DETAILED ANALYSIS OF FLARES, MAGNETIC FIELDS AND ACTIVITY IN THE SUNSPOT GROUP OF SEPT. 13–26, 1963

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Abstract. We analyze large-scale H-alpha movies of the large spot group of Sept. 13–26, 1963, together with radio, ionospheric and magnetic field data as well as white light pictures. The evolution of the group and associated magnetic fields is followed, and the positions of solar flares relative to the fields are noted, along with their morphology. Although the magnetic field is deformed in time, characteristic field structures may be traced through the deformation as the seat of recurrent homologous flares.

We find that most flares are homologous, and some are triggered by disturbances elsewhere in the region. We note events produced by surges falling back to the surface, and one flare initiated by a bright bead seen to fly across the region. In almost every case of an isolated type III radio burst, a corresponding H-alpha brightening could be found, but not all flares produced bursts. Flares close to the sunspots are most likely to produce radio bursts. Flare surface waves in the region all travel out to the west, because of more open magnetic field structure there. In one case (Sept. 25) a wave is turned back by the closed field structure to the east.

In almost all cases the time association of radio or ionospheric events is with the beginning of the flare or with the flash phase.

Several morphological classes of flares are noted as recurrent types.

1. Introduction

The study of solar flares and active regions requires large scale photography with high resolution instruments. In 1963 we placed a half angstrom filter at the Coudé focus* of the 16-inch Climax coronagraph to make such studies, and were fortunate to obtain several fine series of cinematograms of the large spot group that crossed the disk between September 13 and 26. Although the filter used is of an older type without sideband suppression, the high resolution of the telescope and the good seeing in this period led to excellent results. Cinematograms were obtained on Sept. 13, 17–19, and 22–26. Other days were missed because of clouds, part of the above days were missed for the same reason. Pictures were taken at the rate of 4 per minute on the 13th, 22nd, 24th, 25th, and 26th, but on the other days (17, 18, and 23 Sept.) pictures were obtained at only 1 per minute, which is too infrequent to follow fast activity, but which does bring out slower changes. An important advantage of cinematographic review is that the eye averages effects of seeing and film grain, so that much more is seen in the film than in the individual frames.

A number of remarkable events were found on these films, which we will summarize on a day by day basis. Several important characteristics were found:

* For this reason the image rotates in our pictures, we have tried to note the coordinate positions in each photo. When not otherwise noted, N is at the top and E on the right.

(1) In periods of numerous flares, there was continual rapid activity manifested by motions of filaments, small rapid brightenings, surges, and waves of brightening or displacement. These waves, similar to those observed by ATHAY and MORETON (1961), are very difficult to display in single frames but are easily seen in the movies. Some are slow enough that highly accelerated movies are needed to observe the effect; others are so fast that we need frequent pictures.

(2) Many flares appeared to be triggered by disturbances elsewhere in the region, usually by a smaller flare. In one remarkable case on September 23 (Figure 20), a bright bead was seen to fly across the region and set off a surge. (A similar event occurred in the same area on Sept. 17.) When the surge fell back to the surface, the bead returned and a small flare followed. We of course do not know what causes the first smaller flare, nor have we made statistical analyses to prove the connection, but we consider it to be real. (These phenomena are best seen on the film and we would be glad to lend 16 mm. prints to interested investigators.) It is obvious that a returning surge must make a substantial perturbation when it hits the surface.

(3) Almost all surges and flares are homologous, i.e., they recur in regions where there have been other flares with the same general shape and evolution. The same regions produce flares throughout the 9-day period, even though the spot configuration changes.

(4) In almost every case of a strong isolated type III radio burst, a simultaneous H-alpha brightening could be found, usually in a particular radio-active area. The radio bursts of Sept. 25 are the best examples. Since our films cover only a fraction of the disk, the few negative results may be attributed to flares elsewhere. The radio burst usually corresponds to the beginning of the H-alpha brightening or to the flash phase when the brightness increases discontinuously.

Unfortunately we did not observe any of the large importance 3 flares in the region, although several class 2 flares were observed. Most of the flares reported here were picked up by the various geophysical flare patrols and classed as importance 1-flares. The fact that many of them correspond to radio bursts and some to ionospheric events makes their listing in flare compilations important. We have no physical estimate of flare importance, but it is clear that some of these 1-flares were underestimated on the basis of area alone. For example, the small brightening at 1842 UT on Sept. 25 produced a strong type III burst and a small cm burst, but was only classed as importance 1-. The large spray and explosive flare at 2309 UT (class 1-) covered the entire region and was the occasion of the expulsion of a great deal of material, yet its radio and ionospheric effects were modest. But the bright surge which triggered this explosive flare gave a large type III burst. We do not have the temerity to propose a new scheme of flare importance classification at this time, but we do feel that radio and ionospheric effects are at least as important in this regard as the H-alpha area.

In our analysis, we have made the following assumptions: (1) Events separated in time and space by intervals very small compared to the mean interval between events may be causally connected. One event may "trigger" the next, or both may be caused by the same agent. (2) Magnetic field structure may be inferred from H-alpha structure. Bright regions mark vertical, enhanced fields, dark filaments mark horizontal fields.

We now define several terms which will be used to describe the various events:

umbral flash: a flash characterized by the rapid outward motion of brightness, in a narrow sector from the umbra.
notch flare: a flare connected with a notch in the umbra or a light bridge across it.
in situ flare: a flare showing only brightening of a given region, with no motion of the bright region. This flare may or may not give a surge.
explosive flare: a flare characterized by explosive outward motion and expansion of the bright region.
flash or flash phase: rapid brightening and spread of brightness in a flare unaccompanied by evident motion.
hourglass flare: filling by large flares of an hourglass shaped region bounded by the two rows of spots of opposite polarity and the neutral lines.

The above is not a classification of flares, but a listing of types observed on these and other films. A number of other interesting events were seen on the films, some of which are illustrated in the accompanying photographs. Among these were:

The development of the flare of Sept. 18 (1400 UT) which gave an X-ray burst observed by de Jager (Figure 14).

Remarkable continuous motion in the prominence of Sept. 19 (Figure 17).

The triggering of a flare on Sept. 23 by a flying bead (Figure 20), previously referred to.

A series of explosive flares from the same point on Sept. 24 and 25 (Figures 21 and 23).

A series of similar small flares accompanied by radio bursts on the 25th (Figures 24, 25, 26).

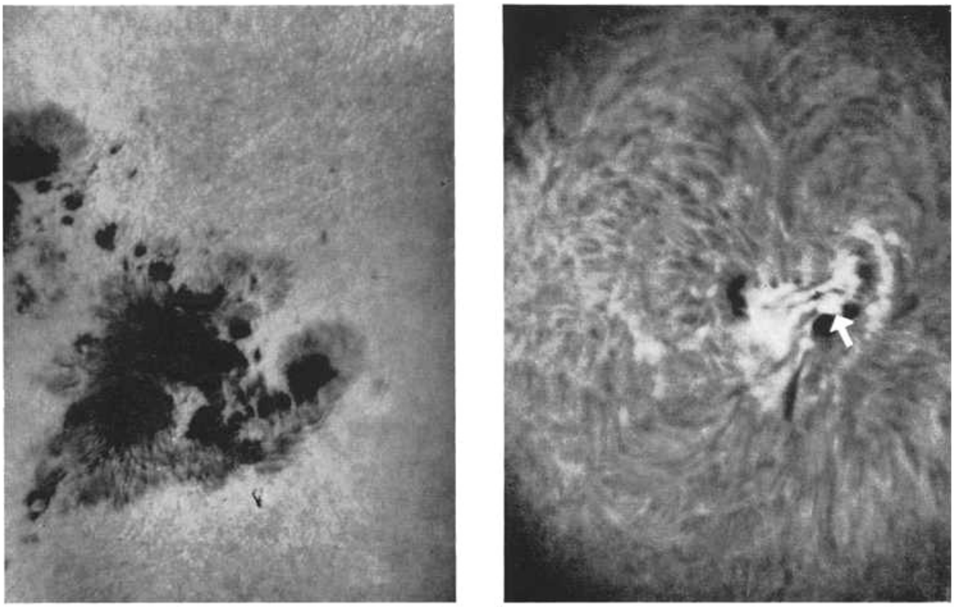
A very rapid, small umbral flash on Sept. 24 (Figure 22), which produced a substantial radio burst.

2. Evolution of the Spot Group

Our photos cover the period Sept. 17–26 in greatest detail; during this time we may follow the general evolution of the spots by the white light photos kindly furnished us by Bumba of Ondřejov and McIntosh of Sacramento Peak, combined with our own H-alpha photos and those made by Ramsey at Lockheed and Sheeley at Mt. Wilson. Although the region changed shape during nine days, most of the original features could be traced through their evolution; the same is true of the magnetic field. We have information on the magnetic fields from cancelled photographic magnetograms obtained by Sheeley at Mt. Wilson on Sept. 16 and 20 (Figure 2); from the magnetic map for Sept. 18 published by TESKE, DODSON, HEDEMAN (1964) (Figure 3) and from the Mt. Wilson spot drawings by Thomas Cragg. Data on flares is taken from the Solar-Geophysical data Part B.*

* Solar-Geophysical Data, CRPL-F, part B, National Bureau of Standards, Boulder, Colorado.

On Sept. 17 (Figure 1a) the spot group was dominated by a large spot of S polarity with a remarkable trio of elongated spots next to it. Just east is another, somewhat smaller spot, and stretching further to the east of the large spot was a comma shaped string of spots of the same polarity (except, possibly, for the easternmost). To the northwest of the large spot appeared a triple spot of opposite polarity connected to the main group by a chain of small spots. These structures may be seen in Figure 1b,



(a) (b

Fig. 1. (a) White light photo by V. Bumba at Ondřejov Observatory Sept. 17, 1963, 1415 UT, showing detailed structure of the group. The three elongated spots at the center are most interesting; they probably have different polarities with the neutral line winding in and around them. N top, E right. – (b) Simultaneous H-alpha picture at Climax. Strands of plage follow the 3 elongated spots. On this, as in any other H-alpha picture, such effects may occur because the dark spots reduce the apparent brightness of the overlying plages. A flare is in progress at point G (arrow) between 2 large spots. None of this activity can be seen on Figure 1a. (Compare with Figure 13.) N upper left, E upper right.

an H-alpha photo made at Climax at 1415 UT on the 17th. A small surge is seen to the southwest. The bright plage area filled an hourglass shaped region, between the neutral line (which runs roughly E–W) and the triple spots on one side (W), and the same line and the comma-like elongation on the E side. It appears from the magnetic data that the neutral line was not straight, but followed a winding path between and around the elongated spots; each of these had polarity opposite that of its neighbors.

The magnetic structure of the region is best revealed by the fine magnetograms made by Sheeley on the 16th and 20th (Figure 2). The TESKE, DODSON and HEDEMAN

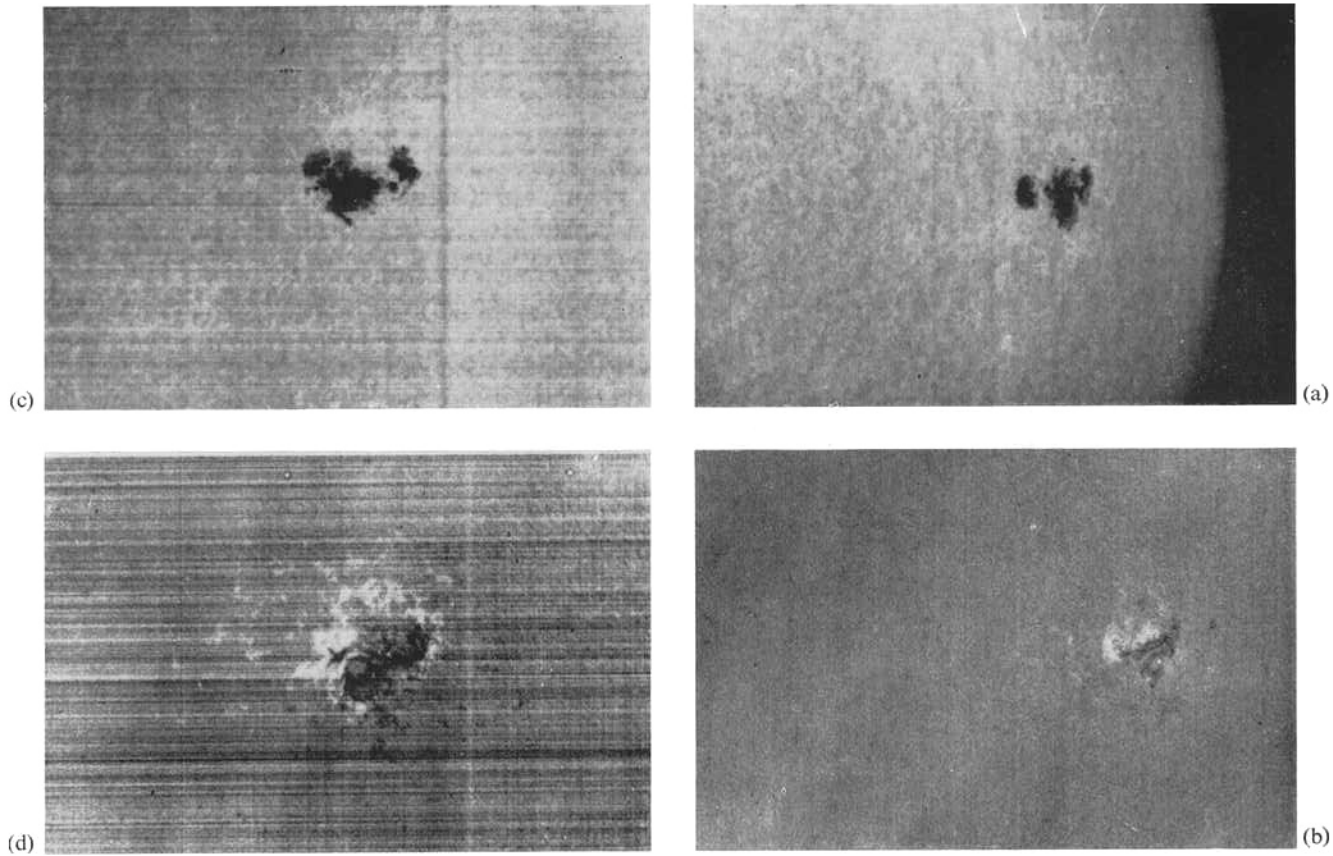


Fig. 2. (a) Spectroheliogram in the continuum in the Ca I 6103 line. – (b) Cancelled magnetogram by Leighton's method, made by N. Sheeley, Sept. 16, 1430 UT. The field is very complicated, except for the triple spots (light is S polarity). A line of strong N polarity runs through the center of the group, and is marked by the boundary of bright plage in the H-alpha picture (Figure 12) taken shortly afterward. – (c, d) Same for Sept. 20, 1445 UT. The triple spots rotated by about 45 degrees relative to the large spot in these 4 days (mostly between Sept. 16 and 18); the straight line of north polarity is now S shaped and there are strong inclusions of field of opposite sign. Note the open structure of the fields toward the west; this presumably is the reason that the flare waves moved out in this direction. N top, E right.

