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# High-resolution spectroscopy of a chromospheric subflare: Ca II K line measurement(*)

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**Summary.** — An investigation of the quiet and active (subflare) solar atmosphere is made using high spatial and spectral resolution observations of the Ca II K line performed at the VTT, Observatorio del Teide, Tenerife. Spectral characteristics $I_{\mathrm{K1}}$, $I_{\mathrm{K2}}$, $I_{\mathrm{K3}}$, integrated intensity $I_{\mathrm{int}}$, separations of K1 minima $\mathrm{Sep}_{\mathrm{K1}}$, separations of K2 maxima $\mathrm{Sep}_{\mathrm{K2}}$ and their ratios are compared for both quiet and active regions. Preliminary results are discussed.

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## 1. – Introduction

Solar Ca II K line spectra observed with high spatial and spectral resolution belong to important tools for diagnostics of the physical conditions in the solar photosphere and chromosphere. The Ca II K line maps both, the upper photosphere (K1 wing) and the chromosphere (K2 peaks, K3 core). Only several statistical works have been made up to now using high spatial and spectral resolution observations of Ca II K line (see, for example, [1-4]). These studies were oriented mainly to the investigation of plages. Theoretical calculations of the models of the solar chromosphere and photosphere frequently utilize the Ca II K line observations as a proof of the validity of the theoretical

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TABLE I. – *Spectra characteristics.*

Spectral line

| line | wavelength (nm) | eqv. width (mÅ) | multiplet | excit. pot. (eV) | Landé factor $g_{\text{eff}}$ |
|---|---|---|---|---|---|
| Ca II K | 393.3 | 20253 | 1 | 3.2 | 1.17 |

Spectra regions

| line (nm) | time (UT) | exposure time (s) | location on the disk $\mu$ | activity |
|---|---|---|---|---|
| 393.3 | 08:01:01 | 2.0 | $\mu = 1$ | quiet region |
| 393.3 | 08:12:48 | 2.0 | $1 > \mu > 0.97$ | subflare |

Dispersion of the spectral region

| line | dispersion per 1 pixel ($10^{-3}$ nm) | dispersion per 1 mm ($10^{-3}$ nm) |
|---|---|---|
| Ca II K 393.3 | 0.2578 | 6.78 |

results. Therefore, any high-quality observation of different solar activity levels using Ca II K line plays an important role in the solar atmosphere investigation.

This contribution is a part of the long-term project investigation of the dynamic parameters of the solar atmosphere in different levels of solar activity performed at VTT, Observatorio del Teide, Tenerife. In this work the Ca II K line spectra observed in a subflare, plage and quiet region are presented.

## 2. – Observations

The data were taken on Vacuum Tower Telescope (VTT) at Observatório del Teide, Tenerife, on June 1, 1993 [5]. More than 1000 spectra of the Ca II K were taken including the calibration spectra for flat-fielding. The relevant parameters of the observed spectral line are given in table I.

For this work we have selected one Ca II K spectrum of a subflare. The spectrum was recorded with a CCD $1024 \times 1024$ pixel camera using a binning of 2. Thus the resulted spectrum was $512 \times 512$ pixels. So, in spatial direction one pixel corresponds to $0.17''$ but real spatial resolution of $\sim 1''$ was estimated using the intensity fluctuations of the continuum near Fe I 557.6 nm line along the slit. The Fe I 557.6 nm line spectrum was taken simultaneously with the Ca II K line. The dispersion in wavelength direction is given in table I. The width of the spectrograph slit was 150 $\mu$m. Simultaneous slit-jaw images in Ca II K and $H_\alpha$ lines were recorded on video tape. In fig. 1 we give an example of the $H_\alpha$ and Ca II K slit-jaw images. The Ca II K spectrum as well as its 3D representation are shown in fig. 2.

