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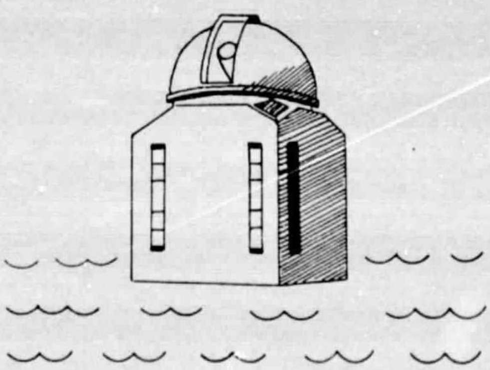

PRODUCTION OF A SHORT-LIVED FILAMENT BY A SURGE

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ABSTRACT

A large surge was observed on September 17, 1971 part of which, after travelling 200,000 km across the surface, returned to the surface to form a filament. The filament lasted about 30 minutes, then rose up and returned to the source of the surge. We interpret this as the filling of a semi-stable magnetic trap.

Analysis of the microwave radio burst shows it to have been produced by a source optically thick at 8800 MHz, with area 4 (arc min)^2 and $T \sim 275{,}000°$, $N_e^2 V \sim 7 \times 10^{48}$. The soft X-ray burst shows a component at 12×10^6 deg with $N_e^2 V \sim 3 \times 10^{48}$.

Surges are ephemeral phenomena, with little relationship to filaments. Filaments, on the other hand, are long-lived accumulations of material in magnetic "traps" in the magnetic field in the solar atmosphere; they form slowly, presumably from condensing coronal material. In the unusual case we report here, a short-lived cloud, very much like a filament, was formed by ejecta from a large surge. The "filament" lasted about 30 minutes, then rose and returned to the source of the surge. Although projection effects may deceive us, several arguments convince us this is a bona fide filament.

The surge is illustrated in Figure 1 as observed with the 10" refractor (it is in the 1971 Big Bear Show Film). The development of the large-scale phenomenon may be seen in our small-scale pictures in Figure 2. The peculiar contrast in Figure 2 is due to the use of a Fabry Perot filter. The source of the surge was a small complex satellite region which developed on the leading edge of a large complex active region (Sept. 15). It developed from an emerging flux region with normal magnetic connections to a small plage crossed by two filaments in a peculiar, sheared configuration. The filaments darkened around 1515 (first frame); at 1523 the filament disappeared; there was rapid boiling, twisting, and some expansion for 20 minutes, till, at 1544 a rapid brightening and acceleration occurred. A bright ball formed for a moment, coinciding with the peak of the 2800 MHz burst; at 1546 outward motion became even more rapid. The large scale outward velocity was 300 km/sec. Various loops and fibrils appeared and were rapidly swept outward, straightening out with the flow. The flow continued steadily for 20 minutes, the base of the surge eventually turning dark. The dark outward flow is seen at the upper left of the 16 05 26 frame (Fig. 1). At 1607 a second fibril erupted, and the flare brightening and outward flow ended by 1638.

The highest parts observed crossed the limb, a projected distance of 360,000 km, at 1614 UT. At about 1605 UT, an additional, lower arm of the surge appeared, which appeared to supply a growing condensation visible in Figure 2 near point (c), 16 15 43 UT, about 200,000 km from the source. Some of the surge material appeared to curve left as well. By 16 18 08 a full-fledged filament appears at points (b) and (c) with four legs of the familiar hedgerow type, and several bright points at its base. The filament remained in place until 1634 UT, when it slowly rose and began to return to the source. This process took about 30 minutes, with peak velocities of 115 km/sec measured. A number of short-lived bright points were seen as the surge material appeared to impact the surface (this is seen at B in the last frame of Fig. 1). Note that the point (c), which as unoccupied by material at the peak of the life of the filament was filled both going at 16 15 43 and returning at 16 43 28. On the large-scale frames (Fig.1) the flare appears to have ended by 1638; but at 1700 the first returning downward falling material arrived. The infall, accompanied by brightening, continued until 1730. But for a period of about 30 minutes, the flare was over at its origin, and the energy was stored at the distant filament.

It is possible that the filament is merely a condensation high above the surface, seen projected against the disk. But several strong points suggest that a real filament i.e. a stable suspension of gas above the surface is seen. These are:

1) The filament material is much darker than the surge material; in fact it is darker than all the other filaments on the disk.

2) The emission points observed can only be at the surface. No such bright points have ever been observed with a broad pass filter against the disk at the top of the surge trajectory; there is simply not enough density to excite Hα by collisions.

3) Material travelling at 300 km/sec abruptly stops, increases in absorption and remains motionless for thirty minutes. Such behavior can only be ascribed to an encounter with a magnetic trap.

4) The filament formed shows the typical filament fibril structure.

