TWO PROMINENCE ERUPTIONS AND THE PROBLEM OF EMISSION*

HAROLD ZIRIN

Mount Wilson and Palomar Observatories,
Carnegie Institution of Washington,
California Institute of Technology, U.S.A.

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Abstract. Two flare unconnected eruptions on January 15 and 29, 1968, are discussed. The first is a filament which turns bright and erupts upward, reappearing an hour later. The second is a large eruptive arch seen against the disk. The arch is bright at the top of its trajectory, turns dark, but produces chromospheric emission at the point of impact. The emission at the top of the arch is ascribed to the velocity shift of the illuminating chromospheric Hα line. It is shown that such emission will occur only if the motion is transverse to the line of sight and the prominence is optically thin.

In November, 1967, the Caltech solar group began observations with a new small photoheliograph on the roof of the Robinson Astrophysical Laboratory on the Caltech campus in Pasadena. The system consists of a Carroll portable spar built by the Thomas Tool and Die Company of Sun Valley, California, a Halle filter, and Photosonics pulse camera. The small image produced by a 5″ $f/14$ singlet objective is magnified to produce a 50 mm solar image of which part is recorded on the standard 16×24 mm frame. Because of the good seeing in Pasadena, a number of interesting events have been recorded.† The observing program is supervised by David Bohlin, Ernest Lorenz, and the author.

In this paper we report on two interesting filament eruptions on the disk, recorded on January 15 and 29, 1968, by Lorenz and Zirin. The two events are quite different in appearance, as may be seen from Figures 1 and 3, but they have in common that there is no obvious flare connection (even though they are in active regions), and that the filament appears in emission part of the time.

1. Prominence Eruption of January 15, 1968

The January 15 eruption occurred near the West limb in an active region filament which had first appeared on January 12 on the North side of McMath plage 9146 (Mount Wilson spot group 16642). Figure 1 shows the region on January 13, 14, and 15. These pictures are instructive as a record of the evolution of several connected active regions in a 48 hour period. On the 13th the preceding spot (above the clock)

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† Because this is a research instrument, flare observations are not presently reported; however, information on particular events can be supplied on request.

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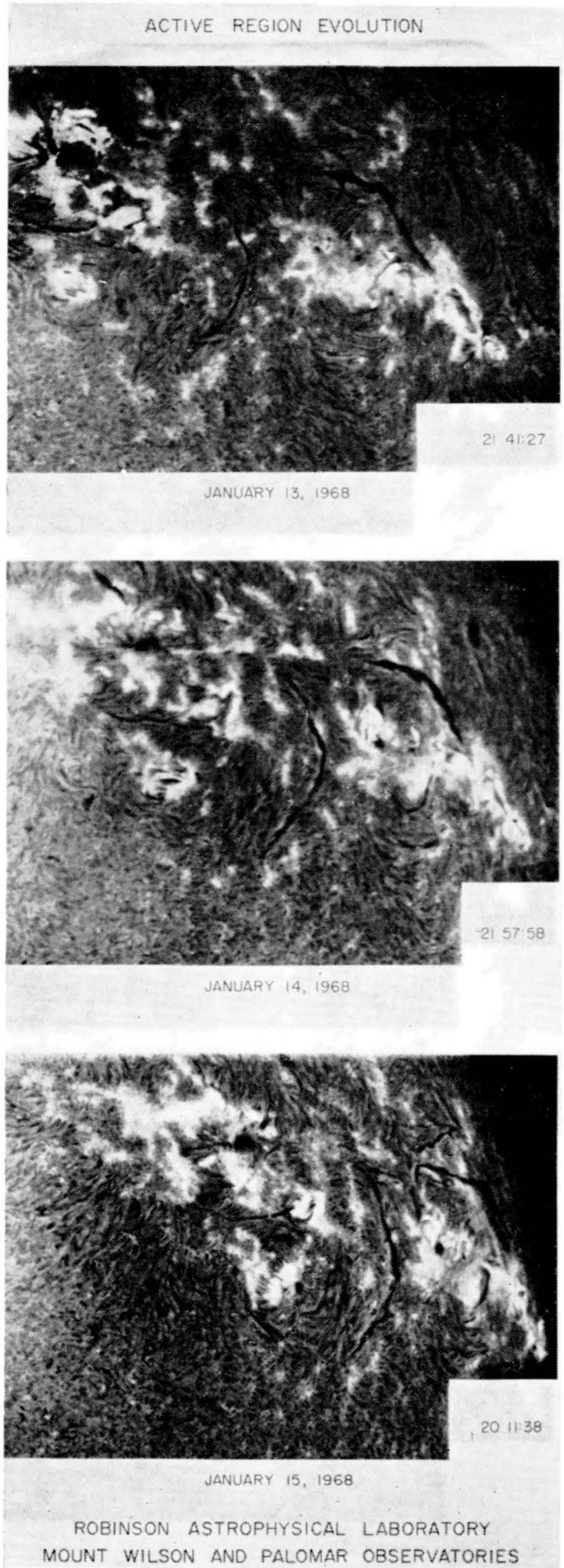

