Filament absorption study using THEMIS and SOHO/CDS-SUMER observations(*)

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(ricevuto il 10 Giugno 2002; approvato il 24 Settembre 2002)

Summary. — A long filament has been observed with THEMIS/MSDP and SOHO/CDS-SUMER, during a coordinated campaign (JOPs 131/95) on May 5, 2000. THEMIS provided 2D Hα spectra, SUMER rasters in the L4 line and spectra of the whole Lyman series and the Lyman continuum, CDS obtained rasters in several EUV lines (*e.g.*, Mg X 624 Å, Si XII 520 Å, Ca X 557 Å and He I 584 Å). A large depression of coronal line emission in the CDS images corresponds to the absorption by the hydrogen Lyman continuum and represents the EUV filament. Non-LTE radiative transfer calculations allow to explain, in terms of opacities, the large width of the EUV filament compared to the width of the Hα filament itself. The optical thickness of the Lyman continuum is larger than that of Hα line by one to two orders of magnitude. This could be of great importance in the understanding of the filament formation, if we consider that cool material does exist in filament channels but is optically too thin to be visible in Hα images.

PACS 96.60.Se – Prominences.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Ultraviolet telescopes on board the SOHO satellite (EIT, CDS, SUMER) observe filaments in UV or EUV lines shortward of 912 Å (hereafter "EUV filaments"). In Hα observations we see large dark regions corresponding to filament locations. These features were already noted by Schmahl and Orrall [1]. Large corridors on the disk had been already detected around a filament in Mg X line observed with CDS [2, 3]. Penn [4] and Mein *et al.* [5] computed the column hydrogen density for filaments observed, respectively,

(*) Paper presented at the International Meeting on THEMIS and the New Frontiers of Solar Atmosphere Dynamics, Rome, Italy, March 19-21, 2001.

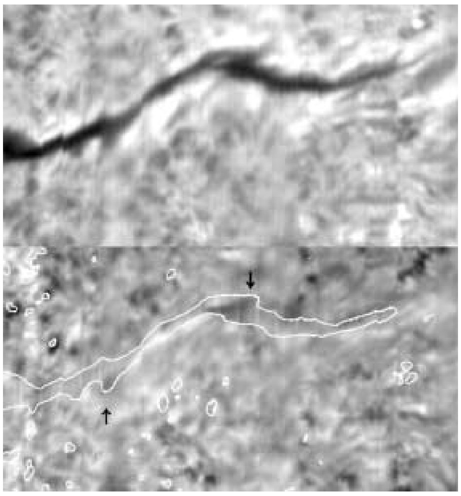

Fig. 1. – Filament of May 5, 2000 in Hα observed with THEMIS/MSDP: the top panel is the intensity map, the bottom panel is the Dopplershift map overlaid by an intensity contour (white/dark regions correspond to blue/redshifted regions). In the filament channel the Dopplershifts are weaker than in the surrounding chromosphere. Note the redshifts at the feet (barbs) of the filament (indicated by arrows)

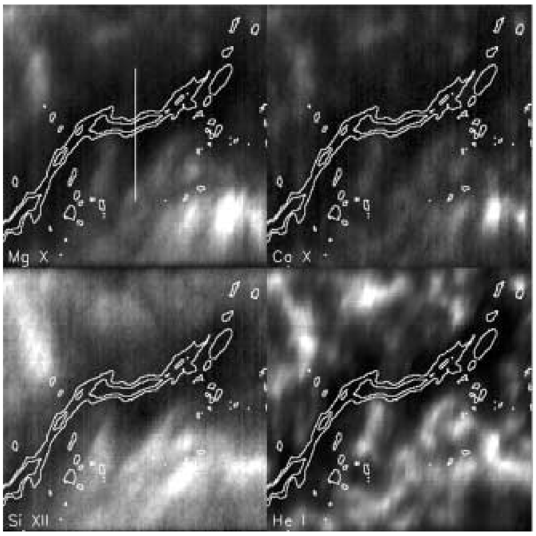

Fig. 2. – Overlay of THEMIS filament contours on the CDS images. The SUMER slit (120$''$) is drawn in the left top panel. The contours correspond to the Hα contrast ($C_{H\alpha} = -0.2, -0.3$, $\tau_{H\alpha} \sim 1$ for $C_{H\alpha} = -0.3$). There is a lack of emission of CDS lines at the location of the filament compared with the quiet Sun. The Hα filament width is between 10 and 20 arcsec. The EUV filament width varies from 50 to more than 100 arcsec according to the locations and the lines.

