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MAGNETIC TRANSIENTS IN FLARES

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ABSTRACT

We present data on magnetic transients (mgtr's) observed in flares on 1980 July 1 and 5 with the Big Bear videomagnetograph (VMG). The 1980 July 1 event was a white light flare in which a strong bipolar mgtr was observed, and a definite change in the sunspots occurred at the time of the flare. In the 1980 July 5 flare, a mgtr was observed in only one polarity, and, although no sunspot changes occurred simultaneous with the flare, major spot changes occurred in a period of hours.

Late in the 1980 July 1 flare, the radio burst position shifted with the optical emission to a new kernel associated with a secondary peak in the 2.2 MeV line.

Mgtr's have now been seen in five large flares, all more than 30° from the Sun center. Only one good case with negative result has been observed near central meridian. We are reasonably, but not completely, sure that they are not artifacts. We present some suggestions as to what might be occurring in the magnetic field. We explain why the mgtr cannot be ascribed to time variation or to emission in λ5324.

We also discuss the remarkable penumbral structure associated with the 1980 July 5 flare.

Subject headings: Sun: flares — Sun: magnetic fields — Sun: sunspots

I. INTRODUCTION

Patterson and Zirin (1980, henceforth PZ) reported two magnetic transients (mgtr's) observed with the videomagnetograph (VMG) at Big Bear in flares on 1980 November 5. They also found irreversible field changes but no sunspot changes. Because the mgtr's did not coincide with the positions of He I D_3 or continuum emission, they concluded the effect was real.

The videomagnetograph typically adds the digital differences of 64 successive pairs of magnetic pictures taken through a 1/8 Å filter, the process taking about 10 s. A ramp in brightness might produce the mgtr, so Patterson changed the program so that each pair is reversed in time, and a ramp could have no effect. Other improvements were also made, notably the installation of a new Plumbicon tube.

We describe here two important flares in 1980 July in which definite transients were observed. The first revealed the most striking mgtr observed thus far, rapid spot change at the same time, and intense blue continuum associated with a 2.2 MeV line event; the second had poorer magnetic data but was a definite transient as well as having remarkable sunspot structure. In both cases, definite changes in the transverse magnetic field as marked by Hα structure are seen, but no permanent change in the longitudinal field measured by the VMG appears, despite the change in small spots.

II. FLARE OF 1980 JULY 1

This flare occurred in region 16943, which was born on 1980 June 28 but was still rapidly growing. On the south edge of the preceding part of the region, a small f satellite spot and some f (white) polarity shared a large penumbra with the p spot. Except for this modest delta characteristic, there was no magnetic portent of high activity in the region except for the occurrence of numerous flares on 1980 June 29 and 30.

Figure 1 (Plate 21) shows the flare in Hα centerline (*right*) and a 20 Å band centered on 3862 Å (this wavelength was chosen to exclude Balmer emission), while Figure 2 (Plate 22) shows the development of the mgtr (*right*) and the D_3 emission. Preflare Hα frames show a bright area bounded by a filament (F) south of the p spots, where the magnetograms showed p (dark) polarity spreading south from the main spots (the filament was already gone in the first frame of Fig. 1). The chromospheric neutral line is marked by a dashed line. The Hα flare erupted along this line and caused a southwestward explosion of the filament F culminating in an outward moving wave. In the continuum a series of flashes occurred near the neutral line of the δ configuration (points A and B), peaking at 1627:37 UT (peak radio–X-ray), while point D at the west edge of the outward exploding matter also brightened.

As these points died down with the X-ray and radio flux, remarkable new brightening occurred at point C, on the extension of the neutral line, peaking at 1629 UT with the greatest intensity of any point. At the same time the Owens Valley Radio Observatory (OVRO) 10.7 GHz interferometer signal (Fig. 3) showed a phase shift matching the projected shift from A to C. Thus the brightening of point C was coincident with a new radio source. A new peak in the 2.2 MeV line emission was reported by Matz *et al.* (1981); its connection to the brightening of point C is discussed by Zirin and Neidig (1981).

The continuum emission at λ3862 was the most intense (2 times continuum) observed so far at Big Bear. Simultaneous continuum measurements at Sac Peak (Zirin and Neidig 1981) show the continuum to have been definitely blue, about 5 times stronger at λ3862 than at λ4275.

The radio burst shows transient circular polarization from 1626:53 UT to 1627:50 UT which may be connected to the magnetic transient (such polarization is observed in most bursts; since our mgtr data is limited, the effect may always be present). The X-rays observed by the *Solar Maximum Mission* (kindly supplied by Drs. K. Frost and B. Dennis) and radio rose nearly simultaneously at 1616:45 UT and peaked, with the biggest Hα increase between 1627:04 and 1627:14 UT. The explosive outward motion occurred at 1627:49 UT and wave ejection at 1629 UT.

The VMG records show the clearest and most intense magnetic transient observed so far. The first VMG at 1627:15 UT (clouds interrupted from 1621 to 1626:45 UT) showed a small white (f) transient at point A; in the 1627:41 UT frame, this transient strengthened and a dark (p) transient appeared just southeast along the neutral line; a weak white transient appeared at point D. The white transient at point A spread, but its intensity decreased. Although the white transient matched the D_3 emission at point A well, the dark transient near point B did not. In the last frame of Figure 2, a fairly strong, dark mgtr is seen at point C. The peak intensity of D_3 occurred at points B and C and was twice the photospheric background; the magnetic field in the transient appears about 1.4 times as intense as the strongest field outside the flare, but we have no reliable calibration, so we can only say that it is stronger than any plage field. There was considerable D_3 absorption from the flare ejecta as well as brightening at the distant point E.

