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Spectropolarimetric Investigation of $H\alpha$ Line Profiles in Moustaches

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Abstract. In spite of the many existing investigations on the phenomenon of solar moustaches, their excitation mechanism is still unclear. Nowadays, there are thermal and non-thermal models. If the moustaches have a thermal origin the $H\alpha$ line polarization would be about 2–3%, both in the line core and in the wings. And there is a large possibility that they will show a center-to-limb variation of the $H\alpha$ line profiles. Moustaches arising from the result of bombardment by energetic particle beams will show a polarization observed in the $H\alpha$ line core only.

This work is devoted to spectropolarimetric investigations of a large number of moustaches in the $H\alpha$ line. We tried to reveal the presence or absence of the different mechanisms using the observed Stokes parameters. We also made an attempt to analyze correlations between the distances from the solar disk centre, the lifetimes and the form of the $H\alpha$ line profiles obtained for moustaches, which show the different types of polarization.

1. Introduction

Moustaches or Ellerman bomb (EB) are shortly living emission features in the wings of strong chromospheric absorption lines sized from 5″ down to the size the diffraction limit of modern (1-meter class) solar telescopes. The morphology, evolution and dynamics have been investigated rather extensively (Severny 1965; Bruzek 1972; Koval 1972; Kurokava et al. 1982; Payne 1993). Nevertheless, their excitation mechanisms are still unclear. Nowadays, several mechanisms for the explanation of the EB phenomenon are suggested. Diver et al (1996) proposed a Kelvin–Helmholtz instability mechanism of a laminar flow along horizontal magnetic fields to explain the phenomena. A further point of view implies a bombardment of the chromosphere by beams of energetic particles (Ding et al. 1998; Henoux et al. 1998). This model attracts the attention by explaining both the brightness of moustaches and the linear polarization observed in them.

Observational results from several authors allow to argue on the existence of different mechanisms for moustaches. Nindos & Zirin (1998) performed simultaneous analyses of Hα line filtergrams and magnetic field maps and extracted two types of the observed moustaches. The class I moustaches (about 64 %) don't correspond to moving features of the magnetic field (MFMF). For all the other moustaches the association with MFMF was revealed. It should be noted

that the size, lifetime and the brightness in moustaches of both classes were similar. Qiu et al. (2000) compared the filtergrams in the blue wing of Hα and UV continuum observations in 1600Å regions. They supposed that resources exciting different moustaches could located in the different lays of the Sun. As the most possible locations for the some of observed moustaches they considered the photosphere and the temperature minimum region.

On the other hand, according to the calculations of Zharkova & Syniavskii (2000) in the case of chromosphere bombardment the by electron beams in the solar flare will show a linear polarization in the range of 2–25% only in the Hα line core. The wings will be fully depolarized by thermal collisions. In the absence of electron beams, the linear polarization is determined by an external chromospheric radiation and it reaches a value of about 2–3%.

Therefore, spectropolarimetric observations of moustaches could make an important contribution to clarify the mechanism of their arising and evolution. However, polarization investigations of moustaches were carried out not so actively as investigation of their structure and motions. In addition, the data of different authors are often inconsistent. Babin & Koval (1985, 1986, 1987, 1988) found that the linear polarization is about 3–10% in the wings of moustaches. Firstova (1986) declared that, according to the her data, the polarization was observed in the line center, and did not exceed 7%. On the basis of the obtained results, an impact polarization mechanism was suggested as the mechanism for the observed polarization. She also showed that the polarization in line wings could be caused by instrumental effects. Rust & Keil (1992) obtained that polarization did not exceed 8% for thirty-two investigated moustaches.

The purpose of this paper is to investigate the profiles of Stokes parameters in moustaches in order to try to reveal features caused by the different mechanisms of their origin.

2. Observations and data processing

In the Summer of 1999, a program of spectropolarimetric observations of moustaches in the *Hα* hydrogen line was carried out at the Large Solar Vacuum Telescope (Skomorovsky & Firstova 1996). The method of observation and processing, basic parameters of the instruments and observations are described in detail in Kashapova (2002). The images of the moustaches spectra are presented in Fig. 1 as an illustration. It is known that moustaches are very sensitive to seeing conditions. During the observations, the image quality varied from 0.5 to 1.2 arcsec, and the relatively short exposure time (0.05 and 0.1 sec) helped to minimize the image tremor. The normalization of the Hα line profiles to the continuum in each strip minimizes the instrumental polarization influence (Firstova 1986) essentially. The results could be seen on the examples of the Stokes parameter profiles of moustaches and quit region below (Figs. 2-3).

