DIAGNOSTICS OF DARK CHROMOSPHERIC MOTTLES BASED ON HIGH RESOLUTION SPECTRA, I - OBSERVATIONAL DATA

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Abstract. High resolution optical spectra of dark mottles in H and Ca lines were observed with the Echelle spectrograph of the VTT at Sacramento Peak Observatory. Until now, only Hα spectra and slit-jaw images were processed. Used methods of identification of the dark mottles in the slit-jaw images and in the spectra, as well as a calibration and correction on the scattered light are described. Individual steps of the procedure, as well as crucial problems are discussed. The finally processed line profiles are comparable to the profiles of dark mottles obtained by other instruments including MSDP.

Key words: Sun - chromosphere - dark mottles - spectra - scattered light

1. Introduction

Chromospheric dark mottles as seen in the Hα line are jet-like structures, their widths are in the range 0.5 - 2 Mm, heights 5 - 10 Mm and lifetimes between 5-10 min. Their temperature is in the interval 7000 - 15 000 K, electron densities of $4 \times 10^{10} - 1 \times 10^{11} \text{cm}^{-3}$ and gas pressure of the order of $10^{-1} \text{dyn cm}^{-2}$, see Tsiropoula and Schmieder (1997), Tziotziou et al. (2003). Mottles are not distributed randomly, but they are usually organized into ”rosettes” and their morphology is determined by the presence of
magnetic flux tubes filled with the plasma ejected from below and streaming outwards from a common centre. Tsiropoula et al. (1994), using Beckers’ cloud model, showed that the predominant pattern of the bulk motion in dark mottles is downwards in their foot points and upwards at their tops. Tziotziou et al. (2003) suggested that the mechanism of the magnetic flux cancellation in the dark mottles is due to magnetic reconnection.

For an estimation of physical properties of chromospheric structures, as dark mottles are, cloud model is often applied. In a general case, hydrogen level populations in many height layers across the chromospheric structure are computed using NLTE theory and radiative transfer for different sets of parameters as temperature, pressure or electron density, geometrical thickness and macroscopic velocity.

In this project we use observations in several lines (Hα, Hβ, Ca II H and Ca II 8542 Å) made with the Echelle spectrograph of the Vacuum Tower Telescope (VTT) of the Sacramento Peak Observatory for deriving the plasma parameters from the cloud model improved by Heinzel et al. (1999). For particular observed structures we plan to use the cloud model formula (Molowny-Horas et al., 1999) where the cloud model is solved gradually from the most bottom height layer to the top of the structure. As incident radiation for the most bottom height layer (i.e. background radiation) we use the radiation from the structure’s vicinity. For higher height layers the radiation from the previous height is taken as an incident radiation. The cloud model is solved using a source function computed for different sets of parameters, then synthetic line profiles are computed for these sets of parameters. Finally we find the best model (set of parameters) by minimization of χ² of synthetic and observed profiles. In the present paper, which is the first part of the project, we describe the data, the dark mottles selection, and then on examples of Hα spectra we explain methods of their calibration, removing the scattered light and choosing of the quiet-Sun profiles.

2. Observation and Data Reduction.

We obtained the observational data with the Echelle spectrograph at the VTT on April 9, 1991. The instrument is described by Cram (1981). In the region located W06 S27 at 20:02 UT altogether 15 slit exposures of 2.5 sec exposure time, each separated from the other by 15 arcsec, were registered.
Figure 1: Hα slit-jaw filtergrams of the solar chromosphere. Dark mottles gathered into rosettes are quite well visible below the thin horizontal line. The thick vertical line marks the slit, while the horizontal one in the image centre represents one of the two hairs crossing the slit, usually used for evaluating spatial scales at individual cameras. Two horizontal dashed lines in the central section delimit the part of the slit visible in the spectra in the Figure 3.

on the photographic film in Hα, Hβ, Ca II H and Ca II 8542 Å spectral lines. The spatial resolution was better than 0.5 arcsec. The spectra were originally made for a study of the bright filament rims, but in the scanned chromosphere we found also many groups and rosettes of the dark mottles and we decided to analyse them.

The spectra registered on the film were later digitized by the film scanner allowing resolution of 2500 dpi. Slit-jaw Hα filtergrams, shown in Figure 1 were used for identification of the particular regions on the solar surface, and especially to recognize individual dark mottles and other tiny
solar surface structures. To do this, one has to take into account the following conditions: The first condition is that the individual dark mottles persist during the time interval to next exposures, which was of the order of half a minute. The next condition and a dilemma is as follows: cross sections of the dark mottles are just comparable to the projection of the slit width, i.e. approximately 1 arcsec. Thus, when a dark mottle is projected onto the slit, light from it comes through the slit and the spectrograph creates a spectrum of it. It means that when a dark mottle is projected onto the slit then it can not be visible on this particular slit-jaw image. Therefore, one is not able to identify it on the slit-jaw image when the slit hits the dark mottle. It is why we used next or previous slit-jaw images, we found there the slit position for the previous or subsequent exposure and in such
a way we identified the dark mottles positions on slit and subsequently in
the spectra. Then, we independently checked the positions of the struc-
tures in the spectrum to have another way of the position testing. Each
spectrogram was calibrated for intensity and wavelength using IDL codes
of Havlíčková (2003). Spectral resolution used is about 100 px per Å which
allows to determine (and recover) the spectral profiles and their detailed
shapes with a high accuracy.