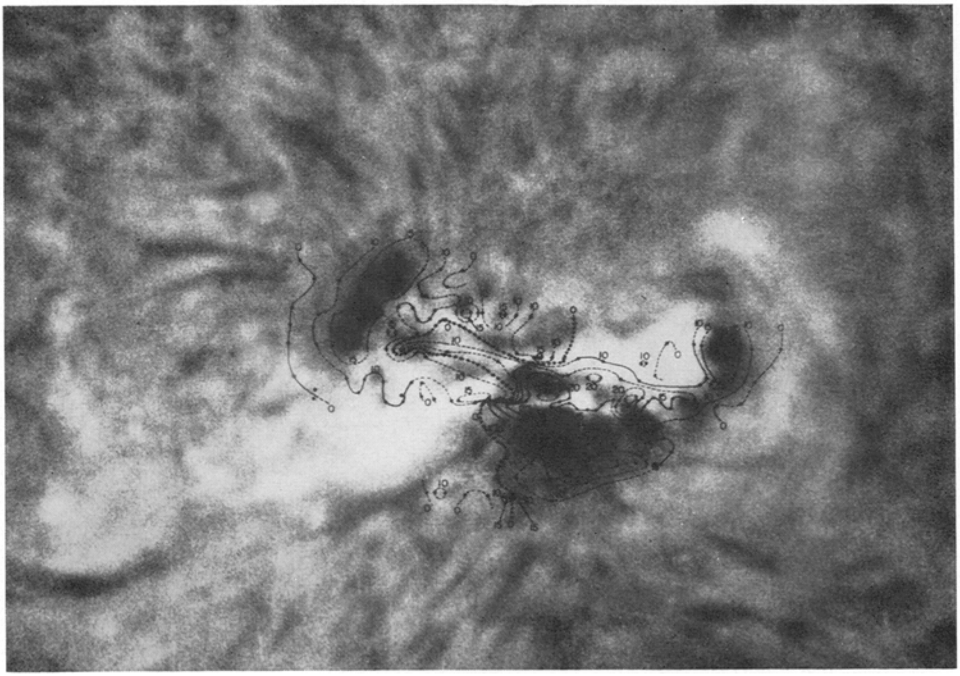


Fig. 3. Contours of longitudinal magnetic field intensity measured by TESKE, DODSON and HEDERMAN (1964), superposed on our H-alpha picture, Sept. 18. The zero field contour should be extended along the filament to the left. Note that brightening never crosses the zero field contours. N top, E right.

(1964) map is shown in Figure 3, superposed on an H-alpha picture. The N and W parts of the group show one polarity, the E and S the other. A sharp field boundary runs through the center of the group, but there are some inclusions of opposite field. The large sunspots show gray because the magnetograms saturate. On Sept. 20 the structure was much the same, except that the triple spot rotated to the N. There is a complex intertwining of strong fields between the triple spot and the large sunspot, through the remains of the elongated spots of Sept. 18. In Figure 4a we show letter designations for different areas Sept. 17–22; in Figure 4b the same is given for Sept. 23–25. A long "streamer" of S polarity came right up to the large spot and ended near a light bridge across it. This light bridge, which we designate A′, appeared on the 17th. A number of flares start with disturbances originating here, moving NE into the bay G. Another region of activity is the intrusion of N polarity near the triple spot, which also appears on the 18th in the TESKE, DODSON and HEDEMAN (1964) map. This area is marked H in Figure 4a. It is quite clear that SEVERNY'S (1958, 1960) point on the importance of regions of strong magnetic gradients in flares is correct – on the other hand we must remember that these areas often show bright plages and they are therefore easily brightened by flare disturbance. But cinematography does show that certain pockets were the sources of disturbance waves associated with flares – these were the plage area I′, which showed medium strength fields of irregular polarity;

the light bridge A′; the intrusion of N polarity H near the triple spot, and the area C just S of the large spot. Sheeley's magnetogram shows all these regions to have very irregular fields of alternating sign.

Comparison of the H-alpha pictures with the magnetograms is most instructive. There is a close correspondence of the H-alpha and magnetic features, as seen in Figures 2 and 3. A filament extended westward from the central spot; we know such

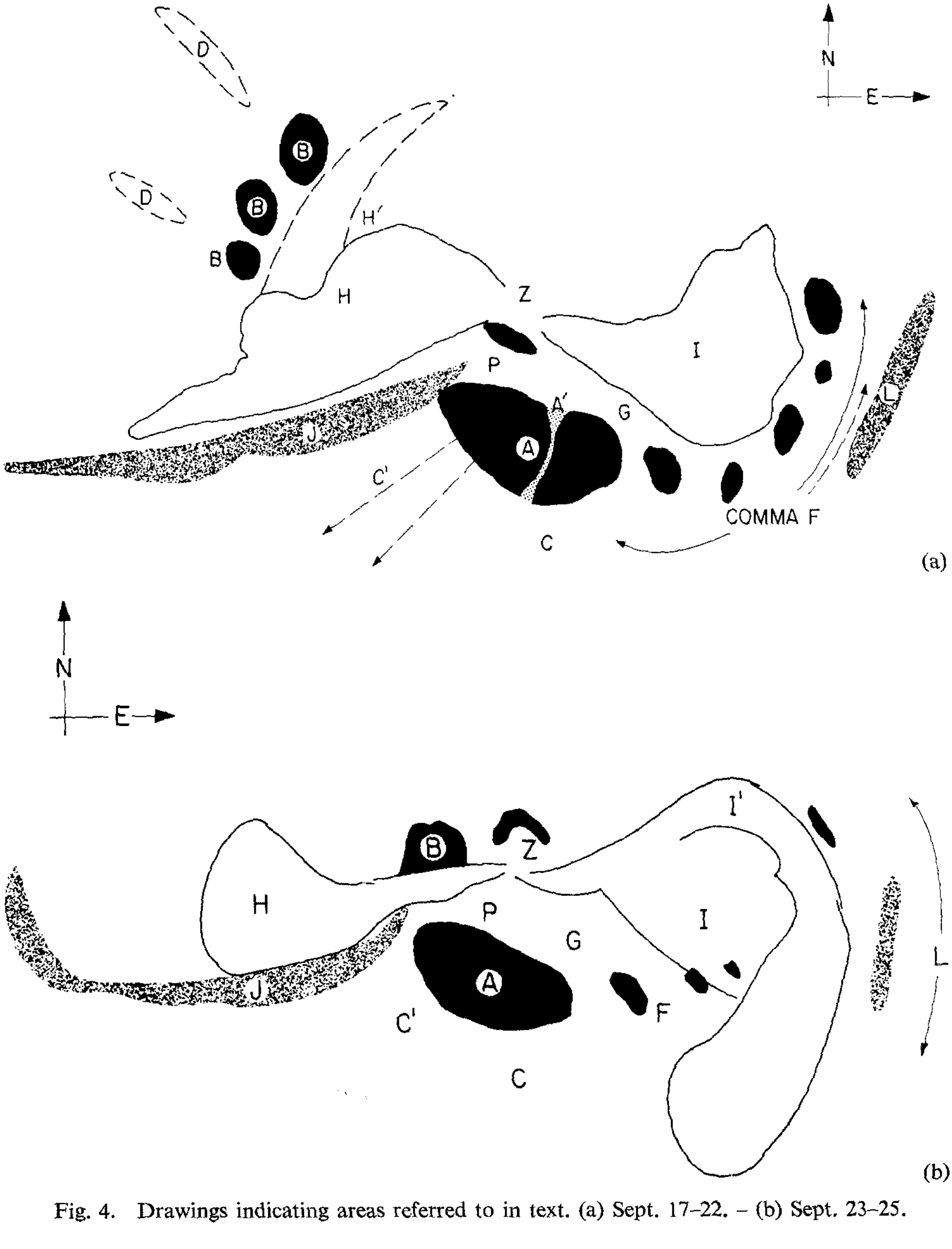


Fig. 4. Drawings indicating areas referred to in text. (a) Sept. 17–22. – (b) Sept. 23–25.

filaments mark the neutral line from the work of HOWARD and HARVEY (1963). This filament joined the zero polarity contour, which wound through the center of the hourglass and out the other side. All of the big flare waves moved out along the neutral line westward along the filament, probably because the field falls off most steeply in that direction. The filament (J) may be followed to the 25th and forms an important landmark. If flare-connected changes occur, we should see them in H-alpha, but in contrast with Severny's magnetograph results, we never do.

We have tried to identify all the rapid phenomena – flares, surges, and waves – occurring in the region during our period of coverage. We have identified the various locations by letter, and tried to compare them with the general structure of the field, to get some insight into the places where flares occur. These letter designations are shown in the drawings Figure 4a for 17–22 Sept. and Figure 4b for 24–25 Sept. On the 18th, most of the big flares started in the light bridge area A′ near the big spot. Most of these flares spread out through the neck of the hourglass (Z) to fill the plage region H and I, and were accompanied by surface waves traveling westward. There is some evidence that one of the Sept. 18 flares was triggered by a small flare in the neck Z, where the steepest field gradients exist. There is rapid traveling of disturbance

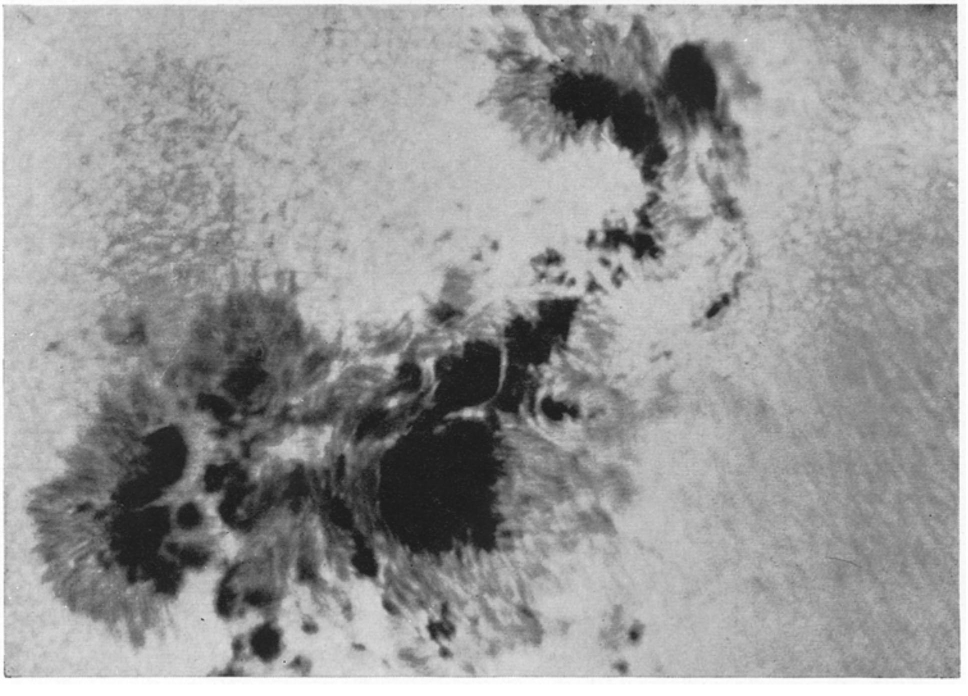


Fig. 5. Sept. 20. White light picture taken by Bumba at Ondřejov Observatory. Only traces of the three elongated spots which were prominent on the 17th remain, but the granules in this region show alignment on a circular arc around spot A. The comma of spots F has become greatly elongated in a northeasterly direction. N upper left, E upper right.

