PLASMA DIAGNOSTICS OF A SOLAR PROMINENCE OBSERVED ON 12 JUNE
1997 by EIT, SUMER and CDS

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ABSTRACT

Plasma diagnostics of a quiescent prominence observed on June 12, 1997 with SUMER, CDS and EIT instruments on-board SOHO in the frame of Joint Observing Programme 9 was carried out. Two sets of SUMER observations were taken in four spectral lines Si IV 1393.76 Å, 1402.77 Å (6 - 8 × 10^4 K) and O IV 1401.16 Å, 1404.81 Å (1.7 - 2.0 × 10^5 K) at two different slit positions on the prominence body. The blend of O IV 1404.81 Å by the second order line O III 702.31 Å was determined. The relative line-of-sight velocities using both Si IV 1393.76 and O IV 1401.16 were derived. From the intensity ratio of O IV 1401.16 to 1404.81 Å, the electron density in the prominence-corona interface was obtained. By analyzing the CDS spectra in He I 584.33 Å and O V 629.73 Å lines the relative line-of-sight velocity maps with regard to the quiet sun were derived.

Key words: SUMER, CDS, solar prominences, plasma diagnostics, electron density, line-of-sight velocity

1. INTRODUCTION

The solar prominence plasma (one hundred times cooler and denser than the surrounding coronal material) is the object of different methods of spectroscopic analysis in order to derive its main physical parameters like temperature, density, velocity, differential emission measure, etc. These parameters are the basis of theoretical models of solar prominences.

Prominence filamentary structures, observed even with the best resolution, make the density diagnostics a very complicated problem. There exist several methods for density determination (for a recent review, see Vial 1998), which give values in the range 10^{10} - 10^{11} cm^{-3} in the cool material and 3 × 10^{10} - 10^{8} cm^{-3} for the prominence-corona transition region (PCTR) (Engvold et al. 1990). In the UV part of the spectrum, the electron density could be determined using the ratio of lines from different ions (Doschek et al. 1978) formed at the same temperature. Through this method, using intensity ratios of O IV, N V, N IV, Si IV lines, Wiik et al. (1993) derived a relatively large electron density (∼ 10^{11} cm^{-3}) for the PCTR. The electron density evaluation from spectral lines intensity ratios of one and the same ion is the most powerful method which depends directly on the value of the density without taking into account the size of the emitting volume or element abundance value (Mason & Monsignori Fossi 1994).

After the launch of the SOHO satellite, it became possible to use a wide range density and temperature sensitive line ratios of UV spectral lines. Using SUMER observations (intensity ratio O IV 1401.16/1399.78), Wiik et al. (1997) derived in different prominence structures, an electron density in the range 3 × 10^{5} to 3 × 10^{11} cm^{-3}.

The aim of the present study was to derive the physical parameters such as density and line-of-sight velocities of a prominence observed on June 12, 1997 with EIT, CDS and SUMER instruments on-board SOHO in the frame of the first MEDOC Campaign.


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2. OBSERVATIONS

We used observations obtained simultaneously by SUMER (Solar Measurements of Emitted Radiation) and CDS (Coronal Diagnostics Spectrometer). As well EIT (Extreme-ultraviolet Imaging Telescope) observations in He II 304.73 Å have been analyzed. The observations were made in the frame of the Joint Observing Programme 09 (JOP09) which also include coordinated observations with the Large Coronagraph of Wroclaw University and other synoptic observations.

2.1. SUMER DATA

The observations were carried out by SUMER (Wilhelm et al. 1996, Wilhelm et al. 1997) in four spectral lines Si IV 1393.76 Å, Si IV 1402.77 Å, O IV 1401.16 Å and O IV 1404.81 Å. Two series of observations (between 07:21:06 - 07:54:11 UT and 09:40:38 - 10:15:32 UT) were taken with a slit 0.3 × 120 arc sec² on detector B at different positions on the prominence body. The spectral resolution was 0.04 Å px⁻¹, the angular pixel size ≈ 1 arc sec and the spectral window 1.1 Å.

During the first series of observations the slit crossed the right hand edge of the prominence body (Figure 1a) and the second one – the prominence in the middle (Figure 1b). Datasets of 171 spectra were taken in the first one and 180 in the second one both with 12.03 sec exposure time.

The observed oxygen lines have a temperature of formation around 1.7 – 2.0 × 10⁵ K and could be used for a density diagnostics of the prominence-corona transition region. The Si IV lines formed at temperature 6–8 × 10⁴ K permit a good dynamics diagnostics of the cool prominence material.

