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A STUDY OF SOME OPTICAL PHENOMENA ASSOCIATED WITH SOLAR FLARES

BY

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Abstract

Sequences of Hα spectroheliograms covering nine solar flares have been examined for flare associated optical phenomena. A detailed description is given of the diversity of changes that take place in the flare region during its outburst and decay. "Disparition brusques" are common features during flare occurrence and the paper contains instances of these phenomena. However, not every flare regardless of its importance, necessarily produces a 'disparition brusque'. A case of sudden disappearance of a dark filament observed in the flare sequence of February 22, 1926 suggests that Doppler displacement caused by a motion of the filament is the cause of its disappearance from the normal Hα spectroheliogram. The incidence of flares both with respect to the spot lifetime and its spatial form have been discussed.

Introduction

Numerous phenomena of interest in solar physics are known to be closely associated with solar flares of different intensity. Among the important ones are, the changes in Hα striation pattern, 'disparition brusque' and the ejection of bright or dark surges from flares. The development of the flare itself is of much interest. In some cases flares appear, as long ribbon-like bright filaments and in other cases as irregular patchy structures. The shape and the formation of flare filaments have a close correlation with the orientation of the spot group around which they flare up. Recently Ellison, Mckenna and Reid (1961) have noted that the Hα striation pattern around the active flare region, lose their contrast during the flash phase of the flare. Smith and Booton (1961) and also Bappu, Bhatnagar and Punetha (1962) have confirmed. that such an obscuration of Hα striation pattern is associated with 'superflares' of importance 3+.

In the present paper, we have investigated some of the above phenomena associated with solar flares observed at Kodaikanal.

The observational data

From the 52 year collection of Hα spectroheliograms we selected nine flares of different importance. The basis for the selection of spectroheliograms is the availability of a proper sequence of photographs taken under good seeing conditions and covering the total duration of the flare,

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The solar image diameter of 60 mm and the narrow pass band (0.3 A) of the spectroheliograph offer an additional advantage over the conventional Hα filtergram, for picking out fine details on the solar disk. The flare spectroheliograms were enlarged without loss of the fine details to yield a final image scale of 13 seconds of arc per mm. A comparison of the prints with the original plates indicated no loss of detail due to the enlargement. The accompanying drawing show important stages of the flare development. The dark filled region indicates the flare, the dotted portion represents the Hα plage region and the hatched region signifies the dark markings (prominence seen against the disk) In the following section we give a brief summary of important changes of various features around the active region during the flare. The Greenwich spot number, the Mount Wilson classification of the spot group which gave rise to the flare, position angle, heliographic coordinates and the importance class are also given for each flare.

Summary of flare development sequence

(i) *February* 22, 1926 —Greenwich spot group No. 9881 and 9882. Mount Wilson classification γ and changed to α type. Importance Class 3+. Coordinates: 23°N, 9°W; P.A. 32°.

This flare had been well studied by Royds (1926) and by Ellison (1949) and recently by Bappu et al. (1962) and is well-known for its large area and intensity of Hα radiation.

The flare developed into a double parallel bright ribbon structure, running between the two spot groups (Gr. No. 9881, 9882), but nearer to spot group No 9881. This group was in a mature stage of development and was on its fourth round. According to the Mount Wilson magnetic classification this spot group was classed as complex γ type on 21 February and on 22 February as an unipolar α type. It seems that at an epoch subsequent to the occurrence of the 'superflare', the complex nature of spot group 9881 changed to an unipolar group. Spot group 9882 experienced a similar change to the βp type from the αp aspect that it displayed on earlier days.

Three regions a, b and c (Figure 1) brightened up separately but later joined to form the double ribbon like structure. During the maximum phase of the flare, ribbon 'b' ran right over the large spot umbra and completely covered it. The decline of the flare was slow, and thus the flare had a total duration of about 270 minutes.

A newly formed dark filament 'A' showed remarkable changes in shape and during the rising phase it vanished completely. A photograph taken at 0306 U.T. with the second slit centred on the red-wing of the Hα line showed the appearance of the same dark filament, though with a slight change in shape. A similar plate taken on the red-wing of the Hα line at 0926, after the flare was over, shows that the filament A, which appeared on 0306 plate does not exist on this plate, while a plate taken earlier with the second slit centred on the Hα line at 0917 shows the presence of this filament A. We believe that the presence of the filament on the off-Hα spectroheliogram taken during the flare phase indicates a bodily movement of the filament so as to exhibit a component of velocity in the direction away from the observer. A portion of the dark filament B also vanished during the rise to flare maximum, but was restored, to more or less its original shape. The recovery of the filament was in segments, a complete restoration being brought about when all the segments were linked together to form the original filament.

