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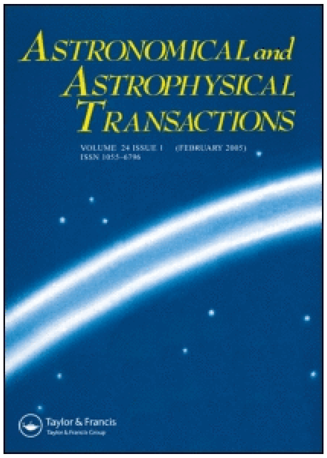

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Analysis of Hα profiles. Physical parameters of chromospheric mottles: A case study

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ANALYSIS OF Hα PROFILES. PHYSICAL PARAMETERS OF CHROMOSPHERIC MOTTLES: A CASE STUDY

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Observations of a well-defined rosette region which consisted of several bright and dark mottles and located almost at the solar disc centre (N5, W5) were made with the Multichannel Double Pass (MSDP) spectrograph mounted on the 50 cm "Tourelle" refractor of the Pic Du Midi Observatory, on June 17, 1986. This instrument records a two-dimensional field on the solar surface and having 11 channels provides at every pixel of the field of view the profile of the Hα line. We have used these profiles to derive several physical parameters of the chromospheric mottles. The basic assumption of the method we used is that the source function is not constant inside the structures, but has a parabolic variation with the optical depth. By using an iterative least square procedure for non-linear functions, five parameters of chromospheric mottles were computed: the optical depth, the Doppler width, the line-of-sight velocity, the source function at the middle of the structure, and the source function's variation factor.

KEY WORDS Chromosphere, fine structure, mottles

1 INTRODUCTION

Analysis of disturbed line profiles provides important information about the physical quantities which are related to that part of the atmosphere where the line is formed. In particular, several physical parameters of chromospheric structures are deduced from a comparison between line profiles emitted by the structure and a line profile emitted by the surrounding chromosphere considered as the background.

A model which has been used extensively in the analysis of Hα observations is the one introduced by Beckers (1968) and is known as the "cloud model". Assuming a constant source function inside the structures this model allows the simultaneous determination of four parameters: the source function, S; the optical depth, τ_0; the Doppler width, $\Delta\lambda_D$ and the Doppler shift, $\Delta\lambda_I$. Based on this model Tsiropoula *et al.* (1993, 1994, 1997) have computed several physical parameters of dark mottles. However, Gouttebroze, Heinzel and Vial (1993) in their effort to model prominence-like structures found that for optically thick slabs the source function was not constant inside them, but decreases symmetrically towards both edges (upper and lower). Heinzel and Schmieder (1994) pointed out that for a given Hα profile two solutions exist: one corresponding to structures which are optically thin, have pressures less than 0.5 dyn/cm^2 and almost constant source function, and the other to structures which are optically thick, have pressures greater than 0.5 dyn/cm^2 and strongly non-constant source function. More recently, Mein *et al.* (1996) found that the source function increases from the top of the structure to its bottom. In this work we propose a method to analyse Hα profiles assuming a parabolic variation of the source function with optical depth. For the application of the method, observations of chromospheric mottles are used.

2 OBSERVATIONS

Two-dimensional Hα observations of a chromospheric region which consisted of several bright and dark fine mottles were performed on June 17, 1986 with the MSDP (Mein, 1977) operating on the solar spectrograph mounted at the focus of the 50 cm refractor of the Pic du Midi Observatory (Schmieder *et al.*, 1991). The MSDP having 11 channels allows the observation of the same point on the Sun simultaneously, but at a different wavelength in each channel. The Hα line profile for each pixel of the field of view can be reconstructed from 11 points using a third degree spline interpolation. A mean chromospheric Hα profile was obtained by averaging all profiles over the observed quiet-Sun region. The observed region was located near the disc centre (N5, W5) and the total duration of the observations was 15 min. From the entire sequence one frame at 06:44:24 UT of very good quality was selected for the present study (Figure 1).

