A METHOD FOR DETERMINING PHYSICAL PARAMETERS IN CHROMOSPHERIC MOTTLES

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ABSTRACT

Hα observations of a rosette region consisted of several bright and dark fine mottles were obtained with the Multichannel Subtractive Double Pass (MSDP) spectograph mounted on the 50 cm "Tourelle" refractor of the Pic du Midi Observatory. The line profiles reconstructed from the 11 channels of this instrument can be used to derive several physical parameters in these chromospheric structures. The basic assumption made for the analysis of the Hα profiles is that the source function has a parabolic variation with optical depth. By using an iterative least square procedure 5 parameters are determined: the optical depth, the Doppler width, the line-of-sight velocity, the source function at the middle of the structures and the source function's variation factor.

Key words: chromosphere; fine structure; mottles

1. INTRODUCTION

The chromospheric mottles are considered to be the principal channels supplying mass and energy to the solar corona. Furthermore there is an indirect evidence that they are the disk counterpart of the limb spicules. Hence a detailed insight into their physical properties is considered to be very important. Recently, observed Hα contrast profiles of dark mottles have been analysed in terms of the classical Beckers' cloud model and several properties and physical parameters of these structures have been reported (Tsiropoula et al. 1993, 1994, 1997). The basic assumption used by this model is that the source function is constant inside the structures. Different authors claim that this assumption is no valid in all cases. Gouttebroze et al. (1993) computed the emergent hydrogen line profiles for a grid of 140 non-LTE models of prominence-like structures. Among other results they found that for optically thick slabs the source function was not constant inside them, but it was symmetrically decreasing towards both boundaries. Heinzell and Schmieder (1994) using the same computational approach in their study of chromospheric mottles concluded that for a given negative contrast 2 solutions exist. One solution corresponds to low-pressure \( p < 0.5 \text{ dyn/cm}^2 \) structures which are optically thin and exhibit almost constant source function and the other to higher pressure models \( p > 0.5 \text{ dyn/cm}^2 \) which are optically thick and have strongly non-constant source function. Mein et al. (1996) using a code devel-

oped by Heinzell (1995) found that the source function increases from the top of the structure to its bottom. In this work our aim is to analyse Hα profiles of chromospheric mottles using a method based on the assumption of a parabolic variation of the source function with optical depth and in this context to calculate the source's function variation inside the structures.

2. OBSERVATIONS

A chromospheric rosette region consisted of several bright and dark mottles was observed in Hα with the MSDP (Mein 1977) operating on the solar spectograph installed at the focus of the 50 cm refractor of the Pic du Midi Observatory The observations of the region located near disk center (N5, W5) were obtained on June 17, 1986 (Schmieder et al 1991). This instrument having 11 channels allows the reconstruction of the entire line profile for each pixel of the field of view. The duration of the present observations was 15 min. From the entire sequence one frame of very good quality observed at 06:44:24 UT was selected for the present study. In Fig. 1 the rosette region at Hα ± 0.5 Å is shown.

![Figure 1. The rosette region at Hα ± 0.5 Å.](image)

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3. COMPUTATIONAL METHOD

The line intensity profile is given by:

\[ I_\lambda = I_0 \lambda e^{-\tau_\lambda} + \int_0^{\tau_\lambda} S_\tau e^{-\tau_\lambda} \, d\tau_\lambda \]  
(1)

where \( I_0 \) is the background intensity profile. We assume a parabolic variation of the source function with optical depth inside the structure given by:

\[ S_\tau = S_o(1 + \alpha(t - \frac{\tau_o}{2})^2) \]  
(2)

where \( S_o \) is the source function at the middle of the structure and \( \alpha \) its variation factor. Furthermore \( \tau_\lambda = \tau_o \phi(\lambda) \), where \( \phi(\lambda) \) is the broadened absorption profile assumed to be given by:

\[ \phi(\lambda) = e^{-y^2} + \frac{a}{\sqrt{\pi} y_0^2} \]  
(3)

where

\[ y = \frac{\Delta\lambda - \Delta\lambda_D}{\Delta\lambda_D} \]  
(4)

\[ a = \frac{\Gamma \lambda_o^2}{4 \pi c \Delta\lambda_D} \]  
(5)

