Dependence of the $\text{He}/H_\text{8}$ emission ratio on brightness, temperature, and structuring of prominences

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ABSTRACT

Aims. We investigate the dependence of the $\text{He}/H_\text{8}$ emission ratio on kinetic temperature and total Balmer brightness.

Methods. The line pair He\(^{\text{i}}\) 3888 Å and H\(^{\text{i}}\) 3889 Å has been observed simultaneously with the Ca\(^{\text{ii}}\) 8498 line in a number of quiescent prominences.

Results. The He/H\(_8\) emission ratio $R$ is found to cover defined parts of a general anti-relation with the total H\(_8\) emission, depending on the kinetic temperature, $T_{\text{kin}}$, of the individual prominence: High H\(_8\) brightness is related to small $R$ and $T_{\text{kin}}$ values, and preferably occurs in prominences with a less significant fine-structure.

Key words. Sun: prominences - helium emission - kinetic temperature - fine-structure

1. Introduction

In a previous paper (Stellmacher, Wiehr & Grupe 1992) it was shown that the emission ratio of the lines He\(^{\text{i}}\) 3888 Å and H\(^{\text{i}}\) 3889 Å within one prominence is strongly related to the value of the non-thermal line broadening parameter. This was explained by the higher (as compared to H\(_8\)) sensitivity of the EUV He-absorption coefficient to the non-thermal line broadening. The general decrease of the emission ratio with increasing H\(_8\) emission, observed for a great number of prominences by Moroshenko (1974) and by Illing et al. (1975) was not discussed, since the range of observed H\(_8\) emissions is too small within the single prominence observed in 1992.

Radiative transfer calculations by Moroshenko (1974) show the important role of the external Lyman continuum radiation on the actual He/H emission ratio. This ionizing Lyman continuum radiation directly penetrates in the prominence fine-structure (‘threads’) thus depending on their structure coefficient. In her calculations, Moroshenko (1974) assumes a constant electron temperature, $T_e = 7500$ K which, however, does not hold for faint outer prominence edges, where higher temperatures are measured (Hirayama 1971). A correct interpretation of the He/H\(_8\) emission ratio eventually allows the determination of the solar He abundance.

The aim of the present paper is to extend our former observations of the He/H\(_8\) emission ratio over a much wider range of H\(_8\) emissions from different prominences, and to relate them to the mean kinetic temperature of each prominence.

2. Observations data reduction

We analyzed 5 prominences observed on July 5 and 8, 1992, with the Gregory Coudé Telescope at Tenerife. The line pair He\(^{\text{i}}\) 3888 Å and H\(_8\) 3889 Å was taken in the 5th grazing order simultaneously with the Ca\(^{\text{ii}}\) 8498 Å line in the 6th order using a spectrum cutter. The spectrograph slit of correspondingly 1.5 arcsec width was oriented perpendicular to Earth’s horizon, i.e., in the direction of the (wavelength dependent) atmospheric refraction.

Spectra were taken with a 1024 x 1024 pixel CCD camera operated at a 2-pixel binning, corresponding to 0.318 arcsec x 5.9 m˚Å in the violet, resp. x 12.9 m˚Å in the infrared. In spite of a 12 sec integration time, the constant seeing conditions allowed a spatial resolution of about 2 arcsec, which is outstanding for highly resolved prominence emission spectra. Accordingly, individual emission streaks were analyzed with a 2 arcsec spatial mean.

Line widths and integrated line emissions (‘line radiance’) were obtained using Gaussian fits. The absolute calibration of the violet line pair was performed by comparison with disc center intensities at $\lambda = 3888.9$, which are assumed to amount to 27% of the true continuum intensity of $I_{\text{abs}} = 4.5 \cdot 10^6$ erg/(s cm$^2$ ster ˚Å at 3999.0 ˚Å (Labs & Neckel 1970). Kinetic temperatures, $T_{\text{kin}}$, were determined by comparison of the H, He, Ca lines as done by Bendlin, Stellmacher and Wiehr (1988).

3. Results

The finally obtained radiance ratio of the He and H\(_8\) emission, R, on the H\(_8\) line radiance is shown in Fig. 1 for the different prominences (indicated by different symbols) together with their corresponding mean kinetic temperature (right side of Fig. 1). Prominences showing less significant structuring in the slit-yaw images are indicated in Figure 1 by roundish symbols. They show highest H\(_8\) line radiance,
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Fig. 1. Emission ratio \( R \) of the violet line pair \( \text{He}^+ 3889 \) and \( \text{H}_\alpha 3888 \) versus the total emission of the \( \text{H}_\alpha 3888 \) line. The different prominences are marked by different symbols. The corresponding mean \( T_{\text{kin}} \) value of each prominence is given at the right side together with the corresponding symbol. Large symbols refer to observed means by Moroshenko (Mo), Illing et al. (ILM), Balthasar & Wiehr (BW).

The smallest radiance ratio \( R \), and smallest mean kinetic temperature \( T_{\text{kin}} \). In turn, the highly structured prominences (non-roundish symbols in Fig. 1) show lowest \( \text{H}_\alpha \) radiance, largest \( R \) and largest \( T_{\text{kin}} \) values. The different prominences cover defined parts of a general relation, corresponding to their individual (mean) \( \text{H}_\alpha \) radiance and kinetic temperature.

Comparison with existing data shows that the data by Moroshenko (1974) are systematically above ours; those by Illing et al. (1975) show a different slope (cf., Fig. 1). We checked that these differences are not due to the higher spatial resolution achieved in our spectra: If we simulate the 20 arcsec spatial resolution achieved by Illing et al. (1975), we neither obtain their different gradient in Figure 1 nor the displacement of Moroshenkos data. In addition, recent data by Balthasar & Wiehr (1993) from a very bright prominence agree with the lower right part of our relation Fig. 1.

4. Discussion

In order to correctly interpret the \( \text{He}/\text{H}_\alpha \) line radiance ratio, one has to consider the actual kinetic temperature \( T_{\text{kin}}(\approx T_e) \), the non-thermal broadening and the structure coefficient (Moroshenko 1974). The latter parameter strongly controls the penetration of the He ionizing EUV radiation (Zharkova & Borchchevskii 1993). We find that highest \( \text{H}_\alpha \) radiance, smallest emission ratio \( R \), and smallest mean kinetic temperature \( T_{\text{kin}} \) preferably occur in less structured prominences. In turn, highly structured prominences show lowest \( \text{H}_\alpha \) radiance, largest \( R \), and largest \( T_{\text{kin}} \). This behavior qualitatively agrees with calculations by Zharkova (1989) which require a slightly higher structure density for brighter prominences.

Without anticipating detailed model calculations, we thus argue that the lower temperatures of cool prominences rather require a denser packing of threads which, in turn, reduces the penetration of the He-exciting EUV radiation.

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