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Ellerman bombs: small-scale brightenings in the photosphere

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Abstract. Observations of small-scale events in the solar atmosphere are limited by the spatial and temporal resolutions of the current crop of observational instruments. Both high-cadence and high-resolution observations of the photosphere have shown the continued dynamics to extremely small-scales. Ellerman bombs, brightening events in the wings of the Hα line profile, are one example of small-scale, short-lived events which have been widely studied due to their fast dynamics in recent years. By combining the Interferometric BIdimensional Spectrometer (IBIS) instrument with the Helioseismic and Magnetic Imager (HMI/SDO), we show the small-scale nature of these events, as well as their link to the background magnetic field. It is found that EBs can be much smaller and shorter-lived than previous estimates have stated, implying the continued dynamics of the solar atmosphere below current observational limits.

Key words. Sun: Photosphere – Techniques: high angular resolution

1. Introduction

Ellerman bombs (often referred to as EBs) are small scale brightening events in the wings of the Hα line profile. They occur in emerging active regions (ARs) especially around regions of high magnetic flux. These events are often small-scale (below 1$''$ in diameter) and short-lived (lifetimes less than 5 minutes) meaning high-resolution and high-cadence data is required to observe them (see, for example, Georgoulis et al. 2002; Watanabe et al. 2011)

EBs are thought to be upper photospheric events, obscured in the complex Hα line centre by dynamic fibrils. They are often found to correspond to brightenings in the 1600 Å continuum emission (Qiu et al. 2000), implying that they have heights ranging around 10^2-10^3 km (Georgoulis et al. 2002). Recently, Jess et al. (2010) discussed a link between an EB event and G-band magnetic bright points finding a cospatial occurrence, hinting that EBs are linked to strong magnetic fields within intergranular lanes.

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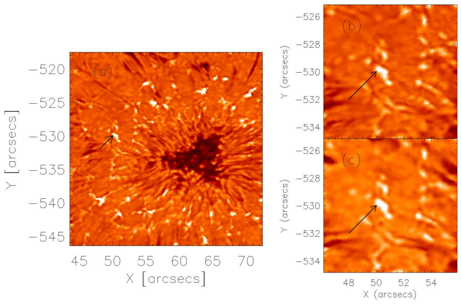

Fig. 1. (a) Zoomed FOV at −0.7 Å from the Hα line centre taken at 1502 UT with a well defined example of an EB in the (b) blue and (c) red wings.

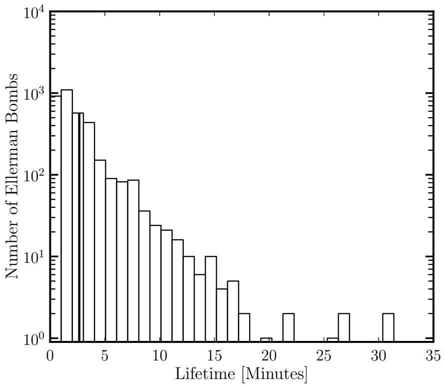

Fig. 2. Histogram showing the lifetime of the 3570 events seen in this study. Note the apparent inverse logarithmic function. The average is included as a solid line.

In recent studies, the relationship of these events to the background magnetic field has been discussed, inferring that EBs occur in regions of strong magnetic flux especially cospatially with bald patches (see Pariat et al. 2004). Due to the lack of magnetogram data with sufficient spatial resolution, further inferences about the evolution of the magnetic field are difficult.

Here, we utilise high-resolution, high-cadence data to study brightenings which occur on the scales of minutes and are well below 1″ in diameter.

2. Observations

We make use of data collected by the Interferometric BIdimensional Spectrometer (IBIS) instrument at the National Solar Observatory, Sunspot, New Mexico. We focus on the leading sunspot within NOAA 11126 (a young, emerging AR). The observations were taken between 1502 UT and 1632 UT in a period of excellent seeing. Figure 1 shows the sunspot and surrounding plasma in the blue wing of the Hα line profile as well as an example of an EB event in the blue and red wings.

IBIS perfomed a 165-image routine consisting of a 15 point Hα line-scan followed by 50 images at ±0.7 Å and the line centre. Each set of 50 images was then combined to one frame using the speckle image processing technique (Wöger et al. 2008). The fully restored IBIS data contains a line-scan and an image of each speckled position every 26.9 seconds. The speckle images have a spatial resolution of 0$''$.192. HMI has a spatial resolution of 1″ and a cadence of 45 seconds.

EBs are detected using an automated algorithm which tracks intense brightenings from frame-to-frame. The algorithm allows a threshold to be selected before filtering single pixel and single frame events. A threshold of 130% of the average background intensity was selected as this included all major EB events whilst limiting random noise.

3. Results

3.1. Lifetime

EBs are very often cited as having lifetimes in the region of 10 minutes (Georgoulis et al. 2002; Watanabe et al. 2011). Using an algorithm developed to track brightenings through time, we find that these events can have lifetimes below 2 minutes.

