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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 through the corona, returned to the surface to form a filament. The filament lasted about 30 min, then rose up and returned to the source of the surge. We interpret this as the filling of a semi-stable magnetic trap.

The energetics of radio, X-ray, and surge expulsion are estimated. The radio spectrum and flux correspond to a thermal source of area 4 (arcmin)^2, $T \sim 190\,000$ K, $N_e^2 V \sim 7 \times 10^{48}$, which is optically deep at 8800 MHz. The soft X-ray source has $T \sim 12 \times 10^6$ K, $N_e^2 V \sim 3 \times 10^{48}$; and if an equal mass is expelled in the surge, the kinetic energy of the surge is similar to the thermal energy of the X-ray source.

Surges are ephemeral phenomena, fast ejections of material. 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 min,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 (S top, E right on all pictures) 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 (September 15). It developed from an emerging flux region with normal magnetic connections into 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 min, 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 s^{-1}. 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 160525 frame (Figure 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

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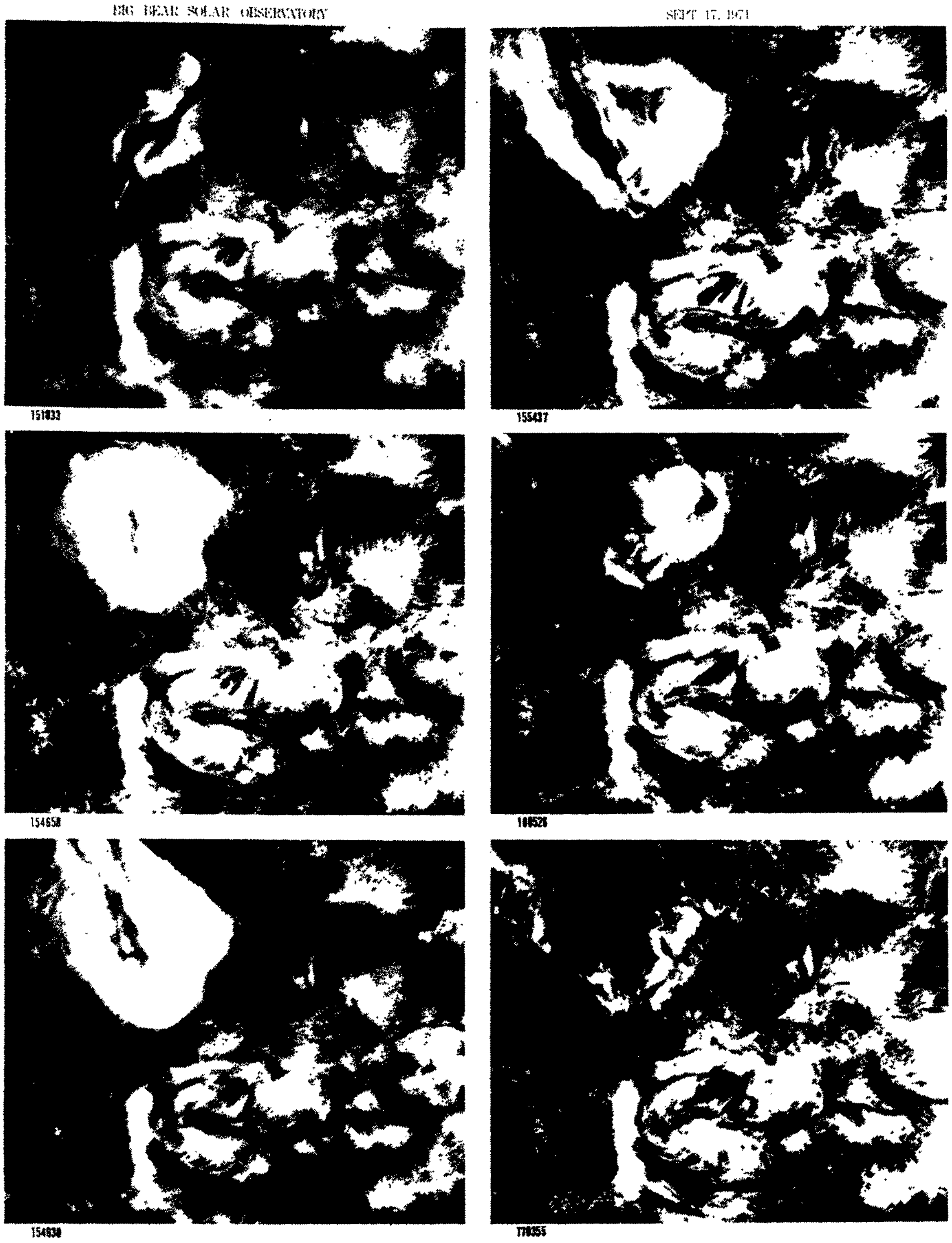

