IMPORTANCE OF ABSORPTION AND VOLUME BLOCKING FOR LINE INTENSITY DEPRESSION IN EUV FILAMENTS

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ABSTRACT

The nature of the EUV filaments, seen as the large dark structures in the EUV coronal lines with wavelength between 504 and 912 Å, can be explained by two processes: absorption by the hydrogen resonance continuum (Lyman continuum) and the volume blocking. For estimation of the relative contributions of those two processes it is necessary to know the optical thickness at hydrogen Lyman continuum (e.g. at its head), height above the surface and the geometrical thickness of the filament. Using a spectroscopic model based on those two processes for modelling of the intensity depression of the EUV coronal lines and modelling of the profiles of hydrogen spectral lines these quantities can be estimated. In this work we are fitting synthetic profiles (computed using the non-LTE one-dimensional slab model) to profiles of the hydrogen Lyman lines, Lyman continuum and profiles of the Hα line observed on May, 5 2000 by SoHO and THEMIS, respectively. We compared results obtained for this EUV filament with results of diagnostics of another EUV filament observed on October, 15 2000. We found that in both EUV filaments the absorption dominates over the volume blocking only in the Hα-parts of the EUV filaments. In the EUV extensions the contribution of the absorption to the intensity depression of the EUV coronal lines is maximally 50% relative to the volume blocking.

Key words: solar filaments; hydrogen Lyman lines; spectroscopy.

1. INTRODUCTION

In our previous work (Schwartz et al., 2006) we made the non-LTE modelling of profiles of the hydrogen Lyman lines Lβ, Lδ – Lγ of the EUV filament observed by SoHO/SUMER on October, 15 1999. For parts of this EUV filament, well visible in Hα (Hα filament) we estimated a large (several hundreds) optical thickness τHα at the head of the Lyman continuum. But the geometrical thickness of the Hα filament is rather small (several thousands of km) relatively to the vertically large EUV extension (area of the EUV filament outside the Hα filament). Therefore the absorption by hydrogen Lyman continuum is causing the intensity depression in the Hα filament and the contribution of volume blocking is negligible.

In the EUV extension there were areas where τHα is very low (≪1) and then only the volume blocking is responsible for the intensity depression observed by the CDS in e.g. the MgX 624.94 Å coronal line. There are also areas with τHα~5 where the absorption contributes only by 16 – 50% to the intensity depression. So the extension is rather inhomogeneous.

In this work we are fitting observed profiles of the hydrogen Lyman lines Lβ – Lγ. Lyman continuum and Hα profiles of a more compact and better pronounced EUV filament with the synthetic profiles computed using the non-LTE one-dimensional-slab model. The Lyman and Hα spectra were observed on May, 5 2000 by SoHO and THEMIS, respectively. This filament was already studied by Schmieder et al. (2003)

2. OBSERVATIONS

An EUV filament near the solar disk was observed on May 5, 2000 in Hα and EUV by the MSDP (Multichannel Subtractive Double Pass spectrograph) (Mein1991, 2002) on THEMIS and by SoHO (Solar and Heliospheric Observatory), respectively. The position of the EUV filament is: solar X = –393 arcsec and solar Y = –353 arcsec (S 25 E 27 in Carrington coordinates). The hydrogen Lyman lines and the Lyman continuum were observed by SUMER (Solar Ultraviolet Measurements of Emitted Radiation) (Wilhelm et al., 1995). These observations are shown in Figure 1. EUV coronal spectral lines (e.g. MgX 624.94 Å, SiXII 520.60 Å, etc.) and EUV transition-region lines (e.g. OⅦ 629.73 Å) were observed by CDS (Coronal Diagnostic Spectrometer) (Harrison et al., 1995). The CDS observations of the MgX line are shown in Figure 2. Hα counterpart of the EUV filament was observed by THEMIS/MSDP. The observations are shown in Figure 3. Many faint dark structures in the vicinity of the very dark and well pronounced Hα filament are noticable. Hα profiles along the SUMER slit

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Figure 1. Observations of the EUV filament in hydrogen Lyman lines Lβ, Lε–L9 and Lyman continuum made by SoHO/SUMER. The major part of the slit is crossing the EUV filament. Only a small part of the slit in the South is outside the EUV filament. This part is marked as a section QS. The quiet-Sun profiles were taken from this section. Two horizontal dashed-line bars mark boundaries of area of the EUV filament taken for our diagnostics.

Figure 2. Observations of the EUV coronal line MgX 624.94Å made by SoHO/CDS during 8:12–9:03 UT. The vertical bar shows the position of the SUMER slit. Full-line contours mark the position of the Hα filament as observed by THEMIS (Figure 3). The coordinates of the raster center are solar $X = -288$ arcsec and solar $Y = -362$ arcsec and the FOV is 244 arcsec x 240 arcsec.

Figure 3. Observations of the filament in the Hα line center made by the THEMIS/MSDP. White dotted bar shows position of the SUMER slit and the arrow shows the direction to North.

were taken from MSDP data and were calibrated according to the quiet-Sun Hα profile of David (1995).