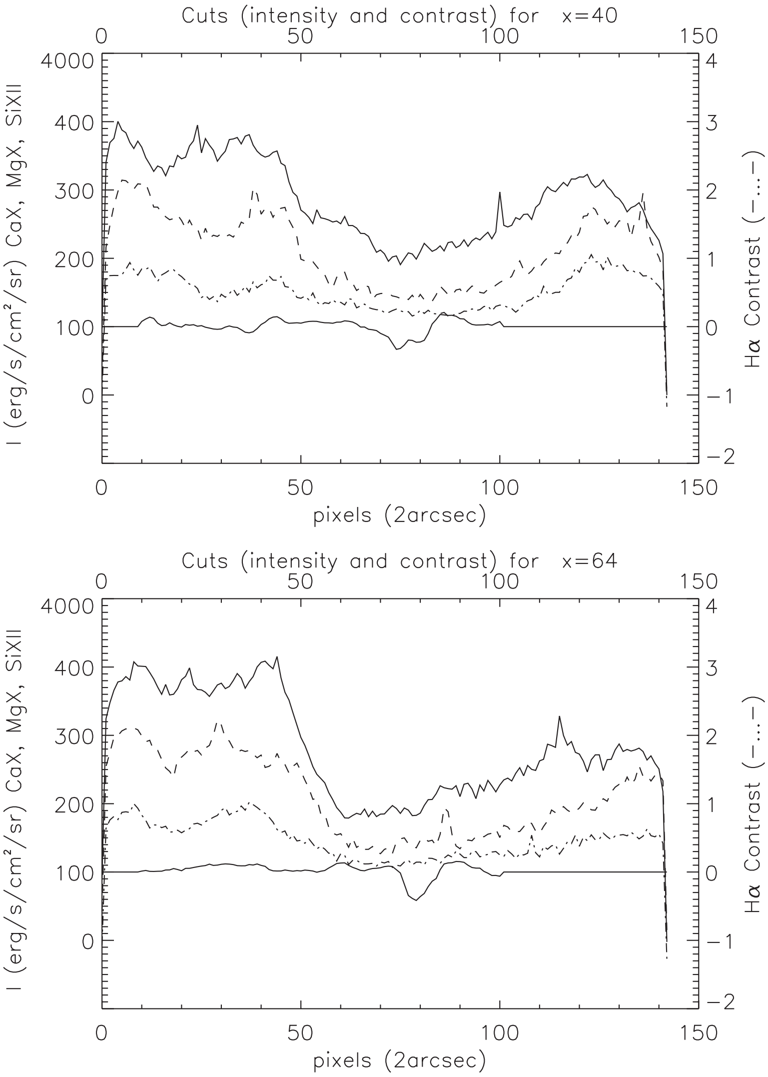

Fig. 3. – Cuts of integrated intensities of CDS lines at different positions, in Si XII (solid line), Mg X (dashed line), Ca X (dash-dotted line). Cuts of the 2D contrast in the Hα image.

with CDS and TRACE. Kucera *et al.* [6] demonstrated that the dark regions observed in UV lines in the corona at the limb were due to bound-free absorption from hydrogen and helium continua in prominence plasma and they computed the hydrogen column density. In this paper we used observations of THEMIS/MSDP, CDS and SUMER spectrographs to explain the large width of the EUV filament compared to the Hα filament. Non-LTE radiative transfer computations allow to derive such a correlation, in terms of opacity difference between the Lyman continuum and Hα line.

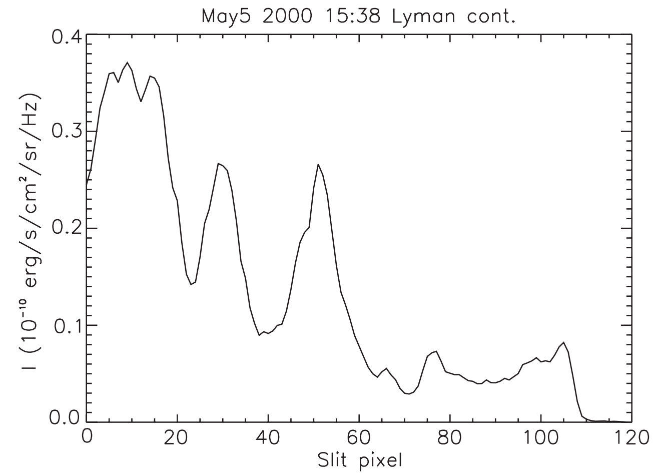

Fig. 4. – Variation of the Lyman continuum intensity through the SUMER slit. The EUV filament corresponds to pixels 70 to 100 with low intensity. North corresponds to low pixel numbers. Unit of the pixel = 1 arcsec.

2. – Observations

On May 5, 2000 a target of a campaign developed at the MEDOC operation center (Orsay) was a filament located at S 25 E 25-30. The observations were done using successively two different Joint Observing Programs, JOP131 and JOP95.