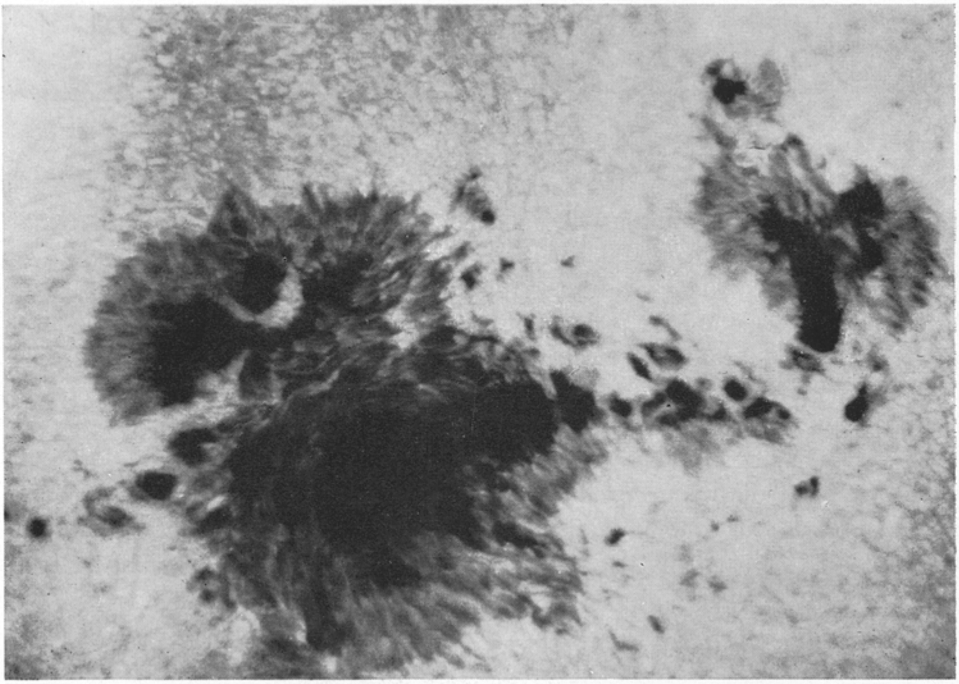


Fig. 6. Sept. 21, 0725.44 UT. White light photograph (Bumba, Ondřejov Observatory). The triple spots B have moved north and somewhat closer to the main spot A. The larger spots in the comma F appear to have broken up into many smaller fragments. The penumbral areas are, in general, larger and more pronounced. The light bridge A′ can also be seen. N top, E right.

back and forth along the E–W axis of the group through the neck Z – this occurs every day of observation, but is best marked on the 18th, 19th, and 23rd.

The spot group evolved rapidly after Sept. 18, as shown by Figures 5–8. By the 20th and 21st the triple spots had moved in very close to the main spot, forming a single large, complex penumbra, while the following comma of spots stretched even further to the east. After the 20th the bright plage I′ was on the north side of the following region, and concave to the south. Presumably there is some connection between the rapid evolution and the great flares which occurred on the 18th, 19th, and 20th. Our movies for the 19th show continual violent motion from 1344 to 1822 UT.

Despite the change in the appearance of the group, flares continued to occur in the same places in the distorted coordinate system. There were several explosive flares on the 24th and 25th in the successor, I′, to the old comma region and some small ones in the neck Z. The surface waves always traveled out through the neck to the west. On the evening of the 24th there was renewed activity at C on the south side of the large spot. Some small spots are seen there in Figure 7. It was here that the series of flares accompanied by type III bursts occurred on the 25th, but many surges had occurred here already on the 17th.

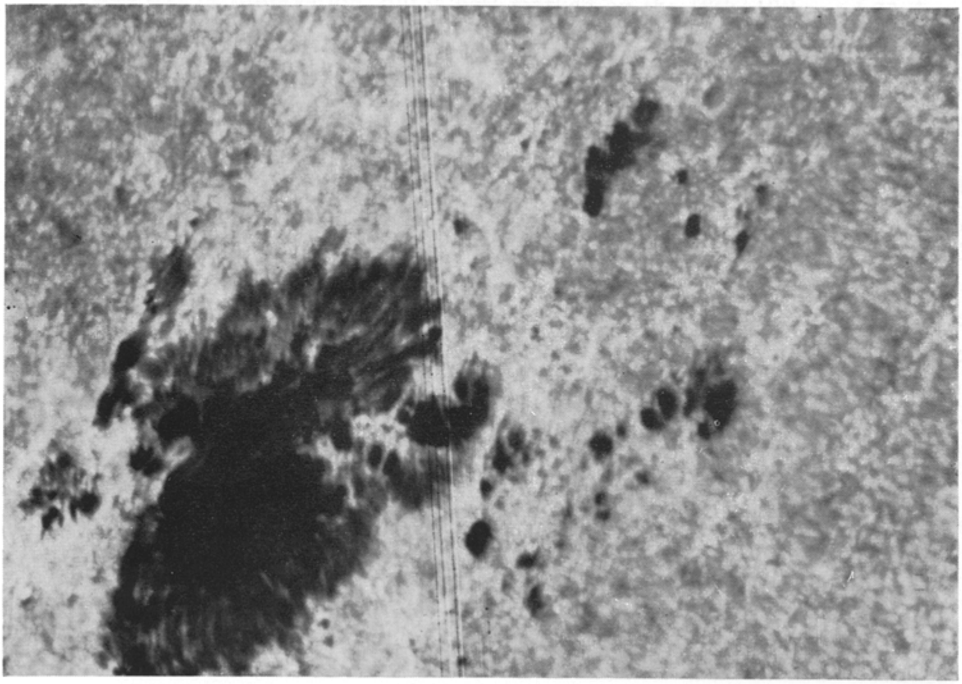


Fig. 7. Sept. 24 (McIntosh, Sacramento Peak). The triple spots B have merged with the large spot A to form a single complex umbra. The comma of spots F is now discernible only as a series of separate small spots stretching in a northeast direction. NE top, SE right.

One interesting result of the persistence of flaring regions is that we can observe similar types of flares near the center of the disk and near the limb. In viewing the pictures, one may easily be deceived into thinking the flares are dissimilar; but we must allow for the fact that we see only a surface plan at the center but a height distribution at the limb. The limb darkening of the background makes fainter features visible, but on the other hand the coarse, irregular structure of the chromosphere and of the active regions obscures many low-lying features near the limb. The sprays seen at D above the triple spot on the 17th and 18th are almost certainly far above the surface, and have little connection with the surface features against which they are seen projected.

In our identification of the times of flares, particularly those connected with simultaneous radio events, it must be recognized that many events are rather subtle. Often we may pick out a brightness increase or a morphological change leading up to a flare, but this may not reach flare brightness for some time. So the listed beginning times are somewhat subjective. We concentrate on the beginning times because these have been shown by many authors (MORETON, 1963) to be closely connected with impulsive activity, and our study bears this out (with the exception of flares with delayed flash phases). It should also be remembered that radio and iono-

Fig. 8. Sept. 26 (Bumba, Ondřejov Observatory). A single large spot with penumbra is seen. Extensive plage areas are seen in this white light photo. N left, E top.

spheric coverage are not always complete, especially after 2000 UT, and that most of the higher frequency records are not sensitive to small bursts. We found Dr. J. W. Warwick's Boulder 15–40 Mc/s data most useful (except during noise storms) because of their great sensitivity.

Correlation of the smaller events with radio bursts is difficult, because there was a continual noise storm at meter wavelengths during this period. Limb darkening eliminated this interference to some extent on the 25th, and we were able to make detailed comparisons.

3. Detailed Description

We give below a detailed description of the events noted on our films for this period compared with ionospheric and radio data. Only the extremely small events (which are very frequent) are omitted. We did not measure flare areas or attribute importance to them, but we include the measured importance in parentheses if a flare was reported by one of the regular flare patrol stations. For ionospheric data, SFD = sudden frequency deviation; SPA = sudden phase anomaly; SLSWF = slow short wave fadeout; SEA = sudden enhancement of atmospherics; SES = sudden enhancement of spherics. (Classification of 2800 Mc bursts is given in Covington's system.) We give the *beginning* of each event unless otherwise specified. The data principally comes from the Solar-Geophysical Data of CRPL. In the tables, events not observed by us are in parentheses.

The active region first appeared over the east limb of the sun on 13 September. Our observations of the region above the limb were made with the disk occulted.

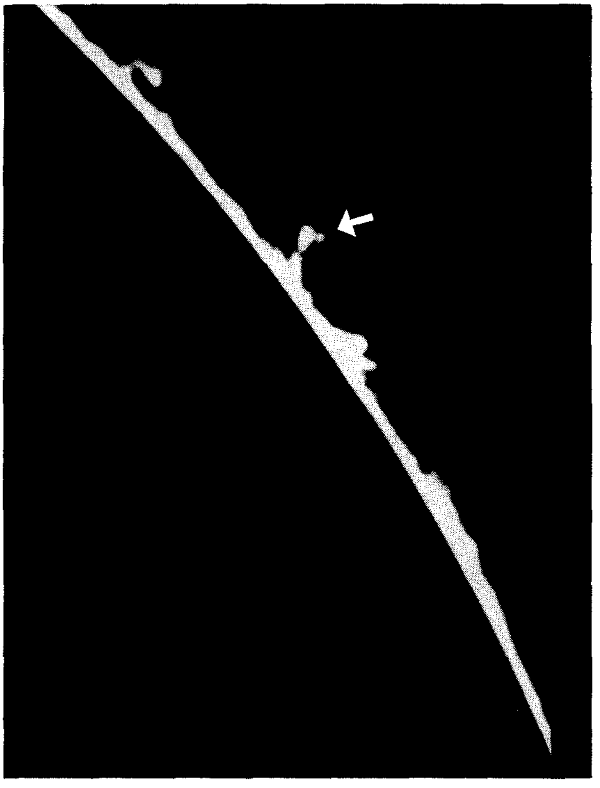


Fig. 9. Sept. 13, 1545 UT. Surges, loops and sprays such as this one (arrow) were observed as the active region appeared on the east limb.

Several events were observed in the short observing period that day, including a fast spray at 1545 (Figure 9), which produced an ionospheric effect and a bright, rapidly changing explosive ball at 1638 UT. The 1656 UT event which gave a simple 3 burst at 2800 Mc looked like a brightening of existing loops and may have been a purely thermal radio event. There were small surges and loops all day.

We had no observations on 14–15–16 Sept., but the development of the region is shown by the spectroheliograms obtained at Mt. Wilson (Figures 10, 11, 12). The region was preceded by a large dark filament dividing the S polarity of the preceding part of the group from the North polarity of the extensive unipolar region to the North. A flare is shown in progress in the picture on the 16th (Figure 12) – it is generally similar to those on later days.

TABLE I

13 September 1963. Observation period: 1346.15–1704.15 UT
Disk occulted, true location not available

Time (UT)	Event
1509	Surge ((1–) flare, 1506–11–24.)
1545	Flare Spray (SFD 1540–4.) (Figure 9.) (Flare (1), 1532–43–50.)
1625	Surge, followed by loops.
1638	(Explosive flare (1–), 1640–52–00.)
1656	In situ flare above limb ((1–), 1701–3–9.)
1657.5	(2800 Mc Burst, 1 simple 1.)

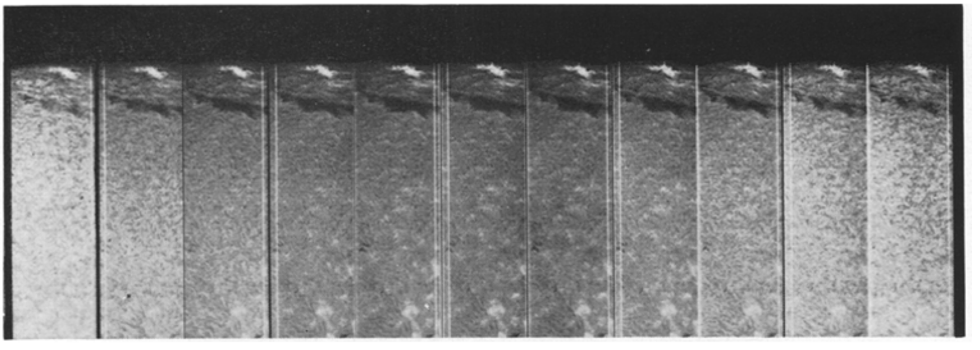


Fig. 10. 1426 to 1433 UT. Series of H-alpha spectroheliograms by Sheeley (Mt. Wilson) for September 14, showing the structure of the region in different wavelengths. Scans start at − 0.35 Å (right) and move through the line center, 0.07 Å/step. E top, N left.

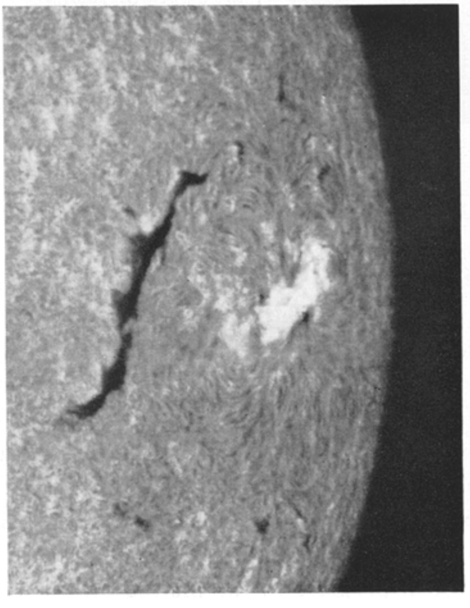


Fig. 11. H-alpha spectroheliogram by Sheeley (Mt. Wilson) for Sept. 15. N top, E right.