A third filament C, lying SE of the active region, also disappeared just around the maximum phase, though this filament was distant from the active region. A bright surge D ejected out just before the maximum, alongside the filament A and towards the filament B.

The zone of indistinctness of striation pattern (the obscured region) Flaround the flare region shows expansion and contraction in area, with flare rise and decline, as has been reported elsewhere (Bappu et al. 1962).

THE FLARE OF FEBRUARY 22, 1926.

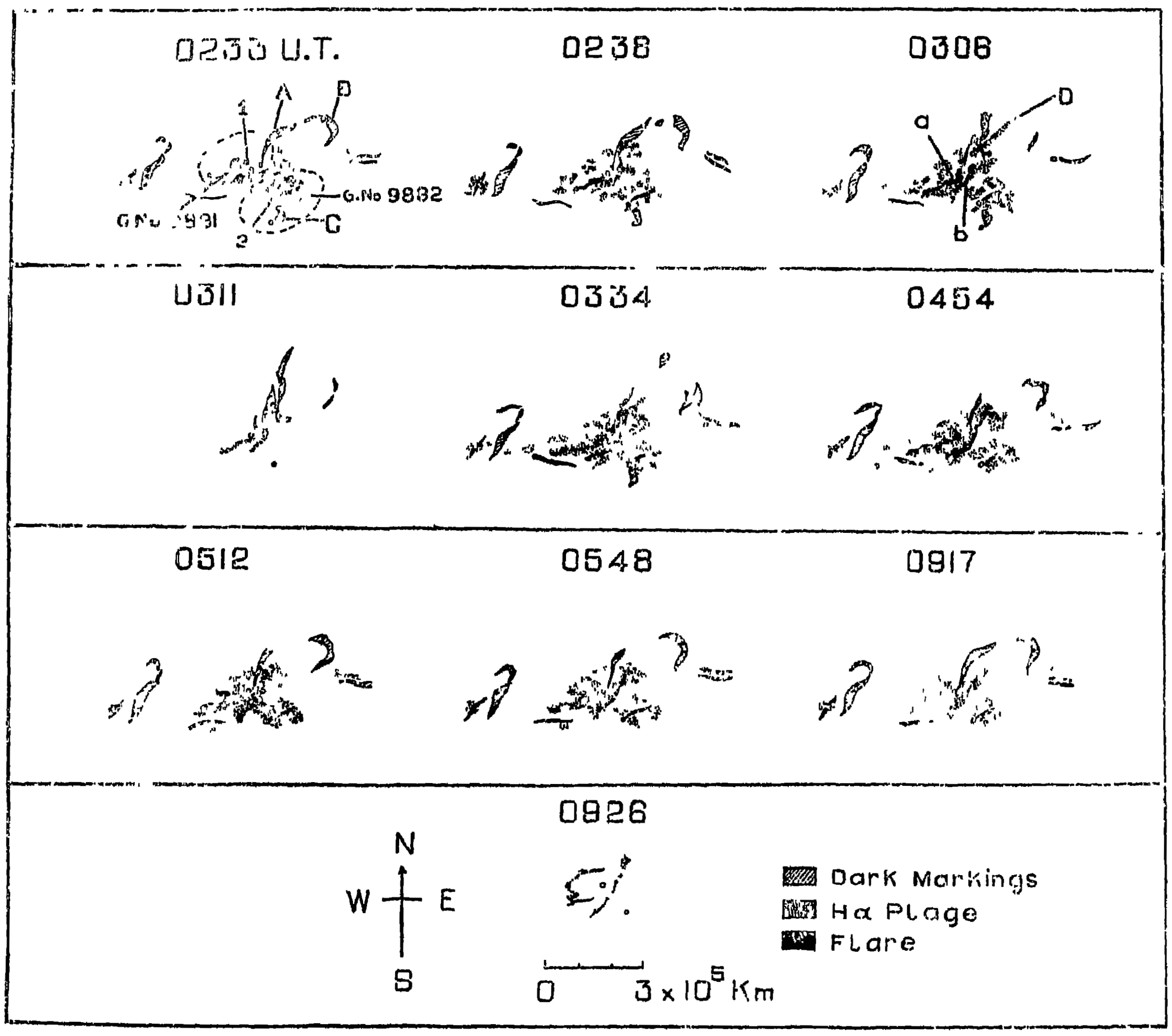

Fig. I.

(ii) *March* 3, 1926.—Greenwich spot group No. 9885. Mount Wilson classification βp. Importance class 2. Coordinates 30°S, 20°E; P. A. 30°.

