MORPHOLOGICAL AND EVOLUTIONAL FEATURES OF ELLERMAN BOMBS

H. KUROKAWA, I. KAWAGUCHI, Y. FUNAKOSHI, and Y. NAKAI

Kwasan and Hida Observatories, Kyoto University, Kamitakara, Gifu, Japan

(Received 10 September, 1981)

Abstract. Morphological and evolutional features of Ellerman bombs were studied with Hα filtergrams of two active regions very close to the solar limb. We quantitatively determined the elongated or spike-like shape of the bomb. The mean apparent length of 174 bombs is 1.1 arc sec, while 80% of 204 bombs have a diameter of less than 0.6 arc sec. The mean lifetime of 77 bombs is about 12 min at Hα − 1.2 Å. The first maximum brightness of a typical bomb is attained, on average in about 2 min. Bombs grow longer in the first brightening phase and their mean upward velocity explains the blue asymmetry of Hα emission profiles of moustaches.

1. Introduction

'There are two conditions essential to observation – good seeing and a large solar image...', says Ellerman (1917) in his pioneering study on Ellerman bombs. McMath *et al.* (1960), who were the first to confirm the identity between Ellerman bombs and moustaches, state that it is quite possible that Ellerman's statement of the stringent conditions necessary for the succesful observation of the bombs has delayed the study of these important objects. Their descriptions are still alive, even at the present status of research for Ellerman bombs: the real features of them can be studied only with the highest spatial resolution.

In spite of this difficulty, several authors have succeeded in revealing some important characteristics of the bombs. Bruzek (1972) found a close correlation between moustaches and continuum facular granules. Vorpahl and Pope (1972) also found that all Ellerman bombs had a cospatial bright feature in the 3840 Å photospheric network. Roy and Leparskas (1973) derived the mean lifetime of Ellerman bombs and pointed out a close relationship between bombs and the ejections of dark or bright material.

The 60 cm Domeless Solar Telescope installed recently at Hida Observatory allowed us to once more attack the problem and to present some new fundamental features of Ellerman bombs.

2. Source of Data

The observations were obtained at Hida Observatory using the 60 cm Domeless Solar Telescope with Zeiss Hα Lyot filter. On Kodak SO115 film the image scale is 150 μm arc sec^{-1}. Two active regions very close to the solar limb were analyzed in this investigation. Table I summarizes the observing parameters.

For McMath region 16224, the central wavelength of the filter passband was sequentially changed across the Hα profile by the order listed in the fifth column of Table I. Some

Solar Physics **79** (1982) 77–84. 0038–0938/82/0791–0077$01.20.

TABLE I

Active regions studied and observing parameters

Active region	Time of observation (UT)	Position	Filter passband	Wavelength shift from Hα center
McMath 16224	Aug. 13, 22:16–Aug. 14, 00:10 Aug. 14, 22:21–23:23 (1979)	S 28, E 80–79 S 28, E 66	0.5 Å	±0.0, +0.8, −0.8, +1.2, −1.2, +1.6, −1.6, +2.0, −2.0, +5.0, −5.0 Å
McMath 16867	June 5, 21:51–23:23 (1980)	S 10, W 78	0.25 Å	−1.2 Å

frames of these filtergrams are of high quality and enable us to study the real shape and size of Ellerman bombs. Two filtergrams in Hα − 1.6 Å and Hα − 2.0 Å are shown in Figures 1(a) and (b).

On the other hand, for McMath region 16867 we took a photograph every five seconds, on average, for 1.5 hr at the fixed wavelength of Hα − 1.2 Å where the bombs show the greatest contrast against the surrounding solar features. This sequential observation of high temporal and spatial resolution enables us to study the evolutional characteristics of Ellerman bombs. Figure 1(c) shows an example of these filtergrams.

3. Analysis and Results

3.1. Shape and Size

Ellerman bombs appear, in general, as small bright points in the light of Hα wing (Lyot, 1944; Bruzek, 1972; Vorpahl and Pope, 1972). There have been few observations which successfully revealed their real shape. In Figure 1, however, due to the good spatial resolution, we can see that almost all bombs have an elongated or spike-like shape. In order to determine this elongated shape quantitatively, we measured the widths and the lengths of 204 bombs in 11 filtergrams which are listed in Table II. The length of a bomb spike was defined as its longest dimension and the width as the shortest dimension. We used two different measuring methods: (a) the dimensions of bombs were measured directly on the negatives with the Nikon Measure Scope in Kwasan Observatory, (b) microphotometric tracings were made along the longest and shortest axes of each bomb and the full half width of the intensity profile was determined for the length or width of the bomb.