The left half of Figure 4 (Plate 23) shows the remarkable growth of the small satellite spot (*arrow*) at the core of the flare. Although the changes are somewhat masked by the flare emissions, it appears that they all occurred during the flare. We cannot tell the polarity of this spot; it does not appear in the Mount Wilson drawing, and it appears to include both points A and B, which are obviously of opposite polarities. The right half of Figure 4 shows the corresponding expansion of the neutral line marked by the edge of the Hα plage and the great expansion of the spot (*arrow*). From the fact that a fibril going to the main p spot at the right now terminates there we might guess that the expanded spot is f polarity. This is one of the best examples we have of Hα change before and after a flare; usually the flare destroys the structure, and the Sun sets before the effects are obvious.

III. REALITY OF THE MAGNETIC TRANSIENT

As noted above, the change in the VMG program prevented any effect due to the time gradient of emission. The Sac Peak continuum measurements show there was no detectable continuum emission at λ5300 until 1629 UT, and then only at point C (Zirin and Neidig 1981). But the close correspondence between D_3 emission and the mgtr raises the possibility that emission in λ5324 spatially coincident with D_3 produced a spurious mgtr. This possibility was dismissed by PZ for the 1980 November 5 flares because the mgtr's did not coincide in position with the continuum or D_3 emission. But in the present case, they do. We have calculated the change in the magnetic signal produced by emission in λ5324, 1/8 Å wide. If the emission is 40% of the continuum, the VMG signal drops to one-third the original, and for 80% we should see a reversed signal with 45% the intensity. The observed mgtr is about 75% above the neutral background, requiring a λ5324 intensity about 120% of the continuum. Thus λ5324 would have to have been as strong as D_3 to produce a spurious mgtr. Such a high intensity has never been observed; in fact λ5324 emission is barely detectable in flares. From the data of Zirin and Neidig (1981), we know the continuum contribution at D_3 was negligible, so the peak intensity of 2.5 times the photosphere is all line emission.

We can estimate the possible λ5324 contribution to the magnetogram by reference to measurements in other flares. For example, spectrograms of the flare of 1970 November 18 taken at the Okayama station of Tokyo Observatory give central intensities between 0.3 and 0.4 for similar iron lines in the blue. But Jefferies, Smith, and Smith (1959) show spectra of a huge flare in which λ5324 is classified as "faint," while D_3 is classified as "very strong" and measured at 1.2 times the local continuum. Although they do not specify what "faint" means, comparison of their quantitative data for λ5016, classified "moderate" and λ4922 (0.2 times continuum) classified "faint," suggests that the lines classified "faint" are <0.3 times continuum, similar to the Okayama result. We recently (1980 October 11) observed a 1B flare in λ5324 with the universal filter at Big Bear and