Fig. 1. Photographs of the Mount Wilson spot group 16642 (McMath plage 9146) on January 13, 14, and 15, 1968, showing development of filaments and spots. Note the expanding bipolar group at left center.

was most active; on the 14th and 15th activity was most intense in the following spot (right of center in 1b; above edge of clock in 1c). We observed a class 2B flare in this spot on the 14th as well as many small flares. At the same time, prominences begin to feed into the spot.

An interesting sidelight is the development of a small bipolar group on the left side of our frame. It is marked by characteristic dark filaments (probably loop prominences) running between bright plages. In this case the group expands in longitude along the classic picture of an expanding flux loop (BABCOCK, 1960).

When the observation began at 17:55 UT on the 15th a flare was just beginning, producing a large surge (Figure 2) of long duration, with continuous ejection of both bright and dark material for 30 min. It is possible that material falling back from this

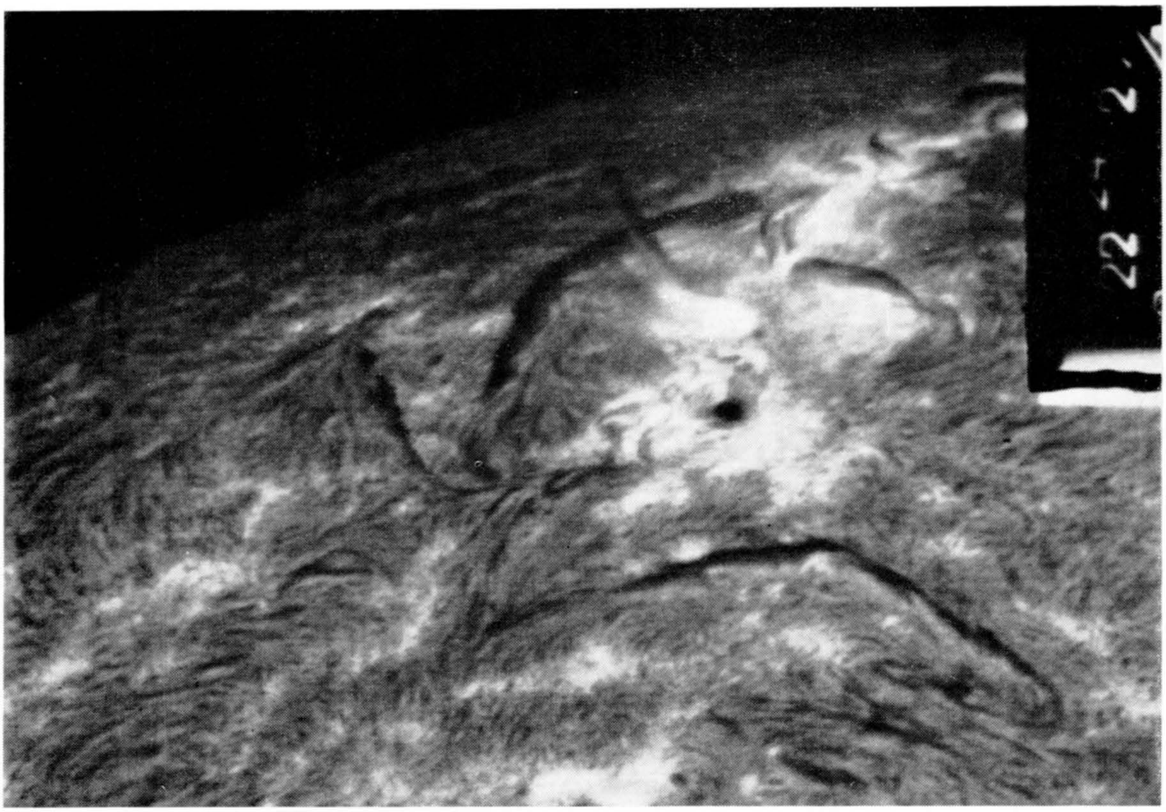

Fig. 2. Bright surge at 18 17:09 UT, January 15.

surge was connected with the later prominence eruption. At 19:09 rapid motion began in the filament (Figure 3a). A series of simple 1 and 3 dm bursts were reported 19:07 through 19:10. Brightening at the base of the filament began around 19:17 accompanied by another decimeter burst. Material appeared to flow from the southwest end (near the data frame) into the center of the filament, then to brighten and erupt upward. Velocities cannot be specified because we see the loci of bright condensations through which the material flows upward. Between 19:35 and 19:40 the rest of the

