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Eruptive Prominences Recorded by the X u.v. Spectroheliograph on Skylab

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Eruptive prominences recorded by the X u.v. spectroheliograph on Skylab

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[Plates 12–15]

Five major eruptions were observed to produce spectacular phenomena above the limb during Skylab. All are seen best in He II 304 Å. The event of 17 January 1974 was the only one that was observed in high transition and coronal lines. This eruption had at least five major parts; their forms were entirely different spatially and they maximized at different temperatures. The observations began not less than 20 min after the main eruptive phase, and extended for 1 h. The greatest detail was present in He II 304 Å; this included groups of long, curved rays of diameter at the instrumental resolution, 2″. Many parts of the He II feature changed intensity but not position. Therefore it is difficult to distinguish mass motion from spatially changing excitation.

Of the numerous eruptive prominences recorded by the N.R.L. X u.v. spectroheliograph on Skylab, the 17 January 1974 event was by all odds the most energetic. It was the only one that showed changes in all lines from chromospheric to coronal.

The instrument was simply a large version of the slitless spectrograph flown by N.R.L. in rockets since 1963 (Purcell, Garrett & Tousey 1964). However, because of its long focal length (2 m), and consequent 18.6 mm diameter solar images, its resolution was not film-limited. Use of of a 3600 lines/mm grating, as on the 22 September 1968 rocket flight, increased the dispersion so that the solar diameter covered 25 Å, thus reducing overlapping of images (Tousey 1971, Purcell & Tousey 1969). The remarkable stability of the Apollo telescope mount (A.t.m.), (*ca.* 0.5″ in yaw and pitch, and even better in roll), prevented deterioration of the image from motion, even in exposures as long as several minutes. The spatial resolution was limited by the instrument itself; 2–3″ over the range extending 100 Å to either side of the position intercepted by the grating normal. Two grating positions enabled securing excellent images from 171 to *ca.* 500 Å. Shorter wavelengths were not recorded because of the $L_{2,3}$-edge cut-off of the Al filter used to eliminate stray light. At $\lambda > 500$ Å the resolution deteriorated because of aberrations, reaching *ca.* 15″ at 630 Å, the long wavelength end of the intense part of the solar spectrum, as transmitted by the filter. Each film magazine carried 200 strips of film, each 250 mm × 35 mm. The film used was 104, the slower, higher-resolving of Eastman Kodak's two Schumann-type emulsions. In all, 1022 exposures were secured. Even though the quantity of information retrieved is tremendous, it would have been nice to have had more film, and so to have followed more nearly continuously the ever-changing detailed structures and forms, present in the X u.v.

Nearly the entire spectral coverage is shown in figure 1,† that combines the one exposure in the long wavelength position (630–320 Å, 19 h 45 to 19 h 48 U.T.), with the first exposure in the short position (320–240 Å, 19 h 44 U.T.). This was about 20 min after first detection of the eruptive prominence from the ground in Hα. This figure does little more than give an overall

† Figures 1–6 appear on plates 12–15.

impression of the extremely different forms of the eruption in the various lines from chromospheric to coronal. The dispersion is horizontal and the S–N line runs from left to right, making an angle of 12.6° clockwise from the dispersion. The eruptive prominence was located on the west limb at 7° N.

This eruptive prominence is believed to have come from McMath No. 12686 that crossed the limb about 36 h earlier. To show the type of activity exhibited by this active region while on the disk, a sequence of images beginning three days earlier is reproduced in figure 2 in three typical lines: chromospheric He II 304 Å; transition layer (0.6×10^6 K), Ne VII, 465 Å; and coronal (2.5×10^6 K), Fe XV, 284 Å. Each image spans *ca.* 7′, and includes 5.7 Å. All are oriented with west vertical and north left (a rotation of 5.6° counterclockwise from figure 1).

It is outside the purview of this paper to discuss in detail the many phenomena that took place in this active region. However, the great activity that it exhibited leads one to view the 17 January event with no great surprise. The development of loops is especially spectacular. On 15 January they must have been closely stacked side by side and viewed edgewise. The reason may have been the presence of an Hα filament that ran N–S and was on the west limb, probably lying under the loops.

January 15 was also a day when many subflares took place in this active region. Of the nine recorded from ground and from Solrad, the M-1 at 10 h 56 U.T. was missed, but the C-5 was recorded in two exposures, at 14 h 26 and 14 h 28 U.T. X-rays (8–20 Å) were first detected at 14 h 10, maximized at 14 h 20, and went to background at 14 h 38 U.T. Because no Ne VII exposure was recorded close to 14 h 28 U.T., an He II 256 Å is substituted, taken after flare maximum. It shows on the limb under the v of XXIV images of the flare in Fe XXIV, 255.1 Å (20×10^6 K) and in a low temperature (? 3×10^6 K) line that is not identified, 0.3 Å to the blue of Fe XXIV. There must have been continuing activity in progress, otherwise the Fe XXIV line would not have been present so late in the flare.

The loops are especially beautiful because of the intense knots at their tops, associated with the edge-on view. Also it is unusual for so many loops to be stacked and to have the same height. In the first 15 January image He II 304 Å shows a double top to the loops because in this particular exposure the direction of dispersion is vertical. This causes the loop-tops in Si XI, 303.4 Å, to lie above those in He II 304.78 Å. In the other images the dispersion is horizontal or nearly so, hence the loops in these two lines are blended.

In these images generally, the loops in Fe XV are much more diffuse than in Ne VII, and seem to extend higher because of greater intensity. On 16 January after the flaring was over, the loops in Ne VII were changed, no longer lying as a parallel stack, and were fewer in number and more varied. On 17 January, only five hours before the great eruptive prominence, the loops had almost gone, a decrease by more than would be caused by solar rotation alone.