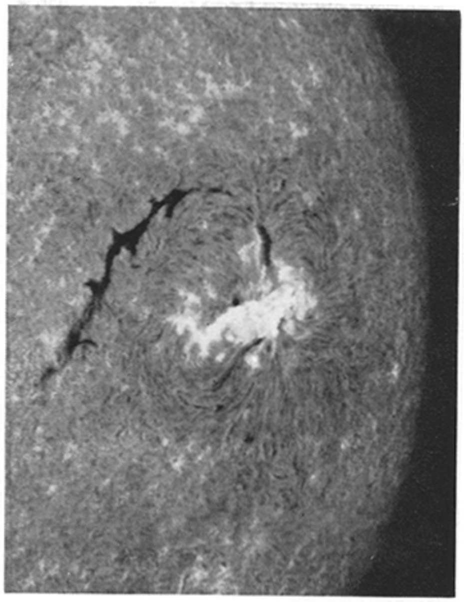


Fig. 12. Same for Sept. 16, showing a flare in progress with characteristic westward development. 1521 UT.

TABLE II

17 September 1963. Observation period: 1413.00–1650.00 UT

Location	Time (UT)	Event
		Continual flares and surging all over the group.
C′	1414	Dark surge.
G	1416	Flare. (Figure 1a, b.)
D	1420	First large spray. Probably high above surface.
C′, G	1427	Wave from returning surge C of 1414 UT travels around spot, producing flare brightening (1432, (1–)) along trajectory from C′ to G, and repeating as surge from C′ at 1438. (Figure 13a, b, c.) (167 Mc burst (BoN), 1429–1517, Type 1, Int. 2.) (IIIG burst, 1449–52 UT, Int. 2, (F.D.).)
C	1500	Small flare and dark surge.
H	1508	Flare.
C	1513	Bright flash (1–) and long dark surge. This region shows continual small brightenings and surges.
	1515–1517	(IIIG burst, Int. 3, (F.D.).)
	1529	(III burst, beginning of noise storm, simultaneous with)
H	1530	Bright wave from flare at H through neck from west to east.
	1552	(3 simple 3, 2800 Mc, Int. 1.5.)
F	1554	Bright flash (1–) duration 6 minutes. Moves along dark whorl around east of comma (L.)
C	1560	Dark surge.
G	1605	Brightening moves back and forth in bay.
D	1613	Second spray from brightening above triple spots.
F	1634	Repeat of 1554 flare (1–).

Table II summarizes the events of 17 September; positions correspond to those given on Figure 4a. The day was characterized by continual surge, spray and flash activity. A remarkable repeating surge occurred at 1414 UT (Figures 13 and 1b). Upon return of the material which surged southwest from C′ (Figure 13a) at 1414 UT, a flare occurred at C′ (Figure 13b) at the bottom of the surge, starting a second surge (Figure 13c); at the same time the wave from the falling surge traveled across the region, and a small flare occurred at G. This is the best evidence we have seen of the importance of the "splash" produced by a returning surge. A spray at D, northwest of the triple spot, at 1420 UT also appeared to be associated with this activity. Activity began in the lower region of the group with a bright wave through the neck Z at 1530 UT. Simultaneous radio and optical activity occurred many times on this day: 1429, 1449, 1515–1517, 1529 and 1613. The radio bursts always occurred before or at the beginning of the optical flare. The spray at 1613 was similar to that at 1420, and two more sprays homologous to those occurred on the 18th. All these sprays probably occurred high above the surface and are seen in projection against the area D, northwest of the triple spots.

The release of energy by material falling to the surface has been discussed before. The 1414 UT *et seq.* activity is a good example of this phenomenon.

We were particularly interested in studying 18 September because (1) fine films of flare activity were available for this day, and (2) the TESKE, DODSON and HEDEMAN (1964) magnetic map (Figure 3) was made on this day and therefore comparison could be made with the H-alpha photos. We could check the location of flare activity with respect to the zero-gauss longitudinal field contour and the region of steepest gradient. The most prominent features of the magnetic field map are a region of strong field gradient at Z, to the north of the spot, and a long loop in the neutral line extending from the large spot NW toward the triple spot. The inside of the long loop turned out to be devoid of activity; in fact the area inside this loop as seen in Figure 3 was always dark but some flares began between it and the triple spot. The region of steep gradient Z showed many small flares. It seems a general characteristic that plage (and flare) brightening only appears between the neutral line and the nearest sunspots. This gives large regions with two rows of spots of opposite polarity a characteristic hourglass shape, the sides of the hourglass being the two rows of spots and the neutral line. In late stages the hourglass evolves into the well-known "2-strand" structure.

There are two points of minor uncertainty in the McMath magnetic field map. First, there was a prominent active region filament at J which curved into a point (P) just N of the large spot, separating it from the adjacent, smaller spot. It is well-established (HOWARD and HARVEY, 1963) that filaments mark the boundary between fields of opposite polarity. Therefore the filament, (J) designates this boundary. The McMath map does not show this boundary, probably because there are not many measurements in the region of the filament. The Mt. Wilson drawings show a spot of opposite polarity just N of the large spot. Bumba's white light photographs as well as our H-alpha photographs show extremely complex structure in the large penumbra

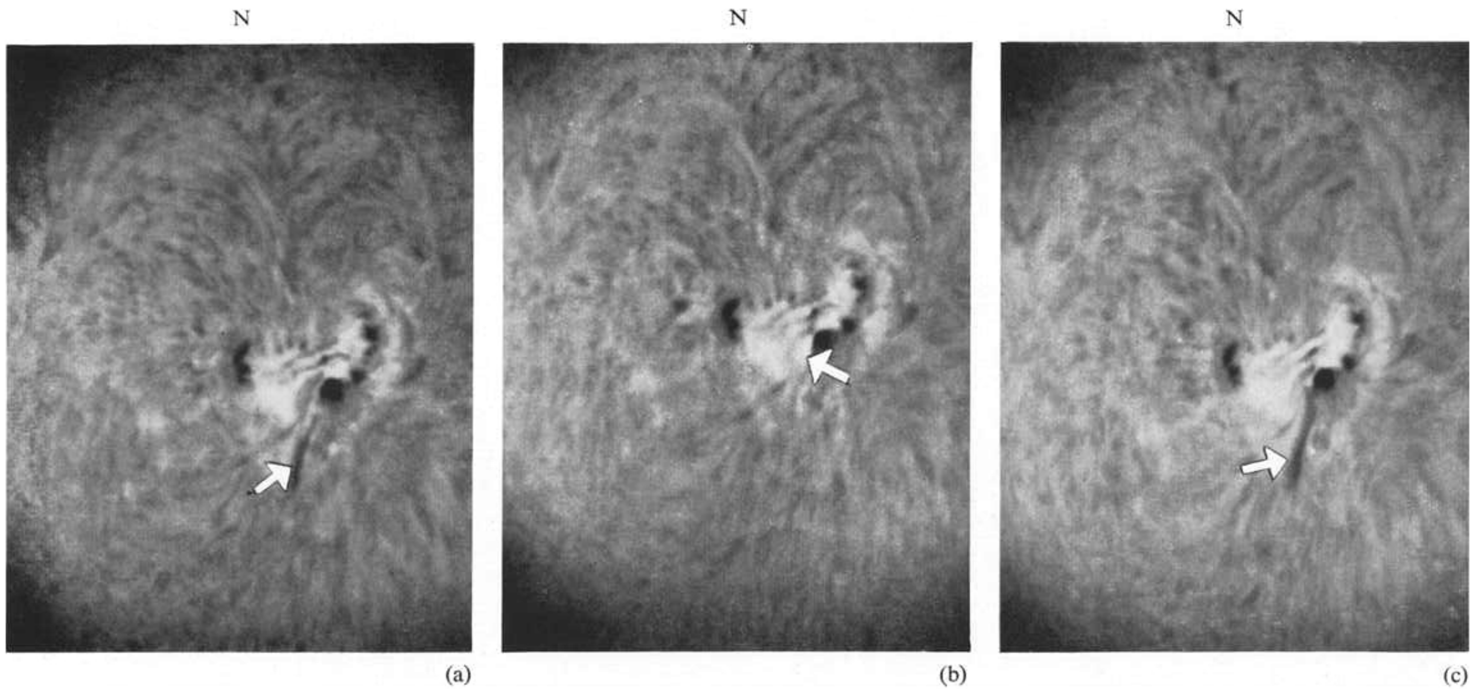


Fig. 13. Sept. 17. (a) 1417 UT. First surge to southwest from C′ followed upon its return by (b) flare at 1434 UT and (c) a second surge and flare at G at 1448 UT. Arrows show each point of interest.

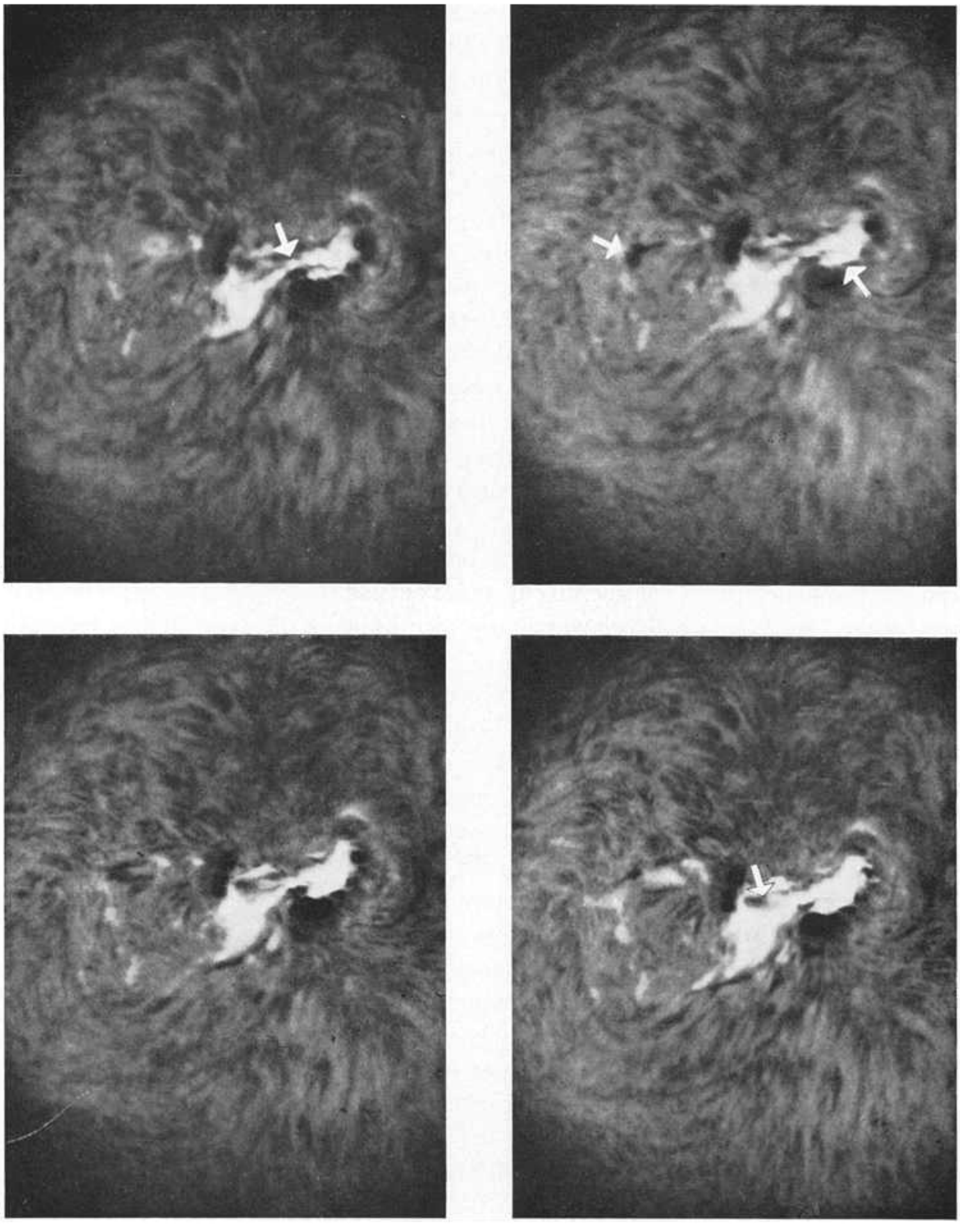
TABLE III

18 September 1963. Observation period: 1333.00–0059.00 UT

Location	Time (UT)	Event
A′ or P	1344	Brightening starts.
D	1357–1416	First spray at D, north of triple spots. Simultaneous with those shown in Figure 14a, b.
Z	1357	Small flare in neck Z; (X-ray burst at 1356.)
H	1354	Flare.
G	1402	Start of Class 2 flare with gradual brightening in G. (SLSWF 1405–23–1515.) (SFD 1413–16.)
All over	1413	Rapid (less than 1 min.) rise to brightness. Probably starts from neck and then fills entire hourglass. (2800 Mc burst.) Figure 14c, d.
D	1414–1434	Second spray.
J, C′		Continual brightening beside filament J and motion of same. Continual small flares and surges at C′.
G	1531	Small flare (1–) spreads from A′ into G. (Weak type III. Radio storm all day (Sydney).)
	1534	(Intense type III.)
	1557	(Intense type III.)
Z	1600	Flare (1–) spreads from both sides of neck Z, fills hourglass, but Z remains unbrightened.
	1612, 1619	(Intense type III.)
G	1700	Rapid flare (1 min. rise) clearly comes out of light bridge A′, fills G and I. (Weak type III.) (SFD (10) 1659–00–02.) Figure 15a, b.
J	1700	Flash and wave along filament J (1–); probably triggered by flash on the N side of H. (Strong type III.) (Figure 15.)
	1710	(Strong type III.)
	1713	(Strong type III.)
J	1857	Flare (1–) NE of filament J.
	2045	(Continual type III bursts.) (Sydney 2216–19G (I).) Clouded out, 1911–1945, 2104–2130.
G	2130	Flare at G. (Strong type III's.) (2132–54G (I) Sydney.) (2130–3–9 SFD (04).) (2130–2400 III Sydney.)
	2131	(Group of bursts, Hawaii and Sydney.)
D	2141	Spray.
B	2143	Flare along SE side of triple spot enlarges, brightens (Figure 16a–d.)
A	2215	Flare from G begins to cross umbra near light bridge A′, but at 45° angle to same (unfortunately). (2231–2–4 SFD (03).)
B	2244	Flare begins crossing first of triple spots.
A	2248	Flare (1) reaches far side of large spot.
B	2303	First of triple spots totally covered, second partially covered.
	2322	Flare assumes 2-strand structure, covering both row of spots.
	2330	(Radio continuum becomes much more intense to sunset.)

