HYDROGEN LYMAN LINES AND CONTINUUM EMISSION IN A POLAR-CROWN PROMINENCE OBSERVED WITH SOHO/SUMER

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ABSTRACT

We present, for the first time, a nearly simultaneous spectroscopic observation of the whole Lyman series of HI and continuum in a polar-crown prominence. Namely, we have extended our previous study of higher Lyman lines to lower members of the series, particularly Lyα and Lyβ. For the latter two lines, we compare our calibrated profiles (free of geocoronal absorption) with previous data from OSO-8 LPSP spectrometer. We demonstrate the importance of Lyman lines for studies of the base of the prominence-corona transition region.

1. Introduction

Hydrogen lines are the most prominent lines observed in solar prominences, particularly, the Balmer Hα which serves as a standard for prominence imaging. The lines of the resonance Lyman series have also been observed since the Skylab ATM experiment. The LPSP UV-spectrograph on-board the OSO-8 satellite has provided calibrated line profiles of the first two members, Lyα and Lyβ (Vial 1982a) and these have been widely used as constraints for prominence non-LTE modeling (Vial, 1982b; Heinzel et al., 1987; Fontenla et al., 1996 - FRVG). Also, the UVSP on-board SMM observed prominences in Lyα (Poland and Tandberg-Hansen, 1983, Fontenla et al. 1988, Fontenla and Poland, 1989). While the Lyα line can be well reproduced using simple 1D non-LTE models with the standard partial frequency redistribution (PRD), Lyβ was found to be much lower than expected as compared to OSO-8 typical data (Vial 1982a, Heinzel et al. 1987). Several studies were then devoted to this problem, trying to increase the computed Lyβ integrated intensity by introducing a prominence-corona transition region (PCTR) and a multithread structure (Heinzel et al., 1988; Vial et al., 1989; Heinzel, 1989; FRVG; Anzer and Heinzel, 1999). Large discrepancies still exist and resolving these is one of the objectives for the current SOHO/SUMER observations of Lyman lines.

Another important objective is to study the structure of the base of PCTR. As discussed previously by Gouttebroze et al. (1993 - GHV) and Schmieder et al. (1998, 1999), the Lyman lines are good indicators of the temperature and pressure structure of lower PCTR, but detailed non-LTE modeling is necessary to infer the proper information (see discussion in Schmieder et al., 1998). While OSO-8 provided only Lyα and Lyβ and Schmieder et al. (1999) have analyzed the higher members observed by SUMER, in this paper we present a new data set (first test observations) which covers the whole Lyman series plus part of the Lyman continuum. We present the calibrated line profiles for lines Lyα to LY1 and discuss their intensities with respect to computed ones. We also discuss the dynamical behaviour of the observed prominence.

2. Observations

During the test of a new option of JOP 12 (called JOP 107) a polar crown prominence (S-W) was successfully observed on March 23, 1999 by SOHO (SUMER and CDS spectrometers) and TRACE. The TRACE program consists of observations at 171 Å (Fe IX/X), C IV and Lyα between 12:00 and 15:00 UT with a field-of-view of 768×768". In Lyα the prominence appears to have fine structures moving rapidly (Fig. 1). In 171 Å we see mainly the absorption of the line by the dense cold material of the prominence at the limb and the filament in the channel. CDS was observing the prominence during these 3 hours in 20 lines covering a large temperature range with a 120×240" field-of-view. Three sets of rasters were obtained, one set lasts around 1 hour. Coronal lines are absorbed by the hydrogen and helium continua. The prominence is visible as the region of lack of emission. In O IV and O V lines, fine structures are observed (Fig. 2).

SUMER was operating during 2 hours (12:00-14:00 UT) with a fixed slit (1×120") centered in the middle of CDS raster (483", -863"). The exposure time


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Figure 1: Prominence observed by TRACE (left panels) in Lyman (right panels) in Fe IX/X 171 Å on March 23, 1999 at 12:18:57.

Figure 2: SOHO/CDS NIS Raster, 23-Mar-1999 11:56:52

PODS1.2 -- Lyman Prominences -- st5699/C0 fits
Center = (-72°, 138°). Size = 22° x 24°.
is 98 sec. In order to be able to observe all the Lyman series lines from \( \text{Lo} \) to the Lyman continuum we selected four wavelength ranges, near 940, 972, 1025, and 1215 Å. Full spectra of around 40 Å are recorded. Strong lines (\( \text{L} \beta \), \( \text{L} \gamma \), \( \text{L} \delta \)) are on the bare part of the detector B and \( \text{Lo} \) is on the attenuator section. The \( \text{Lo} \) profile is contaminated by the detector grid. We destretched the observations using T. Moran’s software, corrected by using the flatfield observed on the day, and calibrated the wavelengths with software developed at ITA in Oslo. The intensity calibration was performed by radiometry procedure of K. Wilhelm. As a preliminary study we have reduced the first 8 spectra. The prominence is quite active and it will be difficult to integrate the information with time. Along the slit we observed the disk (70:120 pixels) and the prominence which consists of 3 parts:

- A (34-69) dense part
- B (38-41) high redshifted part
- C (24-27) very light bubble

In Figures 4 and 5, we show examples of line profiles obtained (a) in the prominence and (b) on the disk. The disk is mainly overlaid by a filament, only a few points represent the true disk. The new calibration leads to intensity values smaller than the previous ones obtained with the calibration of 1997 by 10 to 15% (Schmieder et al. 1999).

