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Calculation of the intensity of Mg I spectral lines in solar prominences using the Cloudy code model

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Spectroscopical observations of several prominences in the MgI lines were carried out from 2014 to 2017. These lines from visible part of the solar spectrum play an important diagnostic role, complementing the UV Mg II resonance lines regularly observed by the IRIS satellite. We found that a rather weak Mg I emission, e.g., in the 5172.6 Å line correlates well with the presence of extended bright areas on the solar disk observed in the 1600 Å SDO / AIA band. However, in many cases the radiation in the 5172.6 Å line is very low, even not detectable, although a bright prominence above the limb or flare on the solar disc were observed. To explain this phenomenon, we have calculated spectra of optically thin plasma using Cloudy code and found that observed ratio of optical lines and UV continuum is possible and the presence of heel processes stimulates luminescence in Mg I and 1600 Å lines.

Keywords: Prominences, solar flare

1 Observations

The following observations were chosen for measurements: 2015-04-21, 13:21:11 UT and 2016-05-22 12:14:48; 12:21:04 UT, which were obtained on a multichannel flare spectrograph (MFS `http://www.asu.cas.cz/~sos/archive_mfs.html`). Figure 1c shows an example of well-observed radiation in Mg I lines. In Fig. 2 we note the position of flares in the "legs" of the prominence and the glow of the prominence and the chromosphere in lines 304 and 1600 Å. In the second case, the emission does not occur in 2016-05-22 12:14:48 UT (Figs. 3, 4). As noted in [Heinzel et al., 2016], we also do not observe glows in the 1600 Å line. The absolute radiation intensity in Hα, MgI 5183 Å (MFS) and 1600 Å (SDO/AIA) was determined from observations. The results of calculations of the intensity ratio for 2015-04-21 13:21:11 correspond

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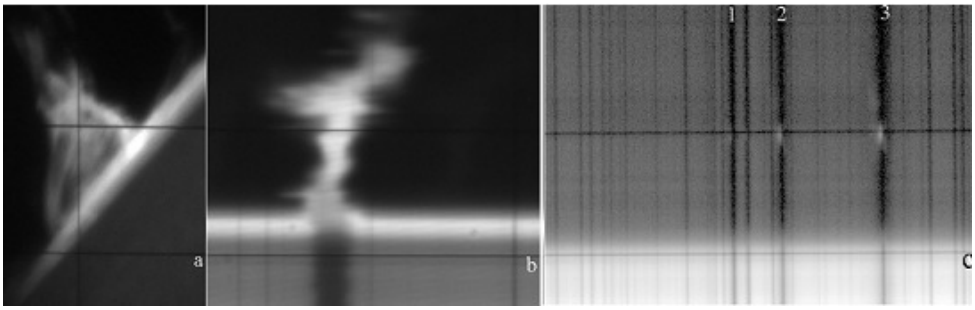


Figure 1 2015-04-21, 13: 21: 11 UT a) slit-jaw image (the vertical line corresponds to the position of the spectrograph slit), lines b) Hα, c) MgI 5167.3 Å (1), 5172.6 Å (2), 5183.6 Å (3), [MFS].

to (Hα / 1600 = 0.352; Mg I / 1600 = 0.130; Hα/ Mg I = 2.70). In the second case, 2016-05-22 12:14:48 UT (Figs. 3, 4), even during a weak flare at 12:21:04 UT (Figs. 5, 6) we do not observe emission in the Mg I line, though it is present in the 1600 Å line.

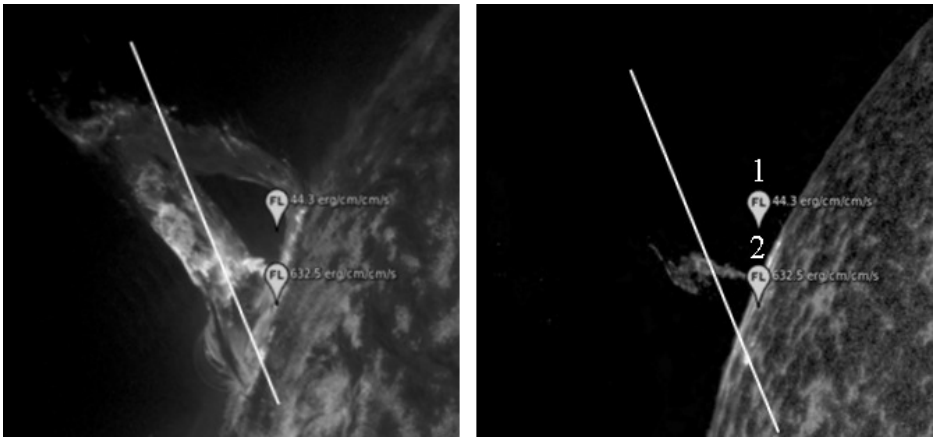


Figure 2 SDO/AIA 304 Å, 1600 Å 2015-04-21, 13: 21: 11 UT the position of solar flares and the peak value of the flux: (1) 44 erg·cm^{-2} s^{-1}; (2) 630 erg·cm^{-2} s^{-1} (white line corresponds to the position of the spectrograph slit).