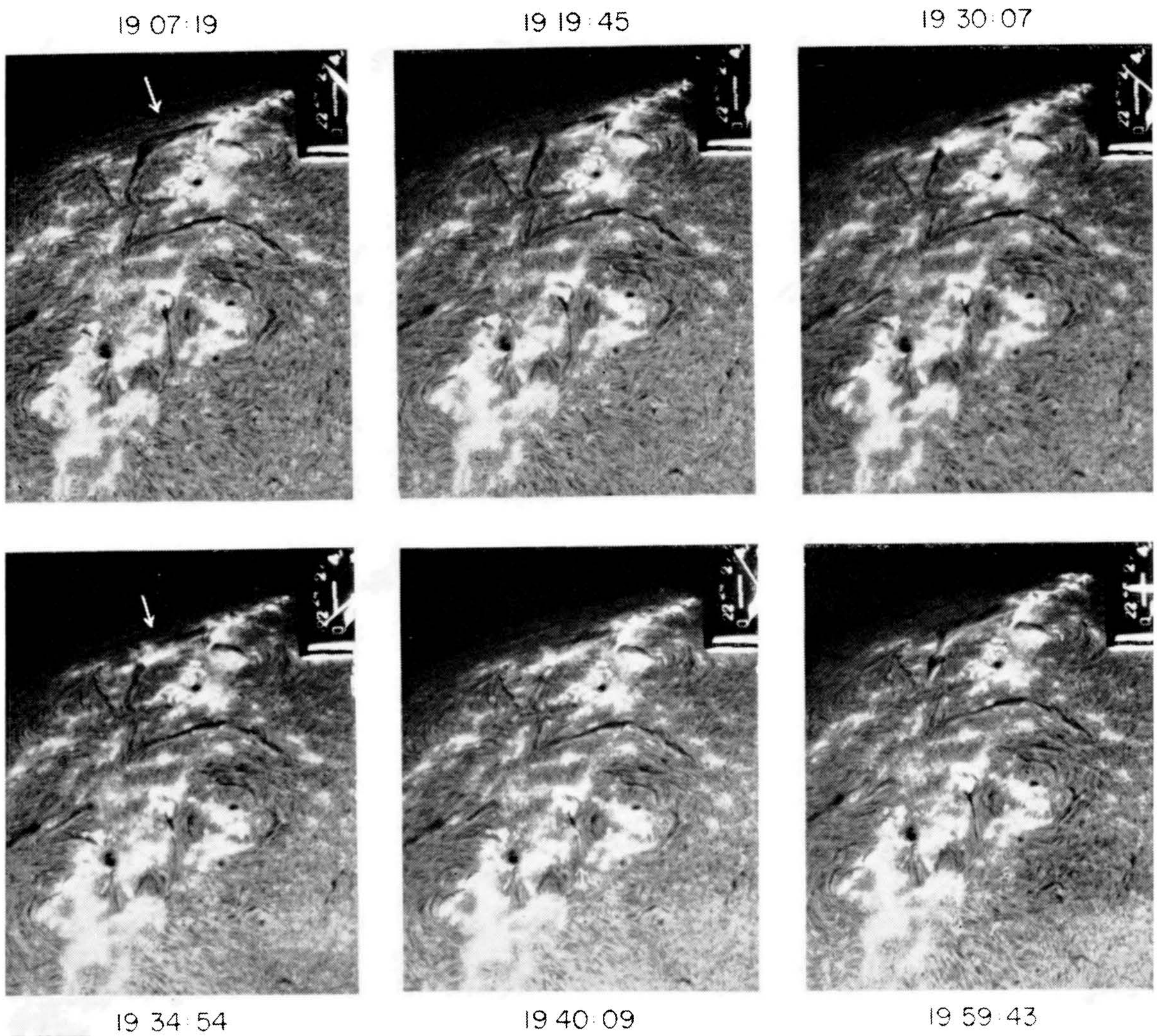

Fig. 3. Six stages in the prominence eruption of January 15, 1968.

filament disappeared. Our films are quite complete and show no visible flare; the event is quite unlike normal filament eruptions. Neighboring filaments were unaffected, although one near the disk center changed somewhat (arrow Figure 3d). This appears unconnected with the erupting prominence. After the eruption the filament quickly reappeared in its original form.

A hard (>7 keV) X-ray burst (Figure 4a) was observed by Peterson and co-workers to begin at 19:00, peak at 19:03 as a precursor, then rise again at 19:07 to a peak at 19:10 of 1000 counts/sec. The burst is clearly connected with the prominence eruption; we would have detected a normal flare producing a burst of this magnitude.

Solar Geophysical Data for January 1968 (p. 166) reports an SID beginning 19:08, and notes that a 'radio flare' was observed by the station HANDS, Boulder, Colorado, with no optical flare reported. It appears that the prominence eruption was the source of all these effects, producing flare-like effects, although it was not a flare in the official sense.

It is reasonable to suppose that the eruption was caused by rapid magnetic field changes. The many flares observed suggest that these were occurring. Just before the eruption a dark line of material appeared at the bottom of the filament showing that surface changes were occurring. But the magnetic changes can only have been temporary since the filament quickly reappeared.