which may not have been resolved in the McMath map. The neutral line must have wound between the long sunspots in a complicated way. However the large scale magnetic structure is fairly consistent with the other data.

The overall structure of the flares in the region clearly depends on the magnetic



(a) (b)

(c) (d)

Fig. 14. Sept. 18. (a) 1358 UT. Small brightening in neck region Z (arrow); spray at D begins above triple spot. – (b) 1400 UT. Spray fully developed and dark (arrow); brightening spreads through the bay of flares (I). This is the beginning of the Class 2 flare. – (c) 1413 UT. Flash phase. Rapid spread of brightness through hourglass. – (d) 1418 UT. Maximum of flare. In this case region along the filament J does not brighten, as in later big flares.

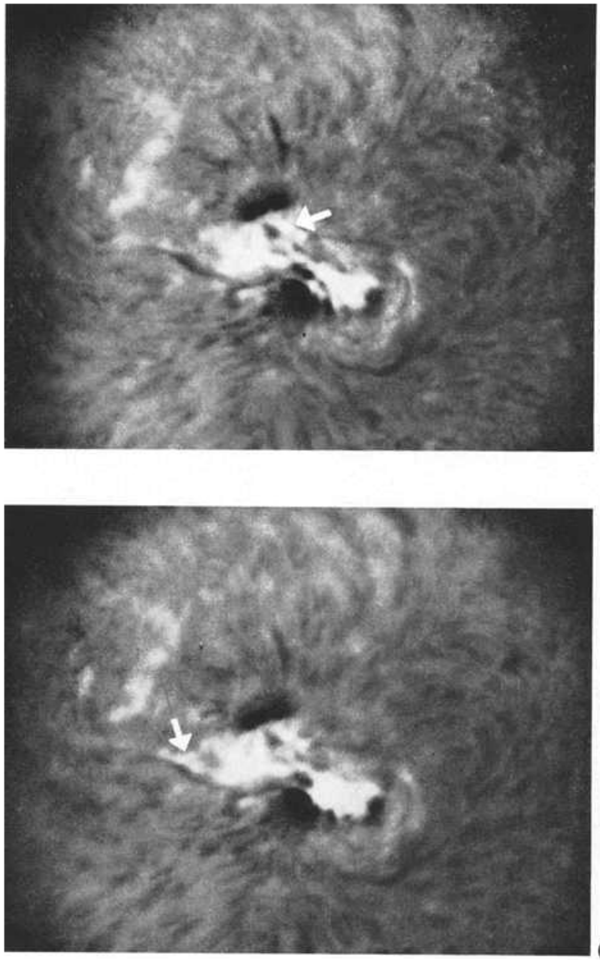
field structure, which, as outlined in H-alpha, *did not change significantly* in the course of the day. The large flares showed at maximum brightness the characteristic hourglass shape (part of which may have been due to the superposition on the relatively dark sunspots) which we have already noted. The west portion H was between the filament and the triple spots of N polarity in the NW and the east portion I was a "bay of flares" between the neutral line and the comma-like chain of spots (of S polarity) F. The northeast boundary of this bay I was also bounded by the neutral line loop extending from the main spot to the triple spots. The large bright regions of the hourglass were connected by the neck Z, where field gradients were the greatest. There were also bright strands connecting the glasses through the point P to which the filament pointed, which must also have been a neutral line, separated from Z by a long sunspot. We must emphasize that the configuration of a flare at maximum area and brightness may have no relation whatever to the configuration in which the flare energy is released – it may only be the locus where this energy is delivered to the surrounding chromosphere. An alternative possibility is that this is the locus of unstable regions where energy release is called forth by a wave of excitation from the seat of the flare.

It is interesting that the region of flare brightening extended along the N polarity side of the filament for a considerable distance outside the group. This is particularly true of the 2215 UT flare, which was almost identical with the Sept. 20 flare recorded by Lockheed.

There were three major flares on 18 September. An initial spray occurred at 1357 UT homologous with those of the 17th. A small flare in the neck region (Z), i.e., the region of steepest gradient, triggered a flare (Class 1) at 1413 UT (Figure 14). After a flash at 1404 UT, a disturbance moved out from this neck region in both directions. A brightening also appeared (1407 UT) south of G inside the comma of spots and spread to the north across the tops of these spots. At 1413 UT a brightening in the glass H spread around the loop in the neutral line. and one minute later a bright wave passed through the neck Z from east to west and the entire flare brightened sharply in less than 1 min. (flash phase). Simultaneously there was a 2800 Mc/sec burst and SFD. Also at 1414 UT there was a small brightening in the region G; again the brightening was preceded by some activity in the neck.

Later in the day a small bright flash at H′ may have been the trigger for a flare coming from the light bridge A′ (Figure 15), filling the east glass I′ and spreading along the filament J. Finally there was strong flare activity beginning at 2130 UT. In its late stages (Figure 16) the 2215 UT flare extended partially to cover the umbra of the large spot and to completely cover the first and part of the second spots of the triple spot group in the characteristic 2-strand fashion noted by Dodson. Most events on this day were preceded by some sort of activity in the Z region. There was a radio storm all day at dekameter and meter wave lengths, but it is sometimes possible, as already noted, to pick out coincidence of flares with various strong bursts superimposed on this background.

By Sept. 19 the large spot A had split into three parts (Figure 17a) – one of the



(a) (b)

Fig. 15. Sept. 18. (a) 1700 UT. Flare begins in light bridge A′, immediately preceded by flash in bright arm H′ (arrow). SFD and intense type III burst occurred. – (b) 1703 UT. Flare spreads across bay of flares I and west along filament. N upper right, E lower right.

dividing lines was more or less where the flare had crossed the large umbra at 2215 UT on the 18th. Although no flares of importance greater than 1- occurred during our short period of observation, there was continual activity, including many small brightenings and a continual waving about of the large filament J (Figure 17b). A small dark surge below the triple spots at 1355 UT and a very small flare at P at 1417 UT next to the large umbra were accompanied by 108 Mc radio bursts. Again much activity occurred near the Z region of steepest magnetic field gradients but the most intense activity was east of A near the small spots broken off from the main umbra. Minor flare activity was observed in the eastern plage region I. A small new spot appeared at C with a very small flare at 1350 UT. On some of the pictures

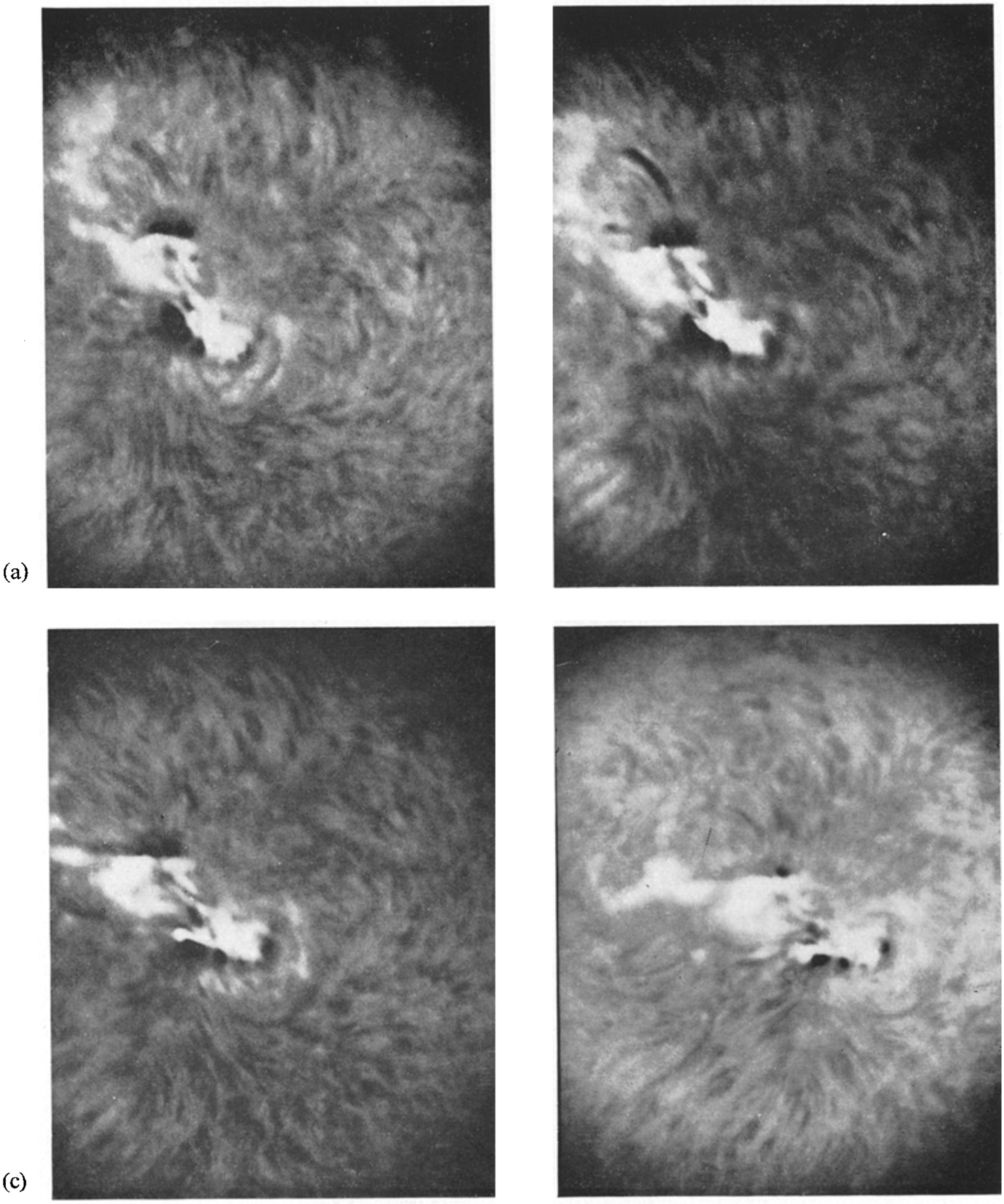
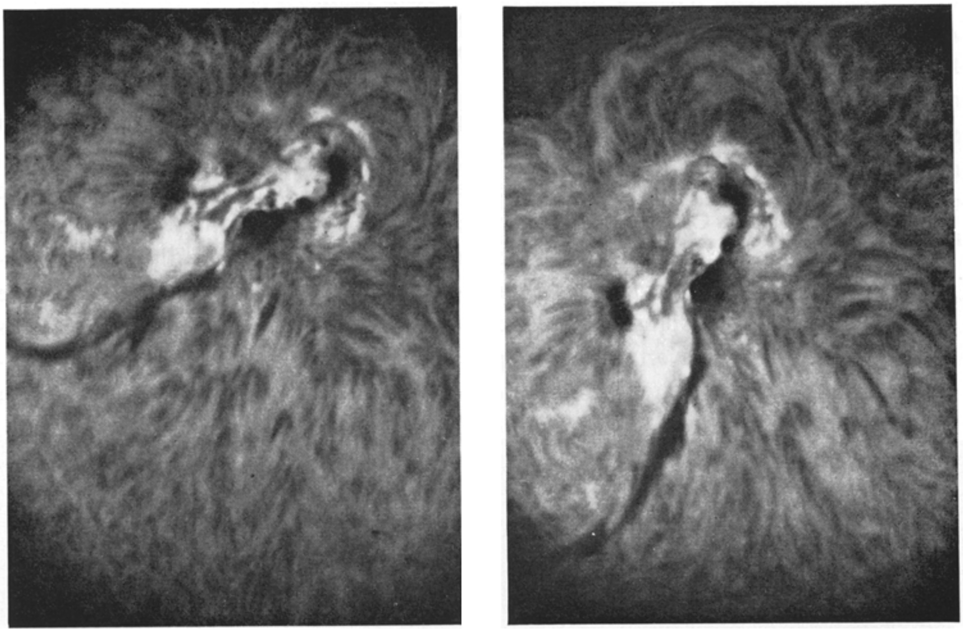


Fig. 16. Sept. 18. (a) 2146 UT. Flare southeast of triple spots. This activity spreads until (b) major brightening begins in the bay I at 2233 UT, and is accompanied by major radio bursts and a spray at D. – (c) 2255 UT. Flare crosses triple spot. – (d) 2339 UT. Late in the flare sequence the appearance is similar to the Sept. 20 flare filmed by Lockheed (Figure 18). W upper left, N upper right.