The preliminary measurements of 30 bombs revealed a systematic difference between the two methods. The values derived by method (a) were generally a little less than those by (b). This difference, about 0.14 arc sec on the average, is negligible for the statistics of lengths but significant for the widths. Then we adopted the more precise method (b) to determine the widths of bombs, and the simple method (a) for the lengths.

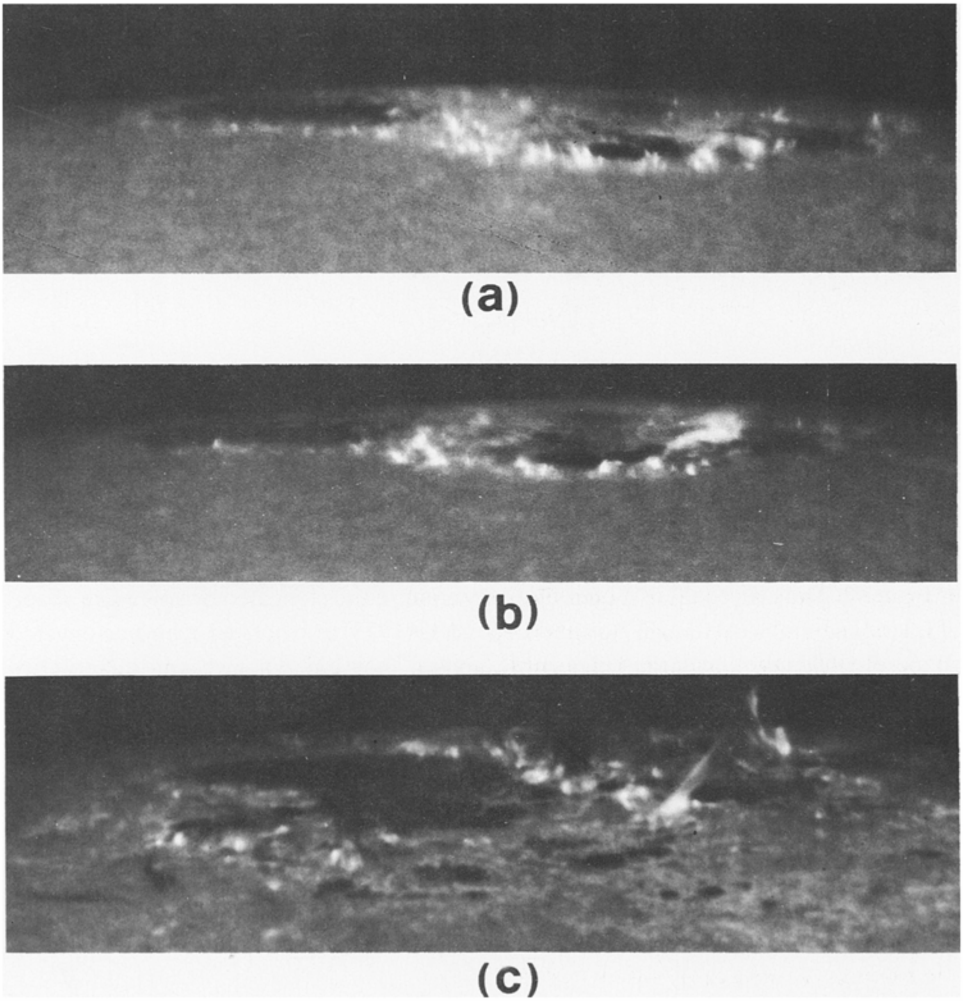

Fig. 1. (a) Filtergram at Hα − 1.6 Å of McMath region 16224 (E 79 S 28) on 14 August 1979, 00 : 04 UT. Many elongated Ellerman bombs are visible. (b) The same as (a) but at Hα − 2.0 Å and 13 August 1979, 23 : 25 UT. (c) Filtergram at Hα − 1.2 Å of McMath 16867 (E 78 S 10) on 5 June 1980, 22 : 25 UT.