3. BRIEF DESCRIPTION OF METHOD OF OUR NON-LTE MODELLING

We used the model of Heinzel et al. (1997) where the filament is approximated by a horizontal one-dimensional (1D) slab. It means that the slab is horizontally infinite and has a finite vertical dimension which is equal to the geometrical thickness $D$ of the filament. We assume that the slab is irradiated only from the solar atmosphere beneath. Temperature is decreasing in the vertical direction symmetrically from two analogous prominence-corona transition regions (PCTR s) to the slab interior. Temperature gradient is steep in the PCTR s while in the slab interior the temperature is almost constant. Pressure is constant in the whole slab and the micro-turbulent velocity does not exceed 10 km s$^{-1}$. For solving the radiative transfer in the slab the MALI method (Rybicky & Hummer, 1991; Heinzel, 1995; Paletou, 1995) with a model of hydrogen atom consisting of 12 levels plus continuum is used.

We could not use the average profiles of the Lyman lines from the QS section as the background irradiation of the slab because intensities in their optically thin wings were much higher than intensities in the wings of the profiles from the EUV extension. Therefore we reconstructed the profiles of the background irradiation from the QS
profiles using the method which was first proposed in Schwartz et al. (2006). The Lyman lines are optically thin in the wings therefore the profiles of background radiation and of the EUV filament should be equal there. Then the wings of the profiles of the background radiation were reconstructed by multiplying the wings of the QS profiles by factors which assure that the average intensities in the wings of the reconstructed profiles are equal to those in the wings of the profiles from the EUV extension. Optically thick line cores were reconstructed using the quiet-Sun profiles of Warren et al. (1998). In that paper there are published the 6 quiet-Sun profiles with different intensities in the wings for each Lyman line (L β–L 11). The cores of the QS profiles were multiplied by such factors that there are the same average intensities in the cores of the reconstructed profiles and in the cores of the Warrens’ quiet-Sun profiles with the intensities in the wings close to intensities in the wings of the profiles of the EUV extension.

We computed grids of non-LTE models for different sets of input parameters (temperature, gas pressure and filling factor). Geometrical thickness of the slab and its height above the solar surface were computed using the spectroscopic model of Heinzel et al. (2003) and the intensities of the EUV coronal lines Mg X and Si XII observed by the SoHO/CDS.

We fitted the observed profiles with synthetic ones searching in the grids for the best model using the \( \chi^2 \) minimization. For the best model we determined also values of the optical thickness \( \tau_0(\text{Hα}) \) at center of the Hα line and \( \tau_{012} \).

4. RESULTS

We did not include Lβ line into our modelling because our isobaric 1D model was not able to fit unreversed profiles of this line when \( \tau_{012} \leq 2 \). So we fitted the unreversed profiles of L β–L 9, H α and the Lyman continuum of the EUV extensions – we took profiles from the area between two dashed-line bars in Figure 3 outside the Hα filament averaged along 5 arcsec long sections. An example of synthetic profiles fitted to observed ones from the EUV extension is shown in Figure 4.

We found that the EUV extension is vertically very large (the geometrical thickness ranges from 30 000 to 100 000 km) and both PCTR s occupy together 30–60% of this thickness. Temperatures in the slab interior around 5 000 K are the same as in the Hα filament but temperatures in the PCTR s are rather high ranging from 30 000–70 000 K. Gas pressure around 0.01 dyn/cm² is quiet comparable to the coronal pressure. Filling factor is very small – only several percent of the geometrical thickness is filled with the EUV-filament plasma.

There are areas with \( \tau_{012} \) both larger and lower than 1 in the EUV extension. The optically thick areas (\( \tau_{012} > 1 \)) are visible as faint dark structures in the vicinity of the very dark Hα filament (see Figure 3) because \( \tau_0(\text{Hα}) \geq 0.1 \) in these areas. The absorption by hydrogen Lyman continuum contributes to depression of the intensity of the Mg X line by 30–50% then the volume blocking mechanism plays an important role in the intensity depression of EUV coronal lines throughout the whole EUV extension.

5. DISCUSSION AND CONCLUSIONS

Comparing the results of our non-LTE diagnostics of the extensions of the EUV filaments of May, 5 2000 and of October, 15 1999 we found that EUV extensions of both filaments are vertically rather large and with geometrically thick PCTR s. Also the relative contribution of absorption to the intensity depression of the EUV coronal lines is similar and the volume blocking plays an important role in the intensity depression throughout the whole EUV extension for both cases.

The difference is only in the temperatures in the slab interior. In the EUV extension of the filament from October, 15 1999 there were also such areas optically thin in the hydrogen Lyman continuum where the temperatures in the interior were around 40 000 K. In case of the EUV extension of May, 5 2000 the temperatures in the interior are low – similar to the Hα filament. So we could assume that the EUV extension of October, 15 1999 was heated. That could also explain the inhomogeneous EUV-filament structure and noncompact Hα filament composed of several islands (see Schwartz et al., 2004 and 2006). But this difference in the temperatures could be also caused by the fact that we used only Lyman lines (no Hα) in the case of EUV filament from October, 15 1999. Lyman lines are not very suitable for modelling of the relatively cold interior if there is a high temperature in the PCTR s.

In this work we are using also the Hα line which is optically thin in the PCTR s so estimated values of the temperature in the interior are more reliable. Now we only have a problem to fit unreversed Lβ profiles when \( \tau_{012} \) is larger then 2. It could be due to the fact that we use a simple one-dimensional and isobaric model. We plan to assume a pressure distribution across the slab in our future non-LTE model which could help to solve this problem.

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Figure 4. An example of the synthetic profiles fitted on the observed ones from the EUV extension.