3 METHOD OF COMPUTATION

The line intensity profile is given by:

$$I_\lambda = I_{0\lambda} \mathrm{e}^{-\tau_\lambda} + \int_0^{\tau_\lambda} S_t \mathrm{e}^{-t_\lambda}\, dt_\lambda \tag{1}$$

where $I_{0\lambda}$ is the background intensity profile. We assume a parabolic variation of the source function with optical depth inside the structure given by:

$$S_t = S_0 \left[1 + \alpha \left(t - \frac{\tau_0}{2}\right)^2\right] \tag{2}$$

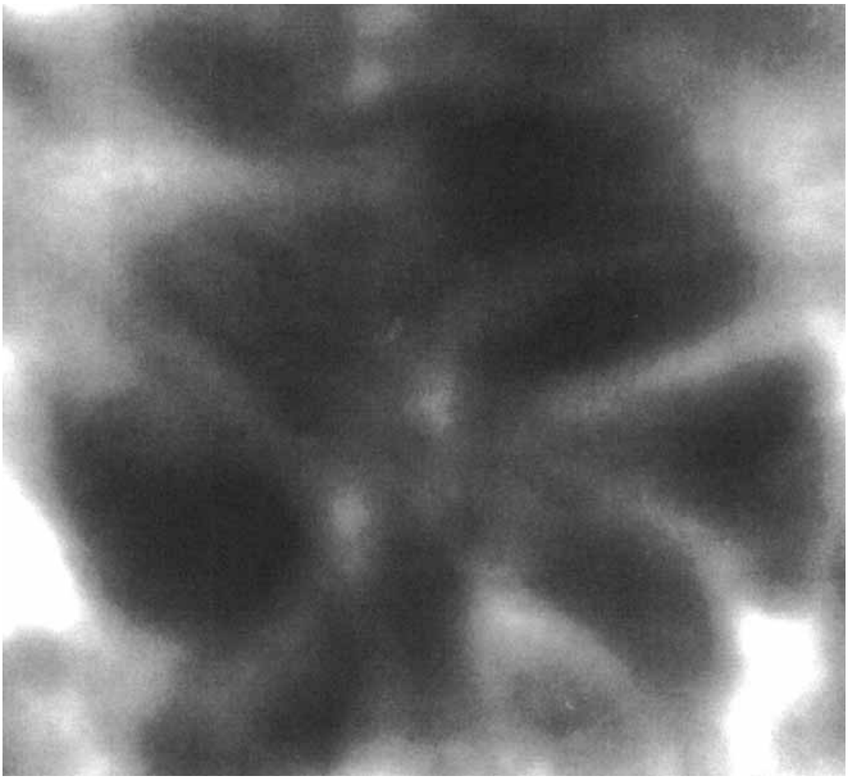

Figure 1 The rosette region at H$\alpha \pm 0.5$Å.

where S_0 is the source function at the middle of the structure and α the variation factor of the source function. Furthermore $\tau_\lambda = \tau_0\phi_\lambda$, where ϕ_λ is the broadened absorption profile assumed to be given by:

$$\phi_\lambda = \mathrm{e}^{-y^2} + \frac{a}{\sqrt{\pi}y^2} \tag{3}$$

where:

$$y = \frac{\Delta\lambda - \Delta\lambda_I}{\Delta\lambda_D} \tag{4}$$

and

$$a = \frac{\Gamma\lambda_0^2}{4\pi c\Delta\lambda_D}. \tag{5}$$

In the above formulation a is the damping width and Γ the damping constant. Then the specific intensity is given by:

$$I_\lambda = I_{0\lambda}\mathrm{e}^{-\tau_\lambda} + S_0\left(1 + \frac{\tau_\lambda^2\alpha}{4\phi_\lambda^2} + \frac{2\alpha}{\phi_\lambda^2}\right)(1 + \mathrm{e}^{-\tau_\lambda}) - \frac{\tau_\lambda\alpha S_0}{\phi_\lambda^2}(1 + \mathrm{e}^{+\tau_\lambda}). \tag{6}$$

