CHROMOSPHERIC EXPLOSIONS AND SATELLITE SUNSPOTS*

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ABSTRACT

Observations of the longitudinal component of the photospheric magnetic fields near sunspots imply that surges and Ellerman bombs occur at neutral points in the magnetic fields (i.e. $|B|=0$) in the chromosphere. The neutral points appear above satellite sunspots, which are defined as polarity reversals (in $B_{\parallel}$) near the edges of large-spot penumbrae. A series of magnetograph observations shows a point of satellite polarity vanishing during a period of almost continuous surge activity. The lost magnetic energy is comparable to the energy release evidenced by the surge.

1. Introduction

Several researchers have used solar magnetographs to study the magnetic-field structure of large sunspots in active regions. They have found that very frequently these spots were surrounded by a number of 'satellite' magnetic features. The polarity of the satellites was opposite to that of the central spot (Bumba, 1960, 1962; Howard, 1959). In most cases these satellites were not visible on white-light photographs. However, Gopasyuk *et al.* (1963) obtained many observations of flare-producing regions which included large sunspots accompanied by small, visible spots imbedded in penumbrae. The smaller spots ('satellites') usually had polarity opposite to that of the main spot. I used the magnetograph at the Mount Wilson Observatory to map the longitudinal component (as indicated by Zeeman splitting in the photospheric Fe I line at $\lambda 5250$) of the magnetic field of the active region of June 2–3, 1967. The region passed central meridian in the Northern hemisphere on June 3. The observations show many satellite sunspots (invisible in integrated light) near the penumbra of the largest spot in the region. The spacial resolution of the scans was either 5 or 10 sec of arc and the noise level was about 2 gauss. The observed size of the satellite magnetic features is at the resolution limit.

2. Observations

As the magnetic measurements were being made, personnel of the Lockheed Solar Observatory made large-scale Hα motion pictures of the region. Figure 1 is an Hα photograph of the region at 1947 UT on June 2. A surge is occurring at the penumbra

* Presented by R. Howard.

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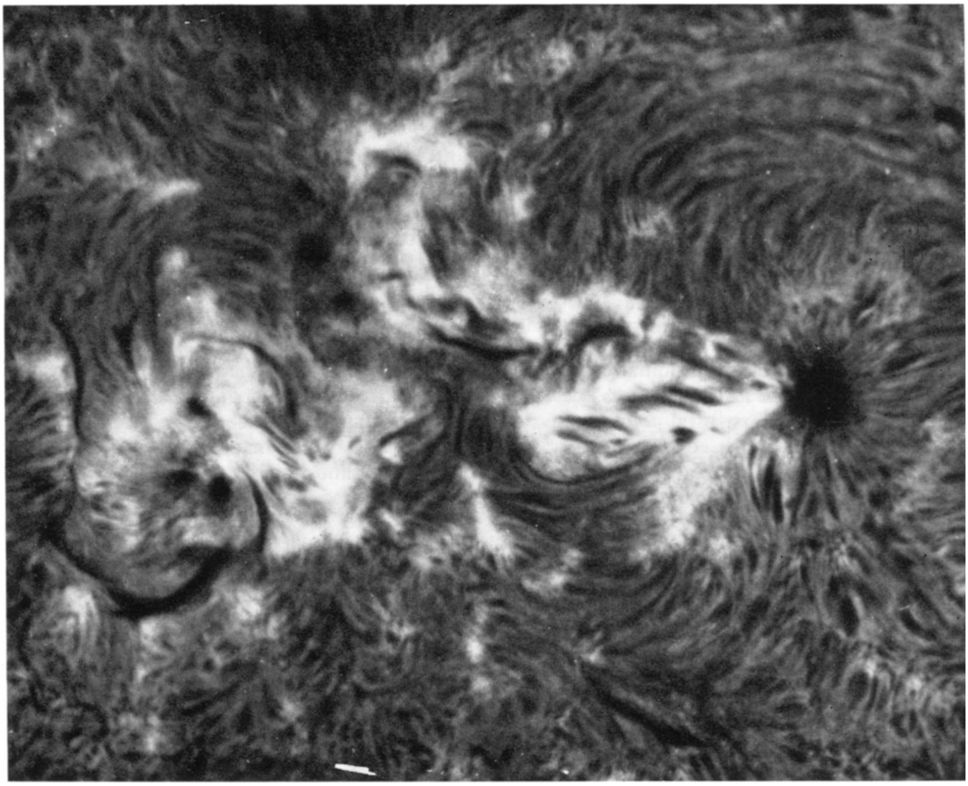

