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MULTI-WAVELENGTH ANALYSIS OF ELLERMAN BOMB LIGHT CURVES

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Abstract. We present the results of a multi-wavelength photometric analysis of Ellerman Bomb (EB) observations obtained from the Dutch Open Telescope. In our data we have found 6 EBs located in the super-penumbra of the main spot in the active region NOAA 10781. We present light curves of EB observed in the Hα line centre and wing +0.7 Å, in the Ca II H line centre and wing +2.35 Å, in the G-band and in the TRACE 1600 Å filter. We have shown that EBs were visible in the G-band and moreover, there was a good correlation between the light curves in the G-band and in the Hα line wings. We also found quasi-periodic oscillations of EBs brightness in the G-band, CaII H line and TRACE 1600 Å filter.

Key words: Sun - chromosphere - Ellerman bomb

1. Introduction

Ellerman Bombs (EBs), also known as moustaches, are small short-lived structures observed mainly as emission features in the Hα line wings but they are also seen in the calcium CaII H line as well as in the UV 1600 Å continuum. For the first time EBs were described by Ellerman (1917). The life-time of EBs is generally estimated to be about 15 minutes (Roy and Leparskas, 1973), but there are also observations of EBs lasting for more than one hour (Herlender and Berlicki, 2010). The light curves of those EBs which were observed for more than 20 minutes consist of few pulses or only one maximum with some brightness oscillations. The line profiles of EBs in the Hα and Ca II H lines (Fang *et al.*, 2006; Pariat *et al.*, 2007), suggest that the whole region of EB is warmer in comparison to a quiescent solar atmosphere and that the heating is significant in layers where the Hα line wings are formed. Magnetohydrodynamic simulations (Archontis and Hood, 2009) shows that EBs could be the result of the reconnection during the emergence of a new magnetic flux, if only such reconnection happened at a proper height in the solar atmosphere.

We present the results of a multi-wavelengths analysis of the time evolution of EBs light curves. In our analysis we used the data from the Dutch Open Telescope (DOT) and from TRACE. The work we present here is based on the data set obtained on June 30, 2005. We detected EBs in G-band images and we found oscillations of the EB brightness in G-band light curves. We also determined the cross-correlation function for the EB light curves at different wavelengths and found that there is a good time correlation between EBs brightness in the G-band and Hα line wings, and between G-band and CaII line light curves. We found the EB for which the maximum brightness at TRACE 1600 Å is delayed relative to the Hα brightness maximum.

2. Observations

In our analysis we used the observations of the active region (AR) NOAA 10781 obtained on June 30, 2005. At that time the AR was located at N15 E39 and consisted of one big spot with positive magnetic field polarity. The main spot was followed by some small pores (Figure 1). In the Hα line centre images it is well visible that the spot was surrounded by penumbral and super-penumbral filaments. There were some brightenings at the ends of those filaments.

The images we used in the Hα line centre and wings Hα+0.7, Hα-0.7 Å, CaII H line centre and +2.35 Å wing, G-band were recorded by the DOT during the time from 08:45 to 09:38 UT with a cadence of 30 seconds. We also use TRACE UV 1600 Å continuum observations from 08:20 to 09:25 UT with a cadence of 30 seconds. All together, we obtained 110 images per filter from DOT except CaII H were we got 55 pictures with 60 seconds interval, and 138 images from TRACE.

3. Data Processing

All images were coaligned by fitting sunspot and pores locations, requiring adjustment of pixel offset, size and orientation. This procedure was especially important for the TRACE data set. After the coalignment all pictures were cropped in order to cover the same part of the Sun. As the next step we chose bright points from images at Hα+0.7 Å and Hα-0.7 Å and plot light curves for all available wavelengths. As a single point of the light curve we