3. Results

Spectrograms of 164 moustaches were processed. The number of frames varied from a singe frame up to 99 frames, the corresponding time of observation varied

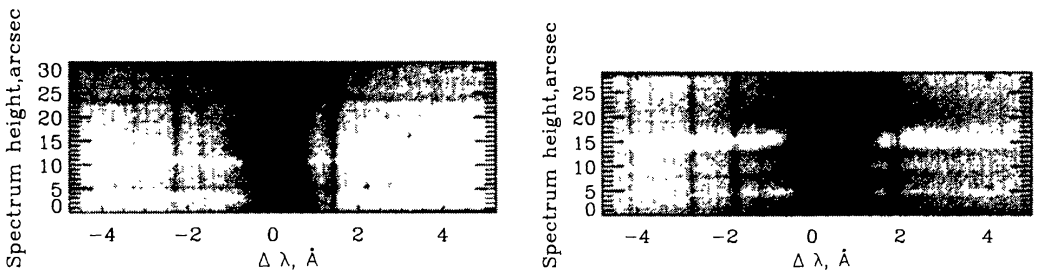

Figure 1. An example of spectrograms of moustaches obtained in the Summer of 1999 with the Large Solar Vacuum Telescope.

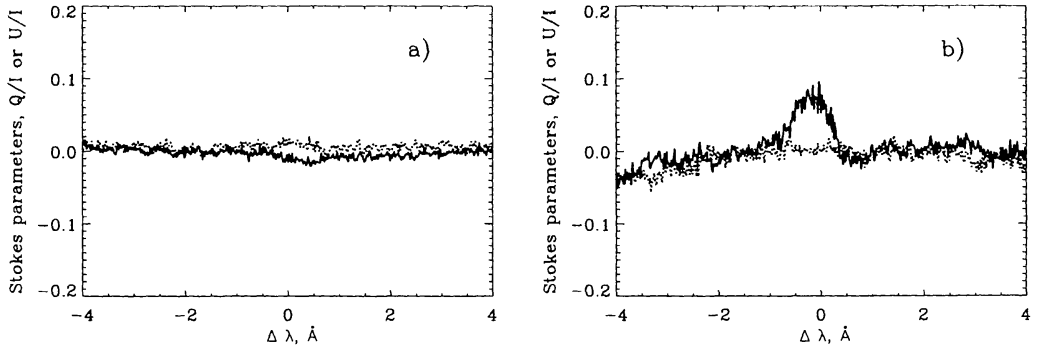

Figure 2. A variation of Stokes parameter along the dispersion for Ellerman bombs with polarization: a) – less than 3%; b) – more than 3%. Solid and dotted lines corresponds to moustaches and quiet region, respectively.

from few seconds to about 40 minutes. The locations of the observed moustaches were distributed from the limb to the solar disk center ($cos(\theta) = [0.24, 0.96]$). Thus we could say that the investigated moustaches were representative enough from the point of statistics.

Investigation of the Stokes parameter profiles revealed that for 142 from 164 EB that polarization was less than 3%. An example of such profiles is shown at the Fig. 2a. It should be noted that about 40% of observed moustaches showed polarization less than 1% and of about 26% moustaches showed polarization value between 1% and 2%. We found that 22 moustaches display the polarization more than 3% in the Hα line center only. An example is shown at the Fig. 2b. This data agree with results reported by Firstova (1986), Firstova et al. (1999) and Kashapova (2002) and the most probable explanation for this group of EB could be a bombardment of the chromosphere by beams of energetic particles (Zharkova & Syniavskii 2000). However, because of the accuracy of polarization measurement($\sim$ 0.5%) the amount of the impact polarization mechanism candidates should be reduced to about 8%.

A little shift of the profile in blue or red wing of Hα was detected in the Stokes parameter profile of several moustaches. The Fig. 3a shows an example of such a profile. Although the number of the blue shift events are a bit more then the number of the red shift events, it's difficult to make a conclusion about a preferred direction. For five of moustaches a polarization was revealed in

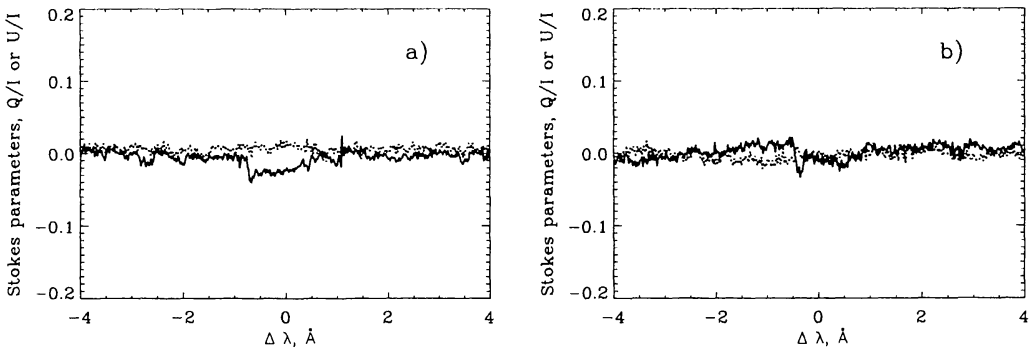

Figure 3. A variation of Stokes parameter along the dispersion for moustaches with polarization less than 3% and a) – a blue shift, b) – polarization in the wings. Solid and dotted lines corresponds to moustaches and quiet region, respectively.