FIG. 1. *The active region of June 2, 1967. North is at the top and East is on the left. This photograph was made in the center of Hα at 1947 UT. During the period of observation (1635 UT, June 2, to 0116 UT on June 3) nearly continual surge activity took place on the Northwest side of the large leading spot. A small surge is shown in this picture. Many flare brightenings occurred in the center and left-of-center plages in the region.*

of the large, leading sunspot, and some traces of a flare brightening are evident in the middle of the picture. There were several flares in the region on June 2 and 3. The motion pictures show continual surge activity in the region. The positions of all the observed surges are shown in Figure 2, which is a magnetogram of the region as it appeared on June 3. Dashed lines inclose negative fields; solid lines inclose positive fields. Solid triangles show approximate surge size and direction. Solid dots are Ellerman bombs and the flare areas are hatched. *Every bomb, every surge, and many flare brightenings originate at the satellite sunspots.* Because of the relatively low resolution of the magnetic measurements, it is impossible to know the real size and the peak field intensity of the satellites. Even if their characteristic fields should be several hundred gauss and their cross-sections only 2 sec of arc, the magnetograph would transform them into broad 5 or 10 gauss features on the magnetic maps. All flaring regions of

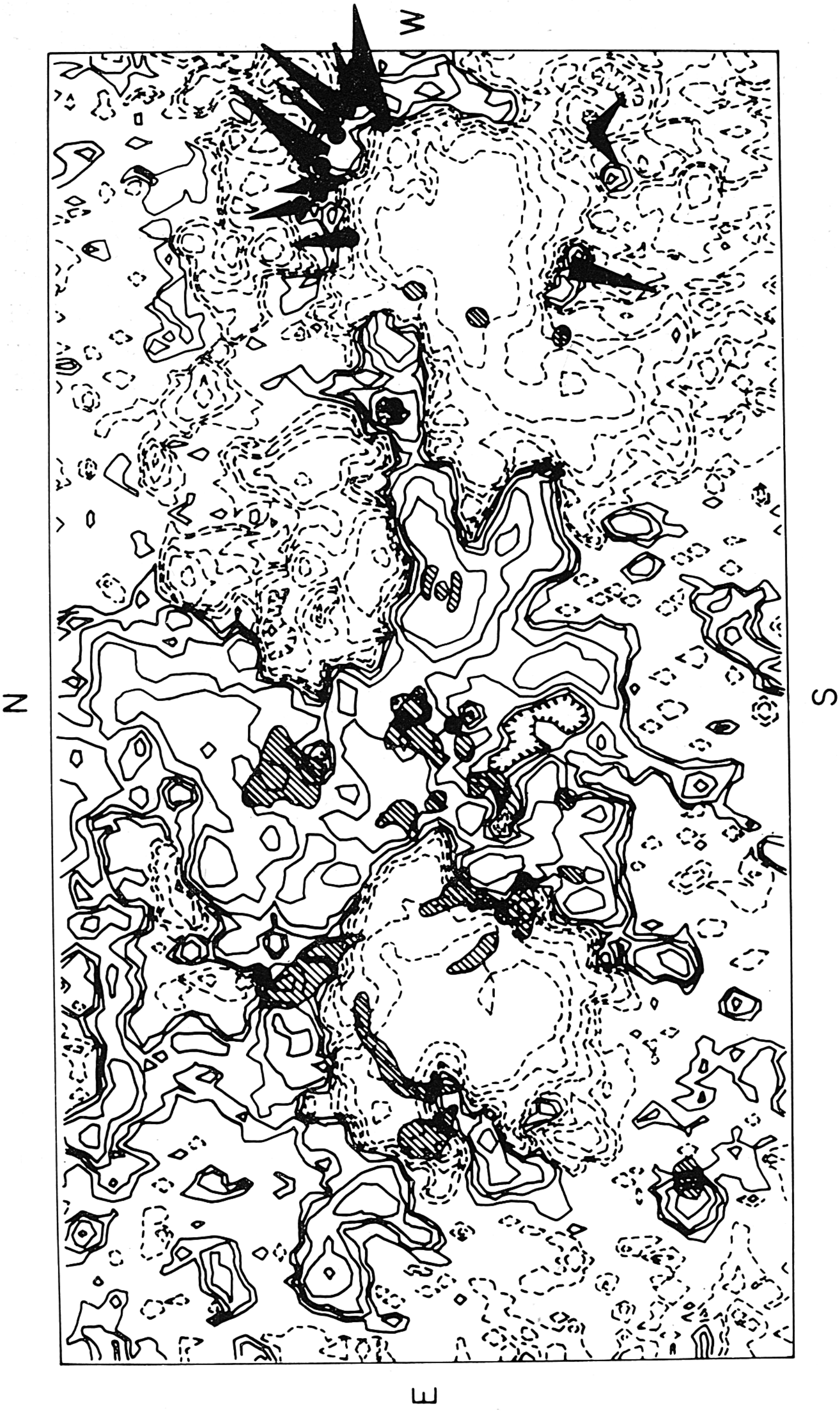

FIG. 2. *Contour map of the longitudinal magnetic fields in the region at 1600 UT on June 3, 1967. Dashed lines inclose areas of negative field, and solid lines inclose areas of positive field. Contour levels are 5, 10, 20, 40, 80, and 160 gauss. Dark surges are indicated by solid triangles. Solid dots denote Ellerman bombs (moustaches) and areas of flare brightening are indicated by hatching. 'Valleys' in the field intensity are distinguished from 'hills' by small converging tick marks. A comparison of the visual sunspot polarities and some valleys on this map reveals that the valleys are really sites of polarity reversals not completely detected with the magnetograph. The resolution is 5 sec of arc.*

June 2 have been included in the figure. Perhaps inclusion of only the points which showed a flash phase would give a higher correlation between satellite spot and flare-brightening positions. More research is needed on this point.

3. The Lines of Force

What do the fieldlines above satellite sunspots look like? To find this out, I used the method of computing the magnetic-field lines developed by Schmidt (1964). His method is to assume that the space above the photosphere is current-free. Potential theory may then be used to calculate the field from the observed flux distribution in the photosphere. Figure 3 shows the lines of force near the largest surges. *The surges follow the lines of force.** On this figure I have drawn the principal neutral lines

