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Behaviour of Hydrogen Lyman lines in a prominence region from SUMER and CDS

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Abstract. We present observations of a prominence, taken on 1998 February 20 in the framework of SOHO Joint Observing Program no. 63. The instruments involved were SUMER and the NIS Spectrograph of CDS. The SUMER spectral range includes the hydrogen Lyman series – starting from Ly-ϵ – down to the head of the Lyman continuum, while CDS observed a number of lines from $T \sim 10^4$ K to $T \sim 2 \times 10^6$ K. For these observations, we were able to obtain a satisfactory determination of the pointing of the SUMER slit relative to CDS. We thus examined – and compared with information from CDS spectra – the main characteristics of the hydrogen Lyman series lines and of other strong lines in the SUMER spectral interval. We also studied the properties (depth, asymmetry) of the central reversal present in several or all of the Lyman lines in some regions of the prominence.

Key words. Prominences – Spectroscopy – UV – Hydrogen

1. Introduction

Hydrogen lines are strong features in the spectra of quiescent prominences. Lines such as H-α are routinely employed for prominence imaging. In the UV range, the strongest lines of the Lyman series – especially the Ly-α and Ly-β lines – have long been studied in detail. In particular, it has been shown (e. g. Gouttebroze et al. 1993) how these Lyman lines could be used as diagnostics of prominence temperature and pressure.

More recently, observations of higher terms of the Lyman series (Ly-δ, to Ly-7) have been discussed (Schmieder et al. 1998), while Heinzel et al. (2001) have presented observations of the hydrogen Lyman spectrum in quiescent prominences, including series terms up to Ly-11.

The observations presented here were taken with the purpose of extending the analysis to the higher terms of the Lyman series, from Ly-ϵ to the head of the Lyman continuum, in conjunction with an analysis of the emission in hotter

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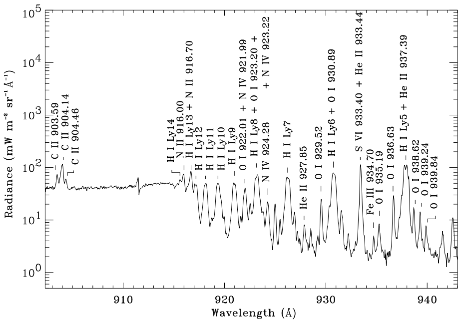

Fig. 1. SUMER spectrum in the range 900-945 Å, obtained averaging over the first five spectra of the observing sequence.

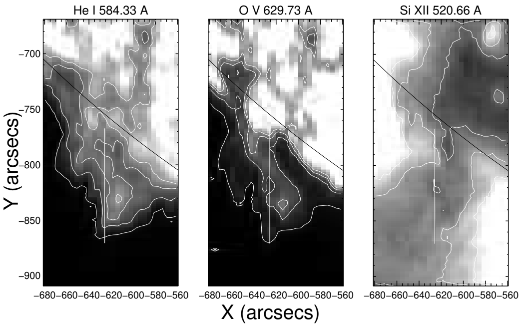

Fig. 2. Line intensity images and intensity contours from one of the CDS rasters taken on 1998 February 20. Both the visible limb and the position estimated for the SUMER slit are overlaid on each image.

lines, from Prominence-Corona Transition Region (PCTR) temperatures up to the coronal temperature range. In particular, the role of the PCTR in the formation of the Lyman lines has recently been emphasized by Heinzel et al. (2001).

2. The Data

The spectra whose preliminary analysis is presented here, were taken with the SUMER spectrograph on board SOHO, on 1998 February 20. The observations comprised an alternate sequence of three spectral windows, each 45 Å wide, centered at $\sim$ 785 Å, $\sim$ 920 Å and $\sim$ 1370 Å, respectively. In Fig. 1 we show an average spectrum in the wavelength band near the edge of the Lyman continuum, with identification of the main lines.

