SPECTRAL STATISTICS OF Fe I AND Ca II K LINES IN THE QUIET AND ACTIVE SOLAR ATMOSPHERE

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Abstract. Based on two Fe I and Ca II K lines spectra obtained with high spatial and spectral resolution we investigated some spectral characteristics of these lines in quiet and active regions. In this paper we present the behaviour of the central line intensities in different types of solar activity. We discuss the obtained results and compare them with the results reported by other authors.

Key words: Fe I and CaII K lines - spectral statistics - solar atmosphere

1. Introduction

Solar spectra with high spatial and spectral resolution enable a diagnosis of the differences in the physical conditions in regions with different stages of activity. To determine the dynamic and magnetic characteristics of some region, it is important to choose suitable spectral lines which are formed at appropriate heights of the solar atmosphere. The analysis of the spectral characteristics of these lines is a base for the theoretical calculation of the solar atmosphere model. This paper is a
part of a project whose aim is to determine the physical parameters of the solar atmosphere based on calculations of the synthetic spectra. In the first phase of the analysis it is necessary to find out the behaviour of the spectral lines and to determine the qualitative characteristics of these lines in regions with different levels of activity. Determination of these characteristics and their comparison for different active regions is a topic of this paper.

2. Observations

The data were taken with the Vacuum Tower Telescope (VTT) at the Observatório del Teide, Tenerife on June 1, 1993. The data include more than 1000 solar spectra taken in three different spectral regions. The parameters of the observed spectral lines are given in Table I. Two Fe I spectral lines were chosen to obtain an information about dynamic and magnetic characteristics at identical height of the solar atmosphere. Both Fe I lines are formed at the same height of the photosphere (≈300 km), but the Fe I 557.6 nm line is purely dynamic and the Fe I 522.5 nm is a magnetically sensitive line. Specific parts in the wings of the third line, Ca II K 393.3 nm, are formed at the same height, but the center of Ca II K is formed in the chromosphere (≈1500 km). Thus we can get also an information about the overlaying atmosphere.

<table>
<thead>
<tr>
<th>line</th>
<th>wavelength</th>
<th>eqv. width</th>
<th>multiplet</th>
<th>excit. pot.</th>
<th>Landé f.</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>

Out of 1000 spectra we selected the 14 best sets of spectra for preliminary analysis and finally for the detailed analysis we used only four sets of spectra, which represent different levels of solar activity.
(Table II). Each set of three spectra (Fe I 557.6 nm, Fe I 522.5 nm, Ca II K 393.3 nm) was taken simultaneously, i.e. the exposition started at the same time. The exposure time was 0.2 s for Fe I lines spectra and 2.0 s for the Ca II K line. The spectra were taken with 1024 × 1024 pixel CCD cameras with binning 2. Thus the final spectra are 512 × 512 pixels with a spatial resolution of 0.17” (along the slit) and the dispersion in the wavelength direction is 3.5×10^{-4} nm for the Fe I lines and 2.5×10^{-4} nm for the Ca II K line. The spectrograph slit was 150 μm wide.

3. Data reduction

The spectra were reduced using IDL software including the IDL KIS LIB (library of IDL programs developed at Kiepenheuer-Institut für Sonnenphysik, Freiburg) and our own IDL programs. The standard dark current subtraction and FFT profiles restoration were applied. A special procedure was used to remove the flat-field. After basic reduction of all spectra we obtained the final profiles from which we determined the spectral characteristics.

4. Spectral characteristics

The following spectral characteristics were determined for our analysis: \( I_c \) – continuum intensity and \( I_o \) – line center intensity (residual intensity).

The resulting two-dimensional spectra for each line (see Figure 1)
Figure 1: An example of the Fe I 557.6 nm spectrum after basic reduction.

contain 419 spectral profiles, so we determined 419 values of $I_c$ and $I_o$ for each spectrum. In addition, it was necessary to eliminate the continuum trend, to calibrate spectra to the real "atlas" continuum, to smooth the profiles using FFT and to eliminate the influence of the atmospheric refraction.
Elimination of the continuum trend and spectrum calibration to the real continuum.