The following points argue against the identification of the feature as a filament:

5) An absorption feature "g", 16 43 28 is seen near the S polar filament. This feature returns at the same time as the "filament" rises. As it is not very dark, and near the end of the surge trajectory,

it represents material near the top of the trajectory which simply falls back, and apply the same argument to the filament. However, we cannot explain why this material remains stationary for fifteen minutes.

6) The location of the "filament" is an undistinguished area of chromospheric network. No filament channel is seen. However the other polar filaments don't show filament channels either.

I have examined the Mt. Wilson magnetogram for this day, but find the magnetic fields in this region too weak for reliable field measurement. The magnetograms show overall negative polarity but the presence of several polar filaments in the Hα pictures show the presence of several field reversals. One can infer the presence of a neutral line by the following argument: The south polar field at that time was minus (R. Howard, private communication). A polar filament (f) is seen in the region directly S of our "filament". This means that the field is plus N of the polar filament. But the Mt. Wilson magnetogram shows the area around the base of the surge to be minus polarity. Thus there must be another neutral line between the active region and the polar filament, and this may be the line along where the filament forms (although we have absolutely no proof that it is).

I have marked on the early frames of Figure 2 several (points a,b,c) of the chromospheric features at the point where the filament lands. They are, so far as we can tell, ordinary parts of the chromospheric network, although the point b may be an ephemeral active region.

The various brightenings observed, although not perfectly understood, are reasonable. The lower edge of the surge is brightened by Doppler-shifted photospheric emission (Zirin, 1969). The impact brightenings late in the event are not the same as the effect discussed by Hyder (1967), who felt they might produce a flare, but they do show that falling material can produce minor brightening. In fact, if material falling from such great heights can only produce these small brightenings, it is hard to see how flares could be produced. The energy of the returning material must be stored in the supporting magnetic field; however in some way as equilibrium must be reached which permits the matter to remain motionless for some time. Presumably the compressed field reaches a stable state, but bounces back when sufficient material leaks out of the filament. In the stationary state the field is compressed by the weight of the material; for a density of 10^{10} and a column 10,000 km high, the pressure is about 0.5 erg/cm^3, and easily sustained by a 5 gauss field. If this pressure is reached by a compression of the field over the same 10,000 km (i.e. compression of field lines from 20,000 to 10,000 km) then the expanding field can produce the observed return velocity of 100 km/sec if it does not have to work against gravity. In fact, the returning material rises but slightly, so the phenomenon is energetically possible, but of course its true nature is probably much more complex.

The reader may perhaps wonder why I have dwelt so long on the question of whether or not a true filament was formed. The significance is that magnetic traps exist in the solar atmosphere, and the fact that even dynamic material may be captured by them shows how prominence material may easily accumulate there in more typical, slower formation.

Important information may be gained from the radio burst, which was most interesting. Multifrequency data from Sagamore Hill was kindly furnished by Dr. Castelli, and 2800 MHz records from NEL by Dr. Bleiweiss. There was an impulsive low frequency burst at the flash phase, peaking at 1546 and ending 1547. At high frequencies, however, only a gradual rise and fall was seen, peaking at 1554 along with the soft X-rays. Further, the peak fluxes were: 15,400 MHz - 11.1 sfu (peak at 1554); 8800 - 9.7 sfu (peak at 1554); 4995 - 5.6 sfu (peak at 1545) and 2695 - 3.5 sfu (peak at 1545). While the impulsive burst can be non-thermal, the peak at 1554 can only be due to a maximum in the area covered by the event. In fact the area of Hα emission is at a maximum at 1554 and falls sharply afterward. The high-frequency flux can then be explained by thermal emission; the area of Hα emission is about 2 arc min. Since the flux is flat above 8800 MHz, we set $\tau = 1$ at that frequency. With an area of 4 (arc min)^2, we got $T_{eff} = 278{,}000°$, and, with L = 84,000 km (2 arc min), $N_e \sim 3.5 \times 10^9$ and $N_e^2 V = 7.3 \times 10^{48}$. On the other hand, if we compare the soft X-ray burst reported by Solrad 9, we find, using the curves of Hudson and Ohki (1972) $T \sim 1.2 \times 10^7$ deg, $N_e^2 V = 3 \times 10^{48}$. This hot component only produces 2 sfu of emission and does not affect the measured flux.

We conclude that the late peak in the microwave burst is produced by the maximum in area of a plasma at 275,000° which is just optically deep at 8800 MHz, and is accompanied by a much hotter component of nearly equal emission measure at 1.2×10^7 deg. Harvard reported a III GG burst at flash phase and type II burst at 1555, as one might expect.

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FIGURE CAPTIONS

FIGURE 1:

Six stages in the surge eruption, photographed in Hα centerline with the 10" telescope.