We did not find any distinct wavelength dependence of these dimensions among the wavelengths listed in Table II, except in Hα − 5.0 Å where the lengths of bombs are, on the whole, shorter than those in other wavelengths. Then the widths of the bombs in Table II are all brought into the histogram in Figure 2. On the other hand, we excluded the bombs in Hα − 5.0 Å from the histogram of the lengths in Figure 2 by the reason described above. The bombs of 22 : 24 UT Aug. 14 were also excluded from the histogram of lengths because of their smaller heliographic longitude which causes the larger perspective effect.

According to Figure 2, the distribution of apparent lengths is nearly symmetrical around the peak number and most of these lengths safely exceed the spatial resolution

TABLE II

Filtergrams measured

Date	Aug. 13 (1979)	Aug. 13	Aug. 13	Aug. 13	Aug. 13	Aug. 14	Aug. 14	Aug. 14	June 5 (1980)	June 5	June 5
Time of observation (UT)	22:22	22:32	23:21	23:25	23:33	00:04	00:09	22:24	21:53	22:25	22:48
Wavelength shift from Hα center (Å)	−2.0	−2.0	+1.6	−2.0	+0.8	−1.6	−5.0	−1.2	−1.2	−1.2	−1.2
Position of active region	S 28 E 80	S 28 E 80	S 28 E 79	S 28 E 79	S 28 E 79	S 28 E 79	S 28 E 79	S 28 E 66	S 10 W 78	S 10 W 78	S 10 W 78
Number of bombs measured	10	13	12	12	6	26	9	20	36	31	29

of our photographs. We can therefore obtain 1.1 arc sec as the mean apparent length of bomb spikes. Due to the foreshortening effect, the real mean length is larger than this apparent length. On the other hand, 80% of bombs have a width of less than 0.6 arc sec in Figure 2. Thus we could first quantitatively confirm the elongated or spike-like shape of Ellerman bombs. Al though Roy and Leparskas (1973) also noticed such an elongated shape of the bombs at large heliocentric angles, they did not give any quantitative measurements of them in their paper.

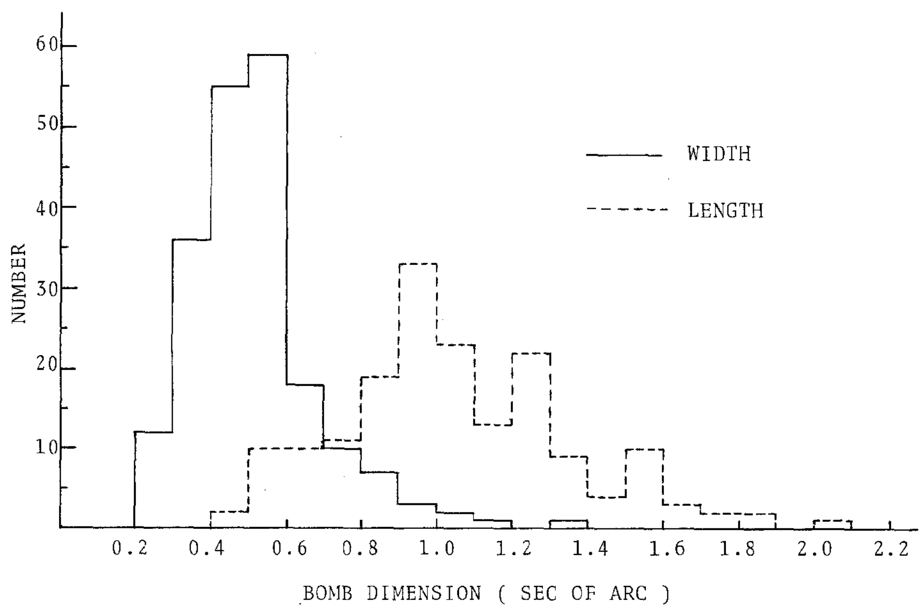

Fig. 2. Histograms showing the distribution of bomb dimensions per interval of 0.1 arc sec. The broken line shows the width distribution and the full line the length distribution.