Two major spots 1 and 2 forming a bipolar group were surrounded by a complex Hα plage structure. The flare evolved near the large spot 2 and proceeded toward a few small spots that lie between the two spots forming the bipolar group. The run of the flare was in a curved path, and appeared as if being 'anchored' in the fine Hα striation pattern located in the immediate vicinity.

A number of dark filaments appear aligned along the 'vertical' structure around the spots. Among the dark filaments which show changes in their shape are A, B and C as shown in Figure 2. These three filaments were 2 to 4 days old and were disrupted into small lengths with conspicuous changes in shape.

Associated with each dark filament is seen a 'barb' like structure of small striations, shown to exist previously by Kiepenheuer (1953). Those 'barb' like structure show changes in all cases, where the filaments show any change in their shape.

(iii) *June* 18, 1937.—Greenwich spot group Nos. 12385 and 12388. Mount Wilson classification *lβγl* and d*βl* respectively. Importance class 2. Coordinates 17°S, 9°W; P. A. 21°.

The flare originated between the well developed spot group No. 12385 and the two day old group designated as G. No. 12388. The spot group G. No. 12385 (Figure 2) had distinctly two active regions I and II. The region I had given rise to a Class 1 flare on an earlier day, and remained inactive on June 18. The flare extended from the Hα plage region near the following spot of G. No. 12385, towards the preceding spot of the developing group (G. No. 12388). The flare extended to the immediate vicinity of this spot and covered the spot completely at maximum phase. It is interesting to note that, though the bright plage existed between spots 1 and 2 as denoted in the figures, the flare ribbons spread towards spot 3, instead of the region that was active the previous day.

Filament F, embedded in the plage structure showed no activity, while filaments D and G show changes in shape even though they are located at a distance from the active region.

(iv) *December* 15, 1956.—Mount Wilson spot group No. 12016. Mount Wilson classification dβf*l*. Importance class 2. Coordinates 20°S, 20°W; P. A. 16°.

Spot 1 of the group appeared only on December 13, while spot 3 of this bipolar group was in its mature stage (Figure 2). The main flare run was between the two newly formed spots 1 and 2, and on either side of a small dark thin filament C Another region Z near the spot 3, also flared up simultaneously. Around the maximum, the flare ribbons completely covered the smaller spot 2, while the larger spot 1, was avoided by the flare; similarly spot 3 was not covered by the flare filaments.

The streaky dark filament C near the active region X and Y vanished during the flare, while filaments A and B remained unaffected.

(v) *February* 21, 1931.—Greenwich spot group No. 11355. Mount Wilson classification . Importance class 2. Coordinates 7°N, 10°W; P. A. 18°.