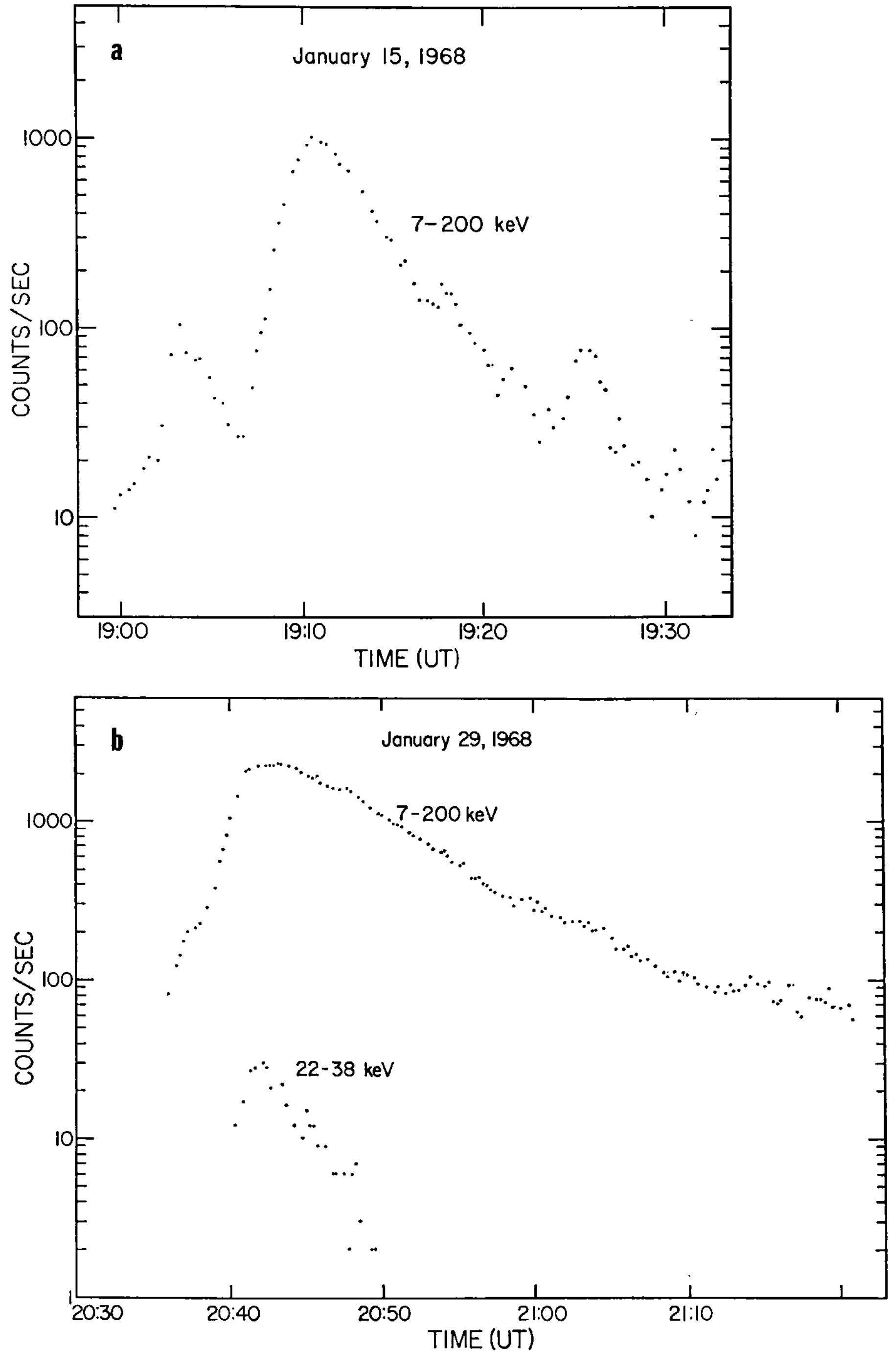

Fig. 4. X-ray flux above 7 keV recorded by PETERSON, HUDSON, and MCKENZIE (1968) with OSO III. The counts are roughly equivalent to the incident number of photons/cm^2 sec. (a) January 15, 1968; (b) January 29. 1968.

2. The Eruptive Arch of January 29, 1968

The second event, on January 29, 1968, is an eruptive arch, a type commonly observed on the limb. A filament (arrow) trailing a large sunspot group began to move about 20:22 UT (Figure 6a). There was a flare at 20:35 in the following plage (Figure 5) which may have been connected. Rapid spiralling motion in the prominence began around 20:40 (Figure 6b), and the dark arch rose up above the surface. The motion was through the expanding arch in one direction only. As the prominence rose, emission appeared, and at 21:50 (Figure 6d) it was in emission high above the chromosphere, whence the material poured rapidly down to the surface. Continual brightening occurred in the chromosphere near the following plage where the descending material hit, as may be seen in Figures 6e and f; this was about as bright as a normal plage (there may have been a wavelength shift effect). Material continued to pour down from the top of the arch until 24:00. In contrast to the spiralling rise, the descending material followed simple curved trajectories.

Peterson (Figure 4b) observed a hard (>7 keV) X-ray burst beginning 20:35 or earlier, and probably connected with the flare in the following region. The X-ray