3.2. Lifetime and Light Curve

At the time of the observation for McMath region 16867, the good seeing condition continued for about 1.5 hr and enabled us to study the lifetime and light curve of the Ellerman bombs in Hα − 1.2 Å. We selected 101 bombs in this active region and determined their lifetimes by tracing them on successive frames of negatives. The lifetime of a bomb was defined as the duration between the first brightening and the complete dimming into the surrounding brightness. The results are presented in the form of a histogram in Figure 3. In this Figure, 7 bombs in the section of 0–2 min and 3 of 2–4 min are all corresponding to the footpoints of impulsive surge activities at the same location. These 10 bombs were excluded from the calculation of the mean lifetime because of their flare-like feature. All the bombs with a lifetime longer than 28 min in Figure 3 were found to pulsate from one to several times before disappearing. Also excluding these bombs from the calculation, we obtained 12 min as a mean lifetime of typical Ellerman bombs. This result is in good agreement with 11 min found in Hα − 2.0 Å by Roy and Leparskas (1973), but much smaller than 15–38 min found by Bruzek (1972).

Next, in order to study the evolutional characteristics of the typical Ellerman bomb in more detail, we measured the time variation of the peak intensity of each bomb with the microphotometer and derived the light curves for 12 typical bombs. Six of them are shown in Figures 4 and 5. Since according to Roy and Leparskas (1973), the lifetimes of bombs hardly depend on the wavelength in the Hα line except near the line center,

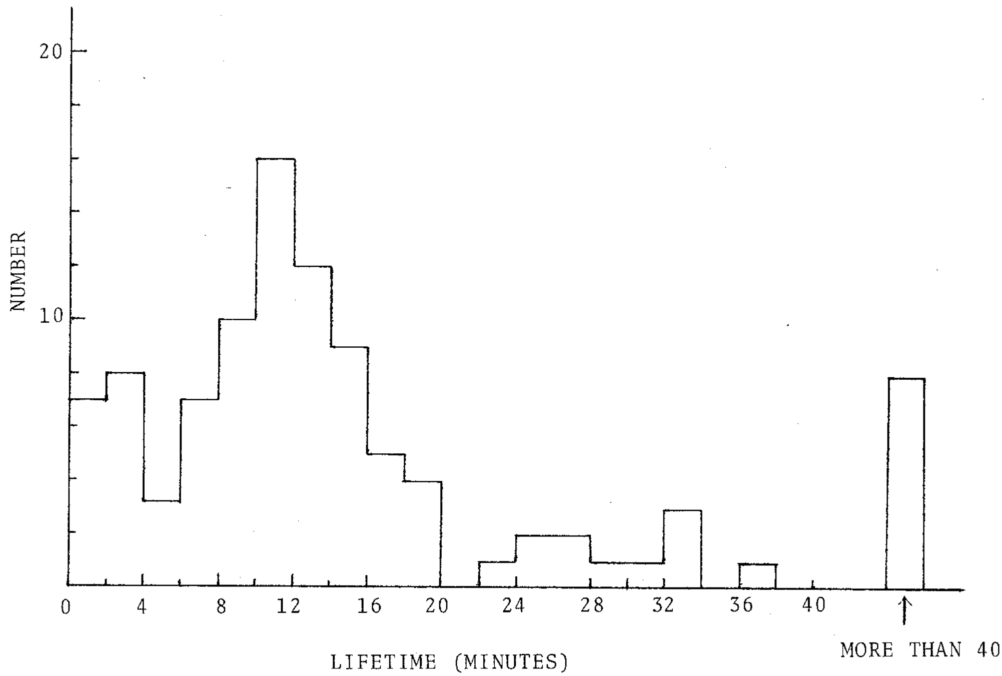

Fig. 3. Histogram showing the distribution of bomb lifetimes per interval of two minutes. The block on the right extremity shows the number of the bombs which have the lifetime longer than 40 min.

we can regard these light curves in Hα − 1.2 Å obtained here as the representative feature of the bomb evolution. Then we estimated the average time scales for the brightening and decaying of these 12 bombs: the first maximum brightness is attained in about 2.1 ± 0.5 min, then nearly the same brightness is kept for about 3.9 ± 1.1 min, and decaying is completed, on average, in about 5.2 ± 1.1 min.