In the above formulation \( \alpha \) is the damping width and \( \Gamma \) the damping constant. Then the specific intensity is given by:

\[ I_\lambda = I_0 \lambda e^{-\tau_\lambda} + S_o(1 + \frac{\tau_o^2\lambda}{4\phi^2(\lambda)} + \frac{2\alpha}{\phi^2(\lambda)}(1 - e^{-\tau_\lambda})) \]  
(6)

Using the above formulation and applying an iterative least-square procedure for non-linear functions we can derive 5 parameters of the chromospheric mottles. These are: the source function at the middle of the structures, \( S_o \), its variation factor, \( \alpha \), the optical depth at line center, \( \tau_o \), the Doppler width, \( \Delta\lambda_D \) and the Doppler shift, \( \Delta\lambda_f \).

4. RESULTS

After the derivation of the 5 parameters by the iteration procedure two-dimensional maps can be constructed. Fig. 2a shows a 2D map of the line-of-sight velocity and Fig. 2b a 2D map of the source function at the top of the structures. On a large scale the velocity is predominantly negative (descending) near the centre of the rosette. Downflows seem to occur in the roots of the dark mottles and in the greater part of the bright mottles, while upflows are observed in the upper parts of the dark mottles. The general behavior of the source function is not the same in the dark and the bright mottles. In the dark mottles the source function shows a smooth variation with a minimum value of 110 to 140 (in units of 1/1000 of the continuum intensity) near the center of each mottle while near the edges is above the value of the background intensity, which is equal to 170. In the bright mottles it has a maximum value of 350 to 400 near their center and diminishes towards both edges.

In order to show the variations of the source function and its variation factor along the axes of distinct bright and dark mottles their values were averaged along a strip extending 0.3" on either side of a central axis. The step along the axis was 0.1". The variation of these two parameters along a dark and a bright mottle marked in Fig. 1 is shown in Fig. 3a, b. The values of the variation factor indicate that the variation of the source function inside the dark structure investigated is negligible, but it varies significantly inside the bright structure. The resulting variation of the Hα source function with optical depth for the whole rosette region is shown in Fig. 4.
Figure 3. Variation of the source function and the variation factor of the source function along the axes of a bright (B) and a dark (D) mottle marked in Fig. 1.

From this figure, an asymptotic increase of the source function from the top of the structure to its bottom is evident (the optical depth at line center being equal to zero at the top of the structures) for the dark mottles, while the inverse is true for the bright mottles. This result is consistent with the results given by Mein et al. (1996) which are based on non-LTE calculations for horizontal slabs.

5. DISCUSSION

We described a method which enables the determination of various physical parameters of chromospheric mottles taking into account the variation of the source function with optical depth. This method is an extension of the classical cloud model which assumes a constant source function and, for this reason, can be applied only to optically thin structures. On the other hand, the method presented is applicable to all structures regardless of whether they are optically thin or thick. An interesting result we found is that although we choose a parabolic variation of the Hα source function with optical depth, the relation we obtain indicates an increase of the source function from the top of the structure to its bottom for the dark mottles (which is consistent with the recent result of Mein et al. (1996)) and the inverse for the bright mottles. The small values of the variation factor we obtain for the dark mottles indicate that the source function has only small variations inside them and thus we can easily assume that these structures are optically thin. On the contrary, the source function seems to vary strongly inside the bright mottle investigated. According to Heinzel and Schmieder (1994), an almost constant source function is related to low-pressure structures ($p < 0.5 \text{ dyn/cm}^2$) (this is also confirmed by Tsiroupolas and Schmieder (1997)), while a variable source function is related to high-pressure structures. A detailed comparison between this method and the classical cloud model will be the subject of a future work.

Figure 4. Hα source function versus optical depth at line-center for bright (B) and dark (D) mottles.

REFERENCES