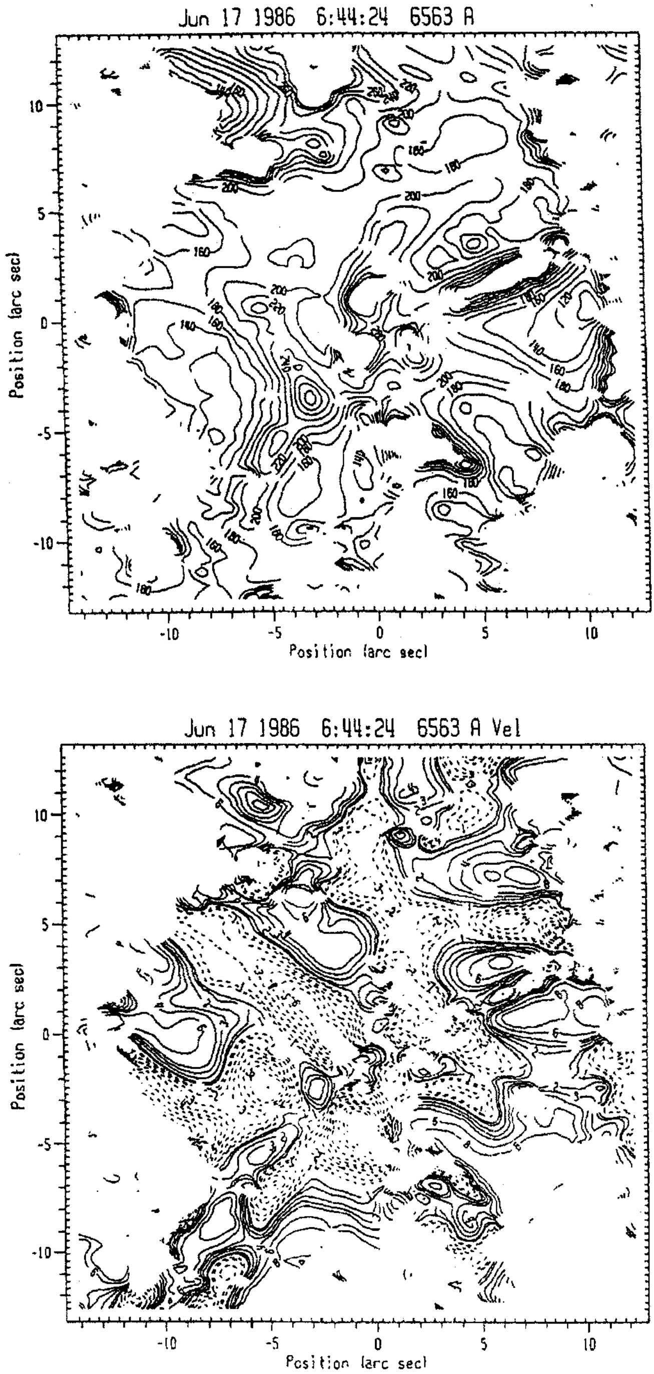

Figure 2 Contour maps of (a) the source function, (b) the line-of-sight velocity (full lines refer to velocities towards the observer; dashed lines to velocities in the opposite direction).

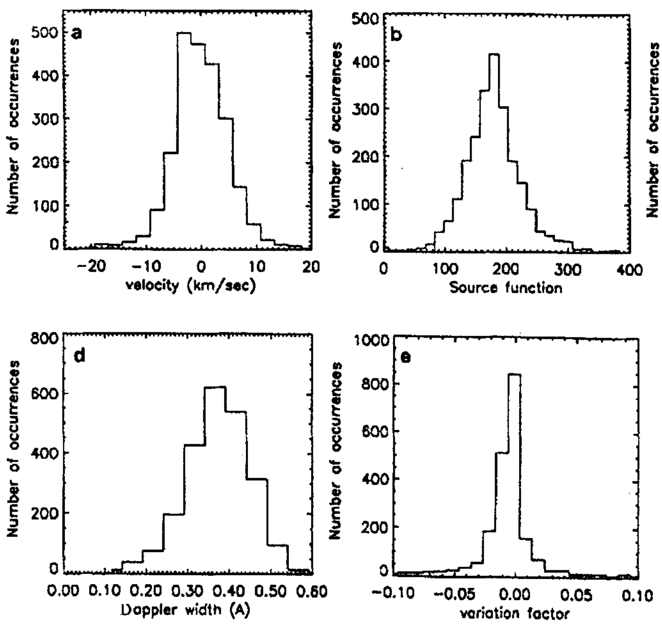

Figure 3 Histograms of the five parameters of the dark mottles: (*a*) velocity, (*b*) source function, (*c*) optical depth, (*d*) Doppler width, (*e*) variation factor of the source function.