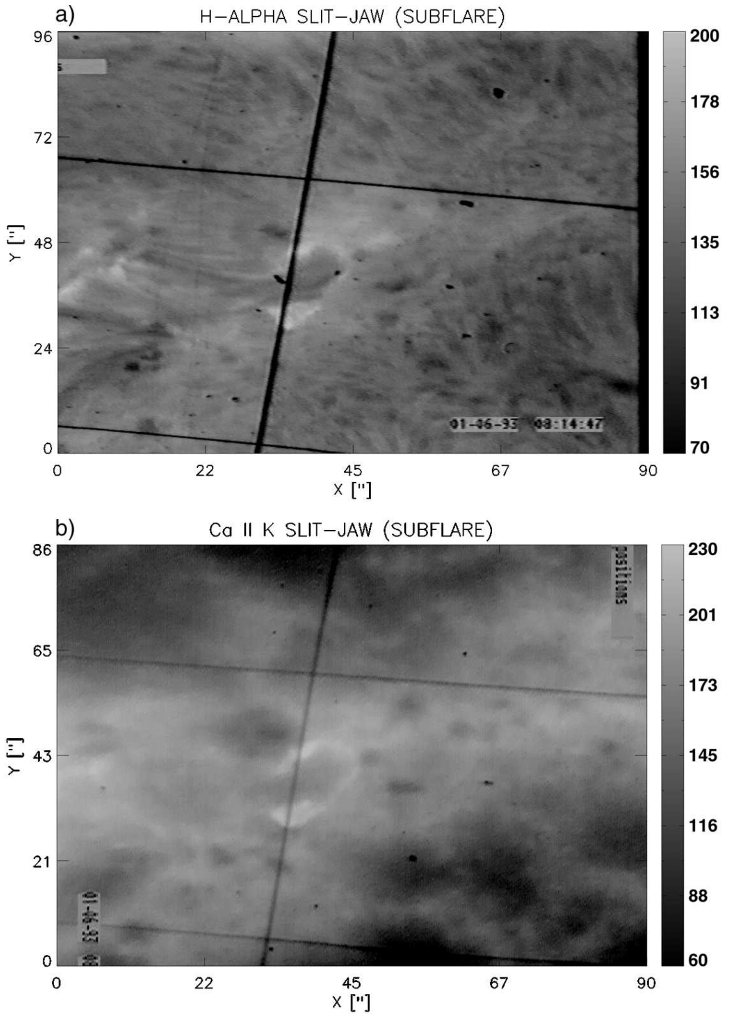


Fig. 1. – The slit-jaw images of the observed subflare region. H-alpha image (top) and Ca II K image (bottom). The intensities are expressed in arbitrary units.

## 3. – Data reduction

The data were reduced using IDL software including the KIS LIB (the Kiepenheuer-Institut für Sonnenphysik IDL library). Standard procedure of dark current subtraction, precise flat-fielding procedure (see [6]) and FFT profiles restoration were applied in the reduction process. The final spectrum consisted of 402 scans (rows). Two high intensive cores of the subflare and large parts of the surrounding plage are remarkable in the spectrum (see fig. 2). Before applying the spectral characteristics calculations we have artificially replaced the first bottom scan by the "quiet scan" which was defined as an average of all 402 scans of the quiet spectrum (see the first point in fig. 3).

For our analysis we calculated the following spectral characteristics:

