FE I AND CA II K LINES IN QUIET AND ACTIVE REGIONS

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ABSTRACT

We investigated Fe I (557.6 nm and 522.5 nm) and Ca II K lines in active and quiet regions. The line intensity ratios and velocities were compared in quiet (disc center) region, plage and subflare. Using correlations of line center intensity and velocity fluctuations along the slit we estimate appropriate layers of the photosphere which are affected by the subflare. Difference between quiet and 'flaring' photosphere is discussed.

Key words: Spectral lines; photosphere; flare.

1. INTRODUCTION

Spectra of the solar atmosphere, obtained with high spatial and spectral resolution are good tool for diagnostics of fine differences of the physical conditions of the solar atmosphere. It is important to select suitable set of lines in order to investigate properly dynamic and magnetic characteristics of the atmosphere in the chosen levels. Such set of lines, then serve for theoretical calculations of the physical models of all types of the solar activity. This contribution is a part of long-duration project of investigation of the dynamic parameters of the solar atmosphere in different types of the solar activity. Determination of the spectral characteristics and investigation of their statistical behaviour is the first step of such analysis. The aim of this paper is to compare spectral characteristics of two photospheric lines, Fe I 557.6 nm (dynamic line), Fe I 522.5 nm (magnetic line) and one chromospheric line Ca II K 393.3 nm, in quiet and active atmosphere after solar cycle minimum, in year 1993.

2. OBSERVATIONS

The data were taken on Vacuum Tower Telescope (VTT), (Schröter et al., 1985, Soltan, 1989), at Observatário del Teide, Tenerife, on June 1, 1993. We observed in three spectral regions. More than 1000 spectra in all three regions were taken including the calibration spectra for flatfielding. The relevant parameters for the observed spectral lines are given in Tables 1, 2 and 3. Both Fe I lines are formed at the same height in the photosphere (~ 300 km) but the Fe I 557.6 nm is dynamic line and the second one Fe I 522.5 nm is magnetically sensitive line with g eff = 2.5. For information about chromosphere, we add Ca II K line to the set of the two Fe I lines. The inner wings of the Ca II K line should form at the same height as the centers of the Fe I lines.

For this work we have selected three sets of spectra (three lines each) for typical quiet region, plage and subflare (see Table 2.) The three lines in one set were taken simultaneously, i.e. the start of exposure was the same. The spectra were recorded with CCD cameras of 1024 x 1024 pixels with binning 2. Thus the resulted spectra are of 512 x 512 pixels. The resolution in spatial direction is 0.17" per pixel. The dispersion in wavelength direction is given in Table 3. The width of the spectrograph slit was 150 µm. The spectra were stored on exabyte tape in on-line regime. Simultaneous slit-jaw images in Ca II K and Hα were recorded on video tape. There is shown one set of spectra together with slit-jaw images in Figure 1.

3. DATA REDUCTION

The data were reduced using IDL software including the IDL KIS LIB - library of IDL programs at Kiepenheuer-Institut für Sonnenphysik, Freiburg. Standard procedures were applied (dark current subtraction, precise flatfielding, and FFT profiles restoration) in the reduction process. For our analysis we calculated the following spectral characteristics:

- $I_c$ - continuum intensity;
- $I_o$ - line center intensity;
- $v_p$ - Doppler shift velocity (in Fe I lines only);
- bisectors (in Fe I lines only);
Table 1. Spectral lines characteristics

<table>
<thead>
<tr>
<th>line</th>
<th>wavelength [nm]</th>
<th>equiv. width [mA]</th>
<th>multiplet</th>
<th>excit. pot. [eV]</th>
<th>Lande factor $g_{eff}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe I</td>
<td>557.6</td>
<td>113</td>
<td>686</td>
<td>3.43</td>
<td>0.0</td>
</tr>
<tr>
<td>Fe I</td>
<td>522.5</td>
<td>68</td>
<td>1</td>
<td>0.11</td>
<td>2.5</td>
</tr>
<tr>
<td>Ca II K</td>
<td>393.3</td>
<td>20253</td>
<td>1</td>
<td>3.2</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Table 2. Spectra finally used

<table>
<thead>
<tr>
<th>n:</th>
<th>line [nm]</th>
<th>time [UT]</th>
<th>exposure time [s]</th>
<th>location on the disk $\mu$</th>
<th>activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>557.6</td>
<td>08:01:01</td>
<td>0.2</td>
<td>$\mu = 1$</td>
<td>quiet region</td>
</tr>
<tr>
<td>2</td>
<td>393.3</td>
<td>08:28:31</td>
<td>2.0</td>
<td>$0.97 &gt; \mu &gt; 0.77$</td>
<td>plage</td>
</tr>
<tr>
<td>3</td>
<td>557.6</td>
<td>08:12:48</td>
<td>2.0</td>
<td>$1 &gt; \mu &gt; 0.97$</td>
<td>subflare</td>
</tr>
</tbody>
</table>