The average lifetime of the EBs found in these observations is calculated from the 5409 events which are selected by the algorithm. Due to the inherent uncertainties associated with solar observations, single frame events are removed from this study. The histogram of EB events from our observations is presented in Figure 2 showing the average lifetime of EBs

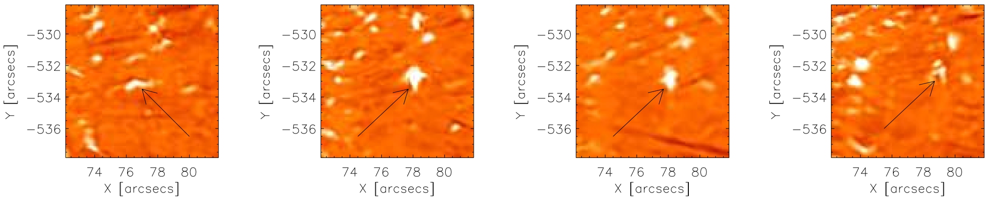

Fig. 3. The progression of an EB through its lifetime. It begins as a small brightening (a) before flaring dramatically (b) and then shrinking (c) before fully fading (d). Approximately 6 minutes elapses between each frame.

to be around 150 seconds. It is interesting to note, that this estimate is significantly lower than previous researches have stated as the average lifetime (see, e.g., Georgoulis et al. 2002; Watanabe et al. 2011). By adding single frame events and, therefore, more uncertainty the average falls below 2 minutes.

Often, EBs can show signatures of oscillations in brightness, therefore, appearing to recur. In Figure 3, we present an example of a long-lived EB event through time. This typical EB shows large variations in both intensity and area throughout its lifetime. Higher-resolution and higher-cadence observations, especially with regard to the magnetic field, would be required to accurately analyse the possible causes of these oscillations.

3.2. Area

It is also found, that EBs can be much smaller than $1'' \times 1''$, the value which has often been cited (e.g. Zachariadis et al. 1987; Georgoulis et al. 2002) as the average area of these events. We find a plethora of events well below this size, even down to the spatial resolution of these observations (around $0.''2 \times 0.''2$).

It has been suggested (see, e.g. De Wijn et al. 2009) that magnetic structuring can occur on scales well below current observational limitations. In Figure 3, we present an oscillating EB in both area and intensity highlighting the rapid dynamics which can occur on small-scales. Each frame is approximately 6 minutes apart. In the second frame, in particular, we see the EB show rapid area enhancements (noted as flaring by Watanabe et al. 2011) followed by a gradual decline.

Flaring appears to take two forms in the EBs observed in this data. The first can be described as a rapid area and intensity increase, as shown in Figure 3, followed by a rapid decrease which occurs in many events. Secondly, limb-like extensions from the main body of the EB are also common. To find the cause of such rapid dynamics, and how they influence the surrounding solar atmosphere, higher-cadence, higher-resolution data will be required.

3.3. Spatial distribution

The spatial distribution of EBs around sunspots in emerging ARs has also been widely discussed in previous researches (Pariat et al. 2007). It was found that EBs often occur at both bald patches and at unipolar regions around the leading sunspots. A good cartoon of these topologies can be found in Georgoulis et al. (2002) as well as numerical simulations within Archontis & Hood (2009).

In Figure 4, we present the distribution of EB events in a zoomed FOV for one frame. This has been spatially and temporally coaligned with a HMI/SDO magnetogram showing the link between brightenings in the Hα line wings and strong vertical magnetic fields. Studying the full FOV, it is possible to find that there is a near ubiquitous covering of EBs around the sunspot, as well as a large number in the trailing region (to the left).

High-resolution and high-cadence magnetograms would be required to fully access the evolution of the magnetic field in these regions.

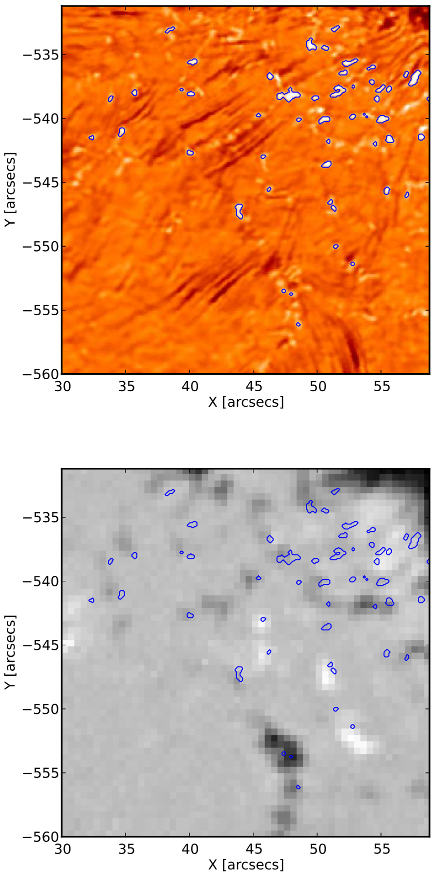

Fig. 4. (a) Spatial distribution of EB events in a zoomed FOV. (b) HMI/SDO magnetogram (±400 Gauss) with EBs selected with a 130% (blue) threshold.

As we have shown in these proceedings, EBs often occur below the spatial resolution of the HMI/SDO instrument, therefore, meaning inferences about the magnetic topologies in these regions is impossible.

4. Conclusions

In these proceedings, we have presented high-resolution, high-cadence data of an emerging AR with specific focus on EB events. We have shown that flaring, discussed by Watanabe et al. (2011), is seen in many EBs and takes two interesting forms:

1. Oscillations in area and intensity.
2. Limb-like extensions.

This flaring can take place on extremely small-scales and indicates the continued dynamics of events within the photosphere below current observational capabilities. The physical interpretation of this flaring is still uncertain. Could MHD waves be leading to the rapid oscillations?

How the layers of the atmosphere couple is one of the main questions to be answered. Numerous events in the photosphere, such as EBs, could have an influence of the complex dynamics of the upper solar atmosphere. Future studies must be undertaken into EBs with particular focus given to how they interact with other structures within the atmosphere.

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