15 18 33 The fibril or small filament (F) crossing the plage at upper left expands and darkens. A boiling commences, reaching intense brightness.

15 46 58 The hot presurge plasma has been formed. The radio burst is reported to start at 1544, at which time brightening becomes rapid.

15 49 30 Rapid outward flow - tangled knots appear and are blown outward.

15 54 37 Continued rapid outward flow. The surge is not a single puff, but an enormous force sweeping material outward. Peak of microwave burst. Type II burst, 1556.

16 05 26 The surge is about over, but dark fibrils still stretch outward.

17 03 55 At point B, a new brightening occurs as matter flows back downward from the filament.

FIGURE 2:

15 58 13 The surge moves rapidly outward, with a bright lower edge.

16 04 03 A great core of outward moving material reaches as f-r as the polar filament f.

16 15 43 Brightening is seen along the surface at c, and dark material to the SW is beginning to condense. Most of the condensation is to take place in the parallelogram formed by cell boundaries a and b.

16 18 08 In these few minutes the new filament has condensed, covering several supergranule cells. The bright edges do not coincide with a and b; allowing for projection we can guess that the left (SW) edge is midway between a and b, and the closer (NE) edge at c is on this side of b, so the filament arches over the cell boundary b.

16 27 08 The surge has disappeared, but a small blob remains at its most distant point, just below the "T" in Sept. We cannot tell if it is high above the surface or near the polar filament f. The new filament at ab is unchanged.

16 43 28 The filament at ab has begun to move back. Most of the ab area is empty and the fila ent is now at c; also the element g has disappeared.

16 57 48 Material continues to flow back toward the spot group

17 08 18 All over, except for a bright remainder at the base of the surge.

