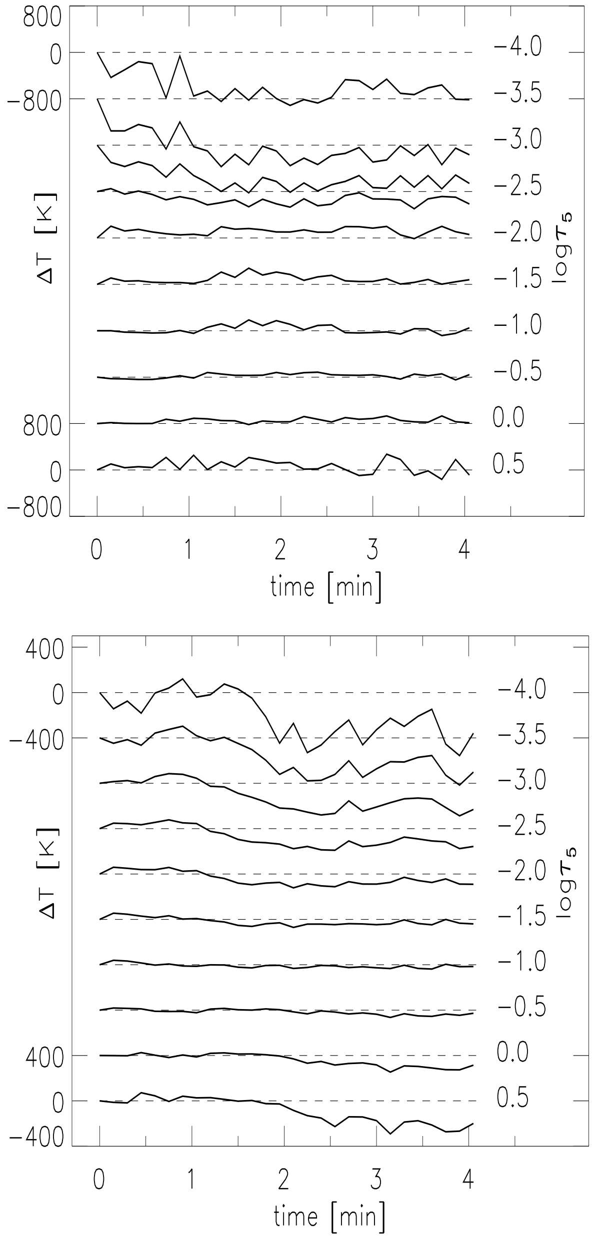

Fig. 3. The temporal evolution of the temperature differences ΔT (solid line) of the intergranular (top panel) and granular (bottom panel) photosphere with respect to the first model at $t = 0$ min (horizontal dashed lines).

of two medium-strong Fe I 522.5 nm and Fe I 557.6 nm lines and the weak Fe I 557.7 nm line have been selected. The time step between exposures of subsequent pairs was 9 s and the whole series catches 4 min of the granular evolution. Additional informations can be found in Paper I. Using those data we identified the bright granule and the adjacent intergranular space at 5 and 7 arcsec along the slit (see Fig. 1) by visual inspection of the individual spectra. Gradual disappearance of the granule has been possibly related with its extinction. For further inversion the Fe I line profiles were extracted from the centres of both selected targets.

3. Results of the inversion

The observed profiles were analyzed by means of the inversion procedure described in Paper II. As an example, two instantaneous intergranular and granular models are depicted against the logarithm of optical depth τ_5 at continuum at $\lambda = 500$ nm in Fig. 2. Also the HSRA model is shown representing the average quiet solar photosphere (Gingerich et al. 1971). As can be seen, the disappearance of the granule is accompanied by a cooling in the continuum forming layers ($\log \tau_5 \sim 0$), where temperature approaches that of the HSRA model, whereas the same layers in the intergranular space keep nearly unchanged temperature. The intermediate layers from $\log\tau_5 \sim -0.5$ to $\log\tau_5 \sim -2$ both in granular and intergranular photosphere remain always hotter than the HSRA model.

The temporal evolution of the temperature differences $\Delta T(\log\tau_5, t)$ in the intergranular and granular photosphere with respect to the original state at $t = 0$ min and at the selected optical depths is shown in Fig. 3. At time t and optical depth $\log\tau_5$, the temperature differences are computed as $\Delta T(\log\tau_5, t) = T(\log\tau_5, t) - T(\log\tau_5, t = 0)$ separately for intergranular and granular models. The layout of the figures makes possible to see the temporal evolution of temperature and simultaneously to estimate the temperature at a given time t and an optical depth $\log\tau_5$.

First, let us concentrate on the evolution of the intergranular space. Temperature structure of the layers from $\log\tau_5 = 0.5$ to $\log\tau_5 = -2$ is stable without global evolutionary changes except short-term and spatially confined heating. In contrast, significant temperature drops reaching up $\sim$800 K are detected in the upper layers ($\log\tau_5 \leq -3$).

The granular photosphere exhibits temperature decrease greater than 100 K in deeper layers ($\log\tau_5 \geq 0$) as a consequence of disappearance of the granule. Similarly to the intergranular space, there are thermally stable layers from $\log\tau_5 = -0.5$ to $\log\tau_5 = -1.5$ unaffected by granular evolution. Finally, significant temperature changes greater than $\sim$300 K are also found in the upper layers ($\log\tau_5 \leq -3$).

4. Summary and discussion

We have studied the temporal evolution of the temperature in a granule and its nearby intergranular space during 4 min. Our results suggest that the granular photosphere (see Fig. 3 bottom) involves three regions which differ each other in the size of the detected temperature changes (i.e. with the thermal variability). The lower and upper layers exhibit temperature changes of hundreds of K, whereas intermediate layers have nearly constant temperature structure. This result may be understood in terms of the scenario outlined by Espagnet et al. (1995). The transformation of the convective energy carried by the granule into radiation takes place just within a very short distance near to the continuum forming layers, thus leaving the intermediate layers thermally stable. Many previous works came also to the conclusion that the photosphere is thermally controlled by granulation up to the certain boundary layer. The values $\sim$ 60 km or $\sim$ 170 km were frequently proposed as the geometrical heights corresponding to this layer. An extensive overview to this topic can be found in Espagnet et al. (1995). We found out that the layer $\log\tau_5 \sim -0.5$ is the uppermost layer (see Fig. 3 bottom) exhibiting some significant temperature variations related with disappearance of the granule. Using the HSRA model (Gingerich et al. 1971) as well as the SIR code we found out, that the geometrical height of about 60 km can be assigned to the layer $\log\tau_5 \sim -0.5$. This our result speaks in favour of the lower position of that boundary level. The similar height of about 50 km was also found by Kneer et al. (1980).

The time interval of 4 min is probably too short for detection of some evolutionary changes in the lower layers of the intergranular photosphere (see Fig. 3 top). The same is also valid for intermediate layers, which are nearly stable except some episodic temperature humps. Large temperature variations are also detected as in the granule in the upper layers. These variations are typical both for the granular and intergranular photosphere and may be associated with some unknown processes taking place in the lower chromosphere exhibiting signatures of highly inhomogeneous environment permeated by CO-cooled clouds (Kneer 1983; Ayers 2002).

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