Two-dimensional Model of a Rotating Solar Prominence
I. Observations and Preliminary Approach

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Abstract. The VTT Echelle Spectrograph of the Sacramento Peak Observatory (NSO) has been used to obtain high resolution spectograms of filaments simultaneously in five lines: hydrogen Hα, Hβ, neutral helium D3 and ionized calcium H and λ8498. The best spectograms have been chosen for an accurate digital photometric reduction. The case of the remarkable filament E24°S13°, observed on 6 April 1991 at 16:51 UT, is discussed. The most narrow and compact part of the filament (about 8000 km wide) exhibited a possible rotation or twisting motions. Preliminary filament models are considered.

1. Introduction

In spite of many existing treatments of the transfer problem for the solar chromosphere and prominences, a variety of better and better observations stimulates further refinement of the existing models and codes. The one-dimensional problem has been fully examined over the last three decades. The basic ideas of NLTE prominence modeling have been summarized by Heinzel (1991). Various departures from classical finite one-dimensional (1D) homogeneous slab models were also discussed in this review. Heinzel & Vial (1983) discussed departures from complete frequency redistribution in hydrogen lines as derived from the comparison of theoretical models with OSO-8 observations. The problem was investigated by Heinzel et al. (1987). It was shown that the amount of partial redistribution effects is significant for the resonance lines, but for the subordinate ones the results are nearly the same. The hydrogen spectrum for 140 prominence models was calculated by Gouttebroze et al. (1993).

Besides the spectroscopic problem, the geometric one is very important. Paletou et al. (1993) drew attention to the multidimensional nature of the problem. A two-dimensional multilevel radiative transfer code with standard partial redistribution for isolated solar atmospheric structures was elaborated by Paletou (1995). At the same time the complex pattern of material motions
in the filament structures makes the analysis even more complicated. We try to demonstrate it with a special case, already discussed by us in the frame of the cloud model (Kotrč et al. 1994), with a constant temperature value equal to 9000 K and turbulent velocities about 5–10 km s\(^{-1}\).

![Image](image_url)

Figure 1. The H\(\alpha\) slit-jaw picture of the Sac Peak Echelle Vacuum Spectrograph with filament E24° S13° 6 April 1991.

2. Observations

An active region filament (E24° S13°) has been observed at solar disc center distance (\(\cos \theta = 0.89\)) on 6 April 1991. The observations have been made by P. Kotrč at Sac Peak Observatory, operated by NSO. This filament is present on a film series of 11 frames, beginning from UT = 16:51. The frame series includes
simultaneous pictures in six cameras (see Table 1): Hα + Hβ, D₃ HeI, CaII H, CaII λ8498 and slit jaw images through Hα filter and in white light. The exposure time was 2₅. The entrance slit of the spectrograph covered a strip of the solar disk 2 arcseconds width and 15 arcseconds long. The spatial resolution of the spectral image has been estimated with the most narrow features measured along the slit. The resulting value is about 0.5–0.8 arcseconds. Frame series (i.e. simultaneous pictures in six cameras) number 3, where the slit passed over the most narrow and compact part of the filament, has been chosen for its best image quality.

Table 1. Characteristics of cameras

<table>
<thead>
<tr>
<th>Camera</th>
<th>Central wavelength, Å</th>
<th>Dispersion, mm/Å</th>
<th>Kodak Emulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα and Hβ</td>
<td>6562.8 and 4861.3</td>
<td>6.60</td>
<td>103AF</td>
</tr>
<tr>
<td>CaII H</td>
<td>3968.5</td>
<td>11.12</td>
<td>2476</td>
</tr>
<tr>
<td>CaII λ8498</td>
<td>8498.1</td>
<td>4.98</td>
<td>2481</td>
</tr>
<tr>
<td>HeI D₃</td>
<td>5875.6</td>
<td>7.54</td>
<td>2498</td>
</tr>
</tbody>
</table>

The observed region of the Sun superimposed on the slit-jaw image is presented in Fig. 1. The dark vertical line is the position of the spectrograph entrance slit. The outer (SE) edge of the filament (facing the solar limb) is sharp and the inner one is rather diffuse. In both directions away from the measured point, the filament spreads and turns into several branches. This pattern agrees with the evidence of filament rotation or apparent twisting motion derived from the Hα line profile analysis that is discussed below. The quiet chromosphere is close to the filament border. The three labelled points respectively indicate the darkest part of the channel (A), its diffuse part (B) and the quiet region close to the filament (C).