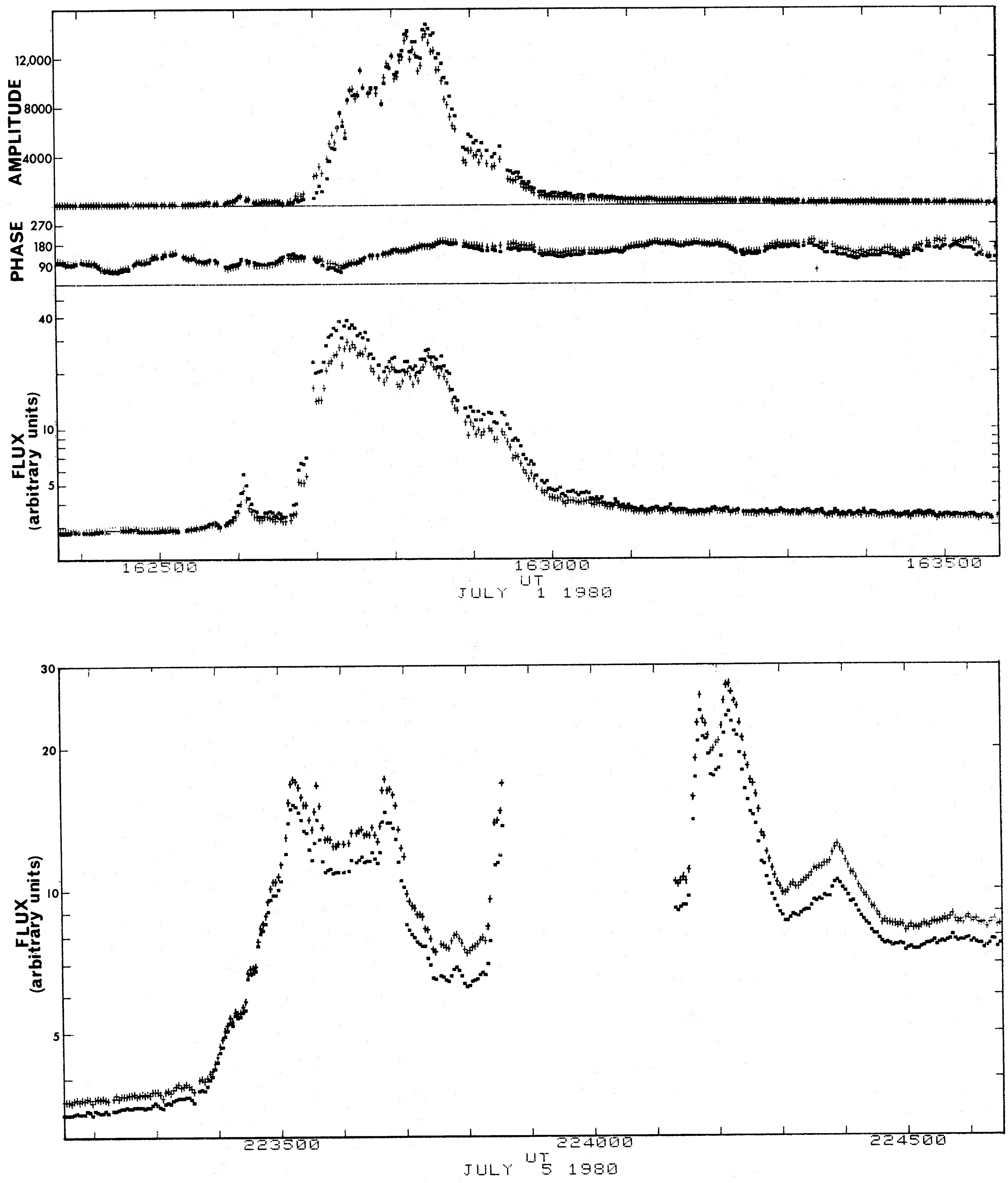

FIG. 3.—Radio records of the 1980 July 1 and July 5 flares obtained by G. J. Hurford with the OVRO solar interferometer at 10.7 GHz. In the 1980 July 1 flare the top graph is fringe amplitude and the second, phase; the third plot is total power measured in one antenna. Note that fringe amplitude peaks at the rise of point C, marking the existence of a small, intense source. *Dots*: right circular polarization; *crosses*: left circular polarization. The precursor at 1626 UT matches the first flare brightening. The bottom plot shows single antenna data for the 1980 July 5 flare; note the compressed scale for this long-lived event. There is an instrumental gap from 2239 to 2241 UT. The other antenna was out of action, so no interferometric data is available.

found the emission less than 10% of the continuum, even though Hα was brighter than 6 times the chromosphere or twice the photosphere. So it is doubtful that the λ5324 emission in our flare exceeded 0.3 times continuum and unlikely that line emission produced the transient. Thus, although we are concerned about the correspondence of emission and magnetic transients, there are quantitative reasons which make it impossible to explain the observed transients by emission in the λ5324 line.

The transient is not a precise reversal, but only approximate. Velocity shifts can also give apparent field reversal, but only with one-half the intensity, as one component is shifted out of the passband. If we had only the present data, we would have misgivings about the reality of the transients. But the transients observed by PZ did not even coincide with the line emission; in fact, each of the four mgtr's now in hand had different characteristics which contradict possible spurious sources. It is interesting that all four cases were some distance from disk center; by contrast, the one large flare for which we have good data and no transient (1980 November 5, the anniversary of the first mgtr observation) was at disk center. It is entirely possible that the mgtr occurs in the transverse field, which normally is not recorded by the magnetograph in the photosphere except very close to the limb.

What is the physical nature of the transient? First, consider the D_3 emission, part of which is cospatial with the mgtr. D_3 emission only occurs when collisional excitation dominates radiative transitions at densities above 10^{13}. Typically we observe the D_3 emission near sunspots and other places where fieldlines converge and the flare particles might well be expected to penetrate the surface. So the D_3 kernels near the neutral line can be thought of as the feet of loops crossing the neutral line made up of sheared loops along the neutral line. But this picture casts no light on the field reversal in the mgtr, the one characteristic of all the transients observed so far. Possibly a powerful current flows along the neutral line opposite whatever current characterizes the preflare neutral line and produces the reversed field. Since this field is tied to the neutral line area where the acceleration occurred, the particles flow into the field reversal region and produce the various emissions. This explains the close temporal and spatial connection to D_3 emission found here and by PZ in one of their two flares.

IV. FLARE OF 1980 JULY 5

The second transient was observed in Mount Wilson 2550 on 1980 July 5. The region (Figs. 5–7 [Pls. 24–26]) exhibited a classic δ configuration, with f and p spots in the same umbra separated by a narrow neutral line. This had come about through the emergence of two new dipoles head to tail on 1980 July 2, the p spot of the follower combining with the f spot of the leader. On 1980 July 4, there was only one f spot, which split in two around 1600 UT on 1980 July 5, the components rapidly separating. There was no relative motion; instead, there was just an erosion of the middle of the spot. The place where the umbra had been was marked by a bright area, about the same intensity as the photosphere (Fig. 7). The splitting may have been connected with a sizable flare (Fig. 5, first frame) at 1557 UT, homologous to the one we will discuss. The separation between f and p spots was no more than a few arc sec; the spots appeared to be sliding past each other, and the field lines must have been sheared along the neutral line. The delta configuration with continual spot changes is well known to produce high flare activity.

The development of the flare in Hα is shown in Figure 5. The first frame shows the homologous flare early in the day. The second frame (Hα+0.7 Å) shows our first picture of the flare at 2234:52 UT (a malfunction had suspended observing for the preceding few minutes; the flare was still rising at this point). The flare process began with the activation at 2224 UT of a filament crossing the region (the remnants of this eruption are visible in the first frame of Fig. 5; the top was blueshifted, and the feet were redshifted). The flare began with several isolated spots in p and f umbrae; because of a malfunction, we just caught the rise at 2234:52 UT. The early brightenings were at the outer edges of the two spots, rather than the neutral line (about 2235 UT). They developed gradually, the emission at the f spot spreading along the whole line of the f spots, and that on the p spot curling around it and filling the neutral line. The flare was complex and long-lived, impulsive radio emission continuing for 10 minutes. High resolution continuum pictures were made in the green with a Schott VG 9 filter; no continuum emission appeared.

The videomagnetograph was not working well this day, and the data are quite nosy, as may be seen in Figure 6, where the transient may be seen. The visibility has been improved in Figure 6 by double printing successive magnetograms obtained one minute apart. A single dark pole appeared over the p spot, coincident with the intense Hα kernel there. It lasted 10 minutes, much longer than the other magnetic transients that we have observed. The Hα flare was correspondingly long-lived. The data are sufficiently noisy that a dipole may have been present, and the long duration of the transient is undoubtedly real. The Hα emission was just as intense over the f spot, but no transient was seen there. The transient peaked around 2240 UT. Note that in both cases discussed in this paper, the transient involves a reversal of the field, which of course is more readily visible. The two transients discussed by PZ were only partially reversals.