The resulting spectra have their own continuum trend in the direction of dispersion. Therefore, it was necessary to correct this trend and reach consistency with the atlas values. The correction was done using the values of the lines surrounding quasicontinua taken from the Liege atlas (Delbouille et al. 1990) To obtain the real values of the continuum we multiplied the intensity of quasicontinua by the correction factors which were estimated using the Liege atlas again.

Elimination of the atmospheric refraction influence.

The observed spectral lines Fe I and Ca II K represent two very distant parts of the spectrum (the difference is 130 nm), so it was necessary to eliminate the influence of atmospheric refraction. Therefore, we rotated the VTT spectrograph tank before observations to an appropriate position to have the slit parallel to the meridian to keep the effect along the slit only. Using the correlation between the intensity fluctuations in Fe I cores \( I_o \) and in Ca II K wings the shift of spectra along the slit was determined. The best correlation was found for an 11 pixels shift between Fe I 557.6 nm and Ca II K and for a 9 pixels shift between Fe I 522.5 nm and Ca II K. Also a 2 pixels shift between the Fe I lines was found. So we found that the Fe I line spectra were shifted in comparison to the Ca II K spectrum by the amount of about 2”.

5. Results and discussion

Figure 2 represents the ratios of the central line intensities \( I_o \) for all 3 lines in all 4 different regions. We keep identical scales in all panels of Figure 2, to display clearly the differences between the quiet region and different active regions.

The ratios of the central line intensities \( I_o \) reflect the temperature and density stratification in the photosphere. For the quiet region the \( I_o \) changes in one Fe I line are reflected in the other one too. This result is expected because both Fe I lines are formed at the same height in the photosphere. The estimated intervals of Fe I \( I_o \) intensities are in good agreement with the values obtained by Berrilli et al. (1999). The
Figure 2: Line intensity ratios in all investigated regions.
intensities in the center of Ca II K do not react to the changes in the photosphere. This corresponds to the results found by Carlsson and Stein (1992) who simulated the behaviour of the Ca II K line in the chromosphere and they have shown that there is a reflection of the photospheric dynamics mainly in the Ca II $K_{2v}$ intensities but no reflection appears in the Ca II $K_3$ intensities.

In the region of a cool filament we can see even a drop in the Ca II K intensities because the filament is a strong absorber of the Ca II K line center radiation.

In the case of a plage all layers of the photosphere and chromosphere are heated, so one can recognize a correlation of the Ca II K line center intensities and the Fe I line center intensities. All intensities are also shifted to higher values due to the higher temperature.

The situation is different for the subflare. Here we can find a high rise of the Ca II K line center intensity without reaction in Fe I lines and also a high rise of the Fe I line center intensities without a reaction in Ca II K. This situation can be explained by the hypothesis of a structured active region, where the flaring plasma spreads in narrow curved bunches (loops) downwards to the photosphere. Thus, the hot plasma loop observed in the chromosphere at a particular point ends in the photosphere at a different position concerning the line of sight. Therefore, at the same position on the slit, we can observe enhanced intensities in the photosphere and no activity in the chromosphere and vice versa.

It is necessary to model the synthetic spectra and compare them to the observed ones for a quantitative determination of the physical parameters in the appropriate levels of the photosphere. This work will be done in the near future.

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STATISTIČKA ISTRAŽIVANJA SPEKTRALNIH LINIJA FeI I CaIIK U MIRNOJ I AKTIVNOJ SUNČEVOJ ATMOSFERI

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Sažetak. Na temelju dvaju spektara linija FeI i CaIIK visokog prostornog i spektarialnog razlučivanja istražuju se neka spektarna svojstva tih linija u mirmim i aktivnim područjima. Prikazuje se ponašanje središnjih intenziteta spektiralnih linija za razne oblike Sunčeve aktivnosti. Dobiveni rezultati se diskutiraju i uspoređuju se s rezultatima drugih autora.

Ključne riječi: FeI i CaIIK linije - spektarna statistika - atmosfera Sunca