THE LIFETIME OF SUNSPOT PENUMBRA FILAMENTS

By R. J. Bray* and R. E. Loughhead*

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Summary

Twenty-seven photographs of a sunspot showing a particularly distinct filamentary structure are analysed in order to obtain an estimate of the lifetime of the penumbral filaments. The photographs have been selected from some 2400 taken over a period of 5 hr. Although the measurements are rendered somewhat uncertain by observational difficulties the results clearly indicate that some filaments remain identifiable for periods of the order of hours.

I. Introduction

No measurements of the lifetime of the filaments observed in the penumbrae of sunspots have hitherto been published, though various authors (Kiepenheuer 1953 ; Macris 1953 ; Waldmeier 1955) have stated that it exceeds the lifetime of the photospheric granulation, which is of the order of a few minutes. In this paper an account is given of a systematic attempt to measure the lifetime of penumbral filaments in a sunspot photographed near the time of its maximum development. Although the measurements are rendered somewhat uncertain by the narrow width, low contrast, and confused structure of the filaments, the results clearly indicate that some filaments remain identifiable for periods of the order of hours. It is not known, however, whether these results are typical of other spots at other stages of development.

II. Observations

The observations were made with the 5 in photoheliograph (Loughhead and Burgess 1958) of the C.S.I.R.O. Division of Physics Solar Observatory. This instrument is designed to photograph any selected region of the solar disk on 35 mm film at 5-sec intervals ; the diameter of the solar image is 20 cm. Plate 1 (*a*) shows the spot selected for study ; this particular spot was distinguished from others contained in the film records of the Observatory by possessing an unusually clear filamentary structure. Even so, the structure is not equally distinct all round the penumbra. Measurements were therefore restricted to the lower, right-hand quadrant, where the filaments are clearest. An enlargement of this region, made with enhanced contrast, is shown in Plate 1 (*b*).

Even on photographs of the quality of Plate 1, where the filamentary structure of the penumbra is well resolved, it is extremely difficult to identify individual filaments on successive photographs. The reason for this is that the structure is complex, the contrast between the bright filaments and the darker

* Division of Physics, C.S.I.R.O., University Grounds, Chippendale, N.S.W.

penumbral material is low, and the filaments are very narrow. In most cases the apparent width of the filament lies between 0·5 and 1 sec of arc, so that the detail is even finer than the photospheric granulation and is, in fact, comparable with, or less than, the theoretical resolving limit of the telescope (0·8 sec of arc). Consequently, the structure of the filaments can be seriously distorted by atmospheric seeing even on photographs on which the granulation is well resolved. For example, a filament which is seen on a given photograph as a continuous line might appear on a subsequent photograph, taken only a few seconds later, broken into two or more segments. Similarly, two neighbouring filaments might appear similar in shape on adjacent photographs, but with a different separation; or one filament might be completely obliterated, although its neighbour remains intact. For these reasons it is impossible to follow in detail any structural changes undergone by individual filaments. However, as shown below, it is possible to estimate their lifetimes.

The spot shown in Plate 1 was photographed over a period of 5 hr on June 7, 1957. Although none of the 2400 odd photographs on the film equals the best hitherto obtained with the instrument, the film contains 27 good photographs distributed fairly uniformly over a period of about 200 min. The measurements described in the next section were made from enlargements of these photographs, which are on such a scale that 1 mm corresponds to 0·9 sec of arc.

III. Reduction

In view of the difficulty of identifying individual filaments on successive photographs it was decided to make maps of the filaments for each of the 27 photographs. This procedure introduces a considerable simplification without losing the essential features of the structure. The maps were restricted to the region of the spot shown in Plate 1 (*b*), where the filamentary structure is particularly clear. In tracing out the filaments a gap was left where there intervened either a dark region or a bright diffuse patch of the type described by Macris (1953). All maps were drawn independently, without reference to one another. Also, to facilitate the intercomparison of the maps, the outlines of the umbra and of a few small adjacent spots were included. However, owing to displacements ($\sim$1 sec of arc) due to seeing, the final matching of any two maps could only be made by slightly displacing one until the best fit was obtained for the filamentary detail.

To systematize the intercomparison of the 27 maps a " key " map was first selected: from the 27 maps, 13 were chosen which appeared to show the clearest filamentary structure; these evidently represent the 13 photographs least affected by seeing. Each of the 13 maps was then compared in turn with the remaining 12, and the degree of correlation in each case subjectively assessed on a scale of 1 (good) to 3 (poor). The number of correlations of class 1 for each map was adopted as a figure of merit for this map. A low value for this figure indicates that the corresponding photograph is affected by seeing; a high value indicates that it closely represents the structure under study. It is interesting to note that, although on visual inspection the 13 photographs appear to be of comparable quality, figures of merit ranging from 1 to 9 were obtained. The map having the highest value for this figure was selected as the key and is shown in Figure 1.* Six particularly distinct filaments on this map are numbered.