The radio burst (Fig. 3) showed substantial polarization, considerably greater than the preflare emission and lasting through the period of the transient. There also was a striking change in polarization between the rise, which was unpolarized, and the main flare. The sense of the change is opposite that of 1980 July 1, where the transient was predominantly of opposite magnetic sign. This flare was about 10 times weaker than the 1980 July 1 event in radio and X-rays; no continuum emission was seen, but we observed only in the green, where flare continuum is weak. We cannot learn a great deal from the mgtr, because the data are noisy.

V. MAGNETIC CHANGES REFLECTED IN CONTINUUM IMAGES

Figure 7 shows the remarkable changes in region 16955 reflected in a series of white light frames through a VG 9 filter. We were unable to find any discontinuous change connected with the flare, nor could we find any change in the overall spacing before and after. But remarkable changes in the white light structure did take place in the hour during and after the flare. Insofar as these reflect the magnetic structure, they show that significant field changes were occurring on a time scale longer than the mgtr.

The first frame in Figure 7 shows the spots early in the day, all closely connected. The dominant change during the day was the steady breaking away of F2 from F1; in the second frame at 2137:22 UT, penumbra and a small white (photosphere?) area appeared between these two spots; in the postflare frame at 2252:45 this opened into a stretch of photosphere marked X, and in the last frame we see the nearby penumbra broken up and the area filled with photospheric granulation. There were also substantial changes in the spot F2 as can be seen by comparing the second and third frames; these occurred between 2145 and 2230, before the flare.

Above the spot P1 we can see a bundle of curved penumbral fibrils which appear to connect the edges of P1 and F2, roughly the location of the first flare brightenings. Because the brightenings always occur at opposite ends of flux tubes, we can conclude that these trace out some of the field lines involved in the flare. Another set of penumbral fibrils just above spot P2 connects P1 and F2. The rapid separation of F2 during the day appeared to stretch these out.

The pattern of penumbral fibrils and the appearance of granulation when they disappear tends to confirm Moore's (1980) suggestion that they overlie the granulation.

VI. DISCUSSION

We have described two magnetograph transients on 1980 July 1 and 5, which coincided with two substantial flares. Although we do not understand exactly what happened in the magnetic field, we conclude that the transients are real. In both cases they agree exactly with the flare in place and time, and no reasonable construct of possible emissions can explain the observed effect. In both cases the mgtr's occur near the neutral line in coincidence with the most intense line emission, but they do not match the continuum emission exactly, either in time or space; for example, the most intense continuum kernel in the 1980 July 1 event displayed only weak mgtr's. The agreement of the mgtr with D_3 emission is excellent and leads us to believe the mgtr may have a role in the formation of the D_3 kernel.

The 1980 July 5 event displays remarkable field twisting in the delta spot which appears to be connected with field emergence and sunspot motion. The relation of this twist to the flare phenomenon has been discussed by Tanaka, Smith, and Dryer (1979) and Tanaka (1981). But strict emergence of twisted flux, although it describes the sunspot *evolution* well, cannot describe the mgtr, as the transient fields would have to move with the intersection of the twisted loop with the surface.

The observers at Big Bear were Steve Allen, Jim Drake, Rick Koenig, and Dave Shafer (Caltech undergraduates), and Alan Patterson and H. Zirin. Margaret Liggett measured the flare intensities. The work was supported by NASA under NGL 05 002 034 and by the NSF under ATM79-11139.

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Note added in proof.—A. P. Patterson and H. Zirin (unpublished) recorded the line λ5324 video signal in a flare on 27 July 1981 and find that part of the transient in that case corresponds to line emission, but part does not. Hence, the transient cannot be due to emission reversal.

