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Line bisectors in granular and intergranular matter *

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Abstract. In this paper we study granular and intergranular spectral line bisectors obtained from spectroscopic images of the solar granulation taken at the THEMIS telescope, in IPM mode. Granular bisectors always maintain the characteristic C-shape, independently of the size of the granules showing an overshoot of ascending hot plumes. Instead the shape of intergranular bisectors is much less curve suggesting that, in the intergranular lanes, the descending plasma has an almost constant velocity. We conclude that the kinetic description of the solar granulation which arises from our analysis is compatible with the results of numeric simulations.

Key words. solar photosphere, granulation, line bisectors

1. Introduction

The physical mechanisms that drive the solar and stellar granulation are still quite obscure. In fact, several recent works (Nordlund et al. 1997; Hirzberger et al. 1997, 1999) have contested the traditional interpretation, which relies on the energy transfer from larger to smaller scales via a turbulent cascade (Espagnet et al. 1993). The numerical simulation of Stein & Nordlund (Stein & Nordlund 2000) has showed yet another paradigm of the photospheric convection, depicting it as driven by the thin boundary layer at the top of the solar atmosphere, where radiative cooling produces the cores of the downdrafts. The realistic model of Stein & Nordlund well represents the properties of the granulation and the profiles of weak Fraunhofer lines arising from large areas of the photosphere, averaging the effects of the granular and intergranular matter. If this picture is true, we should find different shapes between line bisectors arising in granular and intergranular matter. While granular bisectors should show the typical C-shape (Brandt & Schröter 1982; Dravins 1982) due to the vertical velocity gradient in the uprising flow, in the intergranular lanes we expect a straight vertical bisector since the downflow, although turbulent in character, has a constant vertical velocity. Similar results have already been obtained by Hanslmeier et al. (2000) analysing a spectrum taken at the VTT telescope in Izaña which included the 6301.508 Å line, the 6302.499 Å line and the 6494.994 Å line. In all the three lines the granular and intergranular

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bisectors show a different shape, which reflects the suggestions arising from Stein & Nordlund simulation.

In this paper we study granular and intergranular spectral line bisectors obtained from spectroscopic images of the solar granulation taken at the THEMIS telescope, in IPM mode, by one of us (AR) in July 15 and 19, 1999 and in Sept. 27, 2000.

2. Observations

Several series of monochromatic images of the quiet solar photosphere have been observed. Each series reproduces the 5576.1 Å Fe I line and it is formed by 13 images in 1999 observations and by 19 images in the 2000 ones; each series is completed by a continuum image. We selected the 5576.1 Å line because it has a negligible hyperfine splitting and Landé factor $g = 0$. The IPM system acquires simultaneously a monochromatic image and a white light image, in the same spatial region of the Sun. White light images permit to have a spatial reference at $\tau \simeq 1$. The time spacing between two consecutive images of a series is about 2-3 s and between two consecutive series is 1 min. To record the images a CCD with size 256×256 pixels ($35.85'' \times 35.85''$) in 1999 observations and a 512×512 pixel CCD ($54.88'' \times 54.88''$) in those of the year 2000, were used.

2.1. Data reduction

After the usual corrections for dark currents and flat-fielding, we extracted a subimage with size 64×64 pixel from the centre of each image; the sub-image is approximately equivalent to the isoplanetism domain of the field of view. The sub-images in each series had then to be aligned, in order to consider the tip-tilt influence. For this purpose we used, for each series, the cross-correlation function between the continuum image and each monochromatic image. We had to consider another shifting effect, generated by the optics of the Universal Birefringent Filter (UBF) in IPM (Cavallini 1998). To compute the UBF shift we used the FFTD algorithm (Hill et al. 1975) to determine the position of the reference marks at the edge of the images. The tip-tilt and the instrumental shift were then added together.

2.1.1. Image quality

We had to select the best series to extract line profiles and bisectors, because their quality is not uniform and it varies randomly with time, even inside a series. To determine the seeing we computed the Fried parameter (r_0) from the power spectrum of each white light image. r_0 is $\simeq 6 - 7$ cm both in 1999 and in 2000 images. Through visual inspection we finally selected twelve series in total, seeking the best compromise between image quality and homogeneity of the spatial resolution in a series as a whole.

2.2. Line profile and bisector

Each series can be considered as the section of a 3D space with two spatial and one spectral dimensions; therefore, we can extract the line profile from each pixel of the subimages. These profiles have however too few samples in order to study their properties. To reconstruct the line profile we used the Fourier interpolation algorithm (Brault & White 1971), which raised the number of samples of each profile to 256 and consequently lowered the sampling wavelenght interval, to 0.0025 Å . During the Fourier interpolation we also filtered the high frequencies, dominated by noise. The line bisector was then computed for each percentile variation of the intensity (continuum = 100) as the locus of points midway between the two wings of the line profile.