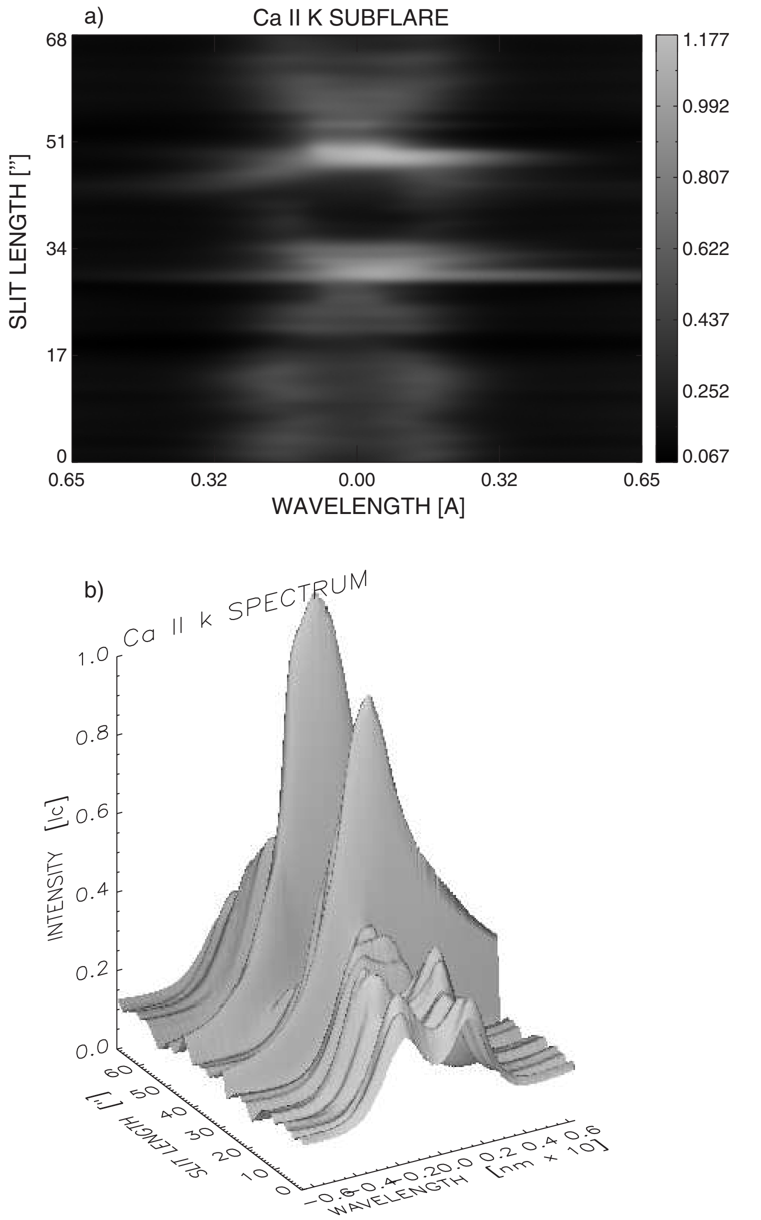


Fig. 2. – The Ca II K spectrum of the subflare region (a) and its 3D representation (b). The intensities are expressed in continuum intensity units.

$I_{\mathrm{K3}}$—central Ca II K intensity;

$I_{\mathrm{K2}}$—average of left and right Ca II K2 peaks intensity;

$I_{\mathrm{K1}}$—average of left and right Ca II K1 minima intensity;

$I_{\mathrm{int}}$—integrated Ca II K intensity within $\pm 0.5$ Å around the line center;

