DYNAMIC COUPLING OF THE CHROMOSPHERIC AND PHOTOSPHERIC FLARING PLASMA

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ABSTRACT

The relaxing phase of the subflare observed in the core of chromospheric Ca II K line and in two photospheric Fe I 522.5 nm and Fe I 557.6 nm lines was investigated. The temporal evolution of asymmetry in Ca II K line and the mean bisectors positions of the Fe I line profiles as well as their correlations are presented. It is documented that the chromospheric down-flow caused by the subflare strongly affects the upper layers of the photosphere. As a consequence of relaxation of the photospheric layers strong downflows and up-fows were measured at the end of the subflare relaxing phase.

Key words: solar spectral lines; photosphere; chromosphere; flare.

1. INTRODUCTION

Simultaneous high resolution observations of spectral lines formed in different heights of the solar atmosphere allow us to study the variations of physical parameters in these levels. The Fe I 557.6 nm and Fe I 522.5 nm lines are analysed in this work together with Ca II K line. Mentioned spectral lines mapped the upper photosphere (370 km), where both Fe I lines are formed, and the chromosphere (1500 km), where the Ca II K line core is formed. The difference between Fe I lines is that the Fe I 522.5 nm line is magnetically sensitive (g_{eff}=2.5) contrary to the Fe I 557.6 nm (g_{eff}=0).

The Ca II K line asymmetry is one of the most obvious indicators of dynamic processes in flare spectrum. The definitions of asymmetry differ between authors (see [1], [2], [3]) but generally the asymmetry reflects the shift of the emission peak (Ca II K line profiles without double reversal), or shows the fact that $I_{K_{1r}} > I_{K_{1v}}$ and $I_{K_{2r}} > I_{K_{2v}}$ and vice versa (in Ca II K double reversal profiles). To cover the wide range of the profile shapes in our work we selected the asymmetry definition independent of the double reversal presence (see Sec. 3).

During the early phases of the flares the red asymmetry in Ca II K line dominates [1]. The red asymmetry of emission profiles is interpreted as a consequence of downward moving chromospheric condensation, however this may not be responsible for the red asymmetry at K_1 because it is formed lower in the atmosphere than the condensation appears. The

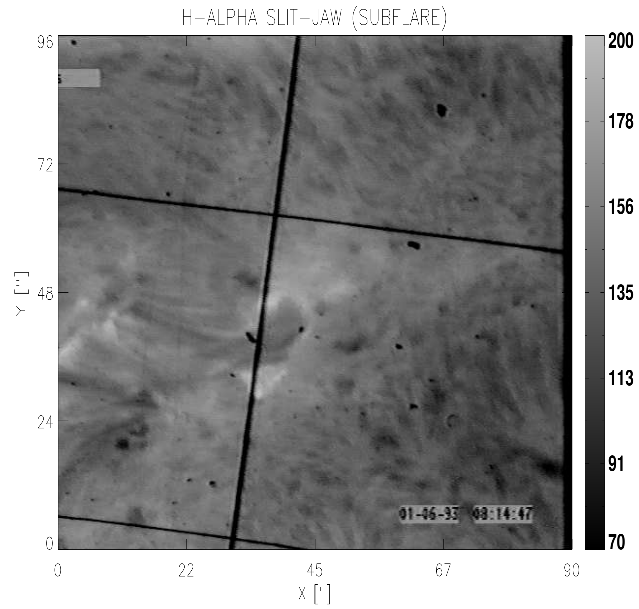

Figure 1. The slit-jaw image of the observed area on solar disc in H_α line. The lower core of the flare within the positions approx. 24" - 40" in y-direction was investigated.

