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Multiwavelength determination of the density and total mass of the EUV filament observed by SoHO/CDS, SoHO/SUMER and MSDP/VTT.

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Abstract. It was found that filaments observed in EUV could be much more extended than observed in Hα. These extended dark structures observed in EUV are named EUV filaments. Their parts seen only in EUV (not observable in Hα because of low opacity at Hα wavelength) are called EUV filament extensions (or simply EUV extensions). For EUV filament observed by SoHO on 15 October 1999 as nothern polar crown filament, only several small dark structures were observed in Hα. So we could suppose that mass of the EUV extension is larger or at least comparable with mass of the parts of filament observed in Hα. In our previous work we determined the 3D structure of the EUV extension of this EUV filament. In this paper we present determinations of mass and average density of this EUV extension. We also found approximate 1D-slab model of this EUV extension with low gas pressure, temperatures from 2×10^4 K to 10^5 K and with extensive prominence-corona transition region.

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1. Introduction

It was found (Heinzel *et al.* 2001, Schmieder *et al.* 2003) that solar filaments observed in EUV lines are more extended than observed in Hα. Parts of the filament visible only in EUV are invisible in Hα due to their very low opacity in this line. These parts were named 'EUV-filament extensions' or simply 'EUV extensions'. Manifestation of EUV filament as dark structure is due to absorption at EUV continuum by EUV filament plasma and due to volume blocking (Heinzel *et al.* 2003a). Volume blocking mechanism is based on fact that coronal line cannot be emitted from volume occupied by relatively cold EUV-filament plasma. Importance of volume blocking and absorption for intensity depresion are comparable (Schwartz *et al.* 2004). Schwartz *et al.* (2004) determined the 3D-structure of an EUV filament using the spectroscopic model of Heinzel *et al.* (2003a) and found that EUV filaments are in heights comparable with heights of of their parts visible in Hα. This was confirmed by Schmieder *et al.* (2004) for another EUV filament where heights were estimated also from on-disk projection (filament was rather far from solar disk center).

The EUV filament studied by Schwartz *et al.* (2004) was observed by SoHO/CDS (*Coronal Diagnostic Spectrometer*) (Harrison *et al.* 1995), SoHO/SUMER (*Solar Ultraviolet Measurements of Emitted Radiation*) (Wilhelm *et al.* 1995), both on SoHO (*Solar and Heliospherical Observatory*) and its Hα counterparts were observed by VTT/MSDP

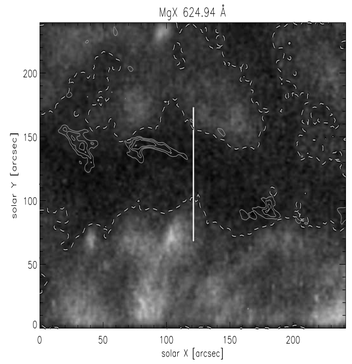

Figure 1. CDS observations of the MgX 624.94 Å line. Dark area of EUV filament is bordered by dashed-line contour. Darkest areas seen in Hα are marked by full-line contours. Vertical white bar is position of SUMER slit.

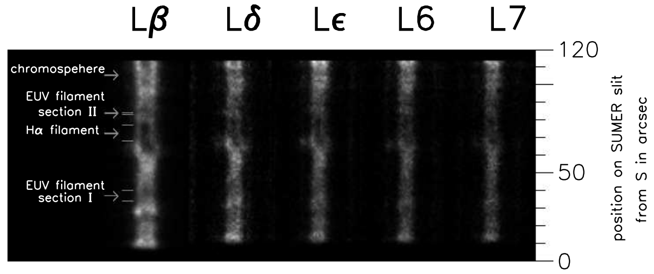

Figure 2. Hydrogen Lyman spectra observed by SoHO/SUMER. Ordinate is position on the spectrograph slit from S. On the left from spectra, there are marked parts of spectra belonging to Hα filament with very deep self-absorption in the line center and to chromosphere with only slight intensity depression in the line center. There are marked also two parts belongin to the EUV extension. Average profiles from these two parts were used for modelling the properties of EUV-extension plasma.

(*Multichannel Subtractive Double Pass spectrograph* on *Vacuum Tower Telescope*) on 15 October 1999 at position N37.6 E19.3 (northern polar crown filament). Only several small Hα islands were observed in a wide EUV filament channel. In 3D-structure determination we used CDS observations of two coronal EUV lines (MgX 624 Å and SiXII 520 Å) with wavelengths between 504 and 912 Å (i.e. between HeI resonance continuum head and hydrogen Lyman continuum head). Therefore radiation of such lines is absorbed only by EUV-filament hydrogen plasma. Resulting heights of the EUV-filament extension are around 15 000 km for the bottom and around 40 000 km for the top boundaries althogh there are significant variations around these representative values.

In this work we present determinations of average plasma density and total mass of extension this EUV filament, estimated using its 3D structure previously determined from spectroscopic model. Using the non-LTE radiative transfer code (Heinzel *et al.* 1997) for computing theoretical hydrogen line profiles we estimated average values of temperature and pressure of EUV-extension plasma.

2. Observations

All observations were made on 15 October between 10:00 and 12:00 UT. For 3D--structure determination of EUV extension (see Schwartz *et al.* 2004) we used Hα observations made by MSDP on VTT and CDS observations of two coronal EUV lines: MgX 624.94 Å and SiXII 520.60 Å. MgX CDS observations are shown also in Figure 1.

To estimate properties of an EUV-filament hydrogen plasma the observations of optically thick hydrogen Lyman lines are needed. We used SUMER observations of hydrogen Lyman lines Lβ, Lδ, Lε, L6 and L7 (Figure 2). made with spectrograph slit crossing EUV filament in center of the CDS raster (see Figure 1.). Position of SUMER slit in CDS raster was estimated by comparison of position of dark structures in Lδ raster observed by SUMER with similar dark structures in HeI 584.33 Å raster observed by CDS.