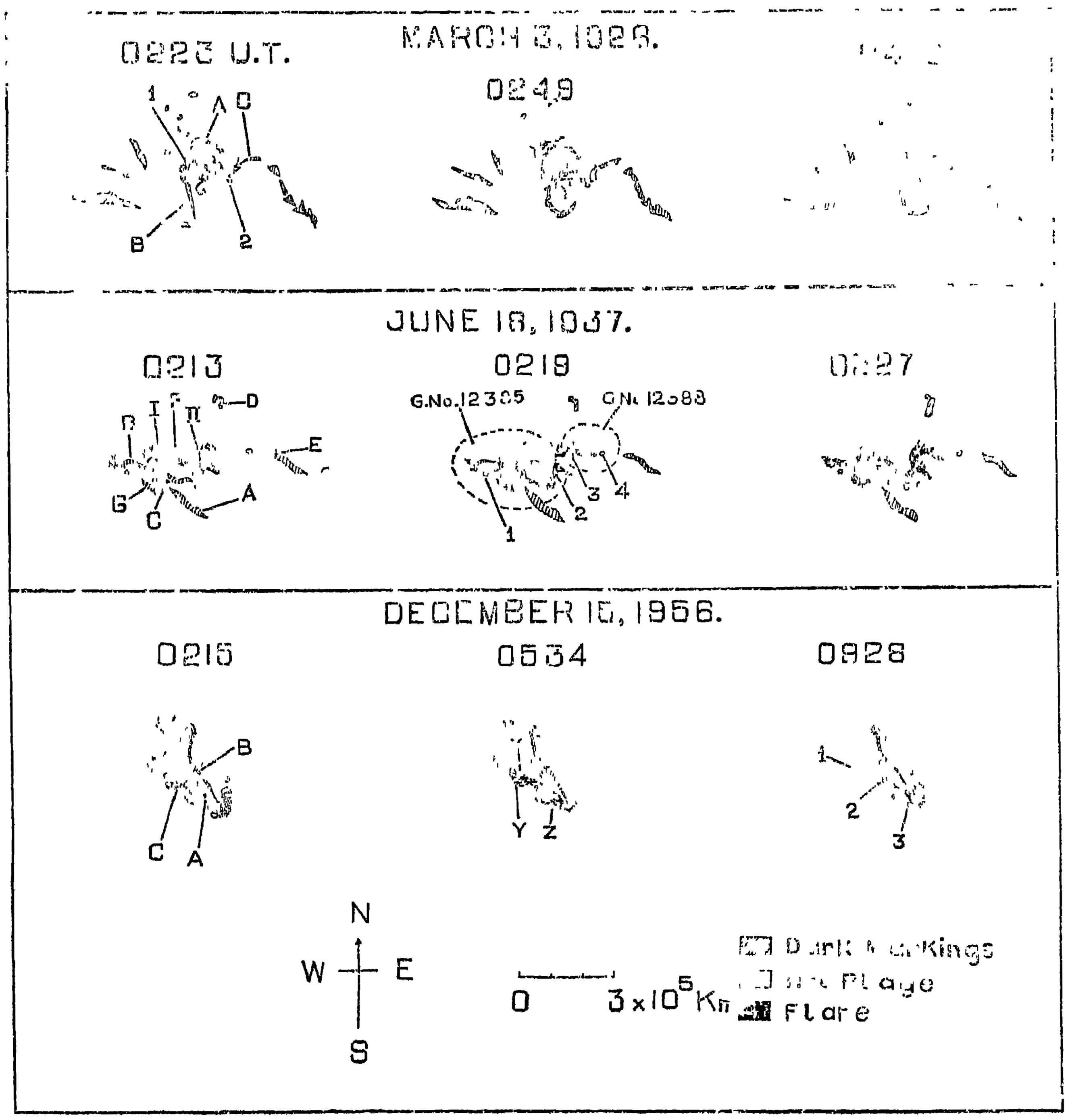
0223 U.T.
MARCH 3, 1928.
0249
JUNE 18, 1937.
0213
0218
G.No.12385
0227
DECEMBER 16, 1956.
0215
0534
0928
N
W
E
S
0
3x10^5 Km
Flare

Fig. 2.

This bipolar group was embedded in the Hα plage structure and a small thin dark filament C (Figure 3) was directed towards the preceding spot Around 0318 U.T. the Hα plage region, near the dark filament, brightened up to form the flare and at about the same time a bright surge S, was seen ejecting out towards the dark filament A The ejection continued upto 0354 or even a little later, while the filament A, had vanished during the initial surge ejection. When the activity in region I was on the decline a region II, between the spots started brightening. The run of the bright ribbons was from the larger of the two spots towards the smaller one. Slight changes in the shape of filament B were noticed, but these could be assigned to its intrinsic activity. The Hα striation pattern and the filaments within the S-W sector, remained unaffected.

(vi) *November* 26, 1938 —Greenwich spot group No. 13086. Mount Wilson classification d$\beta\gamma l$. Importance class 1. Coordinates 12°N, 38°E; P.A 42°.

G. No. 13086 around which the flare of importance 1 occurred, was a complex group containing an extensive stream of spots in a stage of rapid development The Greenwich spot observations show large scale changes in the appearance of the group from day to day. According to the Greenwich photoheliograph results "an extensive lateral oft-shoot from the leader spot on November 26 nearly closes the gap between the leader and the follower, and this link, with its train of nuclei, continues for several days as distinctive feature". On November 26 four separate regions within the group flared up and extended towards the following spot. During the rise and decline the flare avoided spot 1 (Figure 4) but had completely covered the smaller spots of the group.

The dark filaments around the active region show no changes. The arch shaped filament A, which appears to join the two spots exhibit some change. As may be seen in Figure 4 the filament A had lost its contrast till the flare completely subsided.

(vii) *September* 23, 1939.—Greenwich spot group No. 13420. Mount Wilson classification $l\beta pl$. Importance class 1. Coordinates 20°S, 19°W; P.A. 34°.

A few small pores, east of this bipolar spot group by about 10°, were in a stage of development. A dark filament A, was embedded in the plage region near the spot 1 (Figure 4). Two separate regions, one near the spot 1, and the other just over the pores brightened up simultaneously around 0507 U.T. In the active region 'a', the flare developed on either side of the thin dark filament A As the flare proceeded towards the SE direction, the filament A also appears to have increased in length, keeping both the two portions of the flare patch separated. The dark filament B, remained unaffected during the flare. The striation pattern shows no changes other than those which could be assigned to changes in seeing conditions.