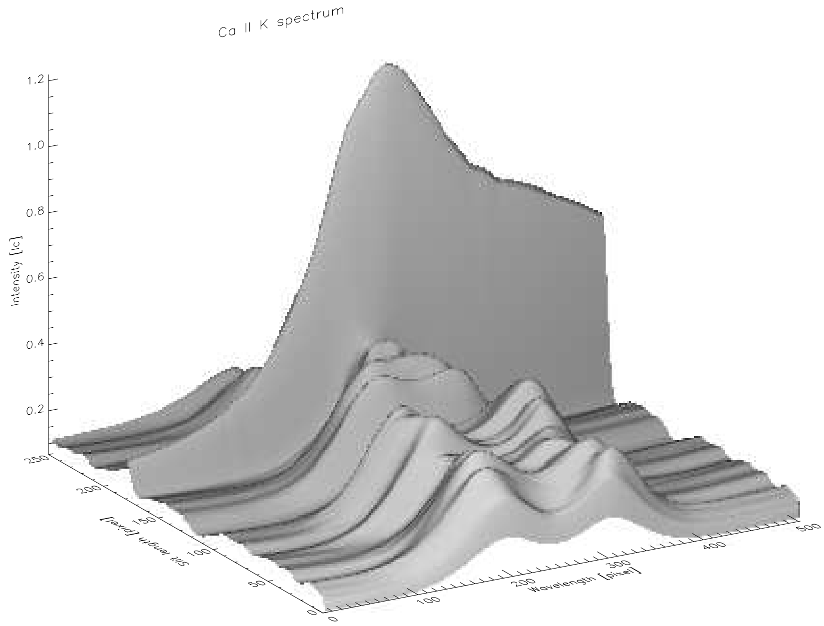

Figure 2. The Ca II K spectrum at the beginning of the time series observed. X, Y and Z axis represents the wavelength, the slit position and the intensity, respectively.

red asymmetry in K_1 wing can be interpreted as a downward moving plasma in temperature minimum region as well as a contracting plasma motion toward the temperature minimum region [2].
The aim of this work is to analyse for the first time not only the asymmetry itself but also the dynamic coupling of the flaring solar chromosphere and photosphere using the high resolution spectra of the Ca II K line and the Fe I lines.

2. OBSERVATIONS AND DATA REDUCTION

The spectra were taken with the Vacuum Tower Telescope (VTT) at the Observatório del Teide, Tenerife, on June 1, 1993. The parameters of the observed spectral lines are given in [4]. For this work we have selected 12 sets of flare spectra (three spectral lines in each) taken at the same position near the disc center in time interval of 08:12:30 UT - 08:14:46 UT. The H_α slit-jaw image of the observed region is shown in Fig.1. The resolution in spatial direction is 0.17" per pixel. The dispersion in wavelength direction for Fe I 522.5 nm, Fe I 557.6 nm and Ca II K 393.3 nm is 3.67, 3.48 and 2.58 mÅ/pixel, respectively. The width of the spectrograph slit was 150 μm.
The reduction process we applied on the spectra was described in [4]. An example of the 3D intensity representation of the observed Ca II K spectrum is shown in Fig. 2.

3. SPECTRAL CHARACTERISTICS AND CORRELATIONS

We have determined the following spectral characteristics of the observed lines: for both Fe I lines the velocities computed from the mean bisectors shifts were calculated. Mean bisector was computed as a mean value of the positions of 30 bisectors in line core up to the 75% of the line depth measured from the line minimum. The asymmetry A of the Ca II K line profile was defined as follows:

$$A = 2 * \frac{\int_{\lambda_1}^{\lambda_0} I_\lambda d\lambda - \int_{\lambda_0}^{\lambda_2} I_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} I_\lambda d\lambda}$$

where the λ_0=393.3 nm is the reference center determined from the flat-field spectrum, the λ_1=393.24 nm and λ_2=393.36 nm. The definition is taken from [3] where the integral boundaries are given by K_1 positions, but because the absence of K_1 minimum in many scans, we integrate through the given interval ±0.64 Å around the reference center.
In each spectrum 250 spectral scans were selected, for which the spectral characteristics were evaluated. The flare atmosphere is located within scans 170-210. The correlation coefficients were calculated for couples of Ca II K asymmetry - Fe I mean bisectors for both Fe I lines for all 12 sets of spectra. First we computed the correlation for the first pairs of the time series. Maximal correlation coefficient was found in this case with the spatial lag of 8 pixels (1.36"). This spatial lag was used for all subsequent pairs of the