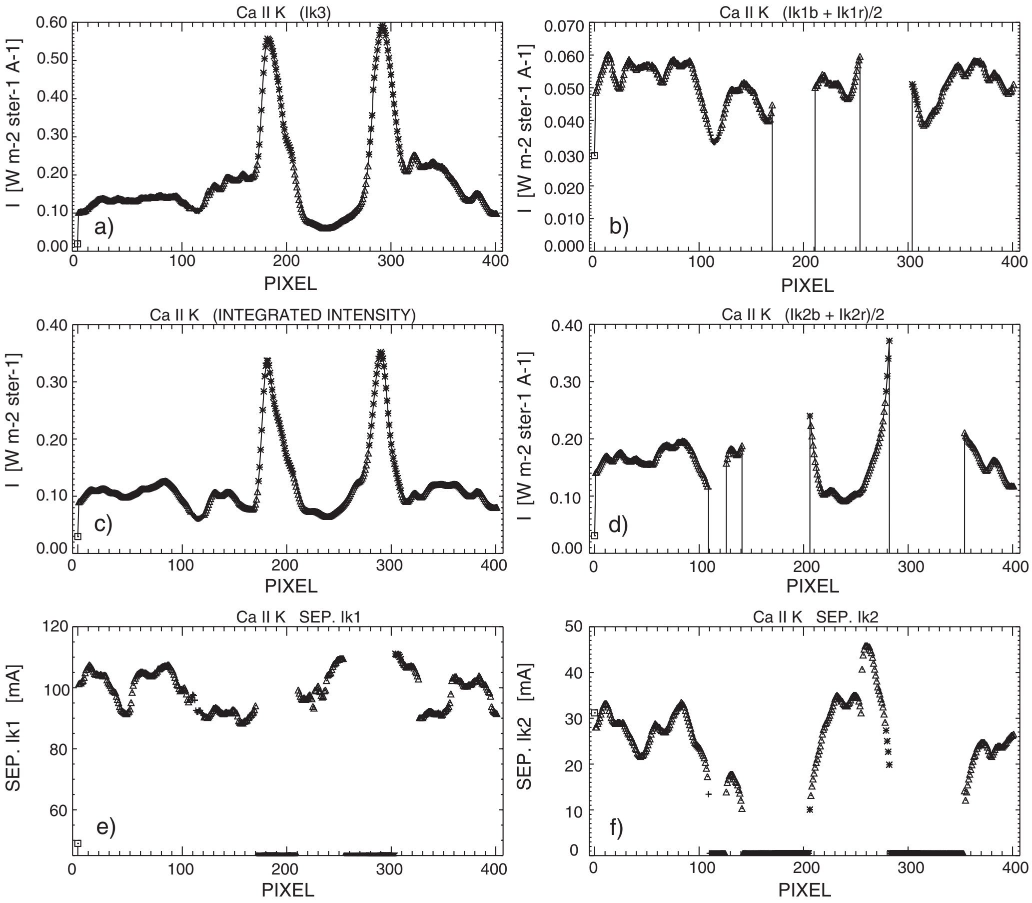


Fig. 3. – Ca II K spectral line characteristics fluctuations along the spectrograph slit. Symbols: "square" for quiet region, "triangle" for plage, "stars" for subflare and "plus" for small pore.

$\mathrm{Sep}_{\mathrm{K1}}$—separation of the K1 minima (mÅ);

$\mathrm{Sep}_{\mathrm{K2}}$—separation of the K2 maxima (mÅ).

A "quasi-calibration" of the spectra to the $I_{c4000}$ was made using the ratio of the $I_{c4000}/I_{\mathrm{K3}}$ for quiet-Sun disk center taken from the Liege Atlas [7]. Then the intensities were re-calculated to the absolute intensities using the results of [8, 9].

First, we have estimated the fluctuations of all characteristics along the spectrograph slit. The results are shown in fig. 3. We use for all figures identical symbols: "square" for quiet region, "triangle" for plage, "stars" for subflare and "plus" for the small pore which appeared also in the spectrum. As one can see, some of the characteristics are missing in some panels. This is caused by two reasons:

1) the particular value really does not exist in the particular scan due to the physical conditions of the solar plasma.

2) The particular value exists, but it is placed out of the frame due to the limited size of the CCD chip.

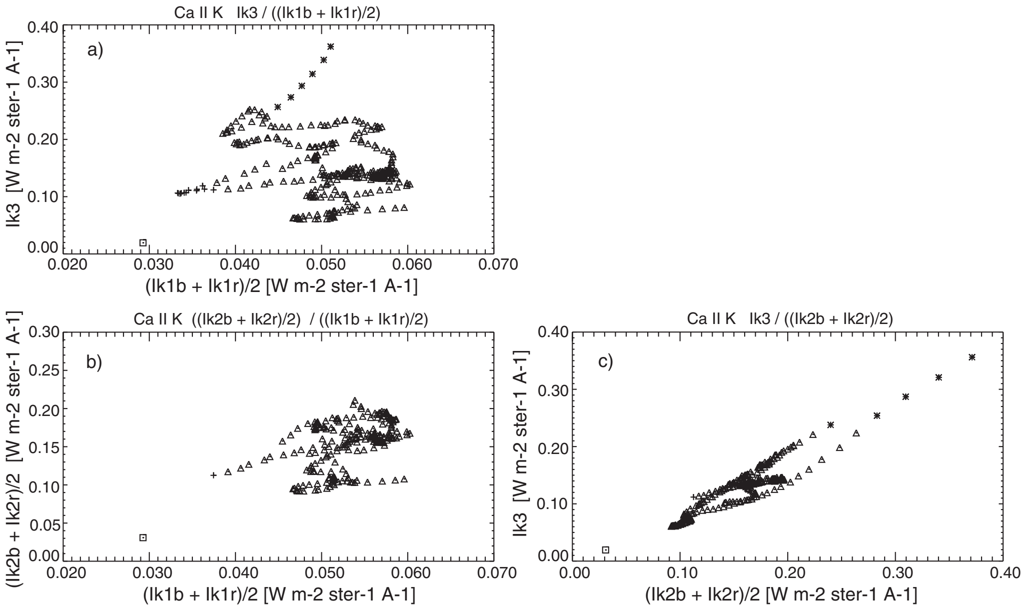


Fig. 4. – The Ca II K line center intensities ratios $I_{K3}/I_{K1}$, $I_{K3}/I_{K2}$ and $I_{K2}/I_{K1}$. Symbols: "square" for quiet region, "triangle" for plage, "stars" for subflare and "plus" for small pore.