The total and accurate microphotometry has been performed at Sternberg Astronomical Institute of Moscow State University. The digital AMD-1 densitometer attached to a PDP-type computer has been used. The photometric slit was of 50 μ x 50 μ size. The scanning step was the same (50 μ) i.e., one step (pixel) corresponds to a distance of 126.5 km, or 0.175 arcseconds, on the Sun. Special attention was paid to the calibration process. A step wedge was used and its images were processed in the same way as the main negatives. The smoothed calibration curve was used to convert densities of negatives into relative intensities. The photometric calibration was done by fitting the reference profiles to standard profiles for the quiet Sun (Kurucz 1990).

Fig. 2 presents the photometric profile along the slit with a logarithmic scale. Positions of the three measured points are marked by vertical dashed lines. The general trend of intensity is due to solar center-limb variation. The filament bright rims are not pronounced around the measured points. There is a rather bright floccule in H₃ CaII line at the distance −15 Mm from the zero-point C in Fig. 2.

The resulting line profiles measured at points A, B, C are given in Fig. 3.
Figure 2. Logarithm of frequency-averaged intensity for all observed lines versus distance along the slit. The curves are arbitrarily shifted for ease of comparison.

Their central intensities in units of the nearby continuum are given in Table 2. The cores of Balmer lines are wide (about 0.3–0.5 Å), but CaII lines are narrow. The brightness of the diffuse border of the filament is nearly the mean of the brightness of points A and C. Line profiles in Fig. 3 have some asymmetry. Over

<table>
<thead>
<tr>
<th>Line</th>
<th>Point A</th>
<th>Point B</th>
<th>Point C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα</td>
<td>4.6</td>
<td>12.2</td>
<td>18.6</td>
</tr>
<tr>
<td>Hβ</td>
<td>4.4</td>
<td>9.0</td>
<td>14.2</td>
</tr>
<tr>
<td>CaII H</td>
<td>4.4</td>
<td>6.1</td>
<td>7.1</td>
</tr>
<tr>
<td>CaII λ8498</td>
<td>21.4</td>
<td>26.6</td>
<td>29.7</td>
</tr>
<tr>
<td>HeI D₃</td>
<td>—</td>
<td>93.7</td>
<td>84.7</td>
</tr>
</tbody>
</table>

the line wings it is most pronounced in Balmer lines. It is not an instrumental effect and should be taken into account in theoretical profiles. The line core asymmetry is presumably connected with the systematic large scale motions of the filament material.

The width of the dark filament channel measured by the distance between the inflection points of the photometric profile corresponds to about 4 Mm in Hα, Hβ and CaII H lines and about 3 Mm for He D₃ and the infrared Ca II lines.
Figure 3. The filament line profiles of hydrogen, ionized calcium, and helium observed at NOAO on 6 April 1991. Full line (A) – filament channel. Dotted line (B) – filament border. Dashed line (C) – quiet chromosphere.
3. The prominence large scale motions

The line profiles were measured in all points along the slit crossing the filament in Fig. 1. The line profiles over this interval vary only in the line core, but not in the asymmetry of the wings. This makes it possible to deduce the positions of the line centers. Fig. 4 presents the corresponding radial velocities $V_r$, obtained from the Hα line profiles. The filament position corresponds to the relative distance between 9.5 and 15 Mm. This part of the curve is symmetrical around the point 12 Mm and velocity value $-2.5$ km s$^{-1}$. It is easy to see a linear dependence of $V_r$ upon distance between the extremes at $-3$ and $+2.5$ km s$^{-1}$. We are tempted to interpret this effect in terms of filament twisting or rotation motion. The angular velocity corresponds to the slope of the curve relating these points. Connecting them with a straight line we obtain an angular velocity

$$w = V_r / \tau = 10^{-3} \text{ s}^{-1}$$

or one turnover per 1.75 hours.

The other hydrogen and Ca lines show the same pattern of velocity distribution with a slightly different zero point, presumably due to different line opacities.

4. Discussion

In this work we described preliminary results concerning the photometric reduction of a large set of observations obtained with the VTT Echelle Spectrograph of the Sacramento Peak Observatory. The first result concerns the precise line profiles of H, HeI and Ca II lines for a specially chosen filament. The most interesting feature is the very peculiar character of motion in the most narrow part of the filament. The velocity field pattern suggests some regular large scale
motion resembling twisting or may be even rotation. Adopting such a model, we obtained the corresponding angular velocity of about $10^{-3}$ rad s$^{-1}$. Other sequences of the same film series are now processed and investigated in order to derive the variation of this velocity field. The other investigation which is going on concerns the calculation of theoretical profiles to compare with these observations. The next paper of this series will treat the results of 2D model computations of line profiles including the partial frequency redistribution for the scattering process and taking into account large scale motions.

References