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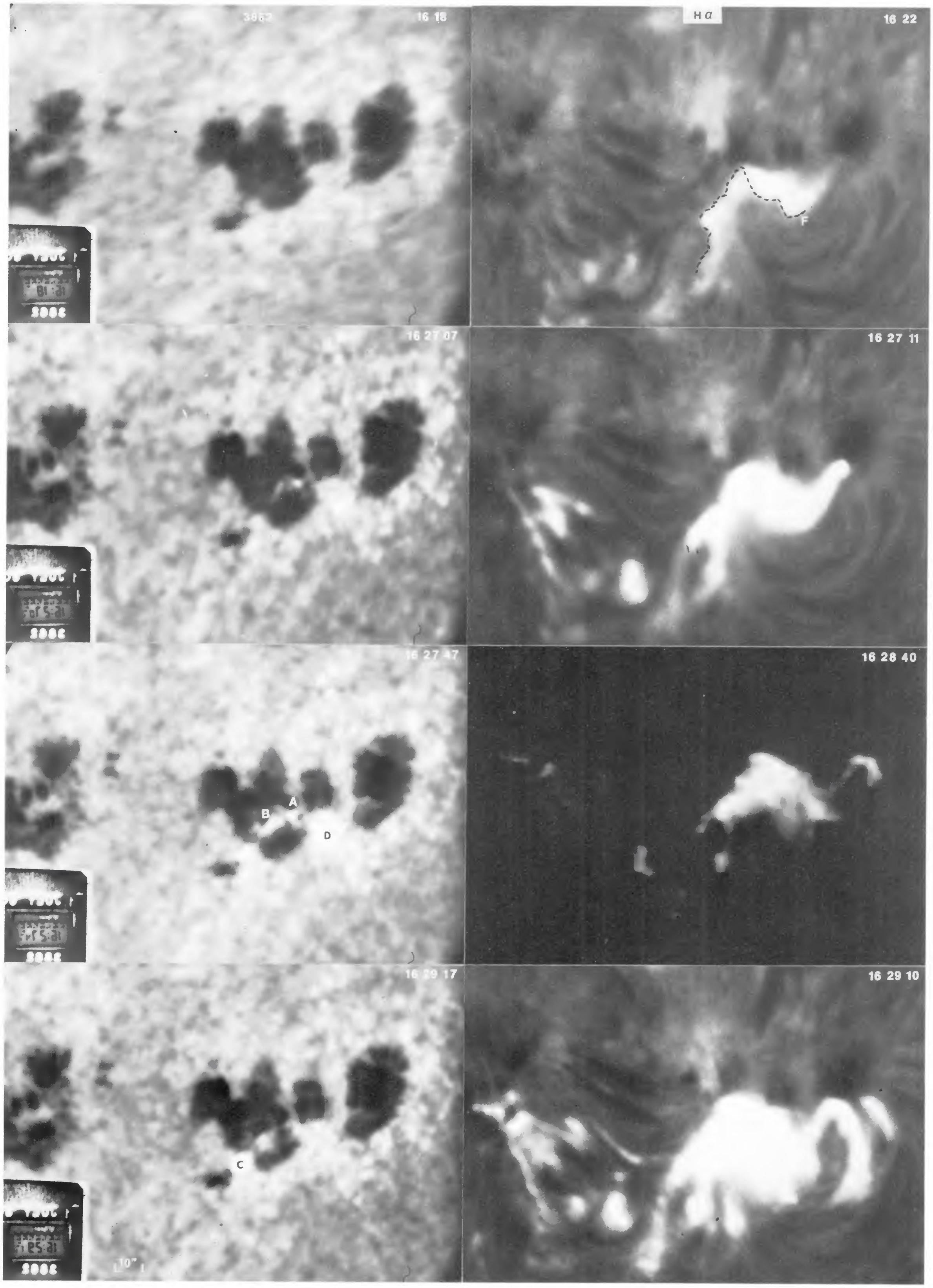

FIG. 1.—The 1980 July 1 flare in λ3862 (20 Å wide) and Hα centerline. One dark print has been included to show the kernels, which match D_3 and the mgtr. Note the outward explosion in the last Hα frame. North is at the top; west is at the right. The neutral line is marked by a dashed line.

ZIRIN AND TANAKA (*see* p. 791)