These observations were part of the SOHO Joint Observing Program no. 63. In coordination with these SUMER observations, co-spatial and simultaneous rasters of the target prominence were taken with the Normal Incidence Spectrograph (NIS) of SOHO/CDS. The CDS spectra included several EUV lines, forming at temperatures ranging from $T \sim 10^4$ K to $T \sim 2 \times 10^6$ K (Fig. 2). The availability in both spectra of lines forming at similar temperatures (e. g. the O IV λ554 line from CDS/NIS, and the O IV λ790 line from SUMER) permitted a good determination of the relative pointing position of the two spectrographs.

The knowledge of the relative SUMER/CDS pointing allows for a detailed comparison of the data from the two spectrographs, taking advantage of the strengths of both. For instance, images derived from the CDS rasters (Fig. 2) provide the morphology of the prominence at different temperatures. In particular, we have established that the SUMER slit actually crosses a region of relatively dense and/or thick prominence plasma, near the location of maximum emission in the He I, He II and in PCTR lines, while coronal emission is strongly depressed, most likely due to bound-free absorption by hydrogen (Kucera et al. 1998) and, for lines below 504 Å, by helium.

Examples of line profiles of the Lyman series are shown in Fig. 3. In the region of the prominence, corresponding approximately to strongest emission in PCTR and helium lines as seen by CDS, the central reversal in the Lyman lines is quite remarkable: it can in fact be noticeable even at the highest terms of the series. An example is the slit spectrum of Fig. 3, which shows strongly self-absorbed profiles, mostly in the central part of the prominence. The corresponding strong enhancement of the He II Balmer-14 line at 925.8 Å is also apparent.

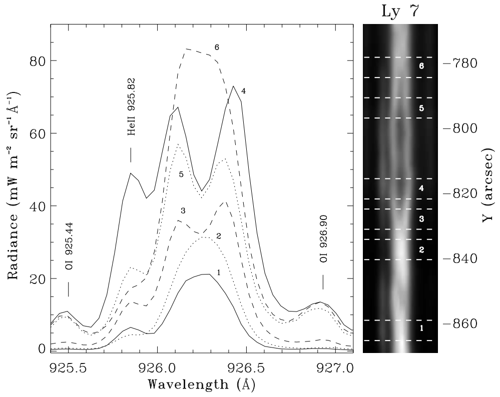

Fig. 3. Average spectra of the Ly-7 line. The regions over which the spatial averages have been taken are the areas between dashed lines.

An analysis of the properties of the asymmetry of the Lyman line profiles in a filament was presented by Schmieder et al. (1998). We carried out a similar analysis on this prominence. In particular, we examined the behaviour of the ratio of the blue (I_b) and red (I_r) peaks to the central intensity ($I_\circ$) of self-reversed profiles, both as function of the serial number (Fig. 4), and along the slit (Fig. 5).

Quantities shown in Fig. 4 where obtained from spectra averaged over three spatial pixels in a central position of the prominence (region no. 4 in Fig. 3). Note how the asymmetry, strongest in the first lines of the series, decreases with serial number, changing eventually sign.

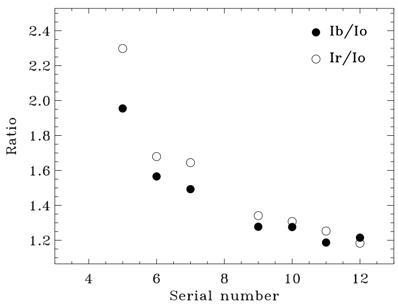

Fig. 4. Variation of the intensity ratio of the blue (I_b) and red (I_r) peaks to the central intensity ($I_\circ$) of self-reversed Lyman lines, as function of the serial number.