(a) (b)

Fig. 17. Sept. 19. This was a day in which continual motion of the large filament J was observed. Note the difference in structure in the filament at (a) 1419 UT and (b) 1621 UT. The image rotation between the two frames is due to diurnal motion seen from the coudé.

TABLE IV

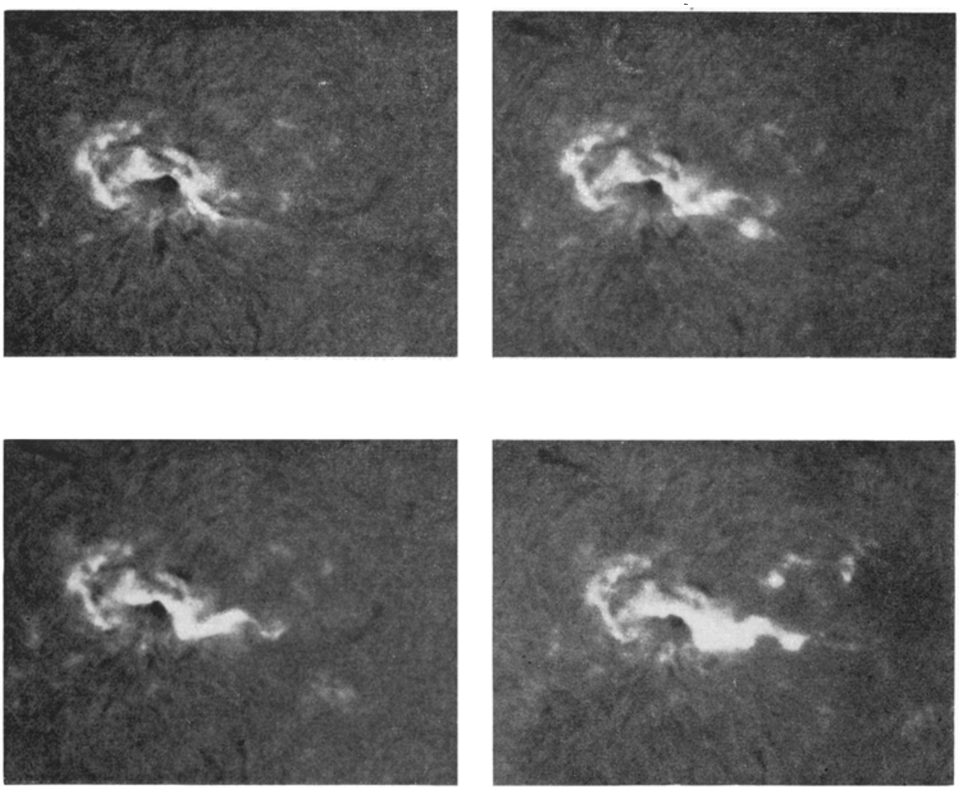
19 September 1963. Observation period: 1344.00–1822.00 UT

Location	Time (UT)	Event
J	1344	Continuous motion in long filament, intensifies at 1407 and lasts to 1822 (Figure 17a, b.)
C	1350	Series of small brightenings in area which becomes prominent plage region later.
Z	1355–1411	Small dark surge below triple spots south of Z.
	1415	(108 Mc burst.)
P	1412–1429	Small flare (1–) in neck P. (Figure 17a.)
		(3 simple 3. 1517–1647–1717.)
		(108 Mc burst, BoN.)
G, L	1604	Fast flash at G; also along filament L.
	1610–1615	(Burst BoN, 108 Mc Bv.)
I	1630	Flare (1–), spreads across region, followed by violent wave through
J	1650	filament. Widespread but not intense brightening.

obtained it is possible to see the lower arms of some of the loops which are formed by the return of the ejected material to the surface of the sun.

Excellent observations were obtained by the Lockheed Solar Observatory of a large flare on Sept. 20 (Figure 18). This "Class 2" flare produced a series of large ionospheric effects, type II and IV radio emission, and a remarkable wave (Figure 18) which is seen on the Lockheed pictures to travel across most of the solar surface. We have examined films kindly furnished by Ramsey, for the purpose of comparing the morphology of this important flare with the others that we observed in this period. Although the Lockheed films were made with a smaller image than ours, they are of very high quality, showing considerable detail.

The appearance of the Sept. 20 flare was very similar to that of the class 2 flare at 2303 on Sept. 18. On the 20th the triple spots had moved considerably closer to the main spot, so the general shape of the region was considerably different. Nevertheless the flare started somewhere near the neck Z and spread westward along the filament. An enormous spray was emitted in the flash phase; the Lockheed observations showed that this was overtaken and apparently accelerated by the magnetohydrodynamic surface wave. The ejected material and the wave both traveled outward in a southwesterly direction formerly marked by the filament J (which later reappeared). This path was followed by surface and excitation waves from almost every large flare in the region, as was apparent from activity in the filament in every case.



(a)

(c)

Fig. 18. Sept. 20. Four stages in the great flare as photographed by Lockheed Solar Observatory. (a) 2349 UT. – (b) 2353:10 UT. – (c) 2357:10 UT. – (d) 2359:40 UT. N top, E right. The flare wave moved off to the west (right). Compare with the flares in Figures 12 and 16.

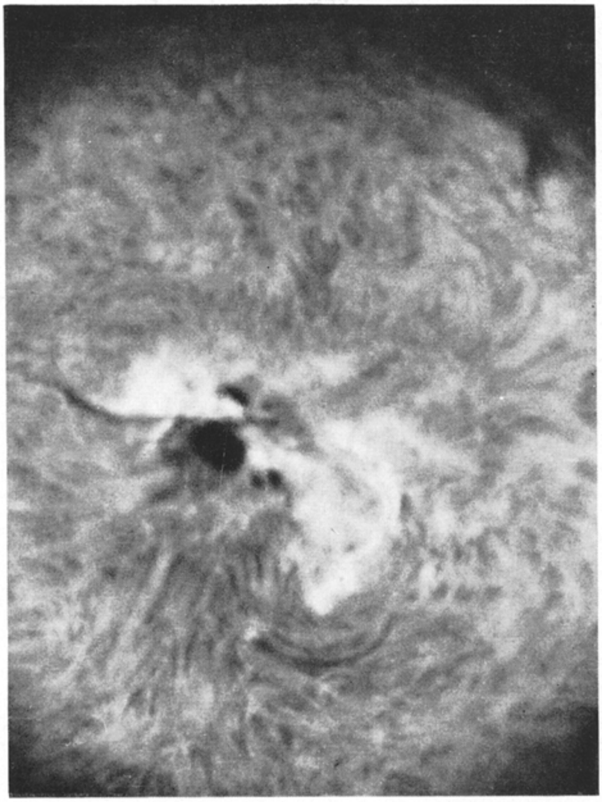


Fig. 19. Sept. 22, 2210 UT. This day was very quiet. The old plage I, along the comma of spots is replaced by a new plage I′ concave to the S. A small flare is in progress at A′, W of the large spot.

By September 22 the appearance of the region had considerably changed (Figure 19). The triple spot configuration had disappeared and there remained only a small spot of north polarity opposite the main spot. The plage region had greatly decreased in area although it still showed the overall hourglass shape. The east branch of the hourglass was now dominated by a bright region I′ arching northward. All that remained of the long comma (F) of spots were two small spots directly east of the large spot. The neck Z between these still connected the two glasses of the hourglass. Although the magnetic configuration may have changed since the last Mt. Wilson measurements on the 20th, the well-developed filament which cut through the group marked the neutral line separating opposite polarities. The umbra A appeared as a single spot on this day. There were a few flares around Z. In general, however, the region was very quiet on the 22nd; a few small surges and brightenings occurred, all of which are listed.

On September 23 activity increased in the region, although the general magnetic configuration and distribution of plage did not seem to have changed. On this day there was a remarkable flow of disturbance back and forth across the region, with

TABLE V

22 September 1963. Observation Period: 2103–0035.00 UT

Location	Time (UT)	Event
I′	2113	Small.
Z	2120	Small flare (1–).
	2122	(Weak type III.)
I′	2152–2158	Surge; (type III burst.) Numerous small surges here throughout the day.
Z	2157	Tiny flare just S of triple spots.
A′	2210–2222	Tiny low-intensity flare; (type III burst (Sydney).) Repeat brightening. (Figure 19.)
A′	2213	(Strong type III observed.)
I′	2219	Large, active flare; no radio bursts.
A′	2220–2222	Tiny flare; no radio burst.
Z	2314	Tiny flare; no radio burst.
I′	2318–2339	Dark surge; begins with a small explosive phase.
Z	0015	Small, fast flare.

one flare or surge triggering the next. This phenomenon is very easy to see on the films. The disturbances moved back and forth along the axis of the plage defined by the curving neutral line through Z and the new curved bright plage I′ on the northeast side of I. Some disturbances from I′ moved across the southeast edge of the large spot Z.

TABLE VI

23 September 1963. Observation period: 1340.00–0037.00 UT

Location	Time (UT)	Event
I′	1421–1425	Small bright bead flies out of filament I′ toward C where the dark surge appears. (Figure 20)
Z	1425	Flare at Z along bead trajectory. (Type III burst.)
C	1428–1507	Dark surge shoots out, falls back
Z	1439, 1453	Sudden flashes west of the 1425 and 1449 flare regions.
Z	1449	Repeat of 1425 flare.
I′	1452–1458	Plage I′ brightens.
Z	1504	Repeat of 1425.
I′	1514	Brightening with return of bead (1–).
	1534	(Type III burst.)
I′, L	1540	Large brightening of entire east end of plage.
J	1638	Tiny bright spot along north side of filament J. Brightening of plage.
	1639	(Type III.)
Z	1641	Dark surge slightly northeast of Z.
I	1652–1739	Small surge.
Z	1713	Small fast brightening east of Z.
L	1742, 1810	Homologous brightening of entire east end of plage, similar to 1540.
	1939	(Weak type III.)
I′	1950	Large rapid dark surge northeast of I′.
I′	2254	Flash. (Type III's at 2258, 2300, 2305, 2310, 2313, 2333 UT.)
J, I′	2314	Bright fast flash north of filament. Simultaneous flash in I′.
I′	0027	Flash.