Fig. 1. Six stages in the surge eruption, photographed in Hα centerline with the 10″ telescope. 151833: The fibril or small filament (F) crossing the plage at upper left expands and darkens. A boiling commences, reaching intense brightness. 154658: The hot presurge plasma has been formed. The radio burst is reported to start at 1544, at which time brightening becomes rapid. 154930: Rapid outward flow – tangled knots appear and are blown outward. 155437: 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. 160526: The surge is about over, but dark fibrils still stretch outward. 170355: At point B, a new brightening occurs as matter flows back downward from the filament.

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), 161543 UT, about 200 000 km from the source. Some of the surge material appeared to curve left as well. By 161808 a filament-like feature 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 min, with peak velocities of 115 km s^{-1} 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 Figure 1). Note that the point (*c*), which was unoccupied by material at the peak of the life of the filament, was filled both going at 161543 and returning at 164328. On the large-scale frames (Figure 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 min the flare ended, and no energy was being released; yet energy was available, perhaps stored in the new filament, to return it to its origin.

It is possible that the filament is merely a condensation in the surge, high above the surface, and it only appears by projection to be a surface filament, and then falls back. But several strong points suggest that a real filament, i.e. a stable suspension of gas close to the surface, is seen. These are:

(1) After 161543 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. It is very unlikely that any part of a suspended surge could be dense enough to emit Hα in projection against the disk. The emission points are similar to those usually seen at the feet of well-established quiescent filaments.

(3) Material travelling at 300 km s^{-1} abruptly stops, increases in absorption and remains motionless for thirty minutes. This is hard to understand at the top of the surge trajectory but reasonable if it falls to the surface and accumulates in a magnetic trap.

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

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

(5) An absorption feature '*g*', 164328 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. So possibly the dark filament material is similar.

(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. There are several field reversals between pole and active regions but we can say nothing about the field where the filament formed.