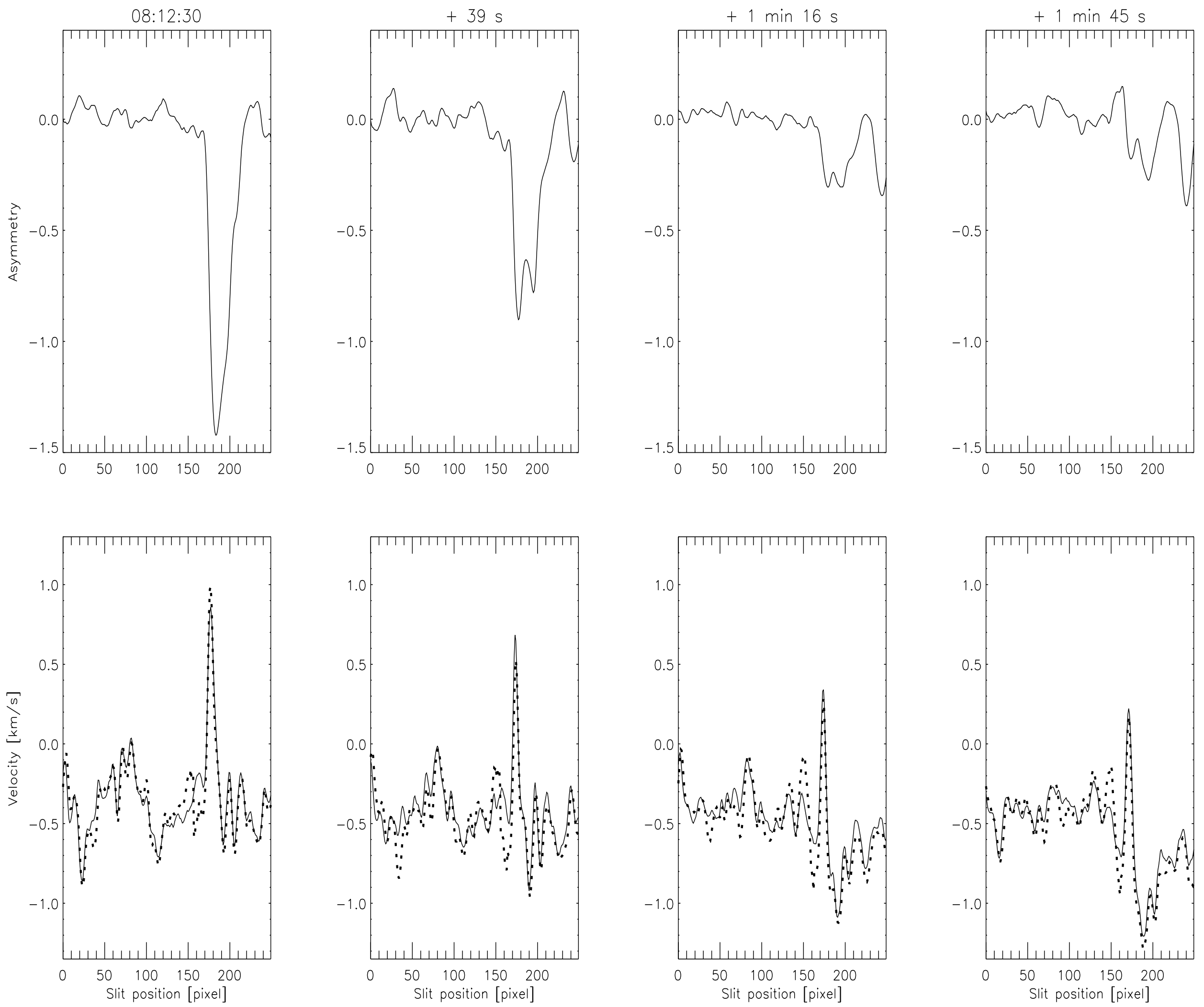

Figure 3. Temporal evolution of spectral characteristics along the slit. Upper row shows four samples of the time evolution of the Ca II K line asymmetry, negative values signify the red asymmetry. Bottom row show velocities determined from the mean bisector positions. Solid and dotted lines stand for Fe I 557.6 nm and Fe I 522.5 nm line, respectively. The downward velocity is prescribed as being positive.

time series.

4. RESULTS AND DISCUSSION

The temporal evolution of the spectral characteristics for the representative sample of the observations is shown in Fig. 3. The observations show that for the flaring atmosphere the red asymmetry in chromospheric Ca II K line is a typical feature. The definition of the asymmetry was independent of the double reversal presence, so it includes both the shift of the emission peak as well as the different intensities of the wings. It is evident from Fig. 3 (upper panel), that the maximal asymmetry appears at the beginning of the observation, when the flare was most energetic. During the relaxing phase the asymmetry decreases, but is still evident after the time delay of more than 2 minutes. This red asymmetry could be caused by the down-flow of the chromospheric material toward the photosphere and/or by the energy flow to the photosphere. To distinguish between the transfer of mass and transport of the energy we used the Fe I lines bisectors. Computed resulting mean bisector suggests that there is a downward moving plasma in the photosphere under the flare. This is evident from the velocity changes appeared at flare positions (Fig. 3, lower panels). The whole undisturbed photosphere is moving upward with velocity of about 0.5 km/s. This velocity could be atributed to the 5 minutes oscilations, for which the spectra were not corrected. But there is strong downward motion at the positions where the flare occurred (slit positions 170 - 190 pixels). These downward motions slow down with time but new upward moving event starts to be remarkable (pixel 190) in the end of the time series. This motion of -0.5 km/s we interpret as a 'repulsion' of the surrounding damped photosphere in the flare region. The velocities have the same course for both the magnetic and non-magnetic Fe I lines except the small region around the pixel of