(viii) *October* 23, 1939.—Greenwich spot group No. 13454. Mount Wilson classification $l\beta\gamma$d Importance class 1. Coordinates 14°N, 17°E; P.A. 19°.

The two spots of this complex group merged together and showed distinctly two umbrae within a common penumbra. This group appeared on the eastern limb and disappeared on October 27, indicating that the flare occurred during the declining phase of the spot's life. The rise of the flare was very sudden and the two halves of the Hα plage structure on either side of the spot (Figure 4) were linked by a bright filamentary structure of the flare. The spot remained covered during the rising and the maximum phase, but was soon visible as the flare declined.

The two radially directed dark filaments remained unchanged, except for the far ends of the two filaments A and B, which did not retain their former shape.

(ix) *September* 19, 1957.—Mount Wilson spot group No. 12622. Mount Wilson classification. d$\beta\gamma l$. Coordinates 22°N, 2°W; P.A. 20°. Importance class 2.+

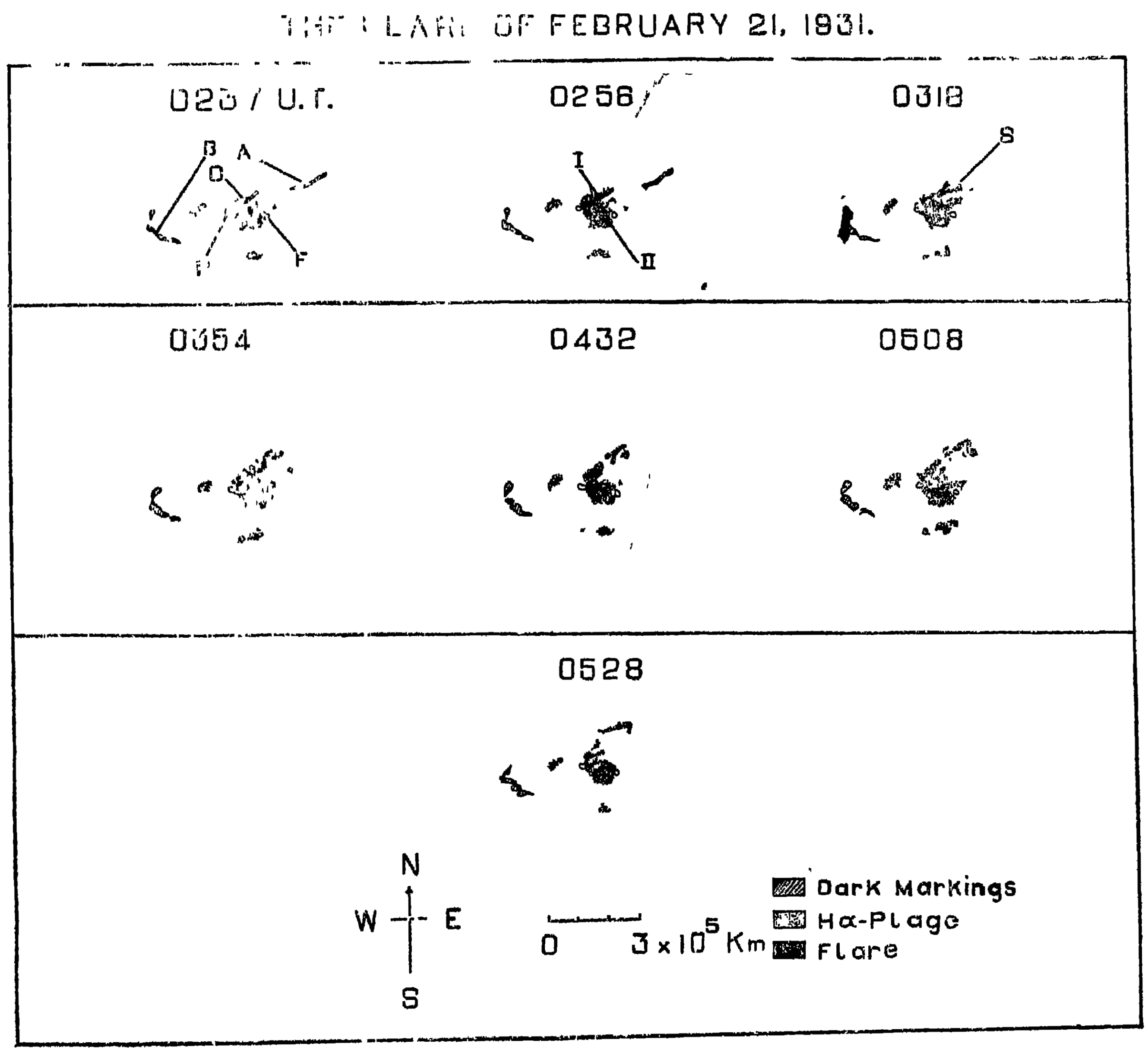
THE FLARE OF FEBRUARY 21, 1931.
0237 U.T.
0256
0318
0354
0432
0508
0528
N
W
E
S
0
3 x 10^5 Km
Dark Markings
Hα-Plage
Flare