The standard data reduction procedure was used including the local gain depression, flat field (created on June 10, 1997) and destretching corrections.

2.2. CDS DATA

The CDS observations were made with the normal incident spectrometer (NIS) (Harrison et al. 1995) in 6 lines λ Si X 347.40, He I 584.33, Si X 356.04, Fe XVI 360.76, Mg IX 368.06, O V 629.73 Å covering a wide range of temperatures from 10⁴ to 10⁵ K (Table 1). Fifteen rasters were obtained between 8:06:32 UT and 11:56:51 UT. The CDS observations started just after the first SUMER series had been finished and only three rasters obtained at 09:44:17, 10:00:39 and 10:17:43 UT were taken simultaneously with the second SUMER series of observations. The rasters size is 240 × 240 arc sec² with an angular pixel width of 4.06 arc sec and a height of 1.68 arc sec. The spectral window for the range 310 – 380 Â was 1.1 Â and 1.8 Â for 520 – 630 Â with a spectral resolution of 0.07 Å px⁻¹ and 0.12 Å px⁻¹, respectively.

Figure 1. CDS rasters in He I 583.33 Å during the first (a) and second (b) series of observations with the corresponding SUMER slit positions. The prominence registered by EIT in He II 304 Â (c).

Figure 2. Intensity images obtained in CDS He I 584.33 Å line.

3. PROMINENCE MORPHOLOGY AND EVOLUTION

The studied prominence is of the polar-crown prominence type, located in a long lived filament channel. It was situated on the North-West limb with mean coordinates N42 W90 degrees. It is well visible on images taken by EIT in He I λ 304.73 Å (Figure 1c) and CDS in He I λ 584.33 Â and O V λ 629.76 Â (Figure 2 and 3).
The prominence shows relatively rapid temporal changes in its structure which in the beginning of the observations had a tree-like shape (Figure 2, at 08:22:25 UT). One and half hours later (at 09:44:17 UT) it reaches the form of a well defined small arch shaped prominence. This shape persists not more than 15 minutes. Later on, the prominence apex becomes fainter, separates into two parts (at 11:06:29 UT) and at the end of the observations assumes almost the same shape as at the beginning (at 12:12:43 UT).

4. PLASMA DIAGNOSTICS

4.1. Line Blends

The observed oxygen lines belong to the O IV 1400 density-sensitive multiplet useful to obtain the PCTR density (Brage et al. 1996). This multiplet produces four lines $\lambda\lambda$ 1399.76 ($2^3P^0_1,2-4^1P^0_{1/2}$), 1401.16 ($2^3P^0_{3/2}-4^1P^0_{5/2}$), 1404.81 ($2^3P^0_{3/2}-4^1P^0_{3/2}$) and 1407.39 Å ($2^3P^0_{3/2}-4^1P^0_{1/2}$).

Two lines $\lambda\lambda$ 1399.76 and 1401.16 Å are clean of any blends which make them excellent for this type of diagnostics.

The $\lambda$ O IV 1404.81 Å is blended with S IV line at 1404.77 (3s$^3$3p$^2$P$^0_{1/2} \rightarrow 3s^2$3p$^2$ $^4P^0_{1/2}$) (Feldman & Doschek 1979). This blend depends on the electron density and according to CHIANTI database S IV line contributes 2-4% to 8-3% to the intensity of O IV 1404.81, when the electron density changes from 10$^9$ to 10$^{11}$ cm$^{-3}$, respectively.

At a density of 10$^{12}$ cm$^{-3}$ the S IV 1404.77 Å reaches 50% from the intensity of the observed line. In our study an average value of 5% was used.

In SUMER the O IV 1404.81 Å is blended also by another line - a second order line $\lambda$ O III 702.31 Å (temperature of formation log$T_e$ = 5.0 K). The $\lambda$ O III 702.31 Å belongs to the triplet $\lambda\lambda$ O III 702.31, 702.81 and 703.85 Å. In the first order, the O III lines blend the O IV 1404.81, S IV 1406.00 and O IV 1407.39 Å lines, respectively (Curd et al. 1977). The blend of 1406.00 and 1407.39 could be determined by applying multi-Gauss fits. Unfortunately, that is not possible for the blend of O IV 1404.81. Using the CHIANTI database we obtained the theoretical ratio of O III 702.31/703.85. After the intensity of O III 703.85 was determined using simultaneous observations of O IV 1404 multiplet, it was found that O III 702.31 line adds approximately 18% to the counting of O IV 1404.81 after the removal of the S IV blend.