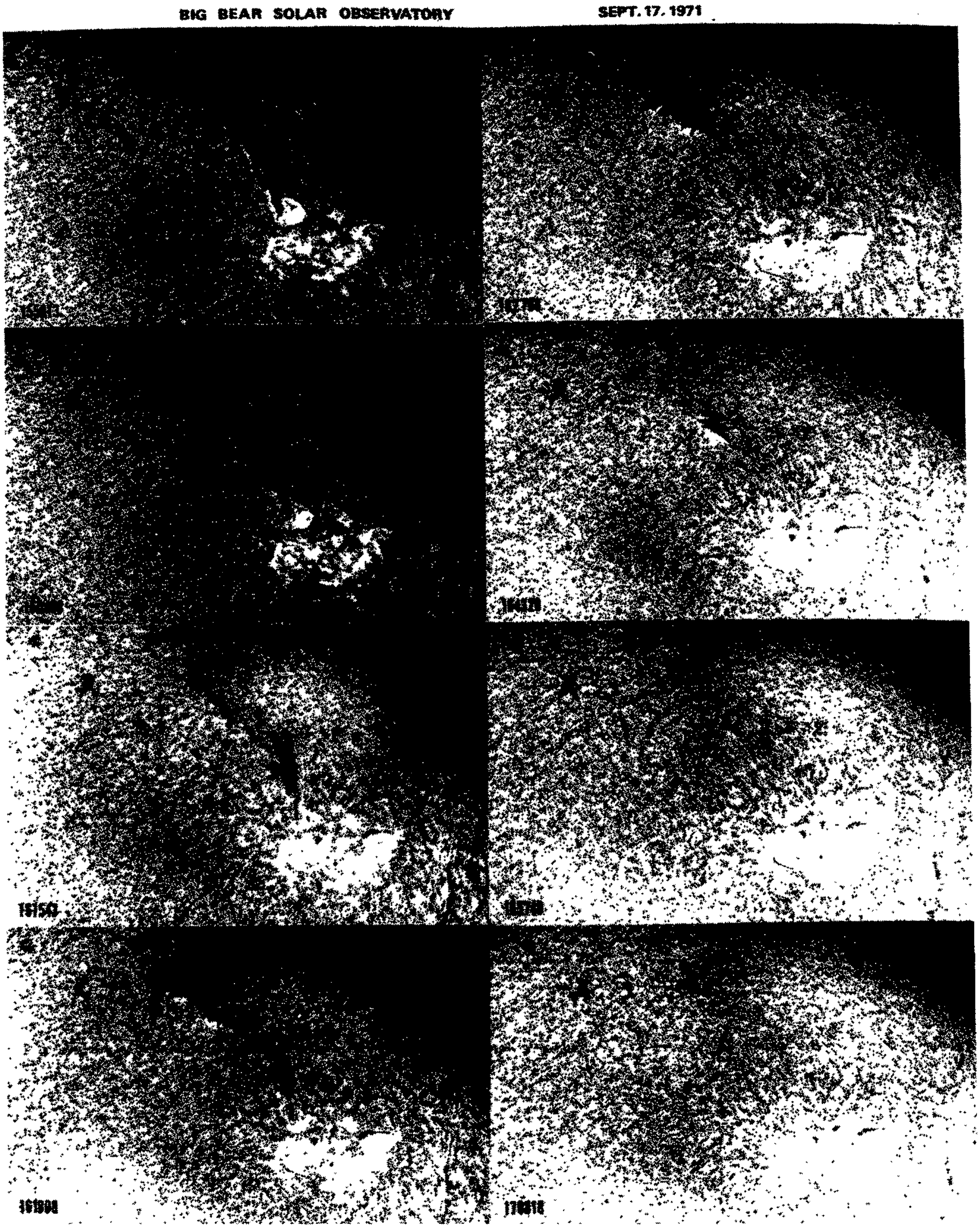

Fig. 2. 155813: The surge moves rapidly outward, with a bright lower edge. 160403: A great core of outward moving material reaches as far as the polar filament *f*. 161543: Brightening is seen along the surface at *c*, and dark material to the SW is beginning to condense. Most of the condensation is to take place in the parallelogram formed by cell boundaries *a* and *b*. 161808: 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*. 162708: The surge has disappeared, but a small blob remains at its most distant point, just below the '*T*' in Sept. We cannot tell if

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 transient brightenings where material appears to hit the surface are not quite the effect discussed by Hyder (1967), who felt falling material might produce a flare, but they do show that such 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. It is possible that the kinetic energy of the returning filament material has been stored in the magnetic field which traps it; however in some way as equilibrium must be reached which permits the matter to remain motionless for some time. A 5 or 10 gauss supporting field is entirely adequate to supply the necessary energy.

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.

A rough idea of the energetics of this event can be obtained by radio and X-ray data at the beginning. Multi-frequency 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 at 1547. At high frequencies, however, only a gradual rise and fall (grf) was seen, peaking at 1554 along with the soft X-rays. Further, the peak fluxes were: 15 400–11.1 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 nonthermal, the peak at 1554 occurs simultaneously with the peak in Hα area of the surge. After 1554, the area of the bright surge falls sharply. Therefore, we assume that the high frequency flux can be explained as thermal emission. The area of Hα emission is about (2 arc min)^2. Since the flux is flat above 8800 MHz, we set $\tau = 1$ at that frequency. With an area of 4 (arcmin)^2, we get $T_{\text{eff}} = 191\,000$ K, and, with $L = 87\,000$ km (2 arcmin), $N_e \sim 3.5 \times 10^9$, $N_e V = 2.3 \times 10^{39}$, and $N_e^2 V = 8.1 \times 10^{48}$. The soft X-ray burst reported by Solrad 9 gives, using the curves of Culhane and Acton (1970), $T \sim 1.2 \times 10^7$ K, $N_e^2 V = 3 \times 10^{48}$. This hot component only produces 2 sfu of radio emission; but if we assume the density of the hot component does not exceed that of the

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it is high above the surface or near the polar filament *f*. The new filament at *ab* is unchanged. 164328: The filament at *ab* has begun to move back. Most of the *ab* area is empty and the filament is now at *c*; also the element *g* has disappeared. 165748: Material continues to flow back toward the spot group. 170818: All over, except for a bright remainder at the base of the surge.

cooler, i.e. $N_e = 3 \times 10^9$, then $N_e V = 10^{39}$ for the soft X-ray source and the total thermal energy for that source is 1.4×10^{30} ergs. If we assume the thermal energy of the X-ray source is in equipartition with the kinetic energy of the surge at 300 km s^{-1}, we find the mass of the surge must be 1.4×10^{15} gm, or $N_e V \approx 10^{39}$. Of course we cannot confirm the mass of the surge by any other way, but the result is reasonable.

The microwave grf is thus produced by the maximum in area of a plasma at 190 000 K which is just optically deep at 8800 MHz: This plasma is accompanied by a much hotter component of nearly equal emission measure at 1.2×10^7 K, and, if an equal amount of matter is involved in the surge, the surge kinetic energy is roughly equal to the thermal energy of the X-ray source. This energy is dissipated in the surge, but some may be stored temporarily in the short-lived filament.

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