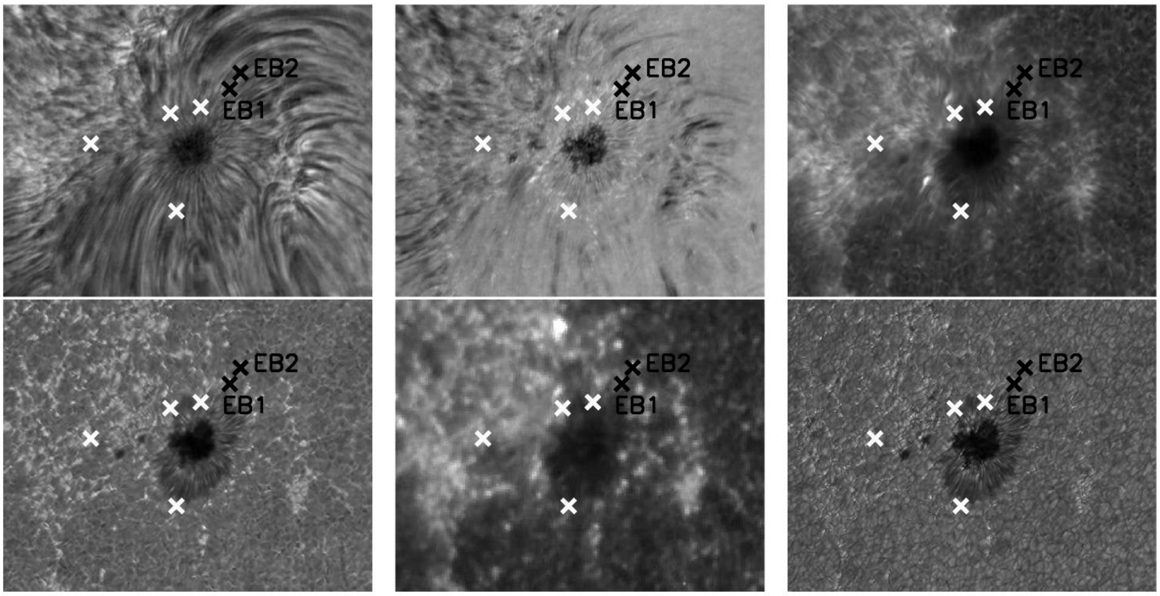

Figure 1: The AR 0781 at 09:12 UT. Upper left: Hα line centre, upper centre: Hα-0.7 Å, upper right: CaII H line centre, lower left: CaII H +2.35 Å, lower centre: TRACE 1600 Å and lower right: G-band; crosses mark positions of EBs, black crosses mark EBs for which we present light curves.

take the mean value of the signal in a square box of the size 9×9 pixels, which correspond to $1''.3 \times 1''.3$. If the brightening was visible in the wings, but not in centre of the Hα line, we classify it as EB. If it was visible in the line wings and in the line centre we classify it as flare-like event (FL). In order to obtain an equal number of data points (110) for all data sets we applied interpolation using splines. This was important for CaII H data, where we got less observing points, and for TRACE, where we obtained 138 images. Finally, for each event we completed cross correlation between light curves for all wavelengths pairs.

4. Light Curves

In Figure 2 there are exemplary light curves of EBs at different wavelengths. One can see that during the phase of maximum brightness of EB in the Hα-0.7 Å there are no, or almost no changes in the Hα line centre. For all EBs the lifetime obtained from the Hα-0.7 Å was shorter than 20 minutes and there were no significant oscillations of intensity in the Hα line wings. In the CaII H line EBs were visible both in the line centre and in the line wing and changes of brightness were generally well correlated. Oscillations