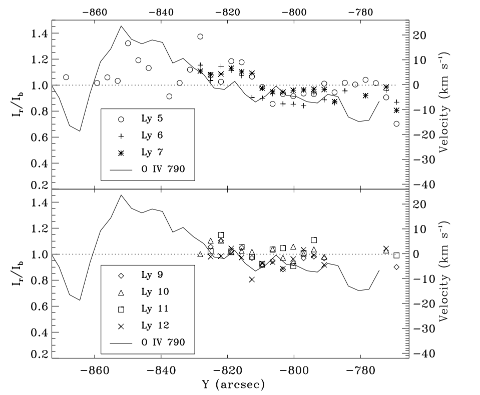

Fig. 5. Asymmetry, I_r/I_b, for the Lyman lines from Ly-5 (Ly-ϵ) to Ly-12, compared with the line-of-sight velocities inferred from O IV λ790 line shift. Positive velocities correspond to blue-shifts.

When inspecting the properties of self-reversed profiles along the slit, we attempted to correlate Lyman line asymmetries with line shifts of the hotter O IV λ790 line (Fig. 5). The trend shown in the comparison seems to indicate a correlation, at least for the lowest lines of the series. In a simple model in which the Lyman line asymmetry is due to macroscopic velocities in the region of line core formation, velocities towards the observer would produce blue-shifted line self-absorption, and thus a stronger red-side intensity peak (as discussed in Schmieder et al. 1998).

A working hypothesis for the interpretation of these observations, to be tested via a more thorough analysis of all the lines in this data set, could be that the PCTR plays an important role in the formation of the Lyman lines, especially of their cores (and reversals). Thus, velocity fields in the PCTR would affect both lines such as O IV λ790, and the self-absorbed core of the Lyman lines (as in Fig. 5).

The fact that asymmetry in the Lyman line peaks decreases towards the highest terms of the series, i. e. decreases with decreasing optical depth (Fig. 4), would also indicate that these velocity fields change substantially along the line of sight, either being suppressed or changing sign towards the inner regions of the prominence.

3. Summary and future work

One interesting feature of the data set we present here, is that it has been possible to determine the relative CDS/SUMER alignment by cross-correlating lines of the same ion observed with both instruments, in spectra separated in time by at most a few minutes. Since CDS provides a number of lines formed at temperatures characteristic of the PCTR, we thus have the opportunity of studying the behaviour of the Lyman series together with diagnostics of the PCTR.

In a portion of the SUMER spectra, corresponding to the central part of the prominence, some or even all the Lyman lines present self-reversed profiles. These profiles typically show an asymmetry between the red- and blue-side intensity peaks. These asymmetries could be interpreted in terms of the effect of macroscopic velocities in the region of the prominence or of the PCTR where the line reversal forms. When comparing these Lyman line asymmetries with the velocities in the PCTR line O IV $\lambda 790$, the impression is that a correlation indeed exists.

Finally, the merging of the Lyman series into the continuum has long been proposed as a tool to infer electron densities in astrophysical plasmas (e. g. Kurochka & Maslennikova 1970). In Fig. 6 we give estimates of the quantum numbers for the last resolved line of the series. In the case of the Lyman series in the data presented here, the treatment is further complicated by optical thickness effects: in some regions of the prominence, the Lyman lines are strongly self-reversed even while merging into the continuum. Thus, the quantum numbers shown in Fig. 6 are to be considered as indicative of a trend only. In this case, a more sophisticated treatment is required, such as the treatment described by Hubeny et al. (1994), which includes both non-LTE effects and a treatment of line-to-continuum merging based on more sound physics, such as the occupation probability formalism of Hummer & Mihalas (1988).

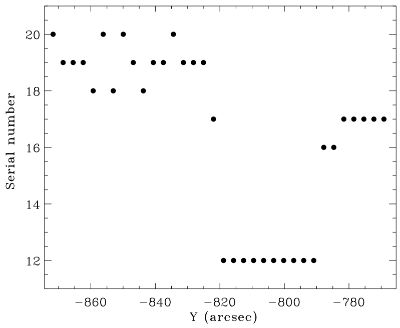

Fig. 6. Last resolved Lyman line before the continuum, as function of the position along the slit. Spectra have been binned over three spatial pixels to improve the signal-to-noise ratio.

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