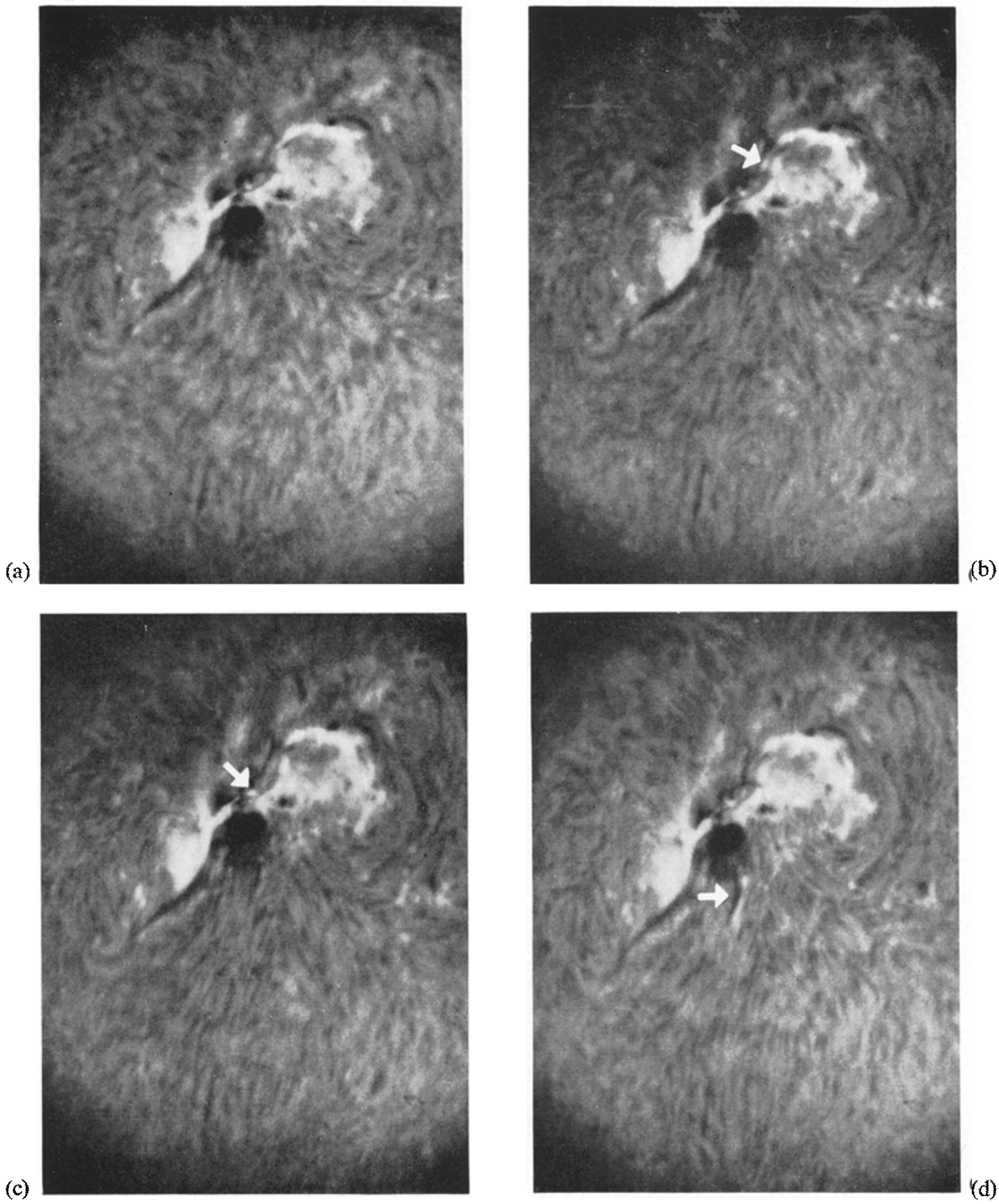
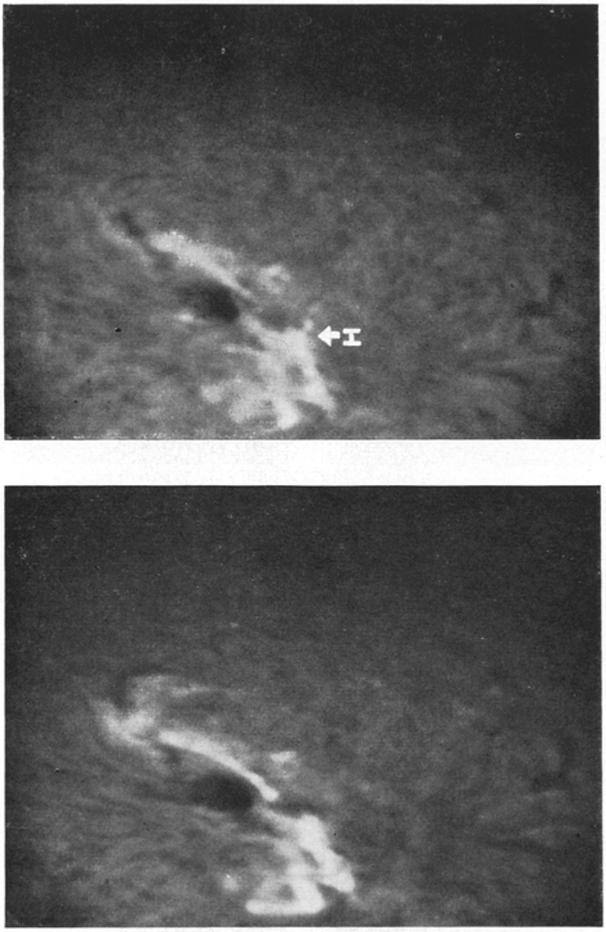


Fig. 20. Sept. 23. (a) 1422 UT. Plage I′ lengthens and (b) at 1434 UT appears to eject a bead which travels (c) along neutral line (1424 UT), producing (d) small flare (1425 UT) and moves on across the spot A to produce a surge (e) from C. After the surge fell back, a return wave produced a second flare in I′. N upper left, E upper right.

The most interesting even on our films that day was the appearance of a bright bead (1421–1425 UT) ejected from I′ in a SW trajectory across the spot (Figure 20). The bead produced two rapid flares in Z (in the plage referred to on the 24th, Figure 21), and when it crossed the sunspot, also produced a flare and surge at C. When the



(a)

(b)

Fig. 21. Sept. 24, 1439 UT. (a) A bright spray at I′ initiates a flare which spreads over the entire region, brightening rapidly in one minute at 1446 UT. – (b) The long bright strand northwest of the large spot is probably suspended above it and appears in other flares. N upper left, E upper right.

surge returned, a disturbance passed back along this trajectory, the bead reappeared, and the entire I′ region brightened, weakly at first, then strongly at 1540 UT. The 1540 UT brightening of the entire plage I′ was repeated at 1742 and 1810 UT.

Disturbances traveled back and forth along the main axis of the group (i.e., the line from I′ through neck Z and out along the filament) all day.

The activity in the region increased further on the 24th, as it approached the limb.

Two very similar explosive flares occurred at the beginning and end of the day. At 1437 UT (Figure 21a) a bright spray was ejected vertically from I′, accompanied by a strong type III burst. The flash phase occurred at 1442 UT with a rapid spread of brightness across the center of the region and westward along the large filament (Figure 21b). It is interesting that the ionospheric effects coincided with the flash phase at 1446 UT and not the spray ejection-explosive phase at 1438 UT – the same is true of the 2800 Mc/sec burst. Possibly the flare produced a great increase in the temperature and density of the corona, including enough energetic electrons to

TABLE VII

24 September 1963. Observation period: 1340.30–0033.00 UT

Location	Time (UT)	Event
C	1417	Small fast surge-flare.
C	1437	Homologous surge-flare simultaneous with major flare brightening (1). Begins at I′ with bright spray.
	1438	(Strong type III. 3 simple 3 (max at 1447).)
J, I′	1445	Brightening and disturbances spread through entire plage, both I′ and along filament J. Figure 21. Continuous violent disturbances moving out along the filament. (2800 Mc burst; max at 1447 UT.) This was probably a class 2 flare, considering the ionospheric effects. (1445–53–1515 SPA (1), SLSWF, SEA (2), SES.)
D	1518	Brightening (1) followed by dark surge.
D	1539–1559	Dark surge followed by brightening at 1549 UT. (Type III.)
D	1703	Small brightening (1–) in D; (type III burst.)
L	1705–1713	Brightening (1–); possibly triggered by small flare at D, with disturbance moving south, at 1703 UT. (Two type II's at 1705 UT and type III at 1726 UT.)
I	1842	Disturbance at I. Bright bead similar to that on Sept. 23 flies out to the west, while a small dark surge goes east. (Type III burst.)
	1919	(Type III burst.)
L	1925–1931	Bright flash (1–). (2800 Mc, 1 simple 1; no 30 Mc burst.)
	1943	(Weak type III.)
Z	1944	Flares (1–).
L	1957	Spray of low brightness.
L	2024–2055	Spray (1–) in progress. New spray begins at 2029 UT. Comes back down rather violently at 2034 UT.
	2103	(Medium type III.)
D	2113–2121	Bright high surge.
	2114	(Very weak type III.)
C	2118	Fast umbral flash at C (in 3 frames). (Type III.) (Figure 22)
	2125–2135	Fast brightening.
	2149	Flare near umbra.
I′	2155	Fast brightening with dark surge.
I′	2204–2225	Dark surge.
	2202	(Type III.)
	2204	(Type III.)
	2219	(Strong short type III;) dark filament gradually appears.
	2337	(Type III.)
L	2337	Small "trigger" brightening at L.
I′, L, Z	2343	The entire region explodes (1–?). (Weak III's at 2349 and 2353 UT.) (Figure 23.)
	2345	(Strong type III.)

produce the non-thermal radiation which accounts for the ionospheric effects. During the flare there was a pronounced waving and changing of the filament at the west, and successive surface MHD waves traveled out along this neutral line, in the general direction followed by the large Sept. 20 wave.

This flare was observed by six stations and classed as importance 1 by all; it probably should rank as importance 2. The reason for this discrepancy is no doubt its proximity to the limb.

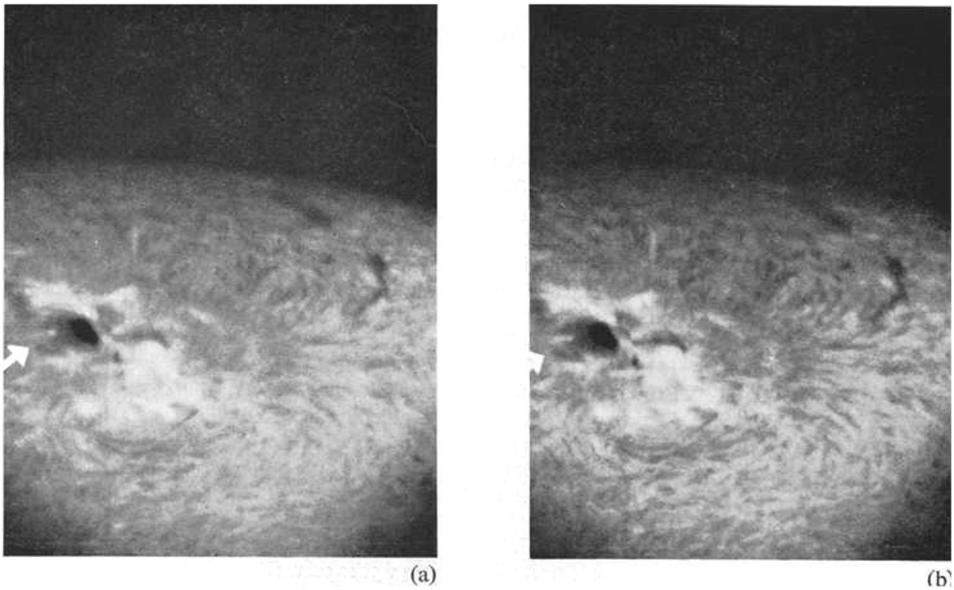
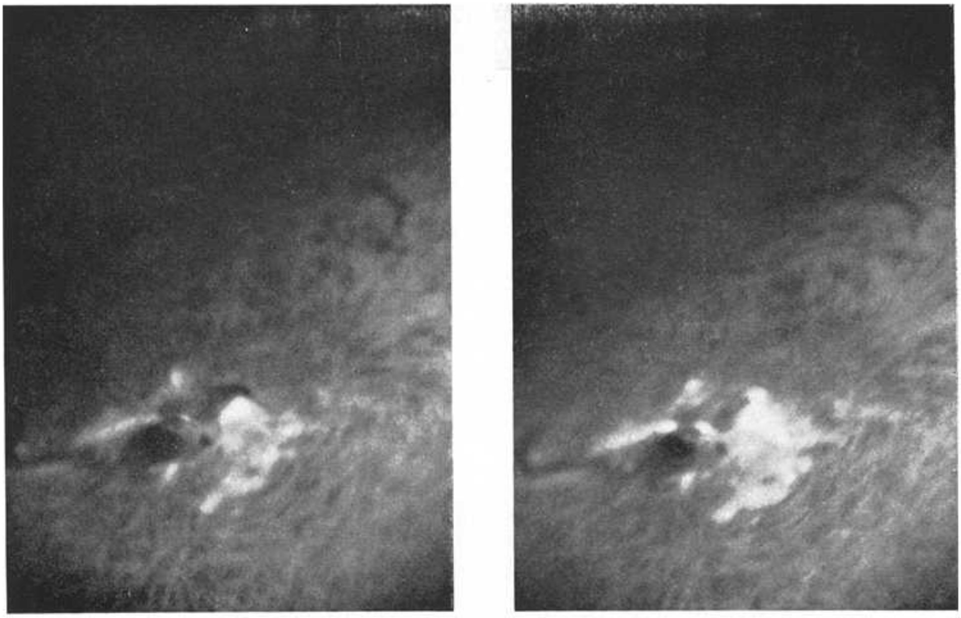


Fig. 22. Sept. 24, 2118 UT. Umbral flash (arrow) shoots out of penumbra to the left. (a) 2118:15 UT. – (b) 2118:30 UT. This flare only appeared on 3 frames but produced a moderate type III burst. N upper right, W upper left.

Figure 22 (a, b) captures a very rapid umbral flash. Within 12 seconds the small area at C′ brightened and material appeared to squirt out very rapidly to the southwest. We have observed about six such flares in other large sunspots. They always are short-lived, relatively faint, and limited to a sector of 20° or less. All the ones that we have seen produced type III bursts. They may appear in the penumbra of a round spot, or come out of a light bridge or notch in the spot. In round spots a faint plage may be seen leading up to the umbra in the flare sector.

During the rest of the observing period on the 24th there were numerous small brightenings, some of which were accompanied by radio bursts, but the general noise storm limited the number of clear events. At 2343 UT (Figure 23) there was a very rapid explosive flare at I′, possibly triggered by a nearby brightening at 2338 UT. In a few minutes the entire region erupted in a bright spray, with simultaneous brightening of different distant points.

