IL NUOVO CIMENTO Vol. 25 C, N. 5-6 Settembre-Dicembre 2002

Ionization states of metallic elements in a quiescent prominence(*)

D. Cirigliano(1), J.-C. Vial(2), and M. Rovira(1)

(1) *Instituto de Astronomía y Física del Espacio (IAFE) - Buenos Aires, Argentina*
(2) *Institut d'Astrophysique Spatiale (IAS) - Orsay, France*

(ricevuto il 10 Giugno 2002; approvato il 7 Agosto 2002)

Summary. — In the frame of the Joint Observing Program 133, which was run during the 6th MEDOC Campaign, a quiet prominence was observed on the 1st of November 2000, between 17:30-20:00 UT. From the data we obtained, we want to characterize the emission line profiles and to study the different ionization states of many chemical elements present in the cool plasma of the observed prominence. We also intend to analyze the macroscopic velocities of the material and compare the results with theoretical calculations.

PACS `96.60.-j` – Solar physics.
PACS `96.60.Sc` – Prominences.
PACS `01.30.Cc` – Conference proceedings.

1. – Introduction

SUMER (Solar Ultraviolet Measurement of Emitted Radiation) and CDS (Coronal Diagnostic Spectrometer) instruments on board SOHO are of great importance for the solar scientific community. Both of them were designed to investigate the solar atmosphere by the detection of spectral emission lines. Moreover, they can explore many solar structures and dynamical processes associated to them.

They present complementary capabilities and together cover up an UV spectral range of more than 1000 Å. This allows us to examine the sun from the chromosphere through the transition region to the inner corona, over a temperature range from approximately 10^4 to 2×10^6 K [1, 2]. These observations permit to perform a detailed diagnostic of plasma densities, temperatures and mass flows between others. The essential common characteristic of these instruments is that they can achieve a high resolution in the spatial, spectral and temporal domains. This fact is of a vital importance when we pretend to analyze the fine-scale structures and the transient phenomena. The resolution permits

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

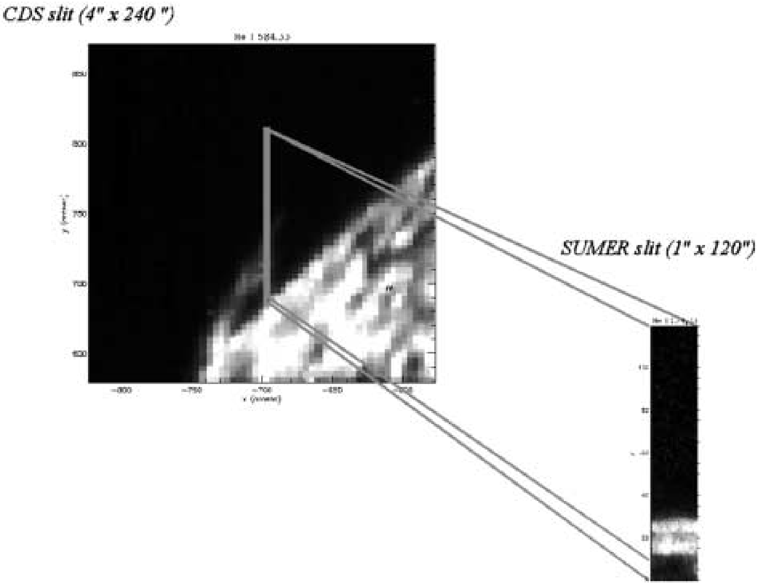

Fig. 1. – Field of view of CDS and SUMER.

to observe solar features approaching to 1 arcsec in the spatial range (approximately 750 km), deduce line-of-sight velocities from Doppler shifts with an accuracy of 1 km/s^{-1}, due to the spectral resolving and the temporal resolution, down to a few seconds or less, to follow the dynamical development of short-lived structures.

Many high-resolution measurements of prime significance for SUMER and CDS are devoted to the study the solar upper atmosphere and structures such as prominences lying in it. The study of solar prominences, defining prominences to be cooler and denser features than the hot coronal material which surround them, has been a fascinating topic for many years until now [3-7].

The aim of this work is to provide a brief explanation of how a set of observations were obtained during the 6th MEDOC Campaign and to present a description of the processing performed on SUMER and CDS data. At this point, it is good to note that we have chosen SUMER and CDS because of their observing characteristics in order to investigate the emission line profiles of a selected number of atoms, in their neutral and ionizated states in a solar prominence. We intend to study the intensities, widths and velocities in several observed line profiles and in future works compare them with theoretical models of prominences that include macroscopic velocities of mass flows [8,9].

2. – Observations

The primordial objective of the Joint Observing Program 133 (JOP 133), run between October the 30th and November the 10th 2000, was to obtain the line profiles for several states of ionization of helium, carbon, oxygen, nitrogen and silicon atoms. We have observed approximately 60 emission lines. In order to determine the physical parameters present in the prominence, it was very important to observe these lines at the same time and with high spectral resolution as well. The central importance of this work is the combination of both instruments, SUMER and CDS, which observe a quiet prominence at the same time, allowing to collect a variety of emission lines from different chemical species. Figure 1 shows the simultaneous spatial coverage of both instrument slits.