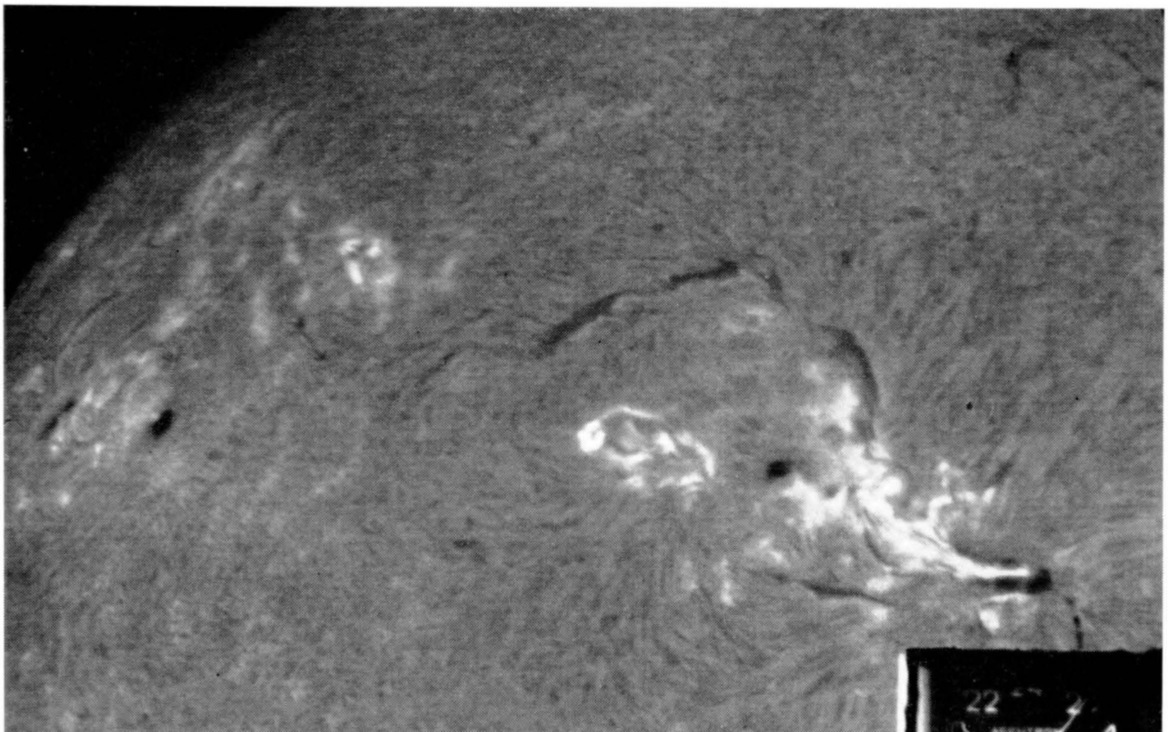

Fig. 5. Flare at 20:32 in following region (center of picture) which may have triggered the eruption. (This print made with low contrast to give better latitude.)

flux decayed slowly, as though a contribution were coming from the eruptive arch. The fact that the prominence landed in the flare region supports this connection.

We have searched our films for a flare close to the base of the arch; although the plage was very bright, no flare occurred; a broad band burst (~50 s.f.u.) was reported by a number of stations around 20:09, but this is connected with a subflare near the preceding large spot.