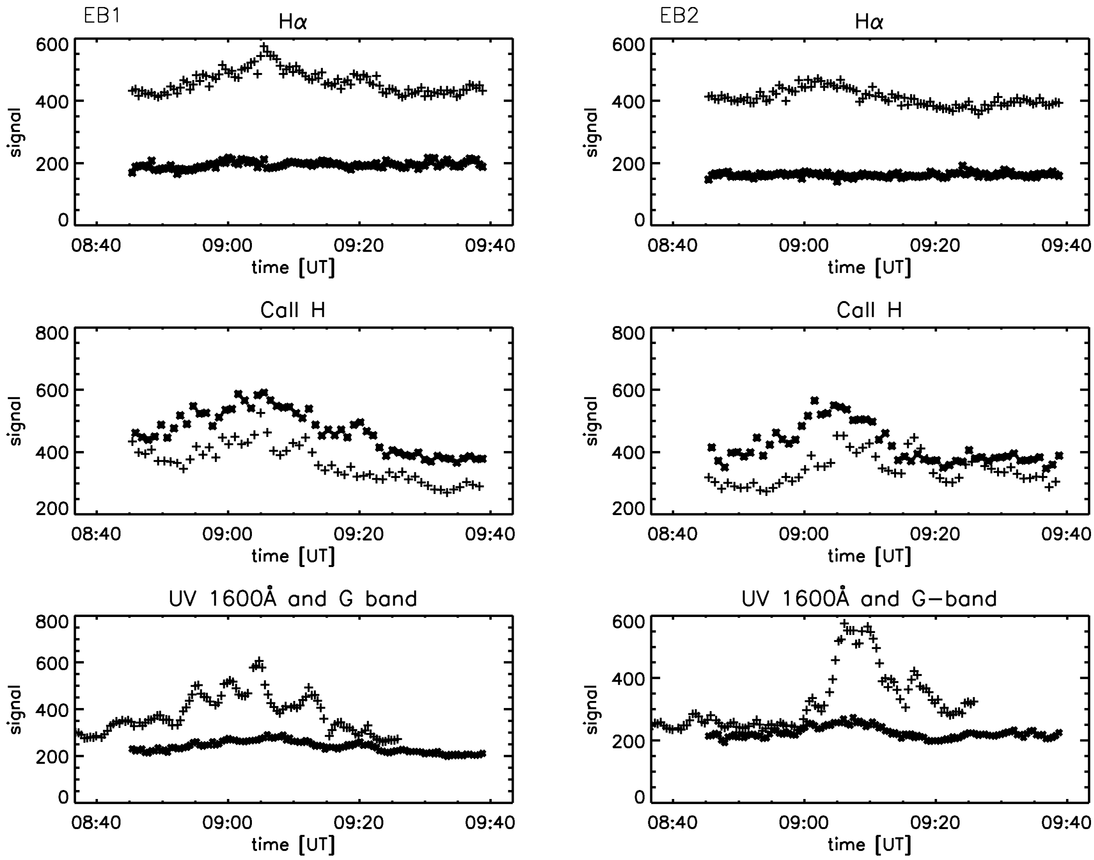

Figure 2: The light curves of the observed EBs. Upper panels: Hα+0.7 Å (+) and Hα line centre intensity (∗); central panel CaII H (+) and CaII+2.35 Å line intensity (∗); bottom panels: TRACE 1600 Å (+) and G-band (∗)

of EB brightness is clearly seen, although the calcium images had two times longer cadence than the Hα ones. EBs were also visible in TRACE 1600 Å and in G-band light curves. Although the excess of intensity in the G-band light curves was small there were visible oscillations of EBs brightness. For EB2 (Figure 2) the shift in time between light curves in the Hα-0.7 Å and TRACE 1600 Å UV is also visible. This time shift is about 5 minutes, while EBs are generally claimed to show no time shift between Hα line wings and TRACE 1600 Å UV continuum.

5. Correlations

Figure 3 shows plots of maximum cross-correlation function between light curves at different wavelengths for EBs and FLs. In most cases the maximum correlation was found for unshifted time sequences. It is obvious that the

