

## Prominence Emission Lines Observed With SUMER and Two Ground-based Telescopes

C. R. de Boer

*Max-Planck-Institut für Aeronomie, D-37191 Katlenburg-Lindau, Germany*

G. Stellmacher

*Institut d'Astrophysique, 78bis Boulevard d'Arago, F-75014 Paris, France*

E. Wiehr

*Universitäts-Sternwarte, Geismarlandstr 11, D-37083 Göttingen, Germany*

**Abstract.** Two sets of H, He, and Ca<sup>+</sup> emission lines were observed in a quiescent prominence simultaneously with the VTT and the Gregory telescope on Tenerife. At the same time, SUMER took two scans of low-ionized EUV emission lines.

The emission ratios of Ca<sup>+</sup>-to-Balmer lines from ground vary little in the prominence, indicating a largely constant gas-pressure. In contrast, the ratio of He-to-Balmer from the ground shows the (known) increase toward the prominence borders, indicating higher temperature there. Similarly, the two-dimensional distributions of the ratios S IV/N II and C III/He I show pronounced bright prominence rims.

The reduced He 537Å and He 584Å line widths are 2.6 and 3.6 times larger, respectively, than those of He D<sub>3</sub> and He 3888Å. Explaining this by the optical thickness yields  $\tau_0 = 10^4$  and  $\tau_0 = 2 \cdot 10^5$  for the two EUV lines. The total He 584 emission amounts to 13 watt/m<sup>2</sup> ster in the main prominence body where the D<sub>3</sub> line yields 4 watt/m<sup>2</sup> ster; existing models, however, predict a factor 0.18.

The widths of simultaneously observed optical lines with different atomic weights yield thermal and non-thermal broadening parameters of  $T_{kin} \approx 8000$  K and  $2.5 < \xi < 6.5$  km/s. The EUV lines, however, show line widths which correspond to much higher temperatures and non-thermal velocities. Assuming for each ion the corresponding ionization temperature, the line widths require non-thermal velocities of 15–40 km/s which is similar to values for the quiet corona.

### 1. Introduction

The transition between cool prominences and hot coronal material is not yet satisfactory explained. Cooling by Lyman radiation, ('cooling trap', Unsöld 1956), would 'rarefy' the surrounding corona. A smooth transition between cool

prominence and hot corona, however, might cause a hot 'skin'. The known structuring of prominences offers the picture that either cool inner 'threads' are surrounded by hotter outer threads, or that each individual thread has a hot 'skin'. Such problems can be treated by EUV observations using the SUMER instrument along with ground based observations.

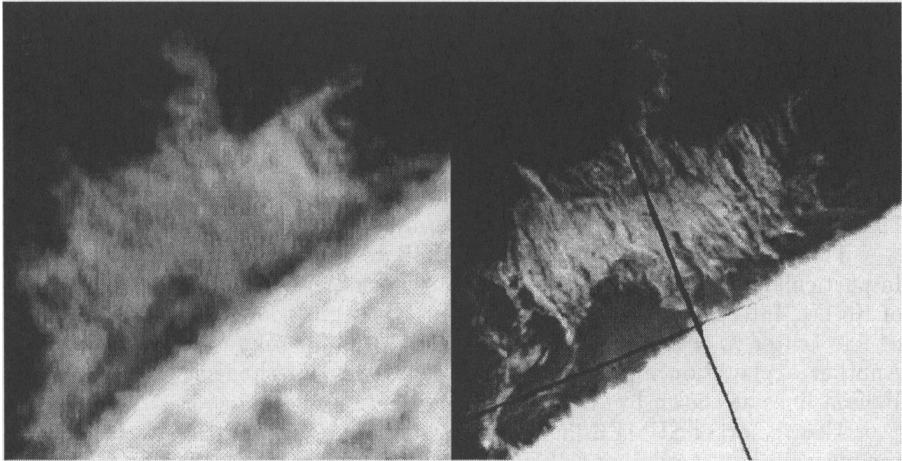


Figure 1. He I 584 Å composite image from SUMER (left) and an H $\alpha$  image from the ground on June 28, 1996.

## 2. Observations

A quiescent hedgerow-type prominence at E20°S was observed on June 28, 1996 with both German solar telescopes on Tenerife and with SUMER. The evacuated Gregory Coudé Telescope (GCT) was used to monitor the emission lines He 3888 Å and H $\beta$  3889 Å simultaneously with Ca<sup>+</sup> 8498 Å on two CCD cameras integrating for 12 s. With the Vacuum Tower Telescope (VTT), H $\beta$ , He-D<sub>3</sub>, and Ca<sup>+</sup> 8542 Å were simultaneously observed with three CCD cameras integrating for 3 s. A fourth CCD took H $\alpha$  slit jaw images. The slit widths for both telescopes corresponded to 1.5 arcsec. The influence of wavelength-dependent refraction was avoided by orienting the slits in a direction perpendicular to the horizon. At the same time, SUMER was used to observe in a first scan the He I 584 Å emission simultaneously with O I 1152 Å, C I 1158 Å, and C III 1175 Å. In a second series, SUMER took He I 537 Å simultaneously with N II 1085 Å, S III 1077 Å and S IV 1062 Å. Figure 1 shows a He I 584 Å composite image from SUMER together with an H $\alpha$  slit jaw image from the VTT.

All CCD images were corrected for dark current and the gain matrices. For the ground-based spectra, the straylight aureole spectrum was subtracted. Finally, all prominence emissions were calibrated in units of the disc center intensities (Labs and Neckel 1970). The obtained emission lines were fitted by Gaussian profiles, from which shifts, widths, central intensities and integrated total emissions were determined.