4.2. Density diagnostics

In our study we determined the density by the intensity ratio of $\lambda\lambda$ 1401.16 Å and 1404.81 Å lines. Both blends of O IV 1404.81 Å were removed, taking an average value of 5% for S IV 1404.77 Å and 18% for O III 702.31 Å.

For the first slit position (Figure 1a) the intensity ratio ranges from 1.9 to 3.5 (Figure 4, top right) which corresponds (according to CHIANTI database) to an electron density 1.3 x 10$^9$ - 1.4 x 10$^{10}$ cm$^{-3}$, respectively. The corresponding electron pressure is 0.3 - 0.31 dyn cm$^{-2}$, respectively.

For the second slit position (Figure 1b), where the slit crosses the prominence body approximately in the middle, the line intensity ratio is from 1.9 to 2.5 (Figure 4, bottom right), which corresponds to a density from 1.3 x 10$^9$ to 5 x 10$^{10}$ cm$^{-3}$ (electron pressure from 0.03 to 0.11 dyn cm$^{-2}$, respectively).

4.3. Line-of-sight velocity

We used SUMER observations in Si IV 1393.76 Å and O IV 1401.16 Å lines to obtain the line-of-sight velocity for the cool (6000 K) plasma material and prominence-corona interface (17 000 K), respectively. Unfortunately, the slit did not cross any part
Figure 4. Intensity along the slit and intensity ratio (O IV 1401.16/1404.81) in the prominence for the first (top) and second (bottom) SUMER slit positions.

Figure 5. Velocity derived in the prominence in SUMER Si IV 1393.76 Å and O IV 1401.16 Å lines for the first (top) and second (bottom) SUMER slit positions.

The solar disk which could be used as a wavelength reference, so we used the diffused radiation on both sides of the prominence as a zero point. The line-of-sight velocities derived in Si IV 1393.76 Å and O IV 1401.16 Å for both slit positions are shown on Figure 5. Comparing Figure 1a, 4 and 5, one can notice at the location of the prominence edge, a velocity reversal within 5 arcseconds. This is an indication of reversed velocity fields between, possibly, different threads. For the second set of observations (Figure 1b, 4 and 5 bottom), the same velocity reversal persists but at a larger scale since the slit now crosses the prominence arch. This result confirms earlier measurements of horizontal velocity fields of the same order of magnitude, located at the edges of prominences (Mein 1977, Vial 1998).

The CDS observations taken in both lines He I 584.33 Å and O V 629.73 Å have been used to obtain velocity maps. Figures 6 and 7 show velocity maps at four different times.

Figure 6. Velocity maps obtained in CDS He I 584.33 Å.

Figure 7. Velocity maps obtained in CDS O V 629.73 Å.

The line-of-sight velocities are determined for each pixel, with respect to the quiet Sun. By analyzing the images taken by CDS in He 584.33 Å, EIT in He II 304.73 Å and synoptic observations, the quiet Sun region has been selected in order to determine the wavelength reference. The pixels with insufficient count rates are shown as a zero velocity. The color bar shows the velocity from black (blue-shift) to white (red-shift). The derived line-of-sight velocities are predominantly negative in respect to the quiet Sun, higher in O V 629.73 Å.

5. CONCLUSIONS

A spectroscopic study of a small polar-crown prominence was carried out using SUMER (in Si IV, O IV) and CDS (in He I, O V) observations.

In order to determine the electron density through the lines intensity ratio O IV 1401.16/1404.81, the high blend of O IV 1404.81 Å by Si IV 1404.77 Å and the sec-
ond order line O III 702.31 Å had to be taken into account. It was found to be 5% and 18%, respectively. The derived electron density is in the range $1.3 \times 10^6$ - $1.4 \times 10^{10}$ cm$^{-3}$ [electron pressure 0.03 - 0.31 dyn cm$^{-2}$] at two different places on the prominence body. These values are in the range of values of the Bier Reference Atmosphere Model of Quiescent Prominences (Engvold et al. 1990). However, in the future observations the blended O IV 1404.81 Å should be replaced by the O IV 1399.78 Å line.

The prominence shows relatively rapid temporal changes in structure with line-of-sight velocities in respect to the quiet Sun usually higher for the prominence-corona interface.

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