In both cases we have artificially set such characteristics to arbitrary value and they are placed at the $x$-axis or below it.

The ratios of the $I_{K3}/I_{K1}$, $I_{K3}/I_{K2}$ and $I_{K2}/I_{K1}$ are represented in fig. 4.

## 4. – Results and conclusions

Using the high spectral and spatial resolution spectrum of the Ca II K line, we have found that the integrated intensity (± 0.5 Å from the line center) of the plage in the subflare region has typical values of about 0.1 $\mathrm{Wm^{-2}sterad^{-1}}$, the small pore exhibits value of 0.06 $\mathrm{Wm^{-2}sterad^{-1}}$ and the quiet region has 0.03 $\mathrm{Wm^{-2}sterad^{-1}}$. Both subflare peaks reached maximum at 0.36 $\mathrm{Wm^{-2}sterad^{-1}}$ what is about 10 times more compared to the quiet chromosphere.

The $I_{K3}$ intensities of the plageous atmosphere near the subflare surrounding reach higher values compared to the plage out of the subflare. No such intensity redistribution has been found in the integrated intensity.

Concerning the $I_{K2}$ intensities, also very high subflare emission peaks still exhibit the $I_{K2}$ reversals of intensity up to 0.37 $\mathrm{Wm^{-2}sterad^{-1}Å^{-1}}$ valid for $I_{K2}$ maxima. An extended region without $I_{K2}$ peaks was found in the cores of the subflare as well as in the surrounding of the hotter plage. The maximum of the $I_{K2}$ separation (0.46 mÅ) appeared in between the two subflare cores.

The $I_{K1}$ have values of 0.029, 0.034 and 0.057 $\mathrm{Wm^{-2}sterad^{-1}}$ $\mathrm{Å^{-1}}$ for quiet region, pore and plage placed far away from the subflare, respectively. On the contrary, the $I_{K1}$ decrease in the profiles which are very close to the subflare. It was impossible to measure the $I_{K1}$ as well as K1 separations in the profiles of the subflare cores because the very intensive $I_{K1}$ were shifted out of the CCD chip.

The line intensity ratios reflect the coupling of the atmospheric layers in the solar atmosphere in which the particular parts of the Ca II K profile are formed. The $I_{\mathrm{K3}}/I_{\mathrm{K2}}$ ratio exhibits an almost linear trend with two "chains" of data. Still fairly linearly behaves the $I_{\mathrm{K2}}/I_{\mathrm{K1}}$ ratio, but the scatter of the data is much extended compared to the previous case. No coupling of the $I_{\mathrm{K3}}$ and $I_{\mathrm{K1}}$ was found, as expected.

Further, more detail analysis separately for blue and red parts of the Ca II K line wings and more extended observational material is in preparation to test the preliminary results determined from only one spectrum of the subflare region. Comparison of the results with the theoretical calculations is also in preparation.

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REFERENCES

[1] SMITH E. VAN P., *Astrophys. J.*, **132** (1960) 202
[2] GROSSMAN-DOERTH U., KNEER F. and UEXKÜLL M. V, *Solar Phys.*, **37** (1974) 85.
[3] BOCCHIALINI K. and VIAL J.-C., *Astron.Astrophys.*, **287** (1994) 233.
[4] LEMAIRE P., *Solar Phys.*, **88** (1983) 31L.
[5] SCHRÖTER E. H., SOLTAU D. and WIEHR E., *Vistas in Astronomy*, **28** (1985) 519.
[6] KUČERA A., HANSLMEIER A., RYBÁK J. and WÖHL H., this issue, p. 703.
[7] DELBOULLIE L., ROLAND G. and NEVEN L., in *Photometric Atlas of the Solar Spectrum from 3000 to 10000* (Institut d'Astrophysique Liége) 1973.
[8] NECKEL H. and LABS D.,, *Solar Phys.*, **90** (1984) 205.
[9] NECKEL H. and LABS D.,, *Solar Phys.*, **95** (1985) 229.