Hα CHROMOSPHERIC MOTTLES AND THEIR UV/EUV COUNTERPARTS SEEN BY SOHO/SUMER

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ABSTRACT

We report on our observations made during the SOHO-GBO campaign in October 2005. In particular, we focus on Hα mottles observed with the Dutch Open Telescope (DOT) and quiet Sun regions seen in O V 629 Å and N V 1238 Å lines by SOHO/SUMER. Hα data provide us with the diagnostics of the Hα line opacity and this can be correlated with the opacity of the hydrogen Lyman continuum, using non-LTE simulations. This continuum opacity is then critical for explaining the mottle contrast in O V 629 Å line. The fact that we see a similar contrast also in N V 1238 Å rises a question of how these two lines, one below and one above the Lyman-continuum head, are actually formed within the highly structured chromosphere.

Key words: Sun: chromosphere.

1. INTRODUCTION

Mottles are jet-like quiet Sun structures (Beckers, 1972) seen on the solar disk as dark features which reside at the boundaries of the chromospheric network and constitute the chromospheric fine structure. They cluster either into small groups called chains (along the common boundary line of two network cells) or larger groups called rosettes (around the meeting point of at least three network cells) and they are believed to be the disk counterparts of spicules. In Hα they are mostly optically thin structures and consist of relatively cool plasma of temperatures around 12000 K (Tziotziou et al., 2003). Mottles/spicules eject quite a lot of cool plasma towards the higher solar atmosphere (Tsipopou & Tziotziou, 2004).

When looking at the quiet chromosphere (e.g. SUMER Atlas, Feldman et al., 2003) in O V 629 Å which is an EUV transition region line shortward of the 912 Å wavelength that represents the hydrogen Lyman continuum head, as well as in N V 1238 Å, which is a line longward of the Lyman continuum head, it seems that it has a similar intensity contrast to that of Hα images, showing similar dark feature distribution on the solar disk.

In this paper we investigate whether the O V contrast is the result of an absorption by the hydrogen Lyman continuum, just like in filaments and filament channels (Chuaderi Drago et al., 2001; Heinzel et al., 2001) and propose plausible mechanisms for explaining the observed N V contrast.

![Figure 1. A high spatial resolution DOT Hα line center image of a quiet Sun area containing mottles.](image)

2. OBSERVATIONS

The observations used in this study were obtained during a SOHO-GBO campaign conducted in October 2005. Unfortunately, we still have not managed to have simultaneous co-aligned Hα, O V and N V observations. For this reason we use for our analysis a) two-dimensional high spatial resolution (∼0.2 arcsec) Hα observations (at line center, ±0.35 Å and ±0.7 Å) of a solar disk center quiet Sun area containing mottles, obtained with the Dutch Open Telescope (DOT) on October 14, 2005 at 10:30 UT (see Figure 1) and b) two-dimensional quiet
3. RESULTS

3.1. Theoretical calculations of $\tau(629)$

A large grid of hydrogen models is constructed with the MALL code which is a multi-level non-LTE transfer code that calculates the H$\alpha$ line formation inside an isolated cloud lying above the solar surface using a five level plus continuum hydrogen model atom (Molowny-Horas et al., 1999; Tziotziou et al., 2001). The grid of hydrogen models depends on five free parameters: kinetic temperature $T$, electronic density $N_e$, microturbulence $\xi$, cloud velocity $v$ and geometrical thickness $Z$. The range for these parameters has been chosen to be representative of mottles and is shown in Table 1 where $H$ is the height of the structures above the solar surface. The results of the calculations for each model of the grid are the hydrogen level populations as a function of the line-center optical depth.

The optical thickness of the Lyman continuum $\tau(912)$ for each of our grid models can then be calculated from the H$\alpha$ line-center optical thickness $\tau_0$ of H$\alpha$ using the relation

$$d\tau(912) = \frac{\alpha_0(912)}{\alpha_0(H\alpha)} \frac{n_1}{n_2} d\tau_0(H\alpha)$$  \hfill (1)

where $n_1$ and $n_2$ are, respectively, the first and second hydrogen level populations and $\alpha_0(912)$ and $\alpha_0(H\alpha)$ the corresponding absorption cross-sections for the Lyman continuum head and the H$\alpha$ line center. The temperature dependence comes partly from $\alpha_0(H\alpha)$ which depends on the H$\alpha$ Doppler width $\Delta \lambda$ and partly from the level population ratio. The calculated correlations between $\tau(912)$ and $\tau_0(H\alpha)$ for all models of our grid are shown in Figure 2. They suggest that as the temperature increases the ratio of the two aforementioned optical depths decreases which is consistent with the results of Heinzel et al. (2001).