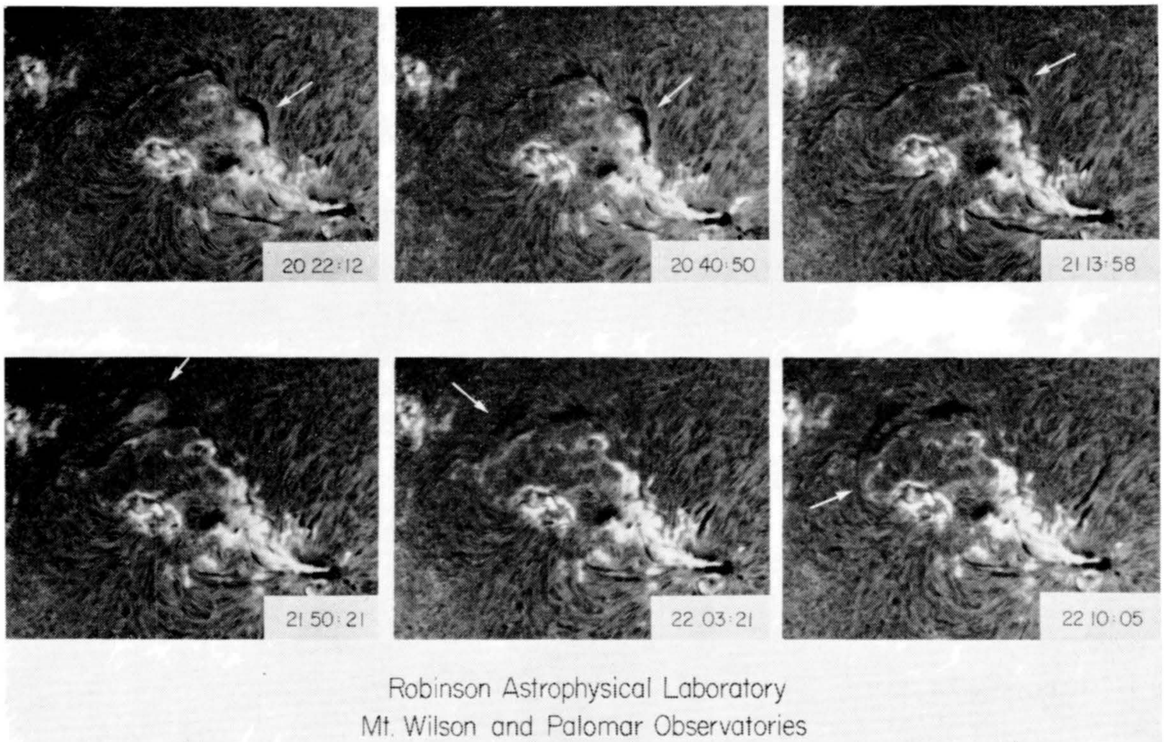

Fig. 6. Six stages in the prominence eruption, January 29, 1968.

Because of projection effects, we cannot calculate the exact height and velocity. But the projected positions have been measured and interpreted with various assumptions for the inclination of a parabolic plane path to the tangent plane (we are indebted to Richard Franz for making the measurements and calculations). The probable maximum heights are as given in Table I.

With the assumption of an 80° inclination, the velocities to produce the projected motion from frame to frame in Figure 6 are 16, 38, 23, 76, and 200 km/sec respectively. There was a marked acceleration in the downward trajectory, as may easily be seen in the movies. Presumably the material was forced upward against gravity on one side of the arch by magnetic forces, and then followed a free fall on the other side. It takes 750 sec for the 200 km/sec velocity to be reached in free fall.

It is interesting that the following filament was left unaffected by the entire proceedings.

TABLE I

Inclination	Maximum height
30°	1.4×10^5 km
50°	1.5
60°	1.7
70°	2.0
80°	2.6
90°	3.7

3. The Problem of Emission

One of the most interesting features of these events is the appearance of the prominence in emission in both cases – at the beginning in the January 15 event, and at the peak in the January 29 arch. In a normal prominence, the principal means of excitation of Hα is absorption and re-emission of photospheric radiation in this wavelength. Since there is a dilution factor of two at each such scattering process, the prominence appears dark against the disk. Normal collisional excitation is insufficient to balance the loss of photons to scattering, unless the prominence is optically very thick. The prominence may be expected to go over into emission if there is a substantial increase in the excitation of $n=3$, either by a sharp increase in temperature and density, or by a new source of photoexcitation which is not subject to the rules of pure scattering. Particularly if the prominence is optically deep, a simple increase in temperature can produce the change to emission. It is well known that bright surges make the opposite transition to absorption at the top of their trajectory as they expand and the density drops.