The bomb (B) in Figure 4 recurred at the same point as the bomb (A), and the bomb

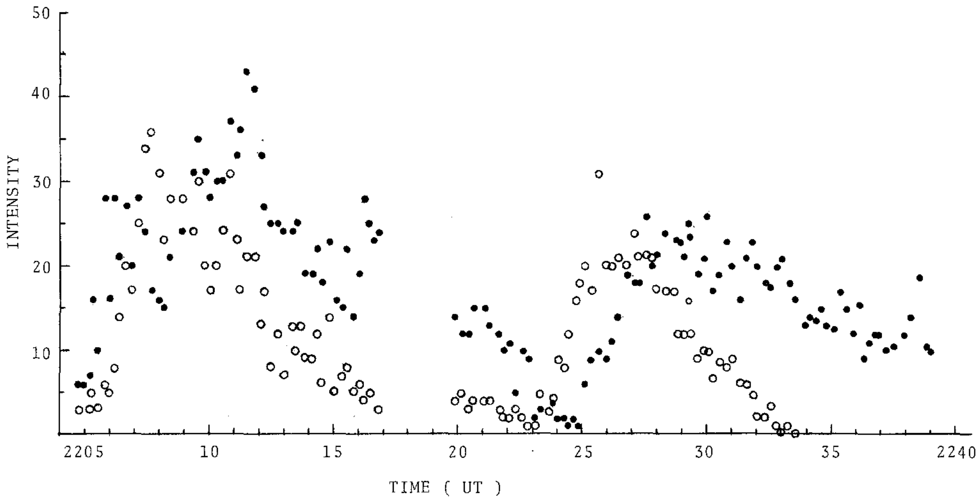

Fig. 4. Photometric light curves of typical Ellerman bombs. The open circles show the brightness variation of bombs (A) and (B), and the filled circles, (C) and (D). The ordinate is the excess intensity of bombs over the background in an arbitrary scale.

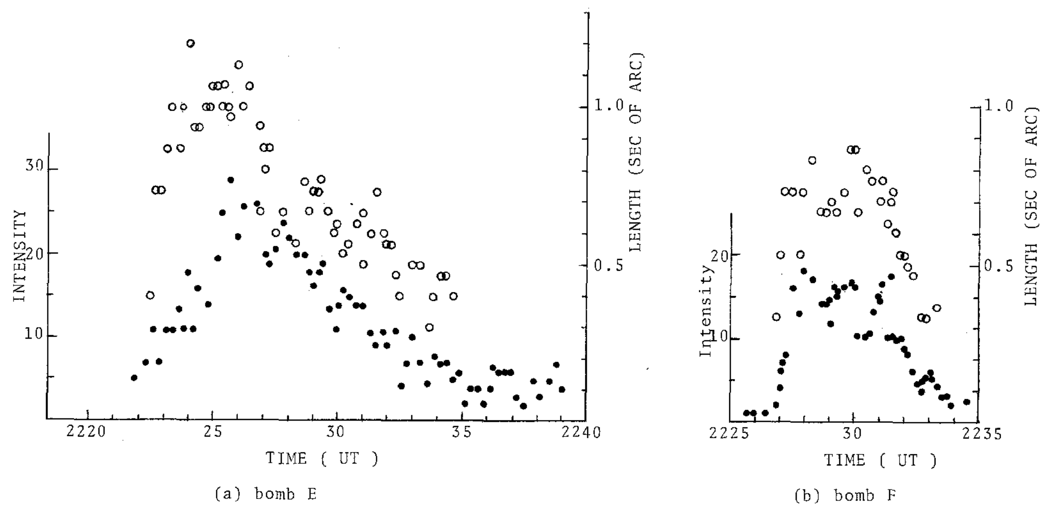

Fig. 5. (a) Photometric light curve and length variation of bomb (E). The filled circles represent the light curve where the ordinate is the excess intensity of the bomb over the background in an arbitrary scale. The open circles represent the length variation of the bomb spike. (b) The same as (a) but for bomb (F).

(D) recurred at the same point as (C). Such recurrence is a rather common characteristic of Ellerman bombs, as pointed out by McMath *et al.* (1960). We have found that 45% of bombs recurred during our observation on 5 June 1980.