Applying an iterative least square procedure for non-linear functions we can derive five parameters of the chromospheric mottles. These are: the source function at the middle of the structures, S_0, its variation factor α, the optical depth at line centre τ_0, the Doppler width, $\Delta\lambda_D$ and the Doppler shift, $\Delta\lambda_I$.

4 RESULTS

The computation of the five parameters was carried out by an iterative least square procedure for non-linear functions which was repeated until the ratio between two consecutive χ^2 values was smaller than 1.0001. About 3670 out of 5200 structural elements of the rosette region can be matched by this procedure. Most of them form the dark mottles, while only three bright mottles can be recognized. Figure 2(*a*) shows a contour map of the source function. In the dark mottles the source function shows a smooth variation with a minimum of 110–140 (in units of 1/1000 of the continuum intensity) near their centre and exceeds the value of the background intensity ($\sim$ 170) near their edges. In the bright mottles it has a maximum value of 350–400 near their centre and diminishes towards both edges. Figure 2(*b*) shows a contour map of the line-of-sight velocities. Downflows seem to occur in the roots of the dark mottles and upflows in their upper part, while in the bright mottles no clear behaviour is apparent. Figure 3 shows histograms of the five parameters

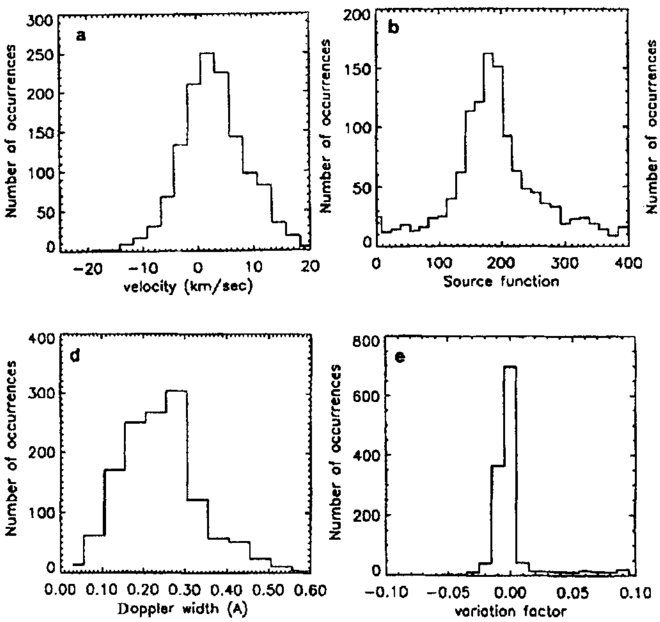

Figure 4 Histograms of the five parameters of the bright mottles: (*a*) velocity, (*b*) source function, (*c*) optical depth, (*d*) Doppler width, (*e*) variation factor of the source function.

derived for the dark mottles and Figure 4 shows histograms of the five parameters derived for the bright mottles. The mean values and standard deviations of these parameters are given in Table 1. Dark mottles have smaller values of the source function and larger values of the optical depth and Doppler width than bright mottles. The velocity histograms are rather asymmetric (Figures 3(*a*), 4(*a*)) for both structures. The velocity histogram of dark mottles peaks around −4 km/sec and of bright mottles around 2 km/sec. The values of the variation factor of the source function are small for both structures which means that they are optically thin.

Table 1.

	Dark mottles		*Bright mottles*	
Parameters	*Mean value*	*Stand. Deviation*	*Mean value*	*Stand. Deviation*
Velocity (km/sec)	1.11	5.05	3.67	5.91
Source function	183.1	42.1	220.1	80.3
Optical depth	1.40	0.95	0.85	1.10
Doppler width (Å)	0.39	0.07	0.27	0.10
Variation factor	−0.0032	0.3461	−0.007	0.180

5 DISCUSSION

We have described a method suitable for the analysis of Hα profiles. This method is based on the variation of the source function with the optical depth and allows the determination of several physical parameters of chromospheric structures regardless of whether they are optically thin or thick. In the special case of chromospheric mottles, where this method is applied, parameters of dark and bright mottles were derived. The variation factor of the source function is small which means that both structures are optically thin. Differences between the parameters of these two structures have been found. These differences should be interpreted by an appropriate non-LTE theory in terms of such quantities as temperature and electron density. As a next step it will be interesting to compare the values derived by this method with those derived by the classical cloud model.

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