Thus we may readily understand the behavior of the January 15 event; a rapid density and temperature increase occurs at the base, producing emission and disturbing the equilibrium so that the prominence begins to rise, whereupon an instability occurs, the supporting lines of force rise, the prominence goes up further, etc. Presumably the observed X-rays are produced by electrons accelerated in this process.

But the emission in the eruptive arch of January 29 cannot be explained this way. Although we might expect a density increase at the beginning of the eruption, the density should decrease as the material rises and expands. So the emission cannot be due to a pressure increase. The emission could also be produced by excitation by fresh coronal electrons encountered or by increased radiative excitation in Hα because of the wavelength shift relative to the Fraunhofer Hα absorption line. The first mechanism may be discarded because coronal densities are very low at the heights observed here (coronal densities above 10^9 are required). The second will work if the optical depth in Hα is not too high, and if the geometry is correct.

The line shift explanation has been proposed for various emission phenomena. It is based on the fact that the exciting radiation in the center of the Hα line is only 0.2 as intense as the photospheric continuum, so small wavelength shifts can produce sizeable increases in the excitation rate. However, this radiation is still subject to the rules of pure scattering, and the prominence will appear dark unless there is a wavelength redistribution of the re-emitted radiation. Such a redistribution will occur in directions at right angles to the velocity of the prominence. In these directions the emission profile is still centred on Hα, although the atoms receive extra excitation from Doppler shifted regions of the photosphere in the directions of the velocity vector.