3. Discussion

We note some strong asymmetric profiles and even some profiles completely shifted. These are the signatures of high dynamical phenomena which need a careful study before giving values of the Doppler shifts, in order to completely understand if it is a bulk flow or complex motions of plasma at different temperatures (Gontikakis et al. 1997). However, that is not the aim of this short report. The primary objective here is to see how this complete set of all Lyman lines plus continuum compares with previous observations (namely by OSO-8) and with theoretical non-LTE model predictions.

For isothermal-isobaric prominence models, the intensities of first three Lyman lines were tabulated by GHV. Later on, FRVG computed four isobaric models in energy balance (gas pressures 0.02, 0.05, 0.1 and 0.2 dyn cm\(^{-2}\)) and presented the integrated line intensities for \( \text{Lo} \) and \( \text{L} \beta \). In Schmieder et al. (1999) three types of prominence models are discussed and profiles of higher Lyman lines are computed which roughly agree with SUMER data. Finally, quite recently Anzer and Heinzel (1999) have computed new models in pressure equilibrium (Kippenhahn-Schüter type models) and give a table of line intensities for \( \text{Lo} \) and \( \text{L} \beta \). The models mentioned also predict the intensity of the Lyman continuum.

\( \text{Lo} \):

The observed intensities (solid lines in Fig. 4) are in general agreement with theoretical calculations. However, the details of this profile are affected by the attenuator as mentioned above and thus we can not rely on them. For example, the minimum intensity \( I_0 \) is \( 0.8 \times 10^{-8} \) erg s/cm\(^2\)/sr/Hz, which is too low as compared to all models. From calculations it follows that the minimum intensity in this line is around \( 1.2 \times 10^{-8} \) erg s/cm\(^2\)/sr/Hz, which is roughly the value of the diluted incident solar radiation. The peak/center ratio is about 1.5 to 2, this is consistent with typical models. Note that the value \( 1.2 \times 10^{-8} \) erg s/cm\(^2\)/sr/Hz for central intensity indicates that the \( \text{Lo} \) is formed at rather low temperatures. The mean integrated intensity in the prominence represents about 1/3 of the disk integrated intensity.

\( \text{L} \beta \):

Let us compare the SUMER and OSO-8 profiles of the \( \text{L} \beta \) line. First, the average peak and central values of the “first and last parts of the orbit” (Figure 4 in Vial 1982a) are respectively: 2.1 and \( 1.2 \times 10^{-10} \)
erg/s/cm²/sr/Hz. Our values are 1.9 and \(1.3 \times 10^{-10}\) respectively. The agreement is remarkably good. The slightly larger OSO-8 reversal could be due to the overcorrection of the geocoronal absorption profile; but it can also be due to the large range of observed values. The ratio of prominence to disk integrated intensities as measured by SUMER is smaller than the 0.5 value found with OSO-8.

Lβ poses a long-standing problem when compared with non-LTE model predictions. Typical OSO-8 integrated intensities are around 400–500 erg/s/cm²/sr, while most of isobaric-isothermal models do predict much lower values (GHV). On the contrary, FRVG obtained intensities much higher, even for lowest-pressure models. Note that the Lβ intensity is sensitive to the filamentary structure, i.e. to the number of threads along the line of sight, namely its peaks (see FRVG, Schmieder et al., 1999). The SUMER value of the integrated intensity is lower than that of OSO-8 which could be reproduced by existing medium pressure models with PCTR and filamentary structure. In particular, we can see a rather low intensity in a bubble (dash-dot in Fig. 5). The mean integrated intensity in the prominence is about 335 erg/s/cm²/sr and is slightly less than 1/3 of the disk integrated intensity.

Higher Lyman lines:
These are less reversed, we detect no reversal for lines higher than L4. Their intensities are consistent with those reported by Schmieder et al. (1999).

Lyman continuum:
The averaged intensity in the range 905–907 Å is about \(4.5 \times 10^{-12}\) erg/s/cm²/sr/Hz. This value is quite comparable to most GHV results. If we compare the average intensity at the head of the continuum with the predictions of the 140 GHV models, one can conclude that it is in general agreement with models having low temperatures (less than 8000 K) or low pressure (less than 0.1 dyn cm⁻²). At high temperatures, the thickness of the layer must be small. One can note that the slope of the Lyman continuum can be an interesting diagnostic tool for the prominence temperature (see GHV and Ofman et al., 1998).

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Figure 4. Lyman lines (Lα- Lδ) observed (a) in the three different locations described in § 3: The main part (A in Fig. 3, solid line), the redshifted part (B, dashed line), and the faint bubble (C, dot-dashed), and (b) on the disk in the filament (dashed line) and outside of it (solid line). The shape of the Lα line is currently dominated by the attenuator grid pattern.
Figure 5. Lyman lines (L5 to continuum) observed (a) in the two different locations described in § 3: The main part (A in Fig. 3, solid line) and the redshifted part (B, dashed line), and (b) on the disk in the filament (dashed line) and outside of it (solid line).