In Figure 4 the fine intensity fluctuations of high frequency are due to the seeing effect and not real variation, but real pulsations of brightness can be noticed in the light curve of the bomb (C); the first maximum brightness is attained around 22 : 07 UT, the second one around 22 : 11 UT, and the third one, which is not clear because of an interruption of observation, around 22 : 17 UT. Such pulsation of brightness is also common for large and bright Ellerman bombs.

In the course of studying the lifetimes, we had the impression that the maximum brightness and maximum length of each bomb are attained nearly at the same time. In order to confirm this we measured the time variations of length for bombs (E), (F), and (G) on the successive negatives. The results are given in Figure 5. We can find that the evolutional change of the bomb length is very similar to that of the bomb brightness. Ellerman bombs do grow longer in the first brightening phase.

4. Discussion and Conclusion

We first confirmed the quantitative features of the elongated or spike-like shape of Ellerman bombs: the mean apparent length of spikes is 1.1 arc sec while 80% of them have a diameter (width) of less than 0.6 arc sec. In addition we must notice that 24% of bombs have a diameter of less than 0.4 arc sec in Figure 2. On the other hand, many large and bright bombs pulsate before dimming as we found for the bomb (C) in Figure 4. Such pulsation may be partly caused by the absorbing matter overlying the bomb, but mainly by the fine structures which brighten and dim one after another inside the large bomb. Actually a single bomb can be seen to separate into two smaller bombs on some frames of the negatives. This suggests that larger bombs often consist of two or more smaller bomb spikes. After all, we tentatively assume that the typical real diameter of bomb spikes is nearly as small as the dimension of the photospheric bright points or filigrees studied by Muller (1981) and Wilson (1981).

From the time sequence observation in Hα − 1.2 Å, the mean lifetime of the Ellerman bombs was found to be about 12 min. The first maximum brightness is attained in about 2.1 min, then nearly the same brightness is kept for about 3.9 min and decaying is completed roughly in the last 5.2 min. The first real brightening phase must be even shorter than estimated here, because the seeing effect possibly reduces the sharpness of the light curve.

We also found that the evolutional change of the bomb length to be very similar to that of the bomb intensity (Figure 5). Ellerman bombs are growing in length in the first brightening phase. If the maximum bomb length of about 1000 km is reached in about 2 min of the first brightening phase, the mean upward velocity will be around 8 km s^{-1}. This velocity may explain the blue asymmetry of the moustache spectra found by Severny (1957) and Engvold and Maltby (1968). Studying Hα spectra of moustaches, Kitai (1981) recently found that the Doppler shifts of emission line profiles are generally blueward and amount to about 6 km s^{-1}. This result agrees well with the dynamical features of bomb spikes found in this investigation.

Acknowledgement

The authors would like to express their deepest thanks to Dr Akira Hattori for his invariable efforts in realizing the new Domeless Solar Telescope of Hida Observatory. This work was supported in part by the Grant-in-Aid for Scientific Research (No. 54460008) from the Ministry of Education, Science, and Culture.

References

Bruzek, A.: 1972, *Solar Phys.* **26**, 94.
Ellerman, F.: 1917, *Astrophys. J.* **46**, 298.
Engvold, O. and Maltby, P.: 1968, in Y. Öhman (ed.), 'Mass Motions in Solar Flares and Related Phenomena', *Novel Symp.* **9**, 109.
Kitai, R.: 1981, in F. Moriyama and J. C. Henoux (eds.), *Proceedings of The Japan-France Seminar on Solar Physics*, p. 202.
Lyot, B.: 1944, *Ann. Astrophys.* **7**, 48.
McMath, R. R., Mohler, O. C., and Dodson, H. W.: 1960, *Proc. Nat. Acad. Sci. U.S.* **46**, 165.
Muller, R.: 1981, in F. Moriyama and J. C. Henoux (eds.), *Proceedings of The Japan-France Seminar on Solar Physics*, p. 142.
Roy, L.-R. and Leparskas, H.: 1973, *Solar Phys.* **30**, 449.
Severny, A. B.: 1957, *Izv. Krymsk. Astrofiz. Obs.* **17**, 129.
Vorpahl, J. and Pope, T.: 1972, *Solar Phys.* **25**, 347.
Wilson, P. R.: 1981, *Solar Phys.* **69**, 9.