Fig.3.

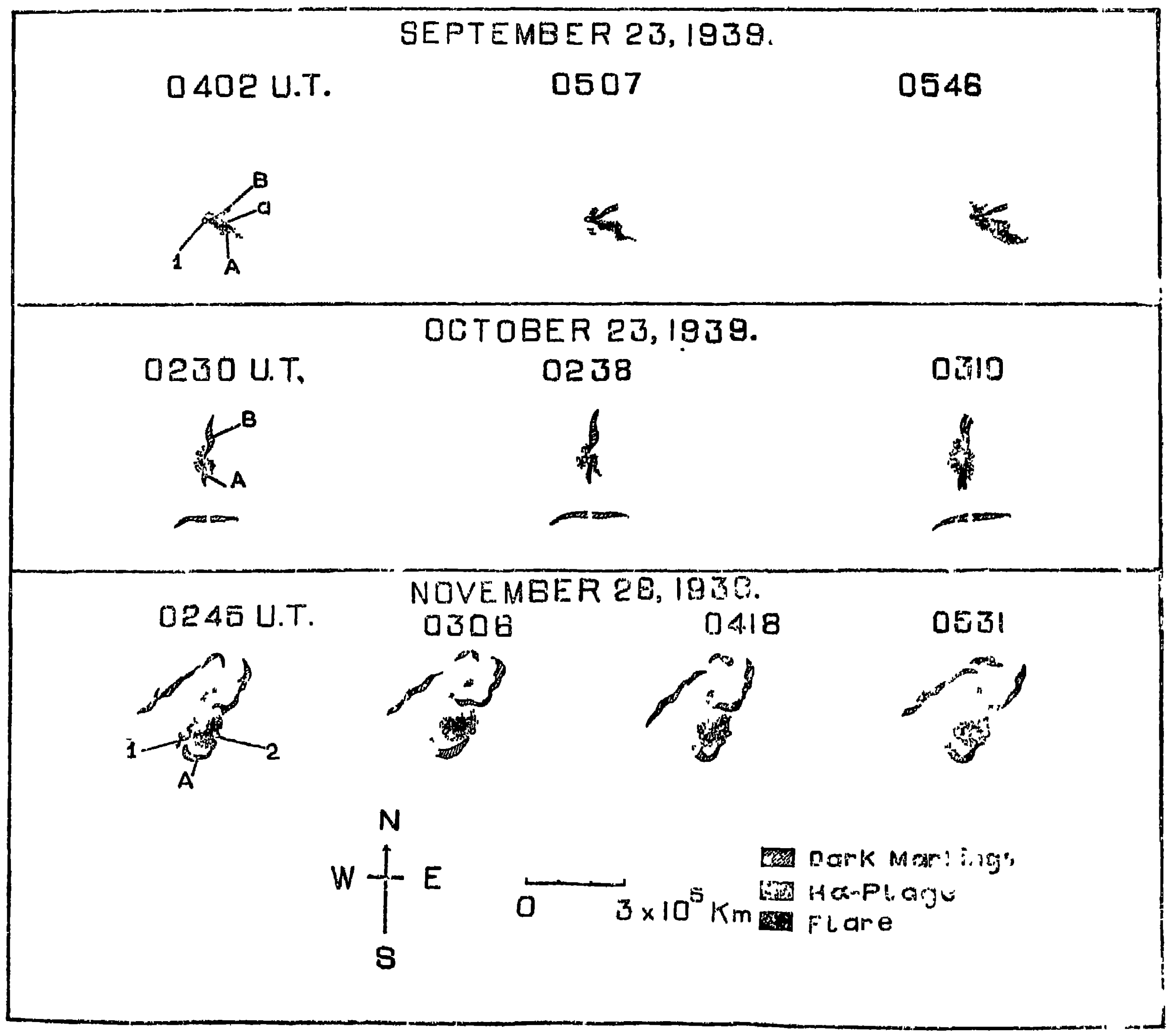
SEPTEMBER 23, 1939.
0402 U.T.
0507
0546
OCTOBER 23, 1939.
0230 U.T.
0238
0310
NOVEMBER 28, 1938.
0245 U.T.
0308
0418
0531
N
W
E
S
0
3 x 10⁵ Km
Dark Markings
Hα-Plage
Flare

Fig. 4.

