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Chromospheric and Transition region He lines during a flare

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Abstract. An observing campaign (SOHO JOP 139), coordinated between ground based and SOHO instruments, has been planned to obtain simultaneous spectroheliograms of the same area in several spectral lines. The chromospheric lines Ca II K, Hα and Na I D as well as He I 10830, 5876, 584 and 304 Å lines have been observed. These observations allow us to build semi-empirical models of the atmosphere before and during a small flare. With these models, constructed to match the observed line profiles, we can test the He abundance value.

Key words. Solar activity – Flares – Helium

1. Introduction

Helium is a very peculiar element in the sense that, despite its high abundance in the universe, its solar abundance is unknown. Unfortunately, its lines are undetectable in the visible photospheric spectrum, and thus the so-called solar photospheric abundance is derived using theoretical stellar evolution models. The accepted value for the ratio $[\mathrm{He}] = N_{\mathrm{He}}/N_{\mathrm{H}} = 0.1$, represents the helium abundance of the nebula from which the solar system formed.

On one hand, there are now strong indications that this value is too large: the inversion from heliosismic data by different authors leads to values of [He], in the convection zone, in the range .078 - .088 (for a review see Boothroyd & Sackmann 2003). On the other hand, measurements of [He] in the solar wind and interplanetary medium indicate that He is depleted by a factor of ≈ 2 relative to the photosphere. Since the abundances of elements with high First Ionizazion Potential (≥ 10 eV) are roughly equal to the photospheric ones (for a review see Meyer 1996), helium is in this respect anomalous.

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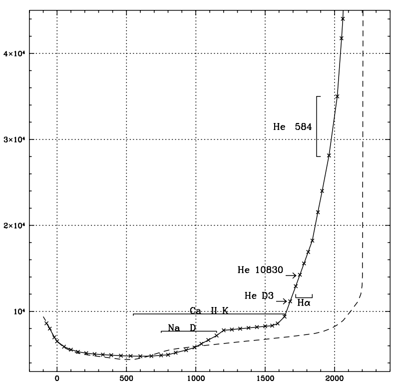

Fig. 1. Temperature vs height distribution of the computed atmospheric model for the active region before the flare (solid line) at 15:15 UT. The quiet-Sun model C (Fontenla et al. (1993)) is shown for reference (dashed line)

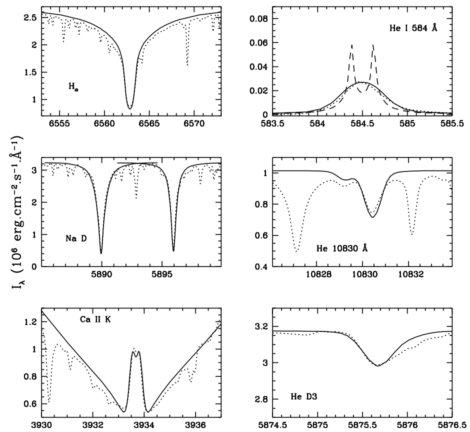

Fig. 2. Observed (dotted line) and computed (solid line) profiles for the lines observed at 15:15 UT. For the He I 584 the dashed line indicates the computed profile with "infinite" spectral resolution and the full line shows the calculations smeared to the same resolution as the observations (0.58 Å)

Where these abundance variations occur is currently not known, but most of the current theories consider the chromosphere the best candidate. However, direct measurements of [He] in the solar atmosphere are available only for the corona. In the quiet corona, at R $\approx$ 1.1 $R_\odot$, a He abundance of about 0.08 has been found (Gabriel et al. 1995, Feldman 1998) suggesting no He depletion in the low corona, while in a streamer, at R $\approx$ 1.5 $R_\odot$, Raymond et al. (1997) found a 50% depletion of He with respect to H.

Therefore, it would be very important to determine the He abundance at chromospheric and transition region (TR) levels directly from line profiles. The strongest He lines in the solar atmosphere are in the extreme ultraviolet (EUV) below 584 Å. From the ground, the only observable He line in the quiet solar atmosphere is at 10830 Å. However, in active regions or flares, all the He lines are enhanced; the D_3 line at 5876 Å, in particular, becomes detectable.

The excitation of these subordinate lines is essentially due to a photoionization-recombination mechanism (Zirin 1975, Andretta & Jones 1997); i.e. to direct photoionization of chromospheric helium atoms by coronal EUV radiation shortward of 504 Å and successive recombination to the excited levels of He I. Therefore, the study of the solar He spectrum requires not only spectral observations of an active region (or flare) in a very large spectral range (from EUV to near infrared) but also an estimate of the coronal EUV radiation.

To this aim we planned an observing campaign (SOHO JOP 139) coordinated between ground based and SOHO instruments to obtain simultaneous spectroheliograms of the same area in several spectral lines (including four He lines) that sample the solar atmosphere from the chromosphere to the transition region. During this campaign we also observed a small two-ribbon flare (GOES class C-1). These observations allow us to build semi-empirical models of the atmosphere before and after the first flaring episode. These models, constructed to match the observed line profiles, give the possibility to test the He abundance value.