Before that, an influence of the atmospheric refraction on the spectra was eliminated. For this, we rotated the spectograph tank of the VTT before the observations to have the slit in appropriate angle to keep the effect of the refraction along the slit only. The resulted shift of spectra between the 'violet' and 'green' spectral regions in 'y' direction (along the slit) was then calculated using the correlations between intensity fluctuations along the slit in the centers of the Fe I lines and in the wing of the Ca II K line. We have found the best correlation with shifts of these intensity fluctuations 11 pixels between Ca II K (wing) and Fe I 557.5 nm (line center) and 9 pixels for the Ca II K and Fe I 522.5 nm. The intensity fluctuations are demonstrated in Figure 2 and the correlations are shown in Figure 3. After the coallment of all three spectra according to the estimated shifts, we calculated the spectral characteristics for every scan (row) in the particular spectrum. There are 413 scans (rows) in the finally reduced spectra. It represents a spatial region of 70.21\'' along the slit.

4. RESULTS

First, we have estimated ratios of the Fe I and Ca II K line central intensities. They are shown in Figure 4. Using the method described by Kučera et al. (1998) we have calculated autocorrelations of the shifts of Fe I lines (Fig.5). Line center shifts fluctuations along the slit were correlated with bisector fluctuations along the slit. Let us explain the idea. If the center of line and also the wings of the line are formed at almost the same height in the atmosphere, the shifts of both line center and bisectors should be identical. The correlation of such shift fluctuations along the slit will be high. If the center of line is formed in different conditions than the wings, the correlation will be weak (for details see Kučera et al., 1998).

5. DISCUSSION

The ratios of the $I_o$ (Fig.4) reflect mainly the temperature and density situation in the atmosphere. There is no coupling, as expected, between photosphere and chromosphere in quiet region. No reflection of higher intensities of Fe I lines acts in Ca II K line center. Contrary to that, plages is characterized by reaction of the Ca II K line intensities to the changes in the Fe I line center ones. More, the intensities are generally shifted to higher values. This indicate hotter photosphere and some coupling of the photosphere and chromosphere even for those layers, in which the lines are formed. Different situation pays for Figure 4 - subflare. Here we
Figure 1. An example of the spectral set observed in plage including two slit-jaw images, three spectra, and 3D plot of intensities of the Ca II K spectrum.
met several types of behaviour of the intensity ratios:

a) High rise of Ca II K intensity without reaction in Fe I lines;

b) High rise of Fe I intensities without reaction in Ca II K line;

c) intermediate behaviour between types a) and b);

Such situation could support the idea, that the energy of the flaring plasma penetrate deeper to the photospheric layers in very structured isolated bent bunches. Therefore we can see enhanced intensities in Ca II K line but at the same position on the slit there is no activity in photospheric Fe I lines and vice versa.

The autocorrelation of the fluctuations of the line shifts in Fe I lines (Fig.5) indicate also changes mainly between quiet and flaring photosphere. While the differences in correlations for quiet and plage atmospheres are rather small, the differences for subflare and quiet region and for subflare and plage are dramatic. In both panels of Figure 5 we can see rapid departures of autocorrelations if we go out from the centers of lines to the wings. The departure is higher for magnetic Fe I 522.5 nm line. The behaviour of the autocorrelations in flaring photosphere exhibits that centers of both Fe I lines are here formed in higher hotter plasma comparing to the situation in quiet region. The Fe I 522.5 nm line is additionally affected by the magnetic field which is presented in the active region.

To describe the behaviour of the investigated parts of the photosphere it is necessary to model them for every particular case (quiet, plage, subflare). This is the aim of our near future work using the SIR code (Cobo, 1998) developed at Instituto de Astrofísica de Canarias.

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Figure 4. Line intensity ratios of the Fe I and Ca II K lines in all three (quiet, plage, subflare) investigated regions.
Figure 5. Autocorrelations of the line center shifts ($v_\lambda$) and wing shifts (bisectors) of the two Fe I line along the slit. The intensity $|I_c - I_o|$ means the line intensity depression. The crosses symbolize quiet region, the stars stay for plage and the squares pays for subflare.

REFERENCES

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