PHYSICAL PARAMETERS OF DARK MOTTLES DERIVED FROM HIGH RESOLUTION
OPTICAL SPECTRA

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ABSTRACT

High resolution optical spectra of the solar chromosphere in several spectral lines (Hα, Hβ, CaII H and CaII 8542 Å) were recorded simultaneously with the echelle spectrograph of the VTT at the Sacramento Peak Observatory together with slit-jaw filtergrams. For this study only Hα and Hβ spectra calibrated and corrected for scattered light are used. The slit-jaw filtergrams are used for the identification of dark mottles, while Hα and Hβ line profiles in different parts of these structures are obtained from the spectra. The observed contrast profiles are matched with theoretical ones and several parameters (e.g. line-of-sight velocity, source function, optical thickness, Doppler width) are derived with a cloud model. The values of the parameters obtained from the spectra in the two different lines are compared.

Key words: chromosphere; fine structure.

1. INTRODUCTION

Mottles constitute the main component of the chromospheric fine structure. They are rapidly changing spike-like structures and their properties suggest that they are the disk counterparts of spicules seen at the limb. They reach heights of 6000 - 10000 km (in Hα observations) and have widths of about 1000 km. Mottles are found at the boundaries of the supergranular cells where they form groups called chains or rosettes. Their existence and geometry is associated with the fine structure topology of the magnetic field.

Simultaneous observations of mottles in several spectral lines can be used for the study of the behavior of the properties of these structures and also to examine if the emission in different lines is emerging from the same parts of the structures.

Figure 1. Hα (left) and Hβ (right) spectra obtained with the echelle spectrograph at the VTT of the Sacramento Peak Observatory.

2. OBSERVATIONS

The observations were obtained with the echelle spectrograph at the VTT of the Sacramento Peak Observatory on April 9, 1991. This spectrograph allowed simultaneous observations in several spectral lines. 15 slit exposures with 2.5 sec exposure time, separated by 15° from each other were registered on the photographic film. The time between exposures was 30 sec. High dispersion spectra were obtained in different lines (Fig. 1).

Furthermore, a slit-jaw viewing system permitted simultaneous photographic exposures. The slit-jaw images record the position of the slit during the exposure, while two cross-hairs on the slit give a fiducial mark both on the spectra and on the slit-jaw image and facilitate spatial scale evaluation. Slit-jaw images are also used for the identification of the individual features crossed by the slit (Fig. 2).

During the spectra calibration procedure quiet Sun profiles (e.g. profiles where no features were found) along
the slit were extracted and were compared to David’s quiet Sun profile. The difference between the calibrated quiet Sun profile and David’s profile (Fig. 3) was attributed to the scattered light in the spectrograph and was corrected (see also Kotrê et al. (2004)).

3. ANALYSIS PROCEDURE

A common procedure for deriving the physical parameters of optically thin chromospheric structures is the application of the so-called “cloud-model” (Beckers 1964; Tziotziou et al. 2004). This is done by using the standard formula which gives the synthetic line profile:

\[ I_\lambda = I_{0\lambda} e^{-\tau_\lambda} + \int_0^\tau S_\lambda e^{-\tau_\lambda} d\tau_\lambda \]  \hspace{1cm} (1)

We assume a gaussian wavelength dependence of the optical thickness:

\[ \tau_\lambda = \tau_0 e^{-\left(\frac{\Delta \lambda - \Delta \lambda_D}{\Delta \lambda_D}\right)^2} \]  \hspace{1cm} (2)

with \( I_{0\lambda} \) being the reference background profile, while the four adjustable parameters are: the source function \( S \), the Doppler width \( \Delta \lambda_D \), the optical thickness \( \tau_0 \) and the velocity \( v \) deduced from the Doppler shift \( \Delta \lambda_I \). All these parameters are assumed to be constant along the line-of-sight.