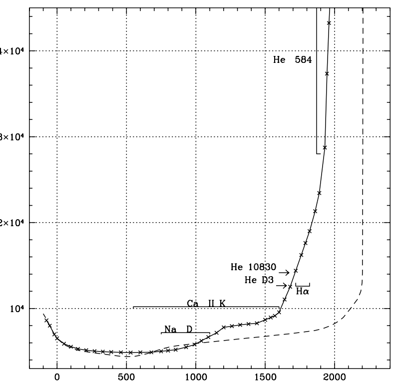

Fig. 3. Temperature vs height distribution of the computed atmospheric model (solid line) for the active region after the first flaring episode at 16:10 UT. The quiet-Sun model C (Fontenla et al. (1993)) is shown for reference (dashed line)

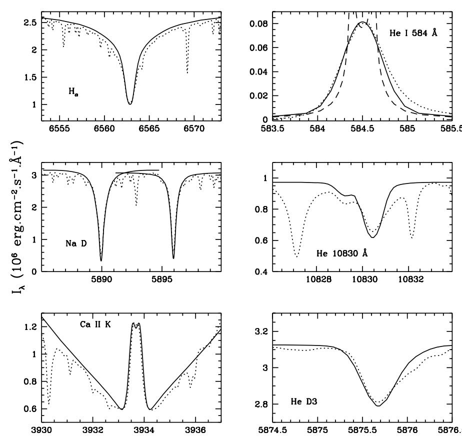

Fig. 4. Observed (dotted line) and computed (solid line) profiles for the lines observed at 16:10 UT. For the He I 584 the dashed line indicates the computed profile with "infinite" spectral resolution and the full line shows the calculations smeared to the same resolution as the observations (0.58 Å)

2. Observations

A detailed description of the observing program is given in Teriaca et al. (2003). We will recall here that spectroheliograms were acquired with the Horizontal Spectrograph at the Dunn Solar Telescope (DST) of the National Solar Observatory / Sacramento Peak in the chromospheric lines Ca II K, Hα and Na I D lines as well as in the He I lines at 5876 (D_3) and 10830 Å. At the same time, spectroheliograms of the active region were obtained in the spectral windows around the He I 584 (log T=4.3), He II 304 (log T=4.8) spectral lines with Coronal Diagnostic Spectrometer (CDS) aboard SOHO.

The EUV flux was monitored by the Solar EUV Monitor (SEM) instrument aboard SoHO (Hovestadt et al. 1995). The instrument measures the full disk absolute solar irradiance integrated between 1 and 500 Å.

3. Models

We built semi-empirical models of the active region and the flare atmosphere at two different times, before the flare (15:14 UT) and after the first flaring episode (16:10 UT) to avoid possible velocity spikes (see Teriaca et al., this issue). The models are constructed to match the observed line profiles. The modelling was done using the program Pandora (Avrett & Loeser 1984). Given a T vs. z distribution, by solving the radiation transfer together with statistical and hydrostatic equilibrium equations, we self-consistently computed non-LTE populations for 10 levels of H, 29 of He I, 9 of C I, 15 of Fe I, 8 of Si , Ca I and Na I, 6 of Al I, and 7 of Mg I, 6 of He II and Mg II, and 5 of Ca II.

The calculations include incident radiation from the coronal lines in the H, He I and He II continua. The spectral distribution of the incident intensity are taken from the compilation of Tobiska (1991) for low-activity coronal source. The specific intensity of the considered active region (before and after the flare) has been derived considering the spatial distribution from EIT images and comparing them with SEM absolute full-disk irradiance. We found that before the flare (15:15 UT) the incident intensity is a factor 2 higher than the low-activity coronal source while after the first flaring episode (16:10 UT) is a factor 20 higher. The estimated uncertainty on these values is of about 30%.

Fig. 1 shows the distribution of the temperature as a function of height, measured from the point where $\tau_{5000} = 1$, for the model obtained for the atmosphere of the active region before the flare (15:15 UT) while Fig. 2 shows the computed and observed line profiles at the same time. These profiles were computed with the coronal incident radiation derived from SEM, and adopting the standard value [He]=0.1. Overall, the agreement with observed profiles is fairly good. Futhermore, we notice that for the He II 304 line we can consider only the integrated radiance and not the profile, because the post-recovery line profiles are particularly broad for NIS-1 spectra. The computed radiance is 1.6 10^5 erg cm^{-2} s^{-1} st^{-1} $Å^{-1}$ and agrees within 2% with the observed one.

In Fig. 3 we show the temperature vs. height distribution of the model obtained for the flaring atmosphere at 16:10 UT and in Fig. 4 the computed and observed line profiles at the same time. For these computations the coronal incident radiation is only a factor 0.25 the coronal radiation derived from SEM observations and the He abundance has the standard photospheric value [He]=0.1. The computed radiance of the He II 304 line is 6.4 10^5 erg cm^{-2} s^{-1} st^{-1} $Å^{-1}$ and agrees within 4% with the observed one. It can be seen that also in this case the general agreement between the observed and the computed profiles is good, but we notice that we should use a coronal radiation a factor 4 lower than the one derived by SEM observations, well beyond the estimated uncertainty. If we use the coronal radiation observed by SEM at this time, the computed emission of the He lines differs from the observed one about a factor 1.5 in the sense that the He 10830 and 5876 show a stronger absorption while the He transition region lines show a stronger emission. A change of the [He] value might give a better agreement: we find that a value of [He]=0.05 in the layers with $T > 10^4$ K gives a good agreement between the observed and the computed profiles.

In conclusion, we can say that before the flare, in the active region our models with a standard [He] can match the observations, while at the present we are able to match the observations during the flare only with a lower [He] in the upper chromosphere/lower TR. This seems to indicate a He depletion during flares.

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