BIG BEAR SOLAR OBSERVATORY SEPT 17 1971

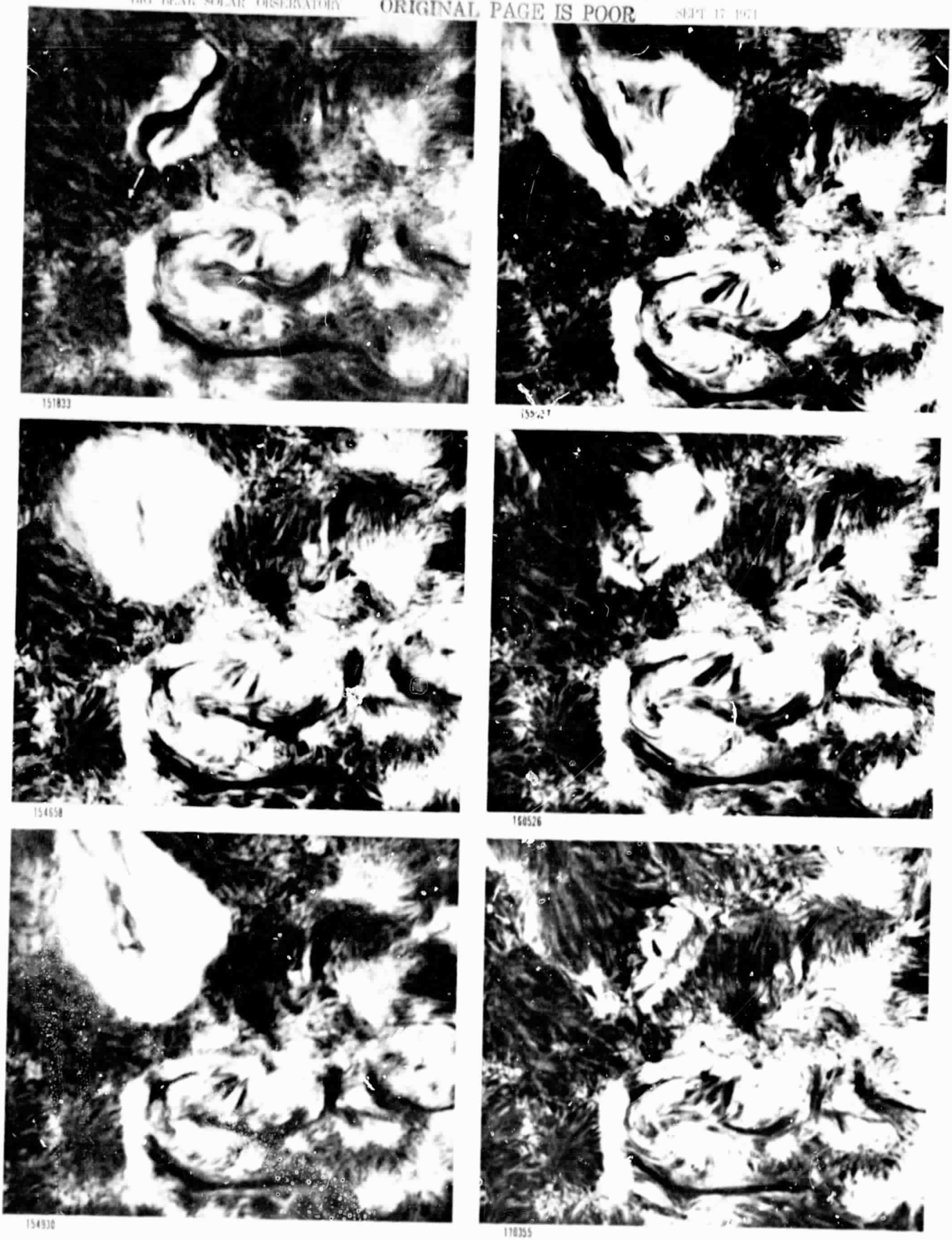

Figure 1

BIG BEAR SOLAR OBSERVATORY SEPT. 17. 1971

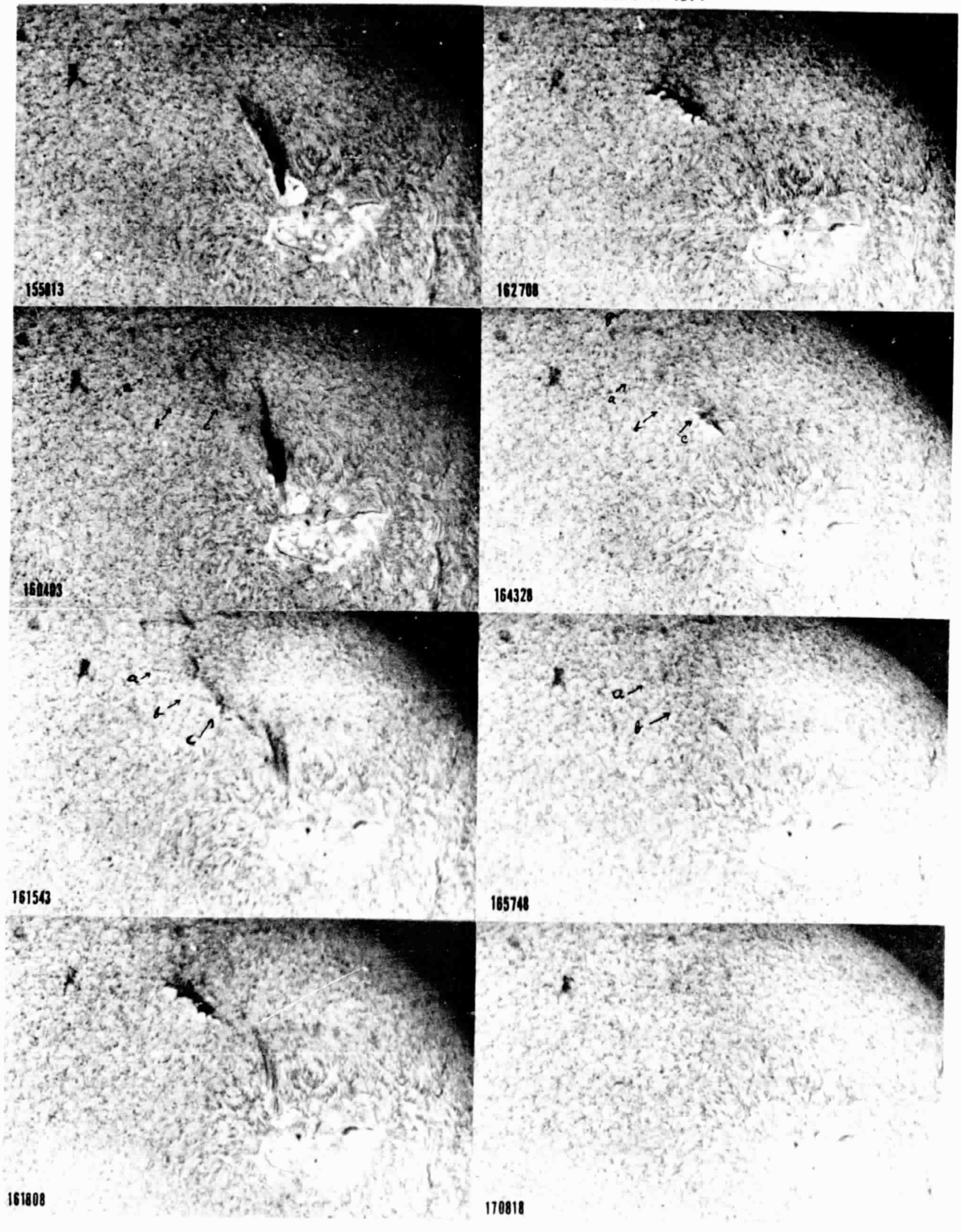

Figure 2