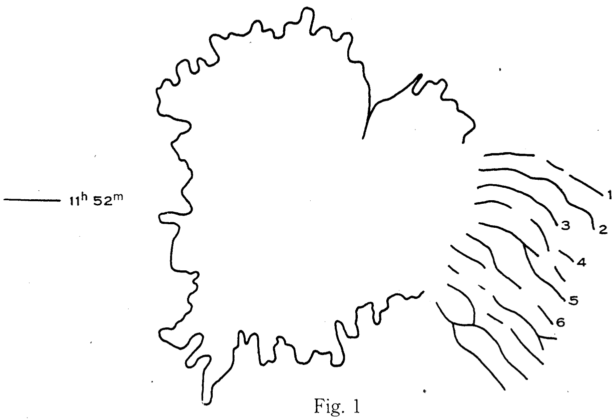

Fig. 1

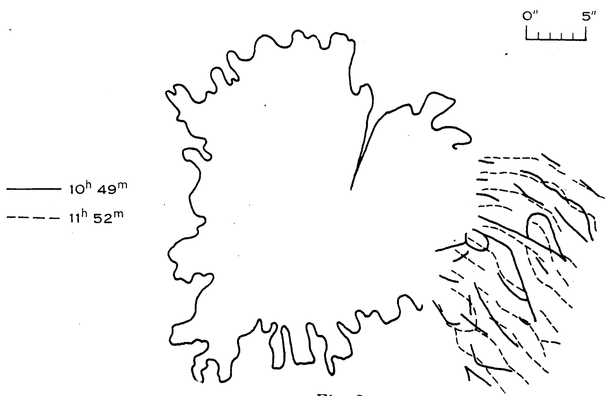

Fig. 2

Fig. 1—Penumbral structure at $11^{\mathrm{h}}\ 52^{\mathrm{m}}$. This figure is the "key" map (see text). In Figures 2–6, the structure at $11^{\mathrm{h}}\ 52^{\mathrm{m}}$ (shown dotted) is compared with the structure at earlier and later times respectively. Note that the umbral outlines correspond to the times of the figures.

In Figures 2–6 the key map is compared with five other maps corresponding to earlier and later times. At $10^{\mathrm{h}}\ 49^{\mathrm{m}}$ (Fig. 2), 63 min before the time of the key map, the correlation is weak, only filament 2 being identifiable. At $11^{\mathrm{h}}\ 8^{\mathrm{m}}$ (Fig. 3), 44 min before the key, the correlation is somewhat stronger, filaments

* This method of selecting the most representative of a number of photographs, all apparently affected by atmospheric seeing more or less equally, is essentially an *autocorrelation technique.* It is clearly only applicable if the interval between successive photographs is significantly shorter than the average lifetime of the features under study. The method favours good photographs occurring near the middle of the sequence. It could be useful in determining the lifetime of other solar features, e.g. the photospheric granulation.

1, 2, 3, 5, and 6 being identifiable. At $11^h\ 58^m$ (Fig. 4), only 6 min after the key, the correlation, as one would expect, is very marked; the close agreement shown here confirms the reliability of the procedure adopted. At $12^h\ 39^m$ (Fig. 5), 47 min after the key, filaments 1, 2, and 3 are identifiable. At $13^h\ 12^m$ (Fig. 6), 80 min after the key, the correlation is much reduced. Figures 2–6 indicate that certain filaments remain identifiable for periods of the order of hours.