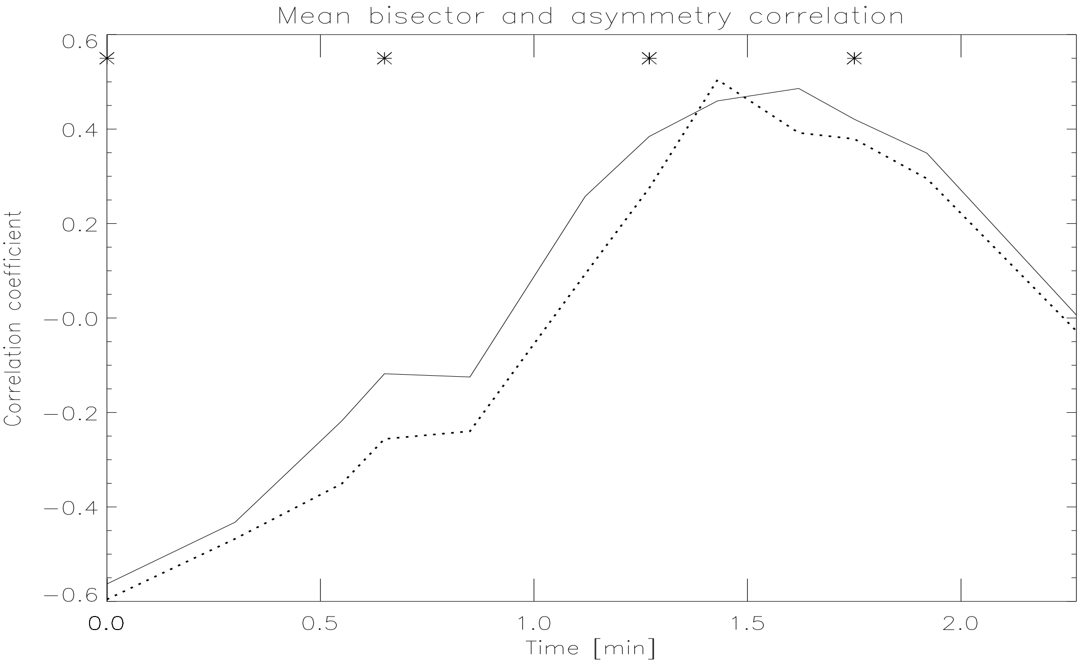

Figure 4. The correlation coefficients of Ca II K asymmetry and mean bisector of Fe I lines for all 12 spectra in the time series. Solid and dotted lines stand for Fe I 557.6 nm and Fe I 522.5 nm, respectively. The moments of the time series for which the samples are shown in Fig. 3 are designated here by the asterisks.

160, where small pore has taken place and its magnetic field affected the shape of the Fe I 522.5 nm line profile. Thus the shift of the mean bisector reflects not only the motions but also the influence of the magnetic field in this case.

The correlations of the Ca II K asymmetry and Fe I mean bisectors positions were calculated with the spatial lag of 8 pixels (1.36"). This lag was due to the different projection of the event from the photosphere and from the chromosphere on the slit. This we interpreted so, that the mass and the energy from the subflare was pushed not directly down to the photosphere, but it was incurved.

The correlation coefficients are plotted in Fig. 4 as a function of time. It is evident, that at the beginning of the time series the anticorrelation is high ($\sim 60\%$). This means that the motions in the chromosphere and photosphere have the same down-ward direction (according to definitions). Later the anticorrelation decrease, which could be caused by the fact, that the motions in one layer become slower than in another. As Fig. 3 shows, the asymmetry decrease while the down-ward velocity in the photosphere remains still strong. After the $\sim$1.4 minute from the beginning of observation the correlation coefficient becomes strongly positive, which is due to the change of motion direction in photosphere or chromosphere. According to the Fig. 3 (lower row, right) it is caused by the appearence of the upward moving event from the 'repulsion' of the photosphere.

The turbulent behavior of the 'flaring' photosphere using the FWHMs of the Fe I lines estimated for the slit positions corresponding to the subflare position will be examined in the next paper.

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