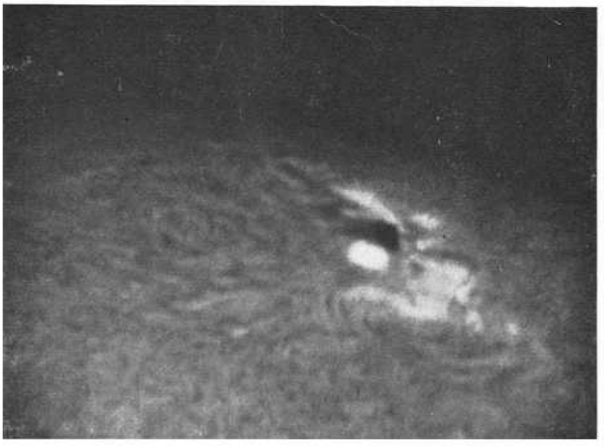


(a) (b)

Fig. 23. Sept. 24. Explosive flare. (a) At 2342 UT a faint flash repeated at the point of the 2118 UT umbral flash. At 2344 UT the neck Z brightened for a minute and faded. (The large looped filament appeared around 2300 UT.) Then at 2345 UT. – (b) the flare exploded outward from I′, spreading across the entire region. This flare deserved more than its official 1- designation. N top, E right.

The 25th of September was one of the most interesting days of this period. The region was one day from the limb, and the height resolution obtained gives a nice three-dimensional effect to the pictures. In addition the seeing remained good all day. The radio noise storm was limb-darkened by the 25th, so that single radio bursts were easy to pick out. New activity appeared to the south of the main spot in C in an area previously fairly quiet except for small surges. All day long there were small bright flares in C and the surrounding area. One type is shown in Figure 24; it repeated several times during the day. The sharp rise in brightness occurred in less than one minute at 1415 UT, accompanied by strong type III bursts at 1415 and 1417 UT. Surge flares, bright and dark, occurred at C′ numerous times. An example is shown in Figure 25. Another type of flare in part of this region occurred at 1842 UT (Figure 26) and 2134 UT. Although these flares were smaller in area, they produced intense type III bursts – the first was also observed in the centimeter range at Ottawa. All of the flares referred to were *in situ* flares, represented by rapid brightening with no apparent motion. A very interesting aspect of these flares is that every one in and around region C produced a strong type III burst on the rather sensitive Boulder records. There were a few flares outside this area during the day – none of them produced radio emission. Apparently the conditions in this region were auspicious for repeated flares and for the production of the energetic streams or waves that

(a)



(b)

Fig. 24. Sept. 25. This flare is typical of several *in situ* flares at C on this day. (a) Region at 1413 UT. – (b) 1415:30 UT with sharp rise to maximum brightness at (c) 1416 UT. W top, N right.

produce type III bursts. There even seems to be a general similarity (not surprising) between bursts from homologous flares, but there is insufficient structure to make definite conclusions on this score.

Late in the day there was another large explosive flare from region I′, very similar to the two of the 24th, but with differences that the reader may judge from the illustrations (Figure 27). It is interesting that this flare was closely preceded (triggered?) by a surge flare in C, and also followed by one; both these flares produced much larger radio bursts than the explosive flare. It is possible to watch the wave of excitation move across the group and trigger the last flare.

In each of the flares a dark prominence (at I′; E of the spot, in Figures 22, 23, and 24) builds up before the flare, similar to the effect noted by the Lockheed ob-

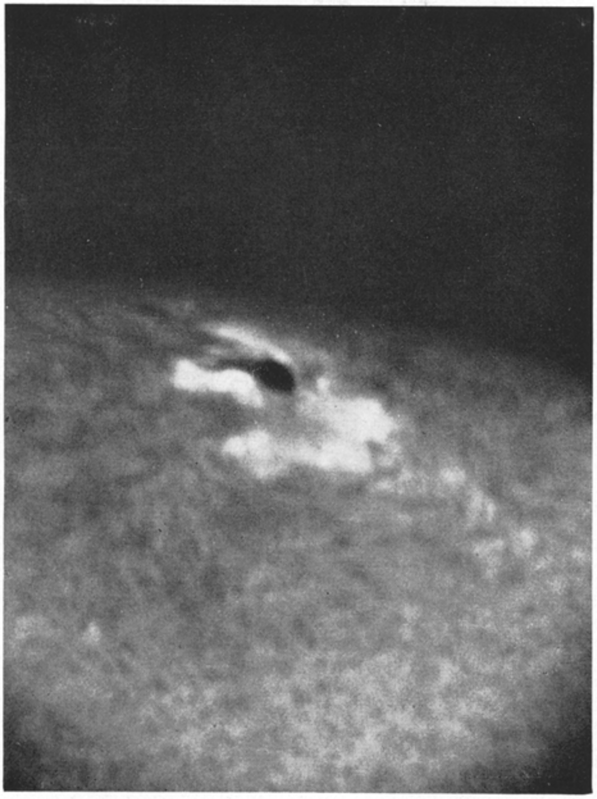
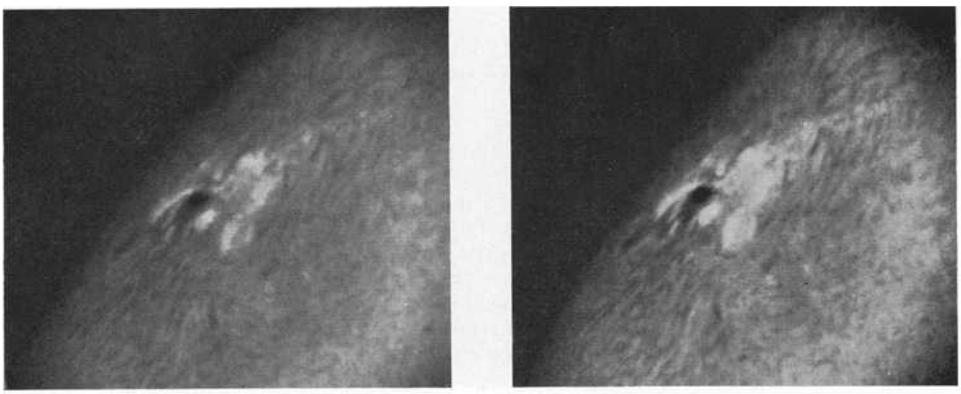


Fig. 25. Sept. 25. Bright surge flare 1823 UT. Several of these occurred at C′ on this day, accompanied by similar type III bursts. W top, N right.



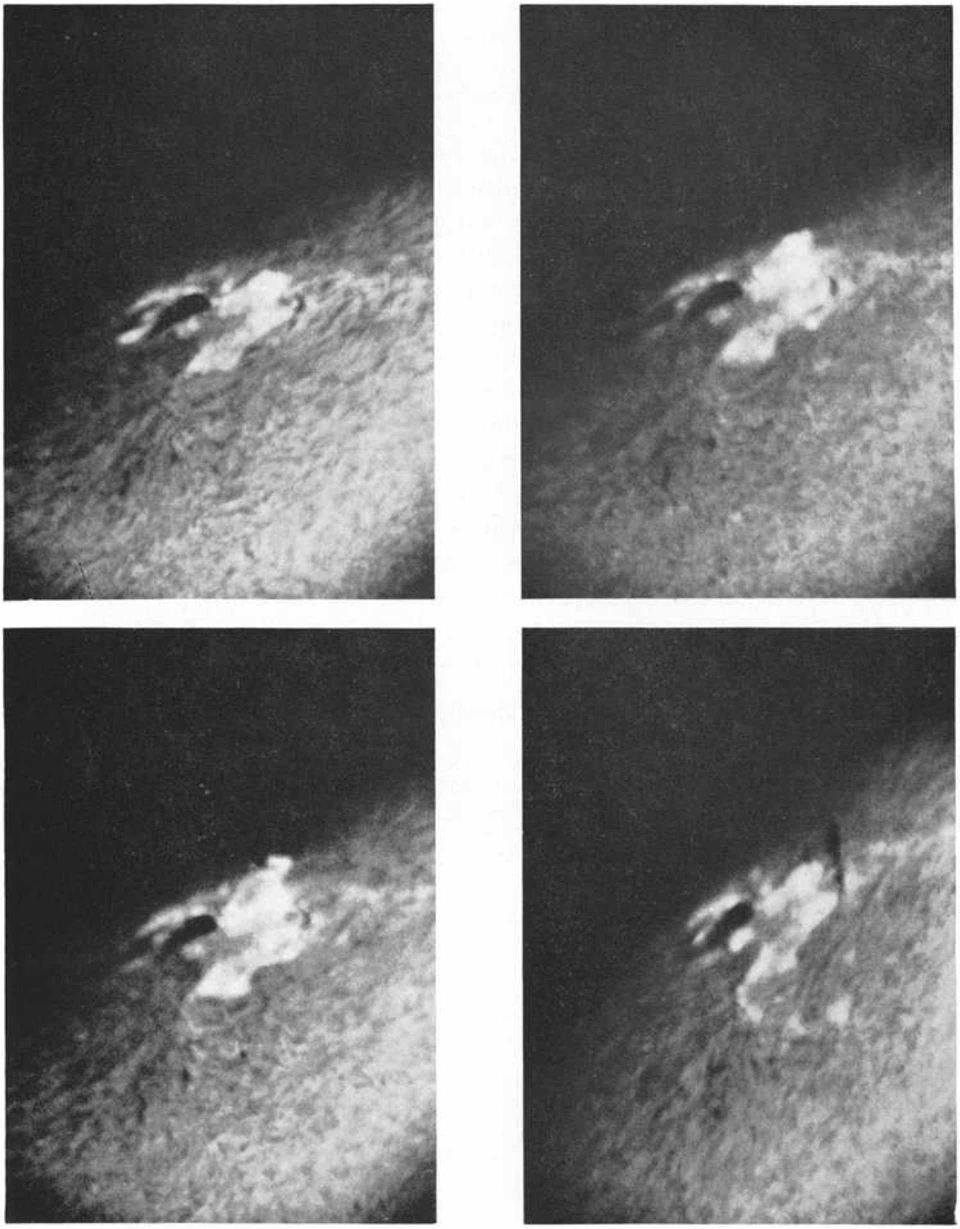
(a) (b)

Fig. 26. Sept. 25. Small (1-) *in situ* flare at C. (a) 1842 UT. – (b) 1846 UT. This flare produced an intense type III burst despite its small size.

TABLE VIII

25 September 1963. Observation period: 1339.4–0033.00 UT

Location	Time (UT)	Event
C	1347	Small brightening south of spot A; (type III bursts.)
C	1358–1402	Flare (1–) south of spot A. Maximum at 1400 UT.
C	1412–1425	Bigger flare, same place, with dark surge from center. Maximum at 1417 UT. Blows off bright material at maximum brightness, turning to dark surge at 1423 UT. (Figure 24.)
	1415, 1417	(Very intense long type III bursts.)
	1429	(Medium type III.)
C	1451	Large dark surge. (Type III at 1448 UT.)
C	1455	Small brightenings on north edge of area C with long surge.
	1520, 1559	(Intense type III.)
C	1609	Small brightening with surge.
	1611	(Weak type III.)
Z	1614	Brightening (1–) with ejection of matter. Repeated at 1623.
C	1633	Flash (immediately preceded by smaller one.)
Z	1633	Small brightening. General brightening of I′.
C	1641	Brightening.
	1643	(Intense type III.)
A′	1658	Rapid flash.
Z	1717–1725	Small flash.
C	1729–1735	Small flash.
L, I′	1730–1739	Flare (1–) simultaneous with brightening of two points of C (identical with 1842 UT.)
A	1757–1774	Spray from A to the southwest more or less along C.
C′	1823	Surge flare.
C	1842–1850	Small flare (1–). Max. at 1843 UT. (Very strong III (Boulder), 2800 MC burst (Ottawa) group of III's observed at Ft. Davis.) The two points of C that brighten here show many small brightenings during the day. Figure 26.
C′	1958–2023	Bright surge.
C′	2000–2011	Small dark surge.
	2025	(Medium type III.)
C′	2029–2043	Small flare (1–); triggers the following event. (Group of type III's.)
C	2037–2049	Bright flare homologous with 1958 UT (1–) with large ejection of matter; max. at 2039 UT.
	2132	(Intense type III's.)
A	2134–2142	Small brightening all through the area near umbra A.
C	2201–2225	Small brightening with major ejection of matter along C′ (bright surge); (medium type III burst.)
C′	2251	Bright surge north of C′; (strong type III at 2308 UT. (1–).)
I′	2257	Large spray (1–); (type III (2308–2309g).)
	2313	(Group of weak type III's.)
	2317	General brightening. (Figure 27.) Propagates along extended lower plage region and out into region 2.
C	2330–2336	Large spray; (group of weak type III's.)
C	2336	(Intense group of type III's.) Small flare with bright surge.
C	2338	Bright flare and large surge; repeat of 2330 UT on larger scale.



(a) (b) (c) (d)

Fig. 27. Explosive flare from I′, Sept. 25. (a) 2311 UT. A bright surge flare from C′ (exact position not clear) at left precedes brightening at I′, which (b) 2321 UT erupts in a spray (c) 2326 UT. Brightness spread through the region, with the eastward spread apparently limited by closed field structure in that direction. – (d) A loop prominence is seen dark against the disk to the right of the flare. A small flare at C is seen.

servers. This is probably the same as the bright mound that appears above the limb and erupts in limb explosive flares.

4. Conclusion

We have given our main conclusions in section 1 and shall not repeat them here. We feel this study shows the value of detailed synoptic study of large scale cinematograms in understanding the structure of flares. It is not only important to know that a flare occurred in a region at a certain time, but where it occurred and what form it took. Our data show that the overall magnetic field structure of the region is merely deformed with the passage of time, and may be followed fairly easily. It is also clear that certain points in the field are more likely to have flares than others.

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