2 Spectra simulation

A realistic calculation of the observed spectrum requires a time-dependent radiative hydrodynamic modeling. Here we restrict ourselves to the study of parameter space

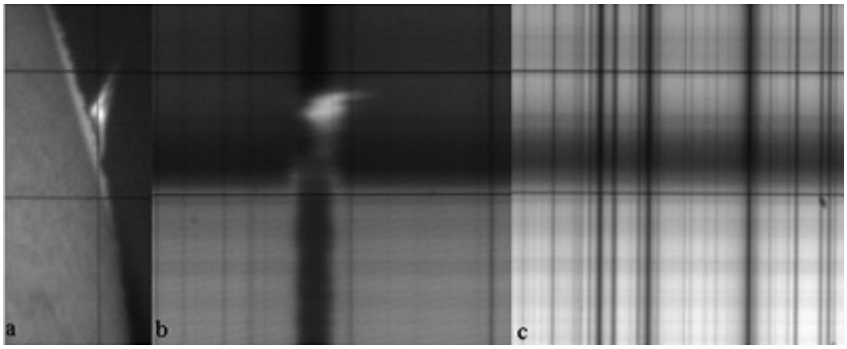


Figure 3 2016-05-22 12:14:48 UT a) slit-jaw image, lines b) Hα, c) MgI 5172 Å, [MFS].

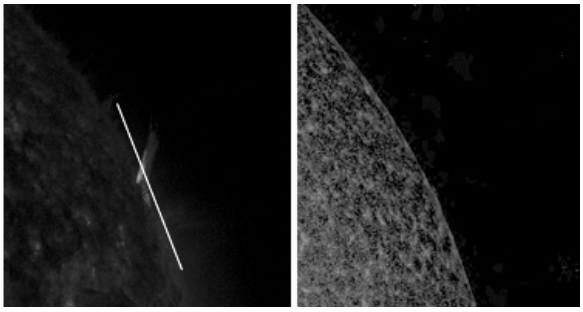


Figure 4 SDO 304 Å, 1600 Å, 2016-05-22 12:14:48 UT.

of solar plasma, at which the observed line ratios can be obtained. To do this, we will apply a simplified model of a steady-state optically thin plasma, calculated with the Cloudy code [Ferland et al. 2017] solve a set of statistical equilibrium equations for populations of atomic levels, taking into account collisional and radiative transitions for lines and continua. The joint solution of the radiative transfer equations was carried out in an approximate way by means of the escape probability technique, but in our case of optically thin plasma limitations of this method are unimportant. Note that at a high density of plasma the accuracy of the Cloudy's results decreases due to the increasing role of unaccounted or approximately accounted collisional processes, in the particular three-body recombination, the cross section of which for most ions is poorly known. To simulate the physical conditions in the prominence, we examined a plane-parallel optically thin layer of gas, placed in a blackbody radiation field with $T = 6000$ K and a dilution of 0.5 (that is, near the surface of the Sun). The number density and temperature of the gas layer are constant and varied in ranges of $N = 10^8$–10^{14} cm^{-3}, $T = 50000$–24000 K. We used the default solar chemical composition, distributed in Cloudy v.17 (in particular, for magnesium (Mg / H)= –4.46, see Cloudy documentation for other elements). A UV radiation is an important factor in simulations of spectra, because it produces significant departures from LTE by shift-

ing the ionisation balance to ions with higher ionization energies. About the local UV radiation field in the particular active region, we considered it as a blackbody radiation with $T = 100\ 000$ K with a dilution factor from 0 to 10^{-8}. We calculated emergent fluxes for Mg I and Hα lines and total contribution of lines and continuum in the 1500–1600 Å band using a grid of about 4000 models. Interpolating over this grid, we find parameters of the gas, at which the observed relations between fluxes in Mg I, Hα and the band 1500–1600 Å are achieved. The spectral width of the SDO / AIA 1600 Å filter was taken from the work [Simöes et al., 2019]. These parameters are shown in the T–log N diagram in Fig. 7, where various dilution factors are shown in different line types. The intersection of the curves of the same type gives the parameters, at which all the relations between the lines are fulfilled. There are several such points and all of them show the presence of a moderate UV background, corresponding to the dilution factor of $10^{-11} - 10^{-9}$ for the assumed blackbody radiation. We conclude therefore that the observed ratio of the lines and the UV continuum is possible and the presence of heel processes stimulates luminescence in the Mg I and 1600 Å lines. However, to derive more reliable gas parameters, a more realistic model should be considered.