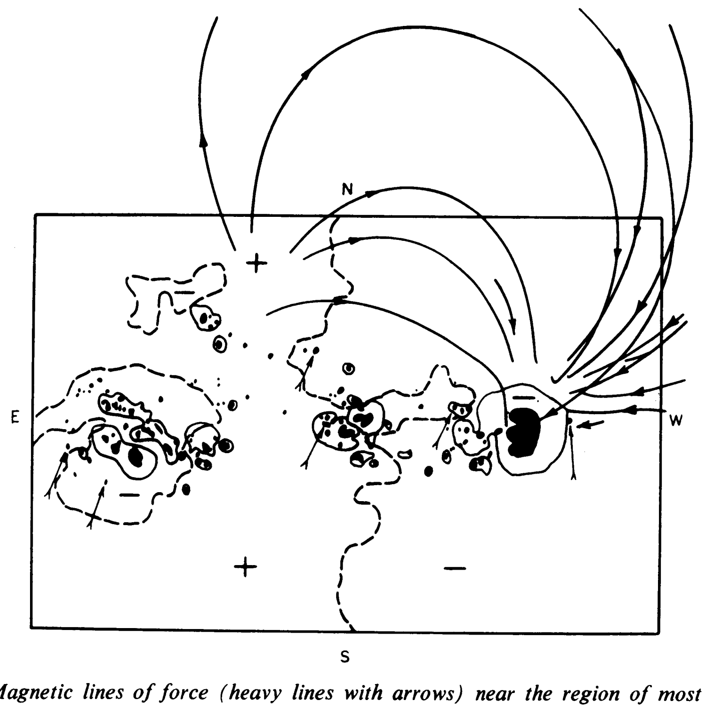

FIG. 3. *Magnetic lines of force (heavy lines with arrows) near the region of most intense surge activity. A comparison with Figure 2 shows that the surges follow the lines of force. The fieldlines were constructed according to the potential theory by considering the chromosphere current-free. The sources of the field are fixed in the photosphere, which is assumed plane-parallel. Heavy dashed lines coincide with the major lines of zero longitudinal field in the region and the polarities on either side are indicated by symbols (+ and −). Thin arrows point out satellite sunspots detected by the routine Mount Wilson sunspot field measurements.*

* I do not intend to imply, however, that the magnetic field above the region was current-free. The surges alone are good evidence for currents. Nevertheless, it is apparent that the lines of force do not deviate radically from those calculated under the current-free approximation.

(heavy, dashed lines) in the measured longitudinal fields. The thin arrows point to the few visible satellite sunspots in the region. A flare occurred near the *visible* satellite in the center of the figure; however, the observed surges and Ellerman bombs all occurred near *invisible* satellites, i.e., near points of isolated polarity detected only with the magnetograph.

4. Neutral Points

The significance of the satellite sunspots for bombs and surges, at least, is revealed in Figure 4. There is most likely a neutral point (i.e. $|B|=0$) in the magnetic field in

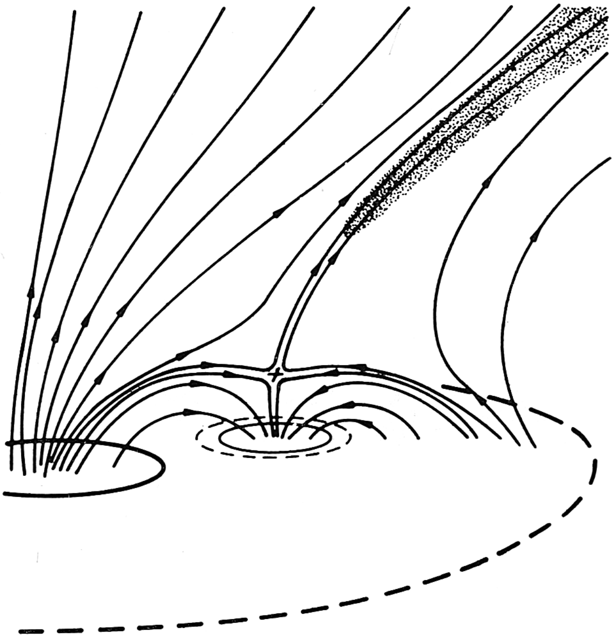

FIG. 4. *Sketch of the fieldlines above a satellite sunspot. An X marks the neutral point where explosive events probably originate. The satellite spots are small features easily overlooked in the large scale (usually bipolar) pattern of the major regions, even though the satellites seem to be an integral feature of most large spots in growing regions (Bumba, 1960).*

the solar atmosphere above every satellite sunspot. It appears that the explosive events of June 2 and 3 originated at the neutral points that are implied by the geometry of the underlying fields. Severny (1965) and Koval (1965) at the Crimean Observatory have come to similar conclusions. It is clear from the figure that the larger the satellite spot relative to its parent, the higher the neutral point will be. For example, bombs are very small and they occur in the low chromosphere. Large flares occur much higher up. Apparently, bigger, higher events occur above larger satellite spots, i.e., those spots which have the more elevated neutral points, but more research is needed to establish whether this pattern is generally obeyed by explosive events.

Neutral points in the magnetic field have played an important role in almost all theoretical discussions of explosive events. At these points magnetic energy may be converted to observable radiative and kinetic forms.