This active McMath plage region 4151, is characterized by its unusually strong recurrent activity. On September 18, Jefferies et al. (1959) observed two class 2^{+} flares and one class 3^{+} flare within this active region. The same region again flared up after about 15 hours to give rise to another class 2^{+} flare on September 19. A spectroscopic study of this flare has been reported by Jayanthan (1959). This complex bipolar group was in advanced stage of development. The active region was surrounded by a number of thin curved dark filaments (Figure 5). These dark filaments show hardly any activation, except for the filament A, which shows a slight change in shape. A small curved dark filament D, though lying close to the active region shows no change. Plates taken before and after the major flare events of September 18, show no changes in filament structure before and after the flares.

On September 19, before the occurrence of the class 2^{+} flare at 0416 U.T., a small class 1^{+} flare had flared up exactly in the same place at 0246 and had ended at 0327 as is shown in Figure 5. The class 2^{+} flare originated when two areas near spot regions 1 and 2 had a simultaneous increase in intensity with a ribbon formation. Around the maximum phase, the flare covered the umbra of spot 1. This flare of September 19, occurred at the same place as that of September 18, with only the active region, west of spot 1, which had shown strong brightening on September 18 remaining inactive. The run in all four cases of major flares had always been along the line joining the two spots of this group.

On the succeeding two days (September 20 and 21) we have observed at Kodaikanal two class 1 flares in the same region. The run of these flares was also along the same path as in the case of earlier flares.

Discussion

The area and the nature of the spot group around which a flare occurs play an important part in the occurrence of solar flares. From the Greenwich photoheliographic results, we see that the major solar flares occur during an advanced stage of formation of the large bipolar or complex multipolar groups. Less intense flares generally confine themselves only to that part of the spot life, when the magnetic field and area are changing, which happens during the development or declining phases of the spot's life. No correlation has yet been detected between the complex nature of spot group and either duration or importance of the flare.

In all cases, both minor and major flares evolve from the pre-existing Hα plage structure lying within the confines of the spot group. In the cases studied above, the portion of the plage nearer to the large spot of the bipolar spot group brightens up earlier and the flare runs towards the smaller spot or spots of the group. If the separation of the two spots is considerable, the flare 'thins out' into ribbon like structure 2×10^3 Km. to 10×10^3 Km. wide on the average for minor flares and about 10^4 Km. in the case of major flares. But, if the separation of the spots is not large, the flare has an amorphous structure.

Minor flares tend to avoid the umbral region of large spots, while they invariably cover the small spots and pores. Flares generally show preference to spread towards the spot which is developing. Major flares in their course of development, generally run right across the group and cover the spot-umbrae which usually have large area and magnetic field strengths. In the case of the February 22, 1926 flare, we find that the duration of extension of the flare over the umbra is confined to only the peak phase of the flare. Very soon after, the flare ribbons over the umbra vanished, even though the declining phase has not set in the rest of the flare. In the case of small flares the duration of the coverage of spots and pores last until the complete decline of the flare.

The portion of the plage structure lying near the large spot of the active group generally brightens up first. In some cases as in the flares of September 23, 1939 and February 21, 1931 the run of the bright filament is usually confined along the length of dark filament 'anchored' in the plage region, and which is known to orient itself along the path of neutrality in the magnetic field. These cases support the argument that flares have a tendency to follow the neutral points.

THE FLARES OF SEPTEMBER 18, 19, 20 AND 21, 1957.