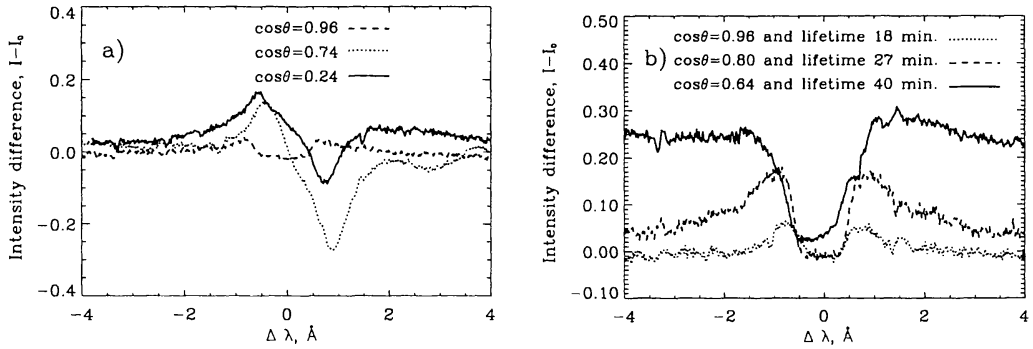

Figure 4. Profiles of intensity difference between the moustaches and corresponding quiet region at the different distance from the solar disk center: a) – polarization is less then 3% b) – polarization is higher then 3%.

the wings (Fig. 3b). This fact coincides with results of Babin & Koval (1985), however the percent of polarization is significantly lower as was reported by them.

Comparison of the profile shape of moustaches with polarization less 3% shows that the variation predicted by Kitai(1983) is applied to the main part of them (Fig. 4a). The center to limb variation for moustaches (probably arose by energetic particle beam bombardment) does not demonstrate a clear dependence on the disk location (Fig. 4b). This result agrees with the mechanism suggested by Ding et al. (1998) and Henoux et al. (1998). It's more possible that a dependence from the lifetime exists for these type of moustaches.

4. Conclusion

Spectropolarimertic investigation of 164 Ellerman bombs was carried out and it revealed the different mechanisms of their arising. The linear polarization was observed in the Hα line center and it exceeded 3% for 22 of processed Ellereman

bombs (13.4%). The most probable interpretation of the observed polarization in this group of moustaches is the impact polarization caused by the beams of energetic particles. The most part of the investigated Ellerman bombs (86.6%) showed the polarization less than 3%.

25 of investigated Ellerman bombs with polarization less than 3% showed a polarization in the wings of the Hα line and the shift to the red or blue region. It should be noted that 12 of the moustaches had a blue shift, 8 moustaches had a red shift and the polarization was observed in the both wings for 5 moustaches.

A comparison of the difference profiles of Ellerman bombs, probably arisen as the result of the energetic particles bombardment, shows that their form depends more on the lifetime than on the distance from the solar disk center. A comparison of the difference profile of the probably thermal origin moustaches shows the limb to centre variation but not for all of moustaches with polarization less than 3%. The result is in agreement with results of theoretical investigations carried out for the different mechanism.

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Discussion

A. GANDORFER: You mentioned that the polarization in the wings could be an instrumental artifact. Do you see anything suspect in the 2-dim Q/I images?
L. KASHAPOVA: We carried out a linear polarization investigation with the help of 2-dim Q/I images for the several moustaches. This method showed the same results as processing by profiles.

J. STENFLO: The impact polarization observations are highly enigmatic, since we have done imaging polarimetry in $H\alpha$ with ZIMPOL at IRSOL in Locarno for a large number of flares, and have not found a single case with linear polarization exceeding a few times 10^{-3}.
L. KASHAPOVA: We are also observing flares with the Large Solar Vacuum Telescope with absence of linear polarization. You can apply statistical results to a number of the flares you have observed and then decide whether or not the detection probability of impact polarization agrees with your results. Of course it should also be taken into account the location on the solar disk and the lifetime of the flares.
J.C. HENOUX: In the three solar flares observed with THEMIS that we started to study in detail, impact polarization is observed in at least three lines $H\alpha$, $H\beta$, D_2. I know that for other flares M. Bianda did not detect polarization above 1%. The origin of this difference has to be found. We cannot say that impact polarization is not present in solar flares only because ZIMPOL II did not observed it.

J.C. HENOUX: The orientation of impact linear polarization bring information on the nature of the particles. Did you determine it?
L. KASHAPOVA: Yes, we tried to estimate the sort of exciting particles for several long-living moustaches. The azimuth of the polarization plane was near to the tangential direction. So the most probable candidates are electrons. Of course it's true if we accept that magnetic field lines are perpendicular to the solar surface.

V. ZHARKOVA: What do you think, does the number of higher polarization in moustaches indicate low percentage of beam of electrons precipitating to the lower chromosphere where $H\alpha$-emission occurs?
L. KASHAPOVA: It's a very realistic explanation of this statistical result.