2˙1. *CDS observations and data treatment.* – For CDS we have selected 10 spectral windows within a raster and the Normal Incidence Spectrometer (NIS) was used to observe them [2]. The selected emission lines were those from He I and He II, CIII, O II, OIII, O IV and O V, Ne IV, Ne V and Ne VI. The pointing for this set of observations was located at: $x = -700$ arcsec and $y = 750$ arcsec, in the heliospheric system of coordinates. The size of the slit used was $4'' \times 240''$ and the raster covered a $240'' \times 240''$ area. The exposure time was 30 seconds for each raster and the total observation time of 37 min 37 s.

We were able to observe a prominence in almost the ten selected spectral windows, and we could also notice its disappearance during the total observing time. The first part of the analysis consisted in the treatment of the rough data in order to obtain the physical information needed to characterize the observed structures, such as the solar disk, the scattered light and the prominence itself. We have identified each of the spectral windows (wavelength range) and treated the data, arranged in a cubic array, where the first dimension corresponds to the wavelength, the second to the x-coordinate and the third one to the y-coordinate. The treatment was performed for all the spectral windows at the same time, where the data was corrected from many instrumental and observational aspects, such as cosmic rays, solar rotation, etc. After, we proceed to calibrate the data to have the intensity of the spectral lines written in physical units. In our case, erg/cm^2/s/sr/Å were used.

2˙2. *SUMER observations and data treatment.* – In the case of SUMER, approximately 50 emission lines arranged in ten spectral windows were chosen. The observed emission lines in this case were those from the following ions: He I and He II, C I, C II, C III and C IV, O I, O II, OIII, O IV, O V and O VI, N I, N II, N III and N IV, Ne III, Ne IV, Ne V and Ne VI and Si I, Si II, Si III and Si IV. The detector A of SUMER was employed and we verified that none of the reference pixels (part over the detector where the line is detected) was found to be placed in the detector attenuator or in the zone where the different parts join (Attenuator-Bare plate or Bare plate-KBr plate) [1]. We have strictly avoided to place the reference pixels there, because the response to the signal is not good and we lose quality in the observations.

The pointing was the same that for CDS, $x = -700$ arcsec and $y = 750$ arcsec. Concerning the type of exposures with this instrument, for strong lines, such as C III 977 Å , we used the $0.3'' \times 120''$ slit and an exposure time of 10 s to prevent a saturation in the detector. On the other hand, for medium intense lines the exposure time was of 30 s and the $1'' \times 120''$ slit was employed.

As with CDS, the first step in the analysis is devoted to the treatment of rough data. We were capable to distinguish between the observed features (solar disk, prominence and scattered light). Once the spectral windows were identified we worked with the data, arranged in a cubic array in the same way as with CDS. However, we have first corrected the data from the fact that the response from pixel to pixel varies. For this, we apply a flat-field correction (taken over the Lyman continuum) to get a uniform image. We also removed the distortion produced over both edges of the images [1]. In addition we cleaned the data of cosmic rays. Finally the data was calibrated using erg/cm^2/s/sr/Å.

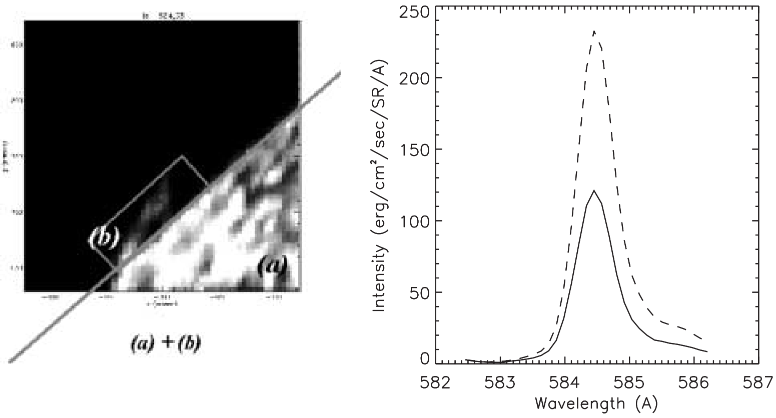

Fig. 2. – Image division for different structures: a) solar disk and b) prominence (left). Line profiles for the corresponding zones (right): prominence profile (solid line), solar disk profile (dashed line).

3. – Line profiles

Once we have performed the necessary corrections and calibration to the data, we are able to obtain the line profiles for some selected transitions observed in the ions enumerated in the previous section. We have separated the images in two different zones: a) solar disk and b) prominence (fig. 2). Then we have calculated the line profile for each zone. In this way we can compare their relative intensities and infer from the solar disk profile where the line line center is situated. This method allows to determine the Doppler shifts and to identify other lines, such as blends that we found in the neighbourhood of the line of interest. In some cases, we observe many intensity peaks in a line profile (we might be observing a blend), so, it is better to separate the whole wavelength interval and isolate each observed intensity peak. This procedure is used when we wish to identify and isolate a line.

