Coordinated Prominence Observations by SOHO and Ground-Based Observatories

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Abstract. Coordinated observations obtained during the JOP12 (Joint Observing Programme between SOHO and ground-based instruments) allow us to analyse the physical conditions in a prominence of 5 June 1997 and its environment in the solar corona. The arch-shaped prominence shows either vertical or horizontal structures according to the observed lines (Hα with the coronagraph of the Wroclaw University Observatory at Bialkow and lines in a broad temperature range by the Coronal Diagnostic Spectrometer CDS). The less dynamic behaviour of this prominence was shown by the persistence of bubbles in the prominence and confirmed by the Dopplershifts measured in CDS lines and in Hα by the Italian Panoramic Monochromator (IPM) filter on the THEMIS telescope in Tenerife. We explain the complex morphology of this prominence by recent 3D MHD models. Finally, we present prominence spectra in higher lines of the hydrogen Lyman series (from Lδ to L-9), together with some other UV lines. These data have been obtained by the Solar Ultraviolet Measurements of Emitted Radiation (SUMER). We demonstrate the basic characteristics of the calibrated line profiles of Lyman lines and compare them with the theoretical profiles computed from isothermal-isobaric models. This leads to some constraints on the environment of the prominence.
1. Introduction

It is well established that prominences are formed of cool plasma confined and supported by the magnetic field in the corona. Even so, the problem of formation and stability of prominences is poorly understood. How they are formed, by coronal condensation or by injection of cool plasma? Does the dynamic nature of prominence play the most important role in the formation, in the stability of prominences? How is their environment? does there exist a transition-region shell around the main body of the prominence or does the prominence consist of many threads of different temperatures? Only coordinated observations can give a good opportunity to have better understanding of the nature of prominences. On June 5, 1997, a prominence (S32-W) was observed in the frame of the Joint Observing Program 12 on prominences, which involves SOHO instruments (CDS, SUMER, EIT) coordinated with GBOs.

2. Nature of the prominence

Bialków large coronagraph observed the prominence in Hα (Fig. 1). The prominence shows a dense foot anchored on the disk and a set of twisted lines with bubbles of material. We have tried to derive some motions of these bubbles
along the threads but unsuccessfully, either the cadence of the observations is not enough to detect such motions, or the material is always condensed at the same place or nearby, in some dipped field lines that we already see at the top of the prominence. The existence of such horizontal structures is confirmed in the images in some lines (He I and He II) obtained by CDS and EIT. In some other lines (O III, O IV, OV) the structures look more vertical (Fig. 2). This observation is in good agreement with recent 3D magnetohydrostatic models of magnetic support for prominence modeled by a twisted flux rope (Aulanier et al. 1998 and references therein). The authors show how a series of horizontal dipped field lines can give the impression of existence of vertical structures due to perspective effects. The cold material is also well observed in hot lines by CDS (Mg X), with a dark part due to absorption by the H I Lyman continuum.

Doppler shifts measured in the prominence in all temperatures (He and O lines with CDS) are rather small (smaller than 5 km/s). THEMIS observed the dense foot of the prominence with the IPM filter between 07:20 and 08:26 UT in Hα (11 successive wavelengths along the profile) (Rayrole et al. 1998). The Doppler shifts are derived and these measurements confirm the non-dynamic nature of this prominence.

3. Lyman lines observed with SUMER

3.1. Data reduction

The SUMER slit (120' along Y-direction) scanned the prominence in 3 positions between 06:31 and 11:47 UT, using three spectral modes: (i) He I 584, (ii) NV...
1239 and 1243, SiII 1260 and 1265, SII 1250, 1254 and 1260, OIV 625 and O V 629, (iii) Lyman lines Lδ to L-9, SVI and OIV lines in this wavelength range. The following steps of the data reduction were followed:
1. Co-alignment of the SUMER slit with CDS and Hα images;
2. Data reduction of the SUMER spectra: destretching, flatfield and diffuse-light correction with the software developed at the ITA (Oslo) and by T. Moran;
Examples of profiles are shown in Figure 3. The symmetric profiles confirm that the velocity field is low.

3.2. NLTE Models

The primary aim of this study was to check whether standard non local-thermo dynamic-equilibrium (NLTE) prominence models lead to synthetic intensities of the Lyman lines comparable to intensities observed by SUMER. Since these higher members of the Lyman series were never observed before, this task is quite new. To compute the theoretical line intensities and profiles, we use here a modification of the prominence MALI code of Heinzel (1995). We extend the number of hydrogen levels to twelve and treat in detail all Lyman transitions plus many others, altogether 78 transitions. Details of the atomic model and numerical approach are described by Heinzel et al. (1997). We started our NLTE modelling with standard 1D isothermal-isobaric prominence slabs as in Gouttebroze et al. (1998) (GHV). For a subgrid of GHV models we have computed the synthetic line profiles for Lγ to L-8, for two directions of emergent radiation with μ=1 and 0.3. The behaviour of this grid is the following:
Figure 4. Theoretical Lyman line profiles for the GHV model with $T=6000$ K, $p=0.2$ dyn cm$^{-2}$, $D=5000$ km, and $v_t=5$ km/s. Solid lines are for $\mu=1$ and dashed lines are for $\mu=0.3$.

- The line-center intensities minimal over the grid correspond to temperature $T=6000$ K and gas pressures not exceeding 0.5 dyn cm$^{-2}$. These are shown in Figure 4, indicating that the observed line-center intensities should not be lower.
- For higher temperatures, the line-center intensities do increase, but mainly the line reversal appears stronger (see Figure 5) and the peak-to-center intensity ratio increases significantly above unity.
- For lines higher than $\text{L}\delta$ the synthetic profiles have only two peaks, contrary to some GHV triple-peak profiles of $\text{L}\beta$ and $\text{L}\gamma$ (see also our $\text{L}\gamma$ here). All models have geometrical thickness $D=5000$ km and a microturbulent velocity $v_t=5$ km/s.

4. Discussion and Conclusion

We observe during a coordinated campaign a quiescent arch-shaped prominence on June 5, 1997. Observations in different lines obtained on the ground (Bialków, THEMIS) and with SOHO instruments (CDS, EIT) show how the aspect of a prominence can be different according to the used line. We observed mainly horizontal structures in He lines, bubbles along twisted lines and feet in H$\alpha$, vertical structures in O lines. The absorption in hot coronal lines (Mg X) has the global shape of the H$\alpha$ emission. This complex morphology can be explained by a model of flux tube and material condensed in dipped horizontal field lines. The vertical structures should be due to perspective effects.

The Lyman lines observed by SUMER give a good diagnostic for the environment of the prominence. From the grid of models discussed above we can see that the computed line intensities match roughly the prominence intensities observed by SUMER. This is an important result which shows that we are able to reproduce quantitatively the SUMER calibrated profiles. However, we are unable to fit all observed lines $\text{L}\delta$ to $\text{L}-9$ by one simple isothermal-isobaric model,
Figure 5. Theoretical Lyman line profiles for the GHV model with $T=8000\; K$, $p=0.2\; \text{dyn} \; \text{cm}^{-2}$, $D=5000\; \text{km}$, and $v_t=5\; \text{km} / \text{s}$. Solid lines are for $\mu=1$ and dashed lines are for $\mu=0.3$

and we arrive at a picture of a prominence-corona transition region - \textit{PCTR} with a temperature gradient. Results of this study indicate that the higher Lyman lines are sensitive to both temperature and pressure and because of their large optical thickness they provide a good diagnostic of the line-of-sight prominence structure.

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