2·1. *THEMIS*. – The observations were performed with the MSDP spectrograph. The Hα filament is shown in fig. 1. Profiles have been calibrated to absolute units with the flat-field profiles which were associated to the quiet sun.

2·2. *CDS*. – With both JOPs (between 08:00-12:00 and 15:40-17:00 UT), the CDS program run Efinar1 study (6 lines in 50 min), followed by Efinar2 study (14 lines in 30 min). The data have been reduced and calibrated using the CDS software. In fig. 2

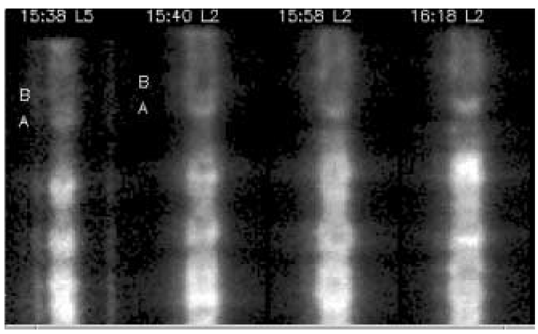

Fig. 5. – SUMER spectra of Lϵ and Lβ through the filament (AB) along the 120$''$ long slit. North is down. The slit top (south) crosses the filament, note the reduced intensities and the central reversed profiles in B.

TABLE I. – *Optical thickness of Hα, Lyman continuum and Mg X 624 Å lines.*

THEMIS $C_{H\alpha}$	Cloud Model $\tau_{H\alpha}$	NLTE code τ_{912}	λ^3-law τ_{624}
−0.5	$\gg 1$	10^3	320
−0.3	0.9	100	32
−0.2	0.5	45	15
−0.1	0.2	15	5

we present an overlay of the Hα filament onto the CDS images. We coalign the EUV, Hα brightness and the magnetic network by using full disk images (MDI and Meudon spectroheliogram). There is a lack of emission at the location of the filament compared with the quiet Sun. The EUV filament width is between 50 and 100 arcsec depending on the locations and the lines. A quantitative comparison of the width of the Hα EUV filament is well illustrated in fig. 3.

2˙3. *SUMER*. – The slit of SUMER (120″) is oriented north-south and is in the middle of CDS rasters. Lβ, Lγ, Lδ, Lϵ to Lc were observed during all the CDS observation period. We see a large variation in the Lyman continuum between the chromosphere and the EUV filament (fig. 4). The filament, where the Lβ line is strongly reversed (see fig. 5), is relatively narrow in the SUMER observations compared with CDS observations and comparable with the width of the Hα filament (around 20 arcsec at the slit position).

3. – Filament absorption

3˙1. *Cloud model*. – THEMIS/MSDP Hα observations provide the mean intensity as a reference profile of the background ($I_{\rm b}$) and the line intensity in each pixel of the field-of-view (I). Profiles have been calibrated to the continuum intensity near Hα, $I_c = 4.077 \times 10^{-5}$ c.g.s. (at the disk center). The filament is located at $\mu = 0.488$. Thus the line-center intensity of the Hα background used for calibration is

$$I_0(\mu) = 0.17 \times I_c \times f \qquad (1)$$

with f being the factor of continuum attenuation due to the limb darkening. The limb darkening coefficient at this μ is 0.941. We compute the contrast:

$$C = (I - I_{\rm b})/I_{\rm b}\,. \qquad (2)$$

The Hα contrasts give us $\tau_{H\alpha}$, using a simple cloud model:

$$I = I_{\rm b}\exp[-\tau] + S[1 - \exp[-\tau]]\,, \qquad (3)$$

where $S \sim 0.08 \times I_c$ is an approximate value of the Hα mean source function.

3˙2. *Non-LTE models*. – Using the correlation plots (fig. 6) obtained with the NLTE grid one can find the corresponding Lyman continuum optical thickness τ_{912}. Optical thickness τ at a given UV line is then smaller by the factor: $(\lambda_{\rm line})^3/(912)^3$ which gives 0.32 for the Mg X line, 0.229 for the Ca X line and 0.186 for the Si XII line.