2.2.1. Error evaluation

The relative error of intensity in line profiles due to the photometric noise is 2% on the average, fluctuating from 1.3% near

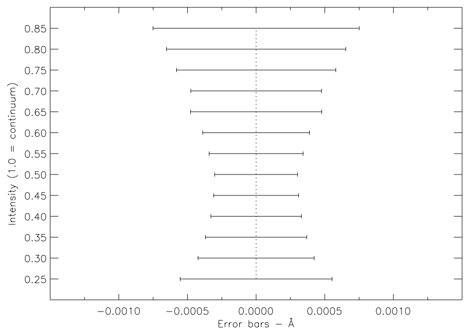

Fig. 1. Variation of the wavelenght error of bisectors with intensity

the continuum to 2.8 at the line centre. To determine the influence of the photometric error in the wavelenght position of the bisectors we used simulated observations of the line profiles, supposing that the photometric noise is the only cause of error for intensity and it follows a gaussian distribution. The resulting wavelenght error for bisectors is quite uniform with depth and it's $\simeq 0.001$ Å 1. To determine the influence of the filtering on the bisector shapes we computed the difference between the measured line intensity and that one resulting after the Fourier interpolation. Then, we considered this difference a "real" intensity error and the simulation program was repeated. The results show that the wavelenght error of the bisectors is very similar to the error calculated from the photometric noise. We can therefore conclude that the filtering has been well calibrated to clean the profiles just from the photometric noise.

3. Results and discussion

We compared granular bisectors with intergranular ones. It can be clearly noticed 2 that granular line profiles are blueshifted, while intergranular profiles are redshifted. The wavelenght difference between the two regimes is $\simeq 10$ mÅ, corresponding to a velocity difference of $\sim 550 ms^{-1}$.

We can also see that bisectors extracted from similar structures have similar shapes. Granular bisectors always maintain the characteristic C-shape, independently of the size of the granules. The C-shape had been interpreted as an effect of low spatial resolution in previous observations (Dravins 1982). In our results bisectors are instead extracted from limited regions of the Sun which have homogeneous physical characteristics, and they seem to contradict other high spatial resolution observations, in which the bisectors have a chaotic appearance (Hanslmeier at al. 1990). The inversion point of bisector curvature is usually at $\sim 60\%$ of continuum. Above the inversion point the wavelenght position of the bisectors varies swiftly with intensity, while under it the trend is smoother. On the contrary, the shape of intergranular bisector is much less curved; they have quite the same wavelenght position independently of intensity, although in some bisectors there is a sharp redshift near the continuum that creates a "Γ-shape" bisector. From the analysis of the line profile we can also see that the red wing is more "rigid"; that is, the position of the red wing of the profiles is more stable than that of the blue one in the transition from granules to intergranular lanes. We have also computed the FWHM of the line profiles. It seems that the FWHM of the granular profiles is smaller than that of the intergranular ones. This result suggests that the plasma in the intergranular lanes is more turbulent than in the granules.

The well established wavelenght shifts of line profiles (redshift in the intergranular matter, blueshift in the granules) are in full agreement with the kinetic structure of the granulation accepted at present: there are locally upward motions in the granules and descending flows in the intergranular lanes (for a review see Bray et al. (1984)). The evident curvature of granular bisectors is compatible with the hypothesis that the local plasma flows have a strong vertical velocity gradient, independently of the size of the observed granule. The bisector inversion point, which corresponds to the maximum velocity of the ascending flow, marks

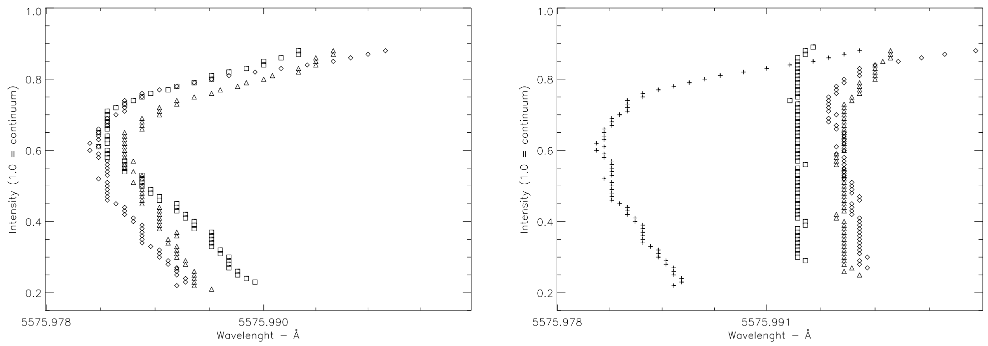

Fig. 2. Left panel: three granular bisectors, taken from series n.142 (July 19, 1999). Right panel: three intergranular bisectors (straight), compared with a granular bisector (curved).

the photospheric layer in which the gradient changes sign and the overshoot phase starts. We cannot extract any other information from the bisector shape, because we need to know the contribution function of the analysed line (Caccin et al. 1977; Kučera et al. 1998). However, the lesser inclination of the lower part of the bisectors suggests that the action of gravity combined with pressure is present in a large part of the photosphere, and therefore the overshoot phase still continues in the layer near the centre of the line, which are ~ 300 km above $\tau \simeq 1$. On the contrary, the straight form of intergranular bisectors suggests that in the intergranular lanes the descending plasma has an almost constant velocity.

Thus, the kinetic description of the solar granulation that appears from our analysis is quite compatible with the numeric model of Stein & Nordlund (Stein & Nordlund 2000).

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