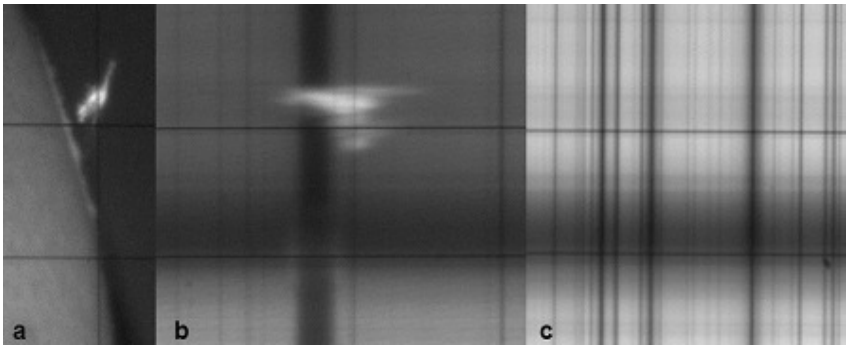


Figure 5 2016-05-22 12:21:04 UT a) slit-jaw image, lines: b) Hα, c) MgI 5172 Å, [MFS].

3 Results

It follows from our observations and modelling that:

a) luminescence in the Mg I lines was observed during the flare processes in the near the limb with a radiation flux in the range of 44 – 630 erg cm^{-2} s^{-1} (observation 2015-04-21);

b) during observation 2016-05-22 12:21:04 UT, when a flare with an energy of 17 erg cm^{-2} s^{-1} occured away from the limb, emission in optical Mg I lines was absent, although it was observed in the 1600 Å line;

c) observed relationship between the lines Hα, Mg I and the continuum UV can be reproduced in the models;

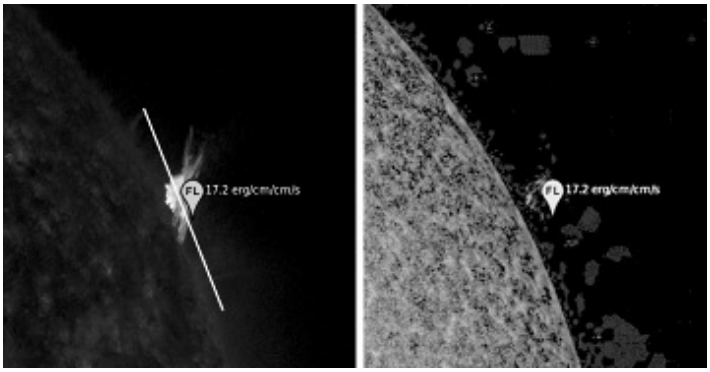


Figure 6 SDO/AIA 304 Å, 1600 Å 2016-05-22 12:21:04 UT the position of solar flare and the peak value of the flux (17 erg·cm^{-2} s^{-1}).

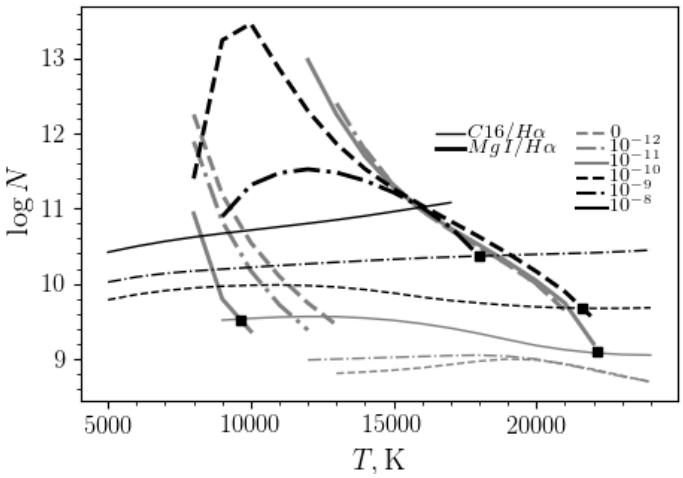


Figure 7 Results of calculations for 2015-04-21 13:21:11 UT (Hα /1600 = 0.352; MgI/1600 = 0.130; Hα/MgI = 2.70). Various line types are for various dilution factors of blackbody radiation with T = 100000 K.

d) the presence of heel processes stimulate luminescence in the Mg I and 1600 Å lines.

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