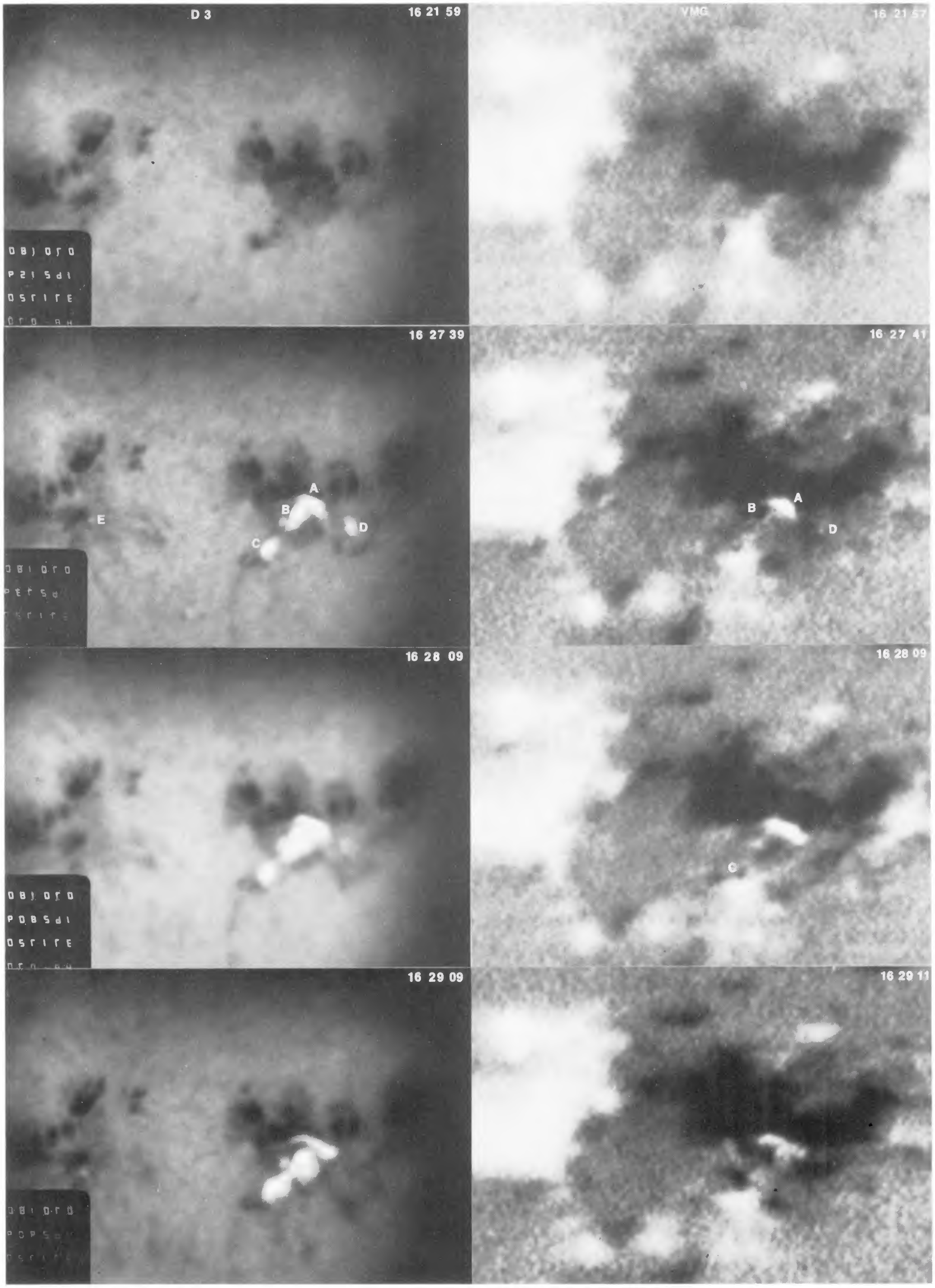

FIG. 2.—The 1980 July 1 flare in He D_3 and videomagnetrograms. The former are obtained through the universal birefringent filter with $\frac{1}{4}$ Å bandpass; the latter are obtained in λ5324 by adding the differences between 64 Zeeman pairs. Dark is preceding polarity.

ZIRIN AND TANAKA (*see* p. 791)

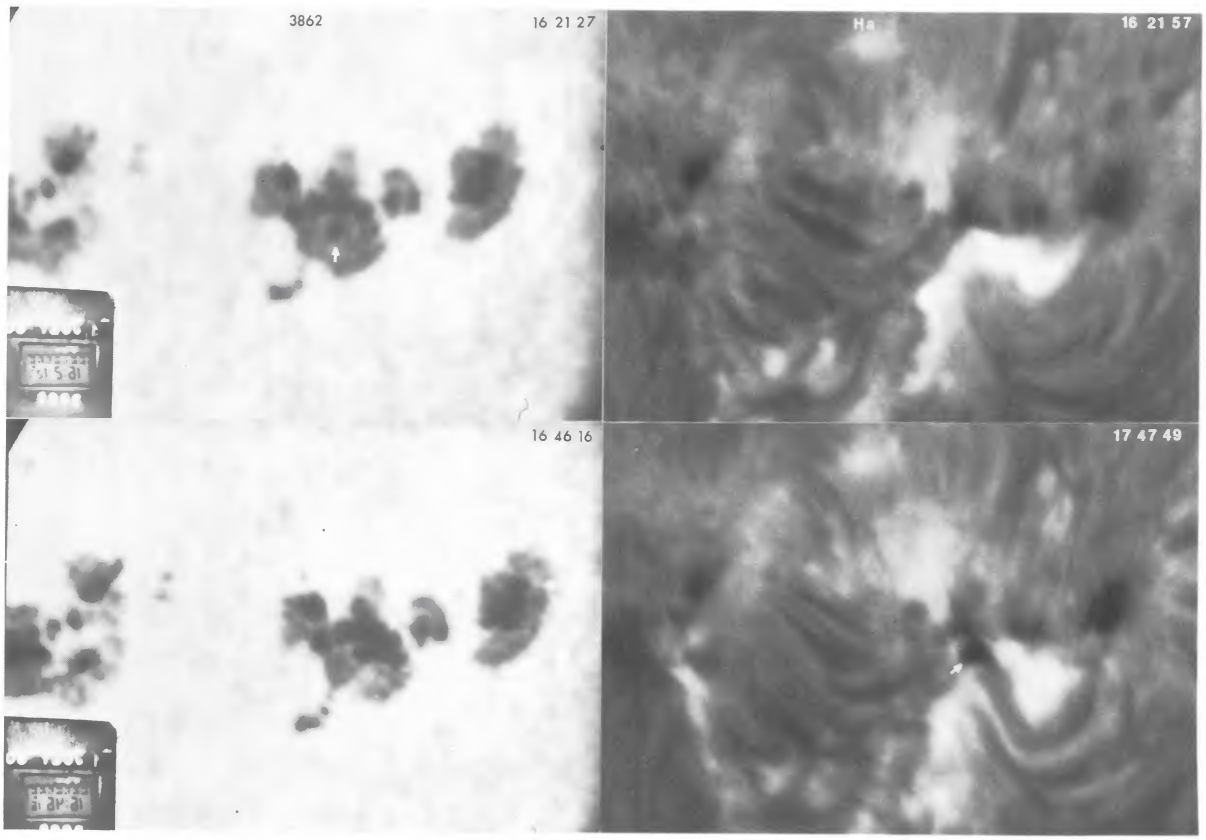

FIG. 4.—Before and after frames showing (*left*) the rapid growth of the satellite spot (*arrow*) after the flare, and (*right*) the large change in the neutral line as seen in Hα. The expansion of the spot is into the area where the flare took place; the same obtains for the Hα.

ZIRIN AND TANAKA (*see* p. 792)