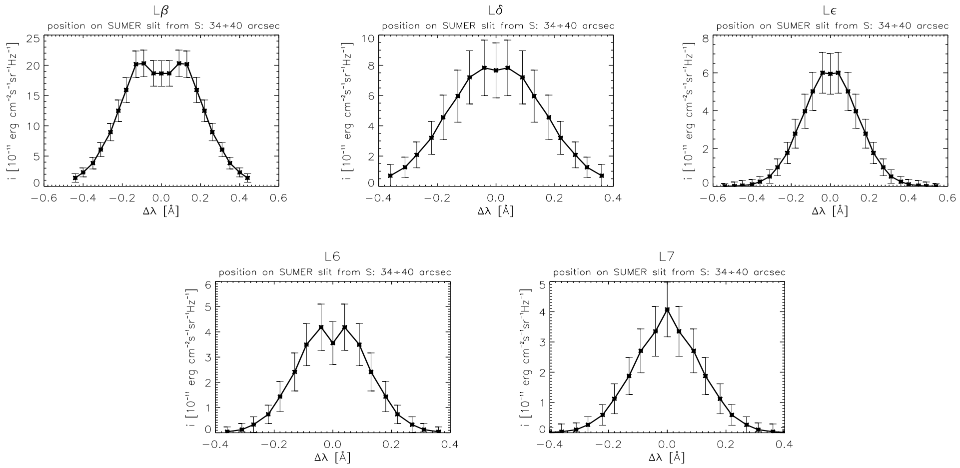

Figure 3. Average profiles of hydrogen Lyman lines (Lβ, Lδ, Lε, L6 and L7) from EUV filament section I (see Figure 2.). Intensity is plotted in units 10^{-11}erg cm^{-2}s^{-1}sr^{-1}Hz^{-1}. To reduce noise the profiles were fitted with Gauss function in wings (similarly as Stellmacher *et al.* (2003)). They were also symmetrized to remove influence of filament plasma moves. For EUV filament section II we obtained similar profiles.

3. EUV-filament density and mass estimations

From 3D structure of EUV-filament extension previously determined by Schwartz *et al.* (2004) it was possible to estimate average density of the EUV-extension plasma and whole mass of the EUV extension. We assumed that EUV-extension plasma contains only hydrogen and helium (abundances of other elements are negligible) and used common ratio of helium to hydrogen concentration 0.1 . Then using definitions for optical thickness at hydrogen Lyman continuum head and at Hα line center we computed EUV-extension plasma density in each pixel of CDS raster (Heinzel *et al.* 2003b). Multiplying these density values by pixel area and by geometrical thickness of the EUV extension in each pixel we obtain column mass in each pixel. Summing column mass values in all pixels within EUV-extension area we obtained total mass of the EUV extension. Then average density is obtained by dividing total mass by volume of EUV extension determined from its 3D structure. Average density ranged from 6.3×10^{-16} to 4.5×10^{-15} g cm^{-3} and total mass from 2.4×10^{14} to 1.2×10^{15} g for τ_{912} between 0.1 and 3. Resulting total mass is comparable to mass of the coronal mass ejections (Simnett 2000, Webb 2000).

4. Estimations of temperature and pressure of EUV-extension plasma

Using profiles of hydrogen Lyman lines observed by SUMER and non-LTE filament model of Heinzel *et al.* (1997) we estimated temperature and pressure of EUV-extension plasma. This filament model is based on radiative transfer of hydrogen Lyman lines emitted only from underneath the filament through the 1D-slab filament approximation. There are two prominence-corona transition regions on the top and on the bottom of 1D slab distributed symmetrically according to central axis of the 1D slab. Temperature decreases from edges to center of the filament steeply in PCTRs but near the center temperature is almost constant. Pressure is constant in whole filament and velocity of microturbulence should not be greater than 10 km s^{-1}. For geometrical thickness D and height h above the solar surface of 1D slab we used values from 3D structure of EUV extension determined previously by Schwartz *et al.* (2004). We used values of D and

h averaged along EUV-filament sections I and II (Figure 2.) on SUMER slit position. We computed grid of such 1D-slab models for different values of temperature, pressure and for different temperature distributions across 1D slab. Then we found best model by minimalization of χ^2 between computed (from 1D-slab model) and symmetrized observed profiles of hydrogen Lyman lines (Figure 3.). For both EUV-sections I and II we found that the observed Lyman profiles can be reproduced with:
– low gas pressure ($\mathrm{p} \approx 10^{-2}\,\mathrm{dyn\,cm^{-2}}$)
– temperature in the filament center $2{\times}10^4 - 3{\times}10^4$ K
– temperature in the filament edge (PCTR) around 10^5 K
– extensive PCTR (both PCTRs together take up approximatelly half of the 1D-slab thickness)
– optical thickness at Hα center much lower than 0.1 (not observabe in Hα).

5. Conclusion

In this paper we presented approximate estimations of average plasma density and mass of the EUV extension of the filament observed on 15 October 1999. This approximate estimations indicate at least that mass of EUV extension is comparable or even larger than mass of its counterparts observed in Hα. Then great mass loading of CMEs (after filament eruption) could originate from EUV extension not seen in Hα. For more reliable mass and density estimations we need to know temperature distribution across 1D slab and gas pressure except EUV-extension 3D structure. In this work we estimated temperatures and mass using just average Lyman hydrogen line profiles and 1D-slab non-LTE model of filament. In future work we plan to construct more fine grid of such modelsand ussing optimalisation techniques we will derive the spatial distribution of EUV-filament plasma parameters which will be suitable for density and mass estimations.

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