In order to investigate how the intensity varies along the SUMER slit, we considered the coordinates where the slit was placed in the heliospheric system. Then we can calculate the solar radius along the y-axis in the slit, covering all the vertical direction. In the set of observations we analyse, the x-coordinate is fixed at -700 arcsec and there was no deplacement during the observation, while the y-coordinate covered the interval between 690 arcsec $< y <$ 810 arcsec. In this way, we have obtained the intensity as a function of the radius in arcsec units. Three different groups were built according the type of signal we received along the SUMER slit allowing us to determine where the prominence was situated. The first group consists in those profiles where we can separate the prominence from other observed structures. In such a case, we perfectly distinguish an emission line profile from a background that can be part of scattered light and instrumental noise. Secondly, we have profiles where we cannot distinct the prominence from the background. Because we find lines such as O VI to fall in this category we may think that this background corresponds to a strong coronal emission coupled to the prominence line profile, plus scattered light. Finally, we have detected in some observations an extremely strong background, where the prominence line profile is totally hidden, we may call this group "useless profiles". See fig. 3.

Having this in mind, we can now proceed with the velocity calculations. We take the

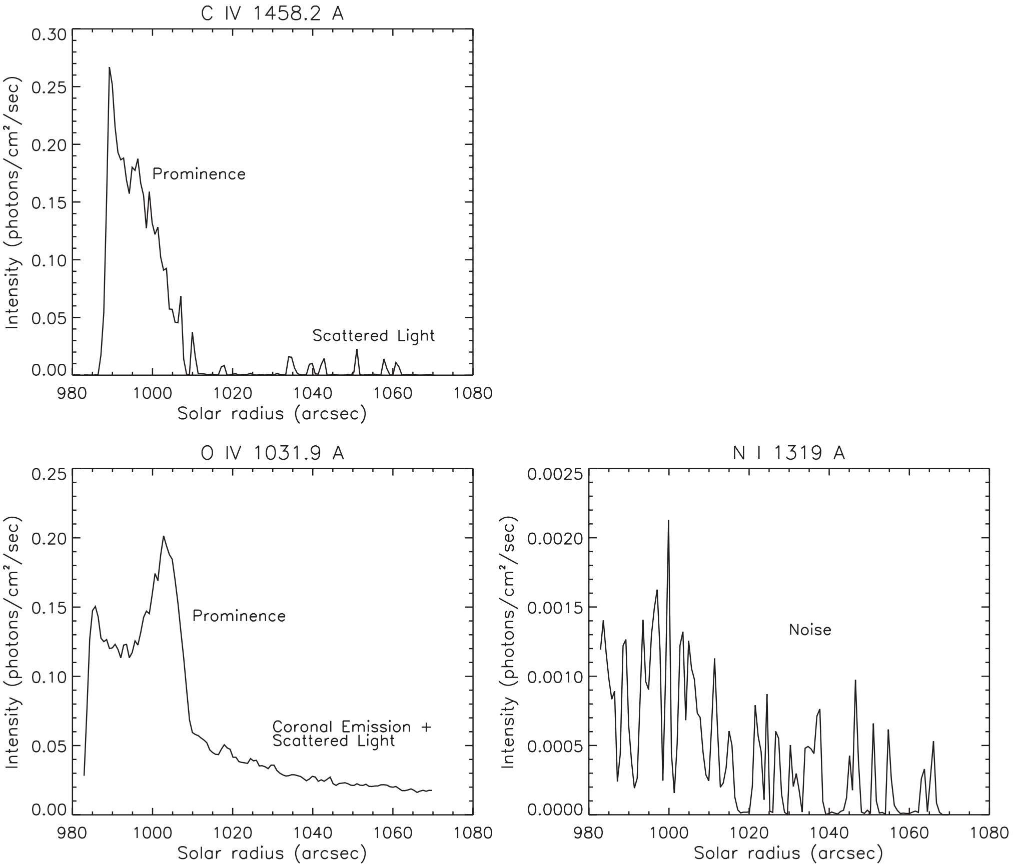

Fig. 3. – Intensity *vs.* radial distance for SUMER observations: well-observed prominence (top), prominence and coronal emission (bottom left) and useless data (bottom right).

disk line profile as reference and then calculate the shift between this reference line and the line profile observed in the prominence. This early analysis permit to have an idea of the existence of plama flows within the prominence material, apart from those resulting of thermal movements.

4. – Near-future objectives

In a future work many theoretical line profiles will be calculated for a several number of atomic elements in many ionization states with a numerical code which includes macroscopic velocities. Comparing this great collection of observed data with the theoretical calculations will contribute to our main purpose, the modelling of solar prominences. Besides, it will help us to determine the structure of the upper atmosphere and infer the plasma parameters such as temperatures, densities, Doppler shifts and macroscopic velocities of the prominence material. We have covered a great part of the UV spectra to include elements such as He, C, N, O, Ne and Si. In this wavelength range, we also have covered a large temperature range according to the ionization energies, allowing us to study several ionization stages of these elements present in the prominence material.

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