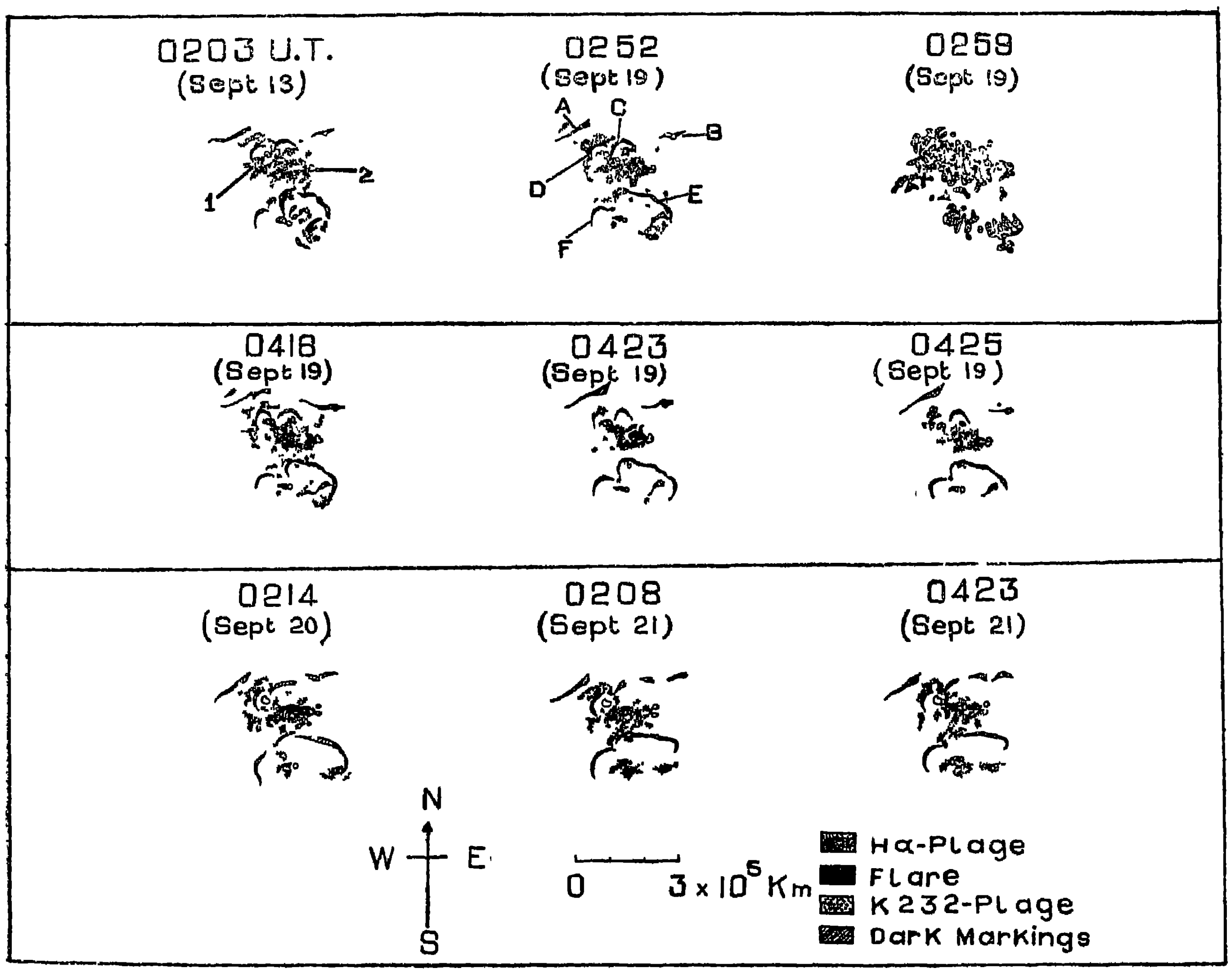

Fig. 5.

When major flares occur, dark filaments lying near the active regions suffer 'disparition brusque' similar to the case of filament A of the February 22, 1926 flare. The minor flares studied do not seem to have any effect on the neighbouring filaments. In the case of the flares of September 18 and 19, no dark filament near the active region was affected. Either the intensity of the ionizing radiations may be less in these flares or the strength of the disturbances originating from the flare was not sufficient for a 'disparition brusque' to occur.

In the normal case of a 'disparition brusque' dark filaments generally vanish suddenly or get disrupted into small parts before they vanish completely. The recovery of the 'blown off' filament is quite slow and in all cases the restoration is effected in small lengths linking together to form the original filament (Kiepenheuer 1953).

Ellison (1949) finds that 50 per cent or more cases of class 2 flares are associated with bright or dark high velocity surges. The phenomenon of a high velocity surge is very difficult to trace on spectroheliograms because of Doppler shift values exceeding the second slit width. In the case of the flares of February 22, 1926 and February 21, 1931, bright surges could be seen. In the above two cases where a surge phenomenon is observed, dark filaments in the geometrical extension of the ejected mass, vanish completely. We consider these as cases representative of an interaction of fast moving surge material with the mass of gas of the dark filament.

As has been mentioned earlier, the obscuration of the striation pattern and the changes of the obscured area with the rise and decline are conspicuous in case of 'super-flares'. No such effect of obscuration could be seen in the case of flares of importance 2 or 2+.

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