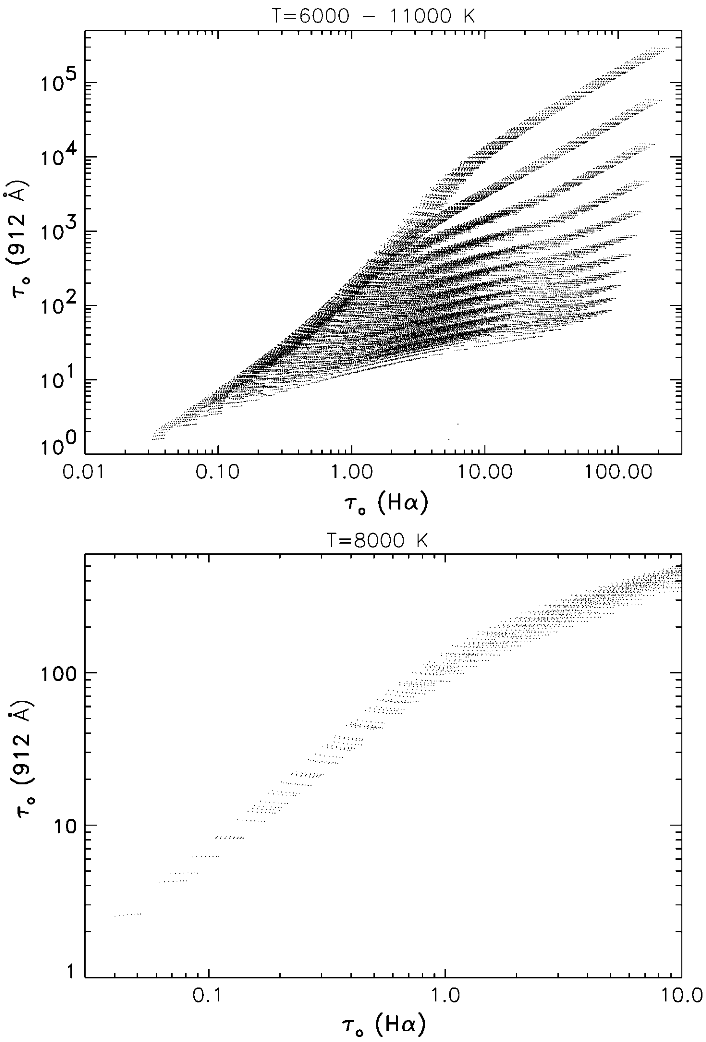

Fig. 6. – (Top) Correlation between $\tau_{H\alpha}$ and τ_{912} for 11 temperatures calculated by a using non-LTE radiative transfer code [7]. Top curve is for 6000 K, the step is 500 K. (Bottom) Correlation between $\tau_{H\alpha}$ and τ_{912} for $T = 8000$ K and microturbulence variation from 3 to 9 km^{-1}.

From table I we conclude that when the Hα filament is visible, τ_{624} is much larger than 1. The Lyman continuum is completely saturated.

3˙3. *Absorption of UV line emission.* – The dark EUV filament observed in the CDS rasters is due to the absorption by the hydrogen Lyman continuum [1, 8]. Using this property we can deduce, from the CDS observations, the optical thickness of the Lyman continuum. The optical thickness at the wavelength of the UV line is given by

$$\tau_\lambda = -\ln[(I_{\mathrm{fil}} - I_{\mathrm{fg}})/I_{\mathrm{bg}}]\,, \tag{4}$$

TABLE II. – *Optical thickness of the Lyman continuum (τ_{912}) derived from CDS observations with the λ^3-law (see the text for notations).*

Line	I_{fil}	I_{QS}	I_{fg}	I_{bg}	τ_λ	τ_{912}
Si XII	120	260	90	170	1.7	9
Mg X	70	180	40	180	1.8	5.5
Ca X	40	80	20	80	1.4	6

where I_{fil} is the EUV filament intensity, I_{bg} is the background intensity (below the filament) and I_{fg} is the foreground intensity. The latter one is taken at the darkest point of the EUV filament, assuming that at that pixel I_{bg} is totally absorbed. I_{fg} represents non-negligible diffuse emission above the filament (see table II). We obtain, for the 3 lines, values of τ_{912} between 5.5 and 9 with an error of 10%. These values correspond to $\tau_{H\alpha}$ values lower than 0.1 for which the contrast is too low to be measurable in the Hα observations (see table I).

4. – Conclusions

When the filament is visible in Hα, the Hα contrast is between -0.2 and -0.5 which corresponds to an Hα optical thickness larger than 0.5 (table I). At positions where the Hα filament is almost invisible (very small τ in Hα), we still see strong absorption by Lyman continuum, which means that there is still enough *cool* material (table II). This also demonstrates for which $\tau_{H\alpha}$ the Lyman continuum absorption is already saturated ($\tau_{H\alpha} > 0.1$). Our results are consistent for Mg X and Ca X lines. Si XII is a coronal line and thus the absorption model (eq. (4)) is probably less accurate.

The presence of cool material in a large filament channel can be explained with the recent filament modeling based on the presence of dips in the magnetic-field–line support [9] and flux ropes [10].

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PH acknowledges the support of CNRS and of the grant S-1003006 of the Academy of Sciences of the Czech Republic. SoHO is a project of an international cooperation between ESA and NASA. THEMIS is a French-Italian telescope operating in IAC. KT acknowledges support through an EC-TMR grant to the ESM network.

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