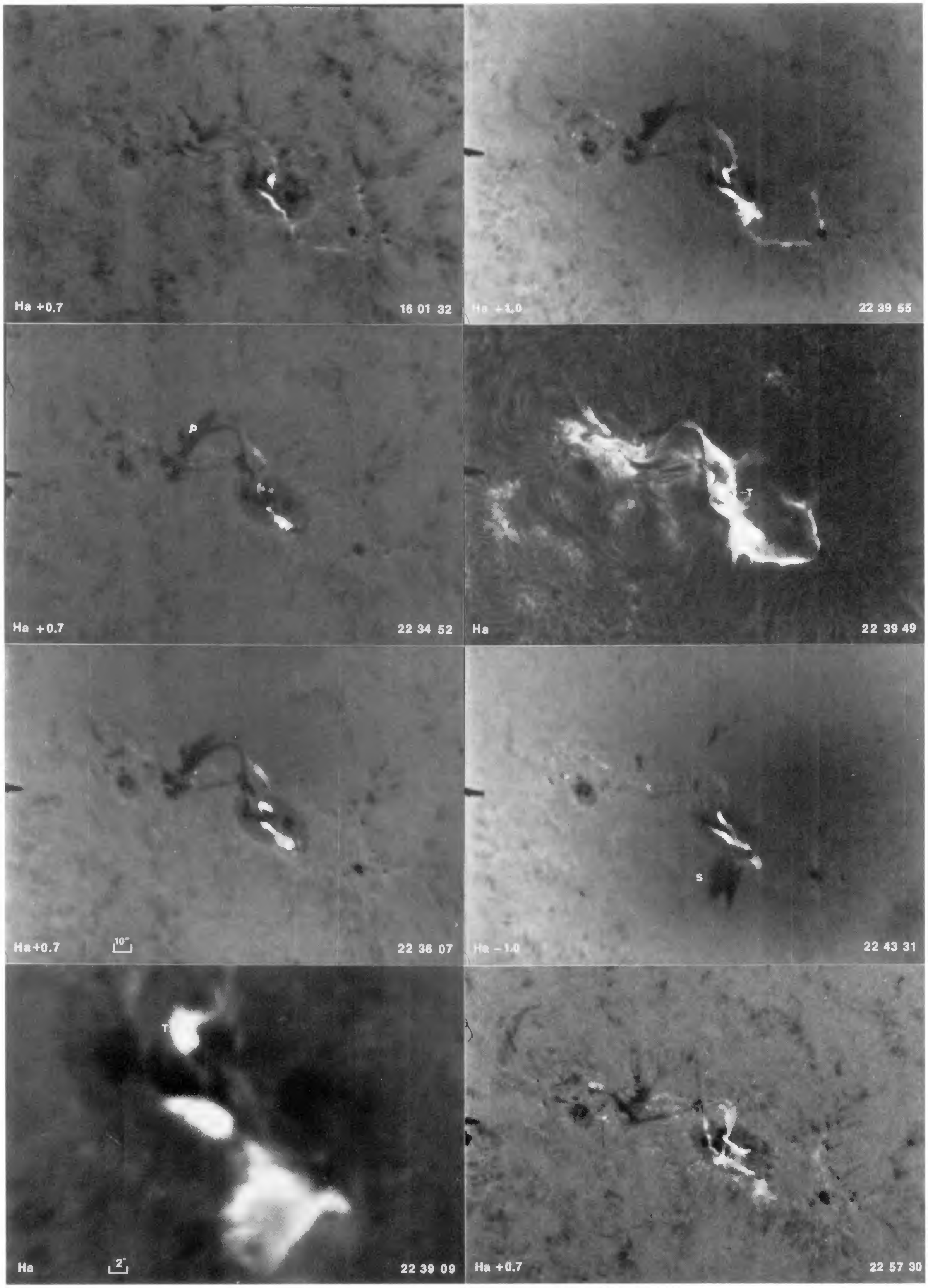

FIG. 5.—Hα development of the 1980 July 5 flare. South is at the top; west is to the left (reversed from preceding). The first frame shows an earlier homologous flare. The next two frames show the beginning of the flare in the red wing (+0.7 and +1 Å; in both of these we can see the preflare prominence activation (P). The fourth frame shows an *enlarged* view in centerline with the 65 cm telescope, with the position of the transient marked by a T. The frames on the right show the further development, the sixth and seventh frames showing the development of a surge (S), and the last, postflare loops arching the sheared fields below.

ZIRIN AND TANAKA (*see* p. 794)