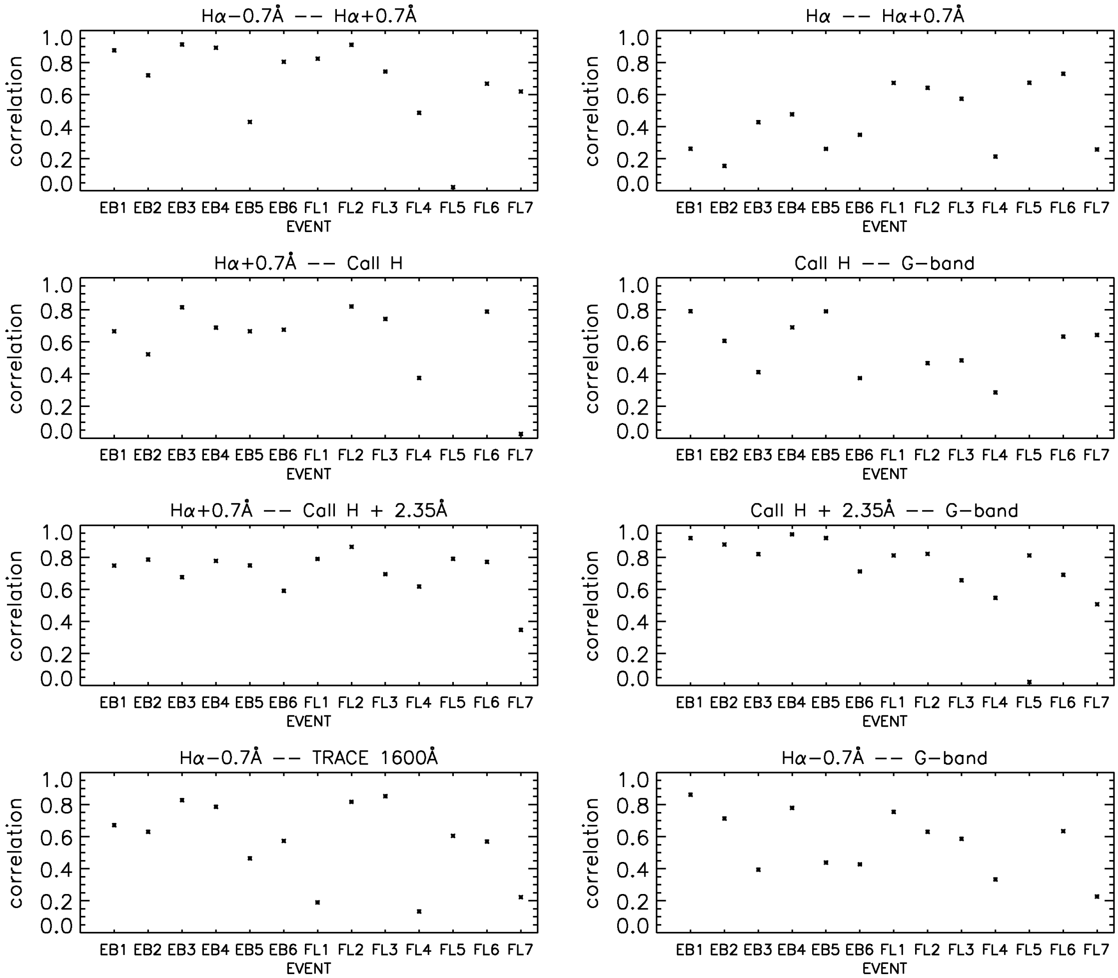

Figure 3: Plots of the of cross-correlations peaks between wavelengths pairs for all EBs and FLs events. In each plot the name of event is presented in X-axes, the y-axes show the value of the correlation.

correlation between light curves at Hα+0.7 Å and CaII H is generally higher for EBs than for FLs. A similar results holds for the correlations: Hα-0.7 Å with the G-band; Hα-0.7 Å with TRACE 1600 Å; CaII H with the G-band and CaII H + 2.35 Å with the G-band. In the case of correlations between the Hα-0.7 Å and CaII H line centre, Hα+0.7 Å and CaII H + 2.35 Å there are no evident differences between EBs and FLs. For the correlation between the Hα line centre and Hα line wings, the coefficient is generally higher for FLs but there are two FLs for which the maximum of the cross-correlation function was as low as for EBs. In Figure 3 it is also visible that the correlation between light curves at Hα +0.7 Å and $H\alpha$-0.7 Å is systematically lower for FLs than for EBs. This suggests that the variability of the Hα line asymmetry is greater for FLs, and therefore the emission from the blue and red wings of the Hα line should be less dependent from each other for FLs than for EBs.

6. Conclusions

In the observed active region we have found several bright points and six of them we classified as Ellerman bombs and seven as flare-like events. It was possible to observe EBs in G-band images and there were visible oscillations of EB brightness in these light curves. There were also a good correlations between brightness of EBs in: G-band and the Hα line wings; G-band and CaII H +2.35 Å wing and between G-band and CaII H line centre. For one EB we observed a five minutes time delay between the maximum brightness for the light curves of TRACE 1600A, CaII H line wing and G-band with respect to the light curve of the Ha line wing.

We observed quasi-periodic impulses of EB brightness which appeared within around four minutes time intervals. These pulses were visible in the CaII H line, TRACE 1600 Å and G-band, but not in the Hα line wing light curves. These impulses could by stimulated by p-mode oscillations (Chen and Priest, 2006).

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