For wavelengths shortward of the Lyman continuum head the absorption coefficient of Lyman continuum varies as $\lambda^3$ (Mihalas 1978). The Lyman continuum optical thickness $\tau_\lambda$ at a given EUV line is smaller than the Lyman continuum optical thickness $\tau(912)$ by a factor $\lambda_{line}^3/(912)^3$ which gives 0.33 for O V (neglecting a weak dependence on Gaunt factors).

3.2. H$\alpha$ cloud model inversion

A common procedure for the deduction of physical parameters of chromospheric structures is based on the cloud model. Their derivation comes from the comparison between H$\alpha$ line profiles formed in the body of the structures and those emitted below the structures using the
well-known radiative transfer formula

\[ I_\lambda = I_0 e^{-\tau_\lambda} + \int_0^{r_\lambda} S_{\tau} e^{-\tau_\lambda} d\tau_\lambda \]  \hspace{1cm} (2)

that provides the observed line intensity profile. For the optical thickness we usually assume a gaussian wavelength dependence

\[ \tau(\Delta \lambda) = \tau_0 e^{-\left(\frac{\Delta \lambda - \Delta \lambda_D}{\Delta \lambda_D}\right)^2} \]  \hspace{1cm} (3)

In the above formulas, \( I_0(\Delta \lambda) \) is the reference profile emitted by the background, while the four adjustable parameters of the calculations are a) the source function \( S \), b) the Doppler width \( \Delta \lambda_D \), c) the line-center optical thickness \( \tau_0 \), and d) the Doppler shift \( \Delta \lambda_f \) which gives the velocity \( v \). All these parameters are assumed to be constant along the line of sight. The cloud model is appropriate for structures lying high enough above the chromospheric background and gives reliable values for the above physical parameters that best describe an observed profile which can be obtained by solving the aforementioned equations with an iterative least-square procedure for non-linear functions (see Tziotziou et al., 2003).

The cloud model method has been applied to the DOT \( H\alpha \) observations shown in Figure 1. The background intensity is the average intensity of a region around the mottles. For this study only \( H\alpha \) profiles of mottles that have a contrast – which is defined as the ratio between the observed profile and the local background minus 1 – lower than zero have been considered.

In Figure 3 we show the histogram distributions of velocity (left panel) and Doppler width (middle panel) derived with the cloud model and the distribution of temperature (right panel) derived from the calculated Doppler width assuming a constant microturbulence velocity of 10 km sec\(^{-1}\), which is considered as a typical value for mottles. We see that the velocity distribution is almost symmetric, indicating the presence of both downflows and upflows while the temperature distribution peaks around 12000 K.

In Figure 4 we show the histogram distribution of the \( H\alpha \) optical thickness (solid line) derived with the cloud model and the corresponding Lyman continuum optical thickness \( \tau(629) \) distribution at O V 629 Å (dotted line) derived from the non-LTE grid of Figure 2 (see text for details).

### 3.3 O V and N V contrast

In Figure 5 we present SOHO/SUMER two dimensional quiet Sun observations in O V 629Å (left panel) and N V 1238 Å (right panel) obtained on October 15, 2005. The contrast similarity of these two lines, one located below
and one above the Lyman-continuum head, is striking and rises several questions.

As we have discussed above the contrast of O V probably results from the Lyman continuum absorption by the relatively cool plasma of mottles. However, Lyman-continuum absorption cannot be the mechanism for the N V contrast since this line is above the Lyman-continuum head. Foukal (1981) claims that dark chromospheric features which were observed in UV lines above the Lyman continuum head by Skylab are due to structures of high density. At high densities, the Cl-continuum absorption could play the same role as the Lyman-continuum one and thus the structures would look also dark. These structures could be mottles/spicules which should have 1 to 2 orders of magnitude higher density ($\sim 10^{12}$ cm$^{-3}$) compared to filaments where the density is around $10^{10}$ cm$^{-3}$. This could also explain why filaments are not visible above 912 Å in chromospheric lines (Chiuderi Drago et al., 2001).

4. DISCUSSION AND CONCLUSIONS

We have studied the similarity of H$\alpha$, O V and N V contrast of quiet Sun images using the non-LTE simulations. We have correlated the H$\alpha$ line opacity in mottles with the Lyman-continuum head opacity and with the help of H$\alpha$ cloud model inversion results explained that the O V contrast is probably due to absorption by the Lyman-continuum. We have also proposed, based on the idea of Foukal (1981) that the N V contrast could probably be explained by a similar mechanism, that is absorption by the Cl-continuum provided that the density in mottles is of the order of $10^{12}$ cm$^{-3}$.

We should mention that another mechanism for the observed contrast in O V and N V could be the “volume blocking”, that is the cool material from mottles and spicules occupying part of the transition region volume where otherwise the plasma would be hotter and emitting in transition region lines (Anzer & Heinzel, 2005). This mechanism could work for both lines. However, since the O V contrast can be easily explained by the absorption, then probably the volume blocking is less important and absorption by the Cl-continuum for N V can play a role.

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