Using an iterative least-square procedure for non-linear functions we can deduce the parameter values that best describe the observed H\(_\alpha\) and H\(\beta\) contrast profiles, i.e.

\[ C_\lambda = (I_\lambda/I_{0\lambda} - 1) \]

4. RESULTS

The background intensity used in these calculations is the average intensity of quiet regions along the slit. Only profiles that have a contrast at the line center lower than 0.1 have been considered. Profiles found along the 15 slit exposures and satisfying the cloud model criteria have been used for the derivation of the mottle parameters from both H\(_\alpha\) and H\(\beta\) profiles. From the obtained values those that correspond at the same positions in the H\(_\alpha\) and H\(\beta\) spectra have been used for the histograms (Fig. 4) and for the scatterplots (Fig. 5).

From the histograms (Fig. 4) it can be seen that except from the velocities, which have almost the same distribution in both lines, the other three parameters (i.e. optical thickness at line center, Doppler width and source function) are larger in the H\(_\beta\) line than in the H\(_\alpha\) line.

Intercomparison of the four parameters derived from the H\(_\alpha\) and the H\(\beta\) contrast profiles are shown in the correlation diagrams (Fig. 5). A linear correlation gives:

\[ \tau_{0,\beta} = 0.21 \tau_{0,\alpha} \]  \hspace{1cm} (3)

and

\[ \Delta \lambda_{D,\beta} = 0.55 \Delta \lambda_{D,\alpha} \]  \hspace{1cm} (4)
Figure 4. Histograms of the 4 parameters calculated by the cloud model from the Hα line profiles (solid line) and from the Hβ line profiles (dashed lines).

Figure 5. Correlation diagrams between the different parameters obtained by the cloud model applied in the Hα and Hβ contrast profiles.
From the definition of the optical thickness at line center and of the Doppler width one can obtain a relation between these quantities in the two lines. Thus for the H\(\alpha\) line:

\[
\tau_{0,\alpha} = \frac{\pi^{1/2} c^2}{m_e c} \frac{f_\alpha \lambda_\alpha^2}{c} \frac{N_2}{\Delta \lambda_{D,\alpha}} d
\]

and

\[
\Delta \lambda_{D,\alpha} = \frac{\lambda_\alpha}{c} \sqrt{\frac{2kT_\alpha}{m} + \xi^2}
\]

where \(N_2\) is the number density of the second hydrogen level, \(f_\alpha\) is the H\(\alpha\) oscillator strength, \(d\) is the width of the structure and \(\xi\) is the microturbulent velocity. By changing \(\alpha\) to \(\beta\) the above relations are equally valid for the H\(\beta\) line. From the above relations assuming that the emission in the two lines comes from the same parts of the structure one can obtain:

\[
\frac{\Delta \lambda_{D,\beta}}{\Delta \lambda_{D,\alpha}} = \frac{\lambda_\beta}{\lambda_\alpha} = 0.74
\]

and

\[
\frac{\tau_{0,\beta}}{\tau_{0,\alpha}} = \frac{f_\beta \lambda_\beta^2}{f_\alpha \lambda_\alpha^2} \frac{\Delta \lambda_{D,\alpha}}{\Delta \lambda_{D,\beta}} = 0.14
\]

The difference between these values and the observed ones given by Eqs. (3) and (4) can lead us to the conclusion that the emission in the two lines does not come exactly from the same parts of the structures. However, from the intercomparison of the different parameters shown in Fig. 5, it is clear that the scatter in the obtained values is rather large and this could also lead to values of the coefficients obtained by the linear correlation that are different from the theoretical ones.

5. DISCUSSION

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.

From the H\(\alpha\) and H\(\beta\) spectra of dark mottles analysed in this work, it was found that the three parameters (i.e. optical thickness at line center, Doppler width and source function) out of the four derived from the cloud model have naturally lower mean values in the H\(\beta\) line than in the H\(\alpha\) line. Differences between the relations obtained for two of the parameters (optical depth and Doppler width) for the considered lines and the relations that one expects from the theory could lead us to the conclusion that the emission in these lines does not come exactly from the same parts of the structures. This is an interesting point for further investigation.

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REFERENCES