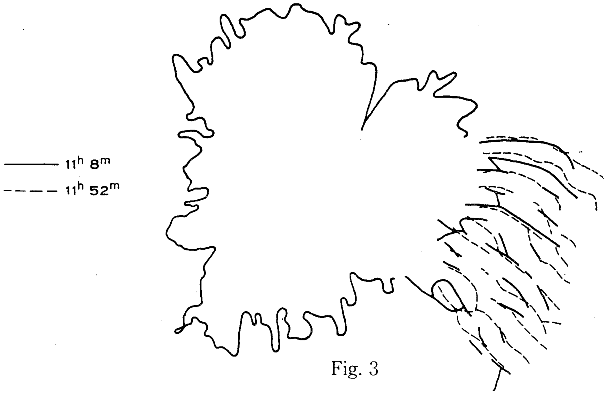

Fig. 3

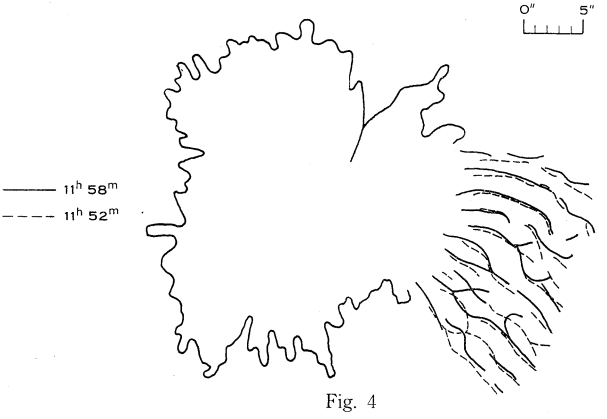

Fig. 4

Estimates of the lifetimes of the 6 particularly distinct filaments labelled in Figure 1 were obtained by a comparison of the key map with each of the 26 remaining maps. In carrying out this comparison, a given filament was arbitrarily taken to be present if it had the same shape, occurred at nearly the same position, and occupied at least 50 per cent. of the length of the same filament shown on the key map. With this criterion the following results were obtained: filament No. 1 can be identified on 12 maps extending from $11^h\ 7^m$ to $12^h\ 39^m$; two maps during this period fail to show it. No. 2 is visible on 18 maps extending from $10^h\ 24^m$ to $14^h\ 21^m$; 7 maps during this period fail to show it. No. 3 is visible on 10 maps extending from $11^h\ 7^m$ to $12^h\ 39^m$; 4 maps during this period fail to show it.

Filaments Nos. 4, 5, and 6 are rather uncertain. They are visible on a photograph taken near $11^h\ 8^m$, but several other photographs taken within a minute fail to show them. No. 4 is only certainly present from $11^h\ 52^m$ to $11^h\ 58^m$ (3 maps). No. 5 is present from $11^h\ 52^m$ to $12^h\ 39^m$ (5 maps); 3 maps during this period fail to show it. No. 6 is visible on 3 maps extending from $11^h\ 52^m$ to $12^h\ 16^m$; 1 map during this period fails to show it.

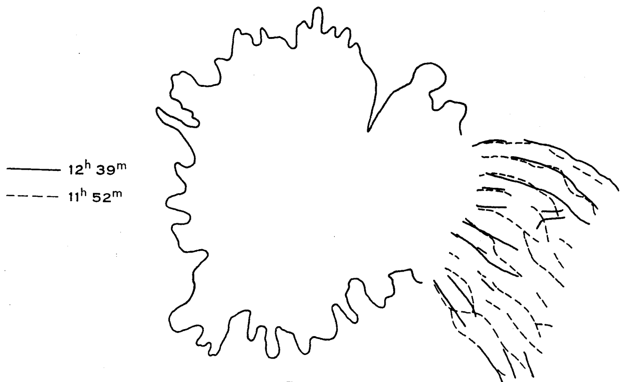

Fig. 5

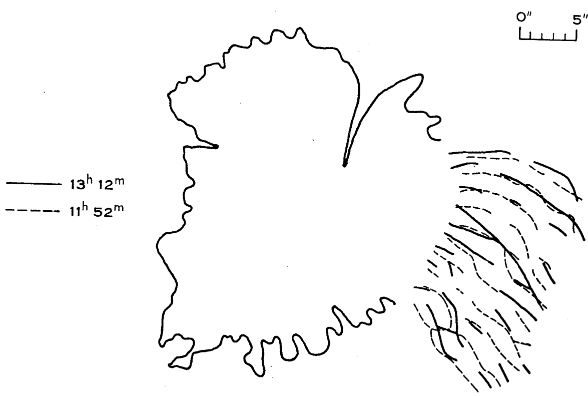

Fig. 6

The results of the measurements may be summarized by stating that values ranging up to several hours have been found for the lifetimes of the six filaments which were distinct enough for a determination to be made.

IV. Discussion

Observations of the lifetime of penumbral filaments may be expected to throw some light on the question of the dynamical stability of sunspots and, in particular, on the Evershed effect. The simplest interpretation of the Evershed effect is that it consists of a laminar flow of matter outwards from the umbra along the filaments, which are probably shallow structures of depth comparable with their width. With an average filament length of 7500 km for the spot under study and a mean Evershed velocity of 1 km/sec (Kinman 1953) the time taken by matter to flow along the entire length of a filament is about 2 hr. It may be significant that this figure is of the same order of magnitude as some of the observed lifetimes.