Scatter plot diagrams of the shifts of simultaneously observed lines from SUMER were used to verify that the lines originate from the same prominence regions in agreement with Wilk et al. (1993). Highest velocities up to 30 km/s mainly occur in peripheral prominence regions. This is also found in the ground based spectra.

### 3. Line Widths

The widths of the emission lines from the ground based observations were used to separate thermal and non-thermal line broadening parameters. The ratio of the reduced  $1/e$ -widths of  $H\beta / Ca^+$  8542 indicates a narrow temperature regime,  $7500 < K < 8000$  K, but varying non-thermal velocities,  $2.5 < \xi < 6.5$  km/s.

The line widths observed with SUMER indicate much larger broadening. In particular, He 584Å has reduced widths which are 3.5 times larger than those of He D<sub>3</sub>. Interpreting this as a saturation effect gives for the optical thickness at line center  $\tau_0 = 2 \cdot 10^5$  for He I 584 and  $7 \cdot 10^3$  for the fainter He I 537 line. Another explanation may be a different excitation mechanism for the various Helium lines as shown by Andretta and Jones (1997).

Also the other SUMER lines are much more broadened than expected from the optical lines. Assuming as kinetic temperature the corresponding ionization temperature, one obtains non-thermal velocities of 15–40 km/s. The range of non-thermal velocities would be smaller if the O I line is assumed 'hotter' than 18,000 K and the C III line 'cooler' than 70,000 K, in agreement with Seely et al. (1997) for the quiet corona.

The line widths depend slightly on the total emission  $E_{tot}$ , but the largest widths do not necessarily occur at the largest  $E_{tot}$ . Instead, we find significantly broad lines for faint emissions, in contrast to Wilk et al. (1993). This might arise from Doppler-shifted superposed faint emissions.

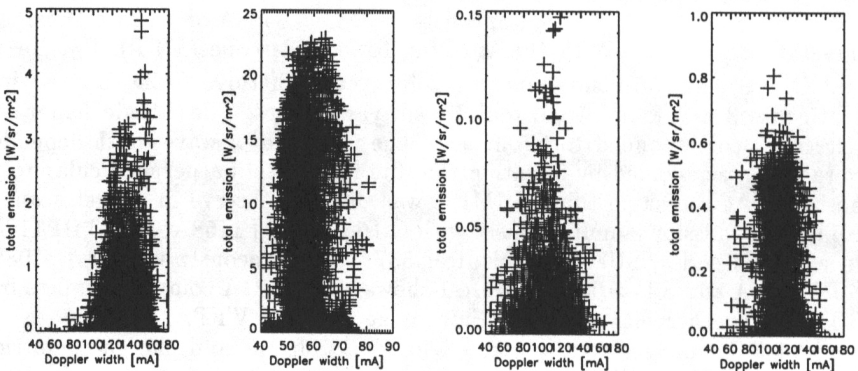


Figure 2. Dependence of the line width on the integrated emission. From left: C III, He I 584, S IV, N II.

#### 4. Integrated Line Emissions

Among the integrated line emissions  $E_{tot}$ , the ratio  $\text{Ca}^+/\text{Balmer}$  is mostly sensitive to the gas-pressure. The almost constant ratio indicates small variations of the gas pressure in the prominence. The temperature-sensitive relation of the He D<sub>3</sub> versus the H $\beta$  emission (from the VTT spectra) shows the known branching (Stellmacher and Wiehr 1995) caused by an easier penetration of the ionizing and exciting UV radiation at peripheral prominence regions. In the spectra from the Gregory telescope, the two violet lines He 3888 and H $\beta$  show a ratio of 1.6 which fit the relation by Stellmacher and Wiehr (1994) for  $T_{kin} \approx 8000$  K. The mean ratio of the total emissions of He 3888 (from GCT) and He D<sub>3</sub> (from VTT) is 0.06, being nearly half of the calculated value 0.125 by Heasley et al. (1974). The  $\text{Ca}^+$  8498 line shows a mean prominence emission of 0.13 of that of  $\text{Ca}^+$  8542, which is in good agreement with Landman and Illing (1977).

The SUMER lines show brightenings at the prominence periphery for the ratios of the C III/He I and S IV/N II emissions. This brightening is only marginally

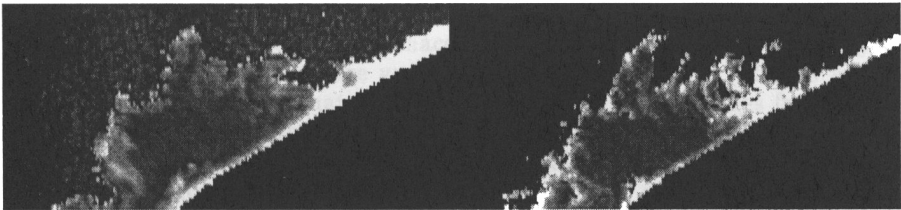


Figure 3. Total emission ratios of C III/He I 584 (left) and S IV/N II.

caused by broader lines but essentially due to an increased emission, similar to the larger He D<sub>3</sub>/H $\beta$  ratio at the prominence borders.

For the total emissions of He I 584 and He D<sub>3</sub> we find in the main body of the prominence mean values of 13 and  $4 \cdot 10^3$  watt/m<sup>2</sup> ster. The ratio of 3.25 is 18 times higher than that calculated by Heasley et al. (1974).

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