5. The Field Changes

Figure 5 shows the appearance of a satellite spot under the surges before and after the most violent activity. The small spot of positive polarity is a stable feature of the first three maps, taken only 8 min apart. After a delay of 1 hour and 50 min, during which no observations were obtained, the region was scanned three more times. The satellite-spot field had disappeared. The disappearance was not permanent, however, since the satellite polarity appeared on maps made $2\frac{1}{4}$ hours after the final scan shown in the figure. Also, the spot was detected on a scan made the following day. The satellite spot was just above the limit of resolution for these maps (10 sec of arc), and it is not impossible that observing conditions had deteriorated enough by the second series of scans to make the field undetectable. However, the fact that it was detected several

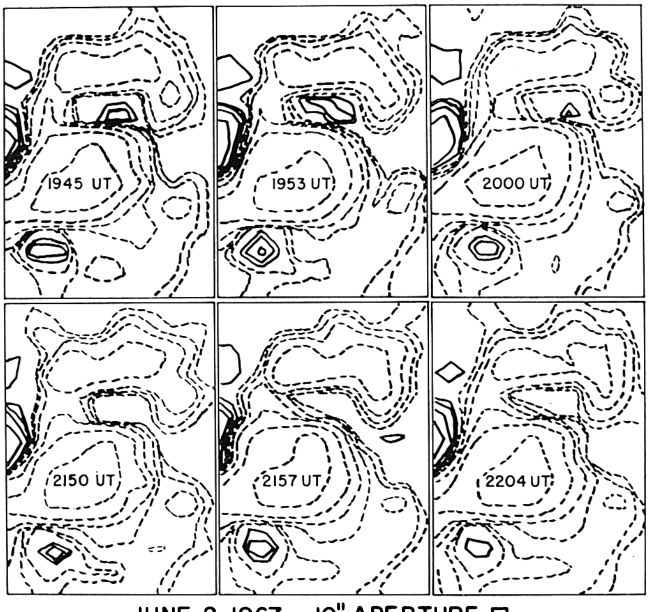

FIG. 5. *A sequence of magnetic maps of the most active surge region. Contour levels are 5, 10, 20, 40, 80, and 160 gauss. The top three maps were made before the largest surges occurred. They all show a small positive feature at the Northwest (upper right) edge of the penumbra of the large negative sunspot. The lower maps all lack the small feature which was at the location of the surges. Note that other features of comparable size are unchanged during these measurements.*

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hours later under even worse seeing conditions, and the fact that similar features everywhere else on the magnetograms did not undergo a similar disappearance tend to support the conclusion: the field of the invisible satellite spot just under the largest surges decreased significantly during the most pronounced surge activity. The later recovery of the field is consistent with other observations of photospheric field changes during minor events in a growing active region (Michard *et al.*, 1961).

6. Energy for Surges

What was the magnetic energy of the vanished spot? The magnetic flux associated with the spot was about 5×10^{18} maxwells. The lines of force symbolizing this flux must pass through the plane of observation twice (see Figure 4). If the field did vanish, we would expect both positive and negative regions to weaken or disappear. However, it is obviously much easier to detect a small change in the weak satellite spot than in the large parent spot which has extensive regions of strong fields. If I assume that there was a change in the negative fields to accompany the change in the small positive spot and that the annihilated flux extended upward to a height of 1000 km, then there was about 2×10^{26} ergs available for the surges. If the radiative and kinetic energy released in a surge are comparable, we can find the total energy required to produce a surge from an estimate of the kinetic energy of the outward-moving material. The velocity of the surges is about 100 km/sec. If I assume a diameter of 1000 km, a length of 5000 km and a density of 10^{11} protons/cm^3, then I find that the surge had a kinetic energy of about 3×10^{25} ergs. Thus, the kinetic and radiative energy of the surge was about 6×10^{25} ergs. This is comparable to the vanishing magnetic energy. Perhaps then, we have a clear case of annihilation of magnetic energy near a neutral point with attendant brightening (at the base of the surge) and acceleration of chromospheric matter. Since virtually all events with pronounced flash phases occur in or near spot penumbrae, I think it is probable that we will find every such event taking place above the satellite sunspots found there.

Acknowledgements

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DISCUSSION

Sturrock: The fact that surges occur above circular neutral lines (zero vertical magnetic field) fits well with the fact that flares occur above neutral lines. However, if the surge energy is derived from magnetic energy, the pre-surge state cannot be current-free and therefore not of the form depicted by Dr. Rust.

Howard: This is true.