Thus emission will only be seen when the line of sight velocity is near zero. In the January 29 case this explanation fits very well.

If the Hα absorption line is a Gaussian of width at half intensity 1.4 Å and maximum depth 0.8, and the prominence velocity profile (for simplicity) has the same distribution (except for a macroscopic velocity V), then the rate of excitation from $n=2$ to $n=3$ will be proportional to

$$F \sim \int_\theta \int_\varphi \int_{\Delta\lambda} e^{-a(\Delta\lambda + 2.2\mathbf{P}\cdot\mathbf{V}/P)} \left(1 - 0.8 e^{-a(\Delta\lambda)^2}\right) f(\theta) \sin\theta \, d\theta \, d\varphi \, d\Delta\lambda , \qquad (1)$$

where $a=(1/0.9)^2$, $\mathbf{V}$ is the velocity, $\mathbf{P}$ is the radius vector from the elevated prominence to a point on the surface, and $f(\theta)$ is a limb darkening function. The Z axis ($\theta=0$) is directed downwards to the surface. The increase in excitation will be the ratio of this integral to the same integral with $V=0$.

The projection of the velocity on the radius vector to each illuminating point can readily be shown to be

$$\frac{\mathbf{P}\cdot\mathbf{V}}{P} = V_x \sin\theta \cos\varphi - V_z \cos\theta .$$

As seen in an eruption at the center of the disk, the re-emitted radiation will be shifted by $V_z \cos\theta$ from the center of Hα.

Without completely evaluating this integral, we can easily see what happens. In the ascending phase, $V_x \approx 0$, $V_z \approx V$. For velocities over 25 km/sec, the shift is sufficient to produce some increase in excitation. But there is no wavelength redistribution along the Z axis; the excited atoms are all shifted out of the center of Hα for an observer looking down. The atoms seen are only those on the red wing of the shifted Maxwellian distribution, which receive only the normal excitation. So there is no effect.

At the top of the trajectory, $V_x = V$, $V_z = 0$. For the velocity observed in our arch, excess excitation is produced by a large solid angle of surface, typically to $\theta > 30°$ and $\cos\varphi > 0.5$. Since $V_z = 0$, there is no shift relative to the observer. All the newly absorbed radiation is re-emitted and an emission prominence is seen. When the prominence falls to the surface we get the previous case and see a dark prominence again.

In an eruptive arch observed near the limb we should expect to see emission through most of the trajectory since motion is perpendicular to the line of sight.

This mechanism will work for any prominence with large proper motion so long as the optical depth is not so great that the photoexcitation per atom is small. Surges have high optical depth, and appear to be in emission as a consequence of high temperature and density. However, bright sprays may well show the velocity shift effect, and it is my feeling (without an extensive study) that those of large proper motion tend to show more emission.

Although the January 15 eruption also showed substantial proper motion, the excitation was very complicated and a clear cut decision cannot be made on the relative importance of velocity shift and pressure increase in producing the emission.

The observational data raise other interesting questions. The spiralling motion at the beginning of the January 29 eruption is characteristic of such prominences. It surely must be due to the interaction between the rising magnetic field and the material it is lifting. The material in the prominence lands in the sunspot group following the large group. There was a small but bright flare in that region just before the prominence erupted. Was this disturbance, communicated along field lines, responsible for the start of the eruption? We cannot tell until we have observed more cases.*

Finally, the chromospheric brightening produced by the falling material on January 29 is typical of a number of instances on our films. These brightenings are never of flare brightness, presumably because there is not enough energy. Thus the mechanism suggested by Hyder (1967) does not appear to work. The fact that the flare follows the *disparition brusque* does not mean that it is caused by it, unless we clearly observe impacting material. In the present case we observe impact at quite high velocities, but the brightening is weak.

The photoheliograph was purchased with funds from the National Science Foundation, the filter with funds from the Advance Research Projects Agency, and the Photosonics camera with funds from the National Aeronautics and Space Administration. It is operated with funds from all these sources. To extend the time coverage, a similar photoheliograph is now operated in Tel Aviv with the co-operation of the Physics Department of Tel Aviv University and support from the NSF.

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* A similar event on May 17, 1968, has since been detected by William Ingham.