However, the observations of St.John (1913*a*, 1913*b*), who found that the Evershed velocity decreases with height, ultimately reversing its direction, throw doubt on this simple interpretation of the Evershed effect. St.John deduced his result from measurement of strong Fraunhofer lines, whose cores are formed higher in the Sun's atmosphere than those of the weaker lines normally used. However, the effective level of observation in the case of a strong Fraunhofer line observed with a spectrograph of moderate resolving power may differ from that of a weak line by only a few tens of kilometres (cf. Hart 1956). This is due to the effect of the outer parts of the instrumental profile, which throw light from the wings of a Fraunhofer line into the core. St.John's results therefore indicate that the Evershed velocity may change appreciably over a very small depth. In view of the great length of the filaments compared with their width it is hard to understand how they can maintain such a steep velocity gradient without disintegration.

V. Acknowledgment

The authors wish to thank Mr. H. Gillett for processing the films and making the enlargements.

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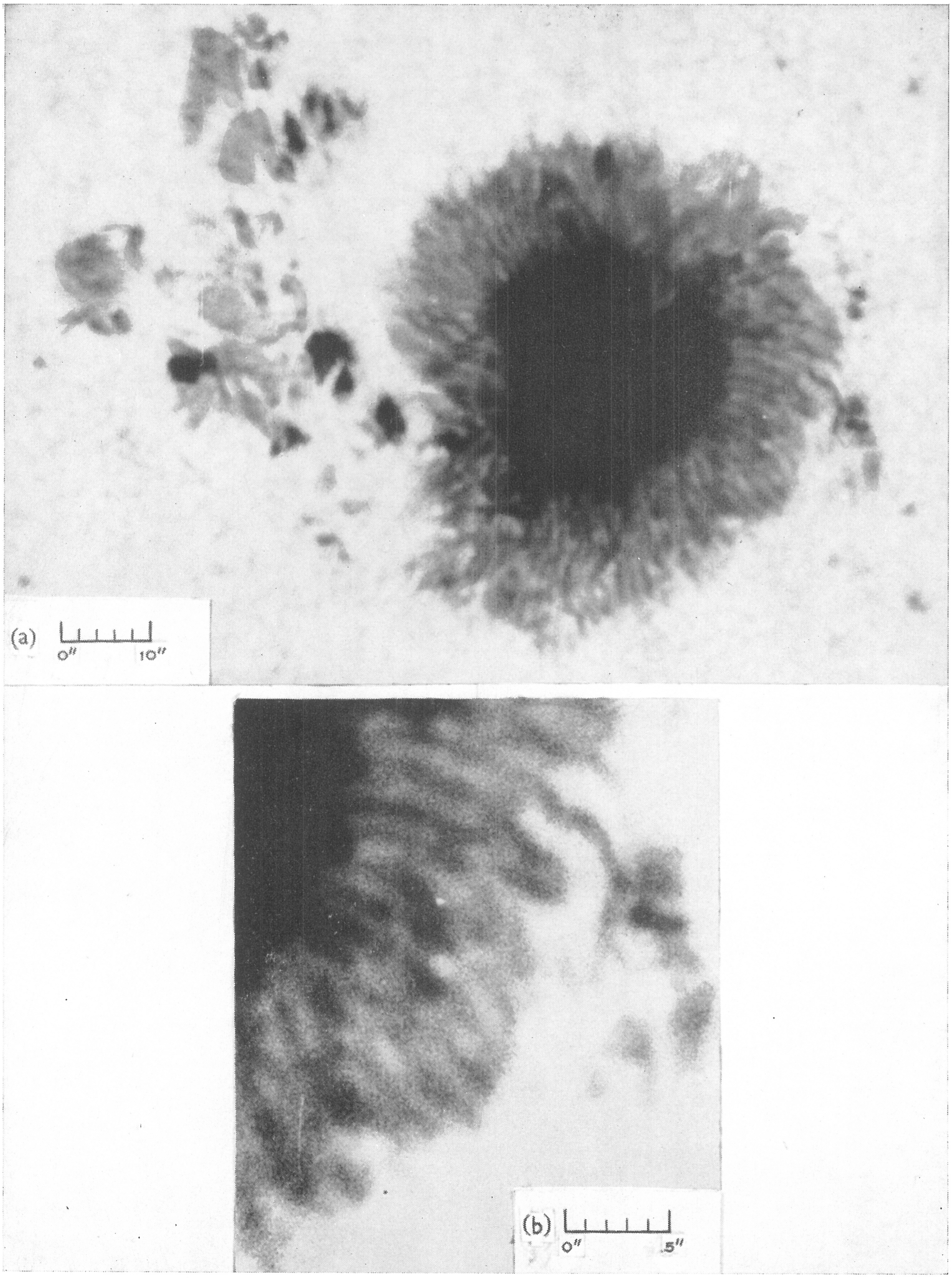

(*a*) Appearance of spot at $11^{h}\,58^{m}$, June 7, 1957. Heliographic coordinates: 17 °S., 8 °W.
(*b*) The region of the penumbra selected for study; the enlargement was made with enhanced contrast.