![Image of spectra](image.png)

*Figure 3: Spectra of the dark mottles taken in the Hα (left) and Ca II H (right) regions. One can compare the image to the slit-jaw filtergram to recognize individual features like a filament in the centre or dark mottles in the lower half of the spectra. Thick horizontal lines emphasize locations of the two hairs crossing the slit.*

3. Scattered Light

Spectrograms have to be corrected for the scattered light and the extracted
calibrated profiles are then used for determination of the cloud model input
parameters. One of the crucial problems we met was an absence of the ab-
solutely undisturbed profile in each individual spectrogram. Moreover, the
derivation of the cloud model parameters was found to be extremely sensi-
tive to that matter. Thus instead of semiautomatic processing of the data
as it was planned and prepared at the beginning of this project, we have
to treat each slit-jaw picture and calibrated spectrogram separately and individually. It concerns the quiet-Sun and dark mottle profiles selection.

During the spectra calibration procedure, the quiet-Sun profiles extracted along the slit were compared to the corresponding reference profiles of David (1961), see Figure 5. An eventual difference of the obtained calibrated and expected reference quiet-Sun profiles was attributed to scattered light which is typical for Echelle spectrographs and also for scanners. The distribution of the scattered light in the calibrated profiles was derived as follows: We selected an internal part of the Hα profile at the position $-1$ Å as a region without any blend and having a quite suitable range of intensities usable for the dark mottles profiles. This part should not be affected very much either by the scattered light or by the noise that occurs in the

\[ \text{Figure 4: White circles denoted by digits mark regions where distinguished dark mottles were identified along the slit.} \]
Figure 5: Scattered light in the observed and calibrated Hα profile represented by the full line at the blue wing is lower than at the red one. The dashed line marks the reference profile of David (1961).

more distant wings of the profiles. There a multiplicative constant was estimated as a ratio of values averaged along this part in our quiet-Sun profile and in the reference one.

As one can see in Figure 5 the red wing of the observed and calibrated quiet-Sun profile is higher than the blue wing. This is attributed to the light scattered in the spectrograph. Distribution of the scattered light along the dispersion was estimated simply as a difference of the reference David’s profile from the calibrated quiet-Sun profile in several points along the dispersion. These points were chosen according to changes in the difference between the observed and reference profiles. So we estimated the scattered light in points where its sign is changing or in points of its local minima. Distribution of the scattered light in the spectrograph is not known at all. According to the spectra survey, one could suppose that intensity of the scattered light would decrease monotonously from the red to the blue edge of the profile and its values should be positive or zero. However, the scattered light distribution depends slightly on the photographic density.
Figure 6: Calibrated dark mottle and quiet-Sun profiles as marked in the Figure 4. The full lines mark the quiet-Sun profiles, the dashed lines are the dark mottle profiles.

and could be caused by additional light scattering on grains of the film emulsion during the process of scanning. It is important to note that values of intensity of the scattered light, estimated from the observed and reference profile difference, are not absolute. It is because the multiplicative coefficient for absolute calibration was estimated from the wavelength where the scattered light was not zero. Therefore, values of the scattered light intensity can be negative, especially in the blue wing of the profile. Values of intensity of the scattered light between chosen wavelengths were computed using linear interpolation. In such a way we received the best fit of the observed quiet-Sun profiles with the reference David’s profile. Due to the best numerical transformation in the calibration curve and the best fitting of the calibrated and expected reference profile we considered this process as optimal for each spectrum and then we used the same numerical procedure including the derived constants for removing the scattered light in calibrated profiles of the dark mottles.
4. Discussion and Conclusion

Removing of the scattered light and selection of the quiet-Sun profile seem to be substantial problems for treating of dark mottle spectra obtained with a large spatial and spectral resolution. The dark mottle profiles shown in Figure 6 are typical by a line core which is broader and darker than the quiet-Sun profiles. They are comparable to the profiles of dark mottles obtained using MSDP and published by Heinkel and Schmieder (1994). However, as our profiles were observed using much higher spectral resolution of several tens pixels per Å, and they seem to be quite suitable for the cloud model calculations, we plan to do in a next paper.

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References

Dijagnostika tamnih kromosferskih tvorbi pomoću spektara visokog razlučivanja opežački podaci

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Izlaganje sa znanstvenog skupa

Sažetak. Spektri visokog razlučivanja u vidljivom području koromosferskih tamnih tvorbi snimljeni su u spektralnim linijama vodika i kalcija spektrografom VTT teleskopa na opservatoriju Kitt Peak. Za sada su obradjeni samo spektri i snimci pukotine Hα linije. Opisuju se korištene metode identifikacije tamnih tvorbi u snimcima pukotine i u spektrima, kao i kalibracija i korekcija raspršene svjetlosti. Diskutiraju se pojedini koraci postupka, kao i ključni problemi. Konačni obrađeni profili linija uspoređuju se s profilima tamnih mrlja dobivenih pomoću drugih instrumenata, uključujući i MSDP.

Ključne riječi: Sunce - kromosfera - tamne tvorbe - spektri - raspršeno svjetlo