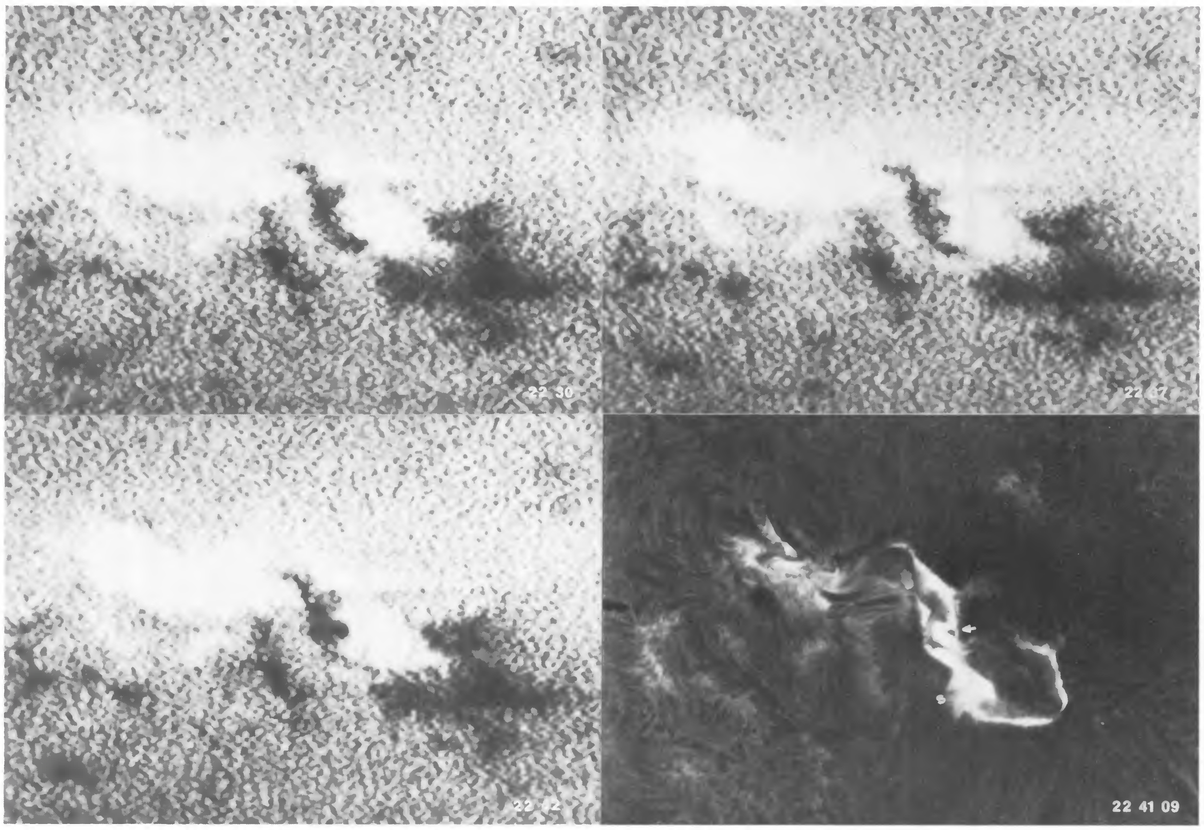

FIG. 6.—A sequence of VMGs of the 1980 July 5 event printed to the same scale showing the magnetic transient. We have superposed successive magnetograms to reduce the nose; thus, each frame is the sum of two VMGs taken 1 minute apart, each resulting from the sum of 64 video pairs. The times shown are midway between each. The dark transient is marked with a T; below the dark transient there is a decided weakening of the dark (f) polarity which may be the other half of the dipole. The transient lasted till 2245 UT. It can be seen beginning in the upper right frame. The lower right frame in Hα shows it to correspond to a knot (*arrow*) of bright emission in the p polarity. Note that the surge (S) comes from the neutral line.

ZIRIN AND TANAKA (*see* p. 794)

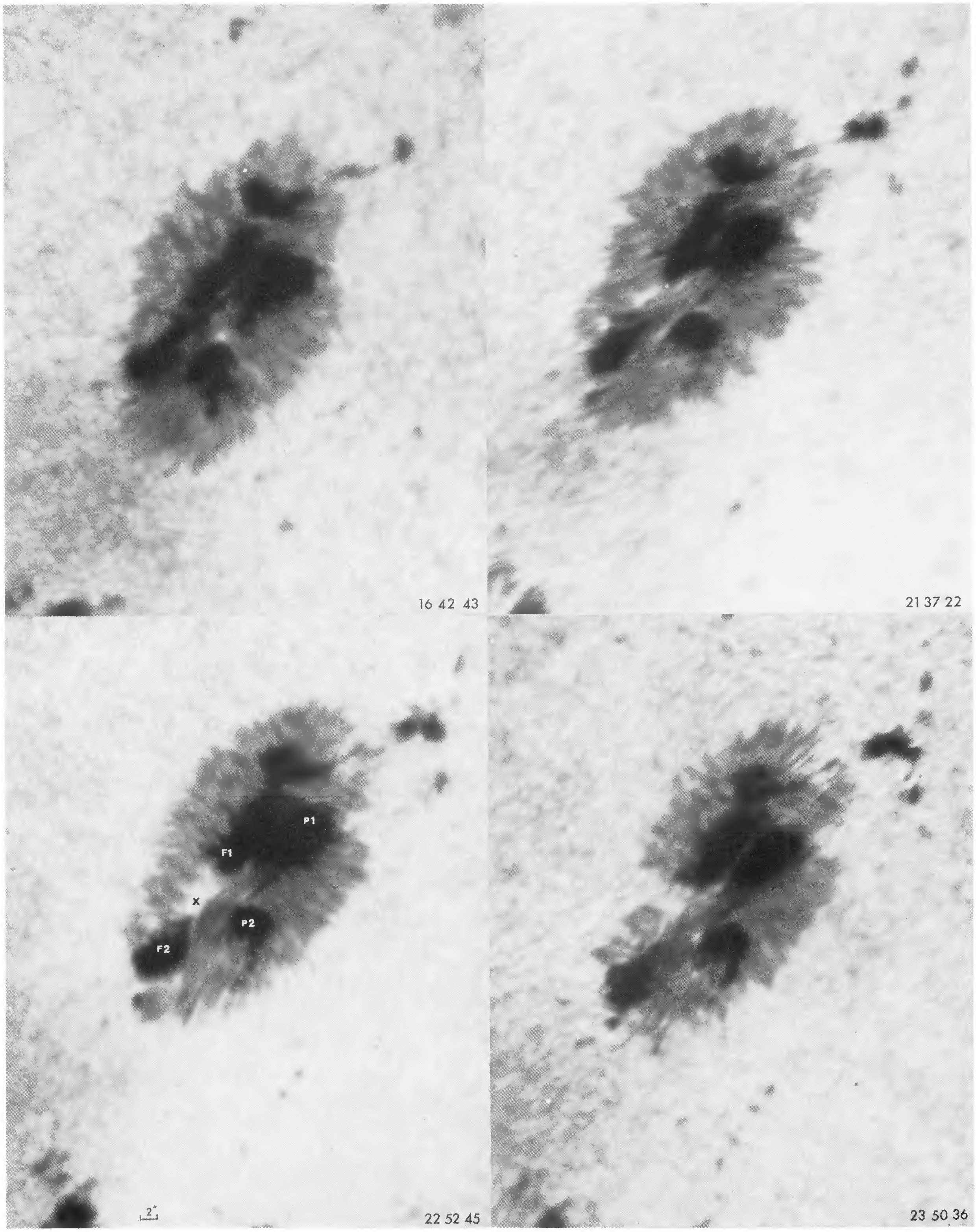

FIG. 7.—White light development of the spots photographed through a VG 9 filter on SO424 film. Along with spot designations, X marks the spot where the penumbra broke up revealing granulation. West is at the top; south is at the right. The fibrils are only 0.3 arc sec across and appear to overlie spots and granulation.

ZIRIN AND TANAKA (*see* p. 794)