It is also of interest that an eruptive prominence took place on 15 January. It was a sheet of rather uniform emission in He II 304 Å, present at 13 h 18, and also at 14 h 28 U.T. when flaring took place. It is barely visible in He II 256 Å. Like all eruptive prominences except the 17 January event, however, it was not sufficiently energetic (or intense) to be visible in transition zone and coronal lines.

The final set of images for 14 h 44 U.T., 17 January, shows the great eruptive prominence when first recorded from A.t.m., and probably at its maximum intensity. Its point of origin cannot be seen because it lies about 20° over the limb. These three images show the great difference in the form of this eruption in chromospheric, transition region, and coronal lines.

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FIGURE 1. The spectroheliogram of the eruptive prominence of 17 January 1974 showing the west limb at 19h 44 U.T. in the section at the bottom and at 19h 45–19h 48 in the others. Approximate wavelengths (Å) are indicated.

(*Facing p.* 360)

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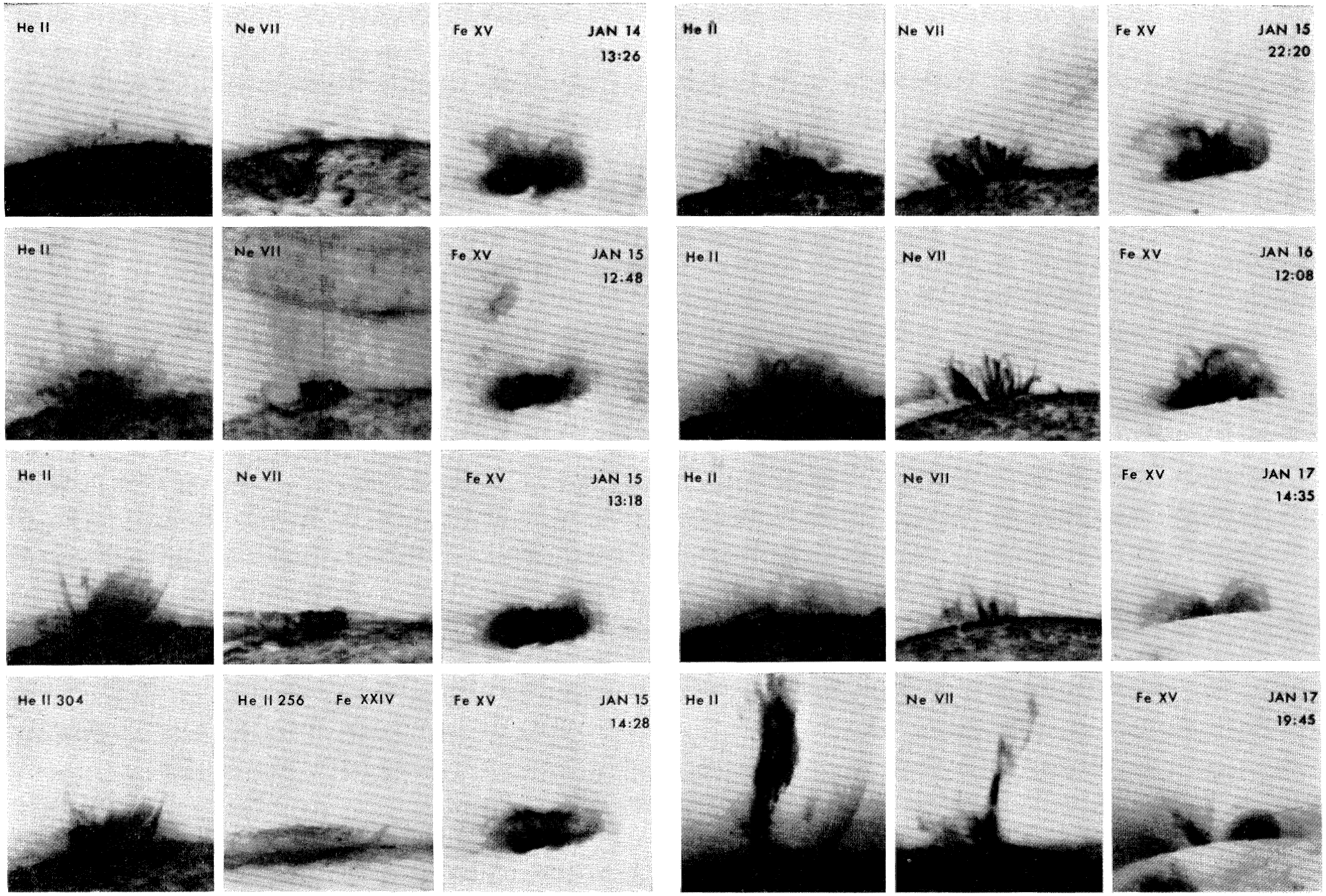

FIGURE 2. Images of active region McMath no. 12686 during its passage over the west limb ending with the eruptive prominence even of 17 January 1974 at 19h 45 U.T. The lines shown are chromospheric He II 304 Å, transition region Ne VII 465 Å, and coronal Fe XV 284 Å, except for 15 January, 14h 28 U.T., when He II 256 Å was substituted for Ne VII. The dispersion is approximately horizontal (λ increasing to the left, and north left), except for 15 January 12h 48 U.T., where the dispersion was vertical, λ increasing down. A flare can be seen on the limb on 15 January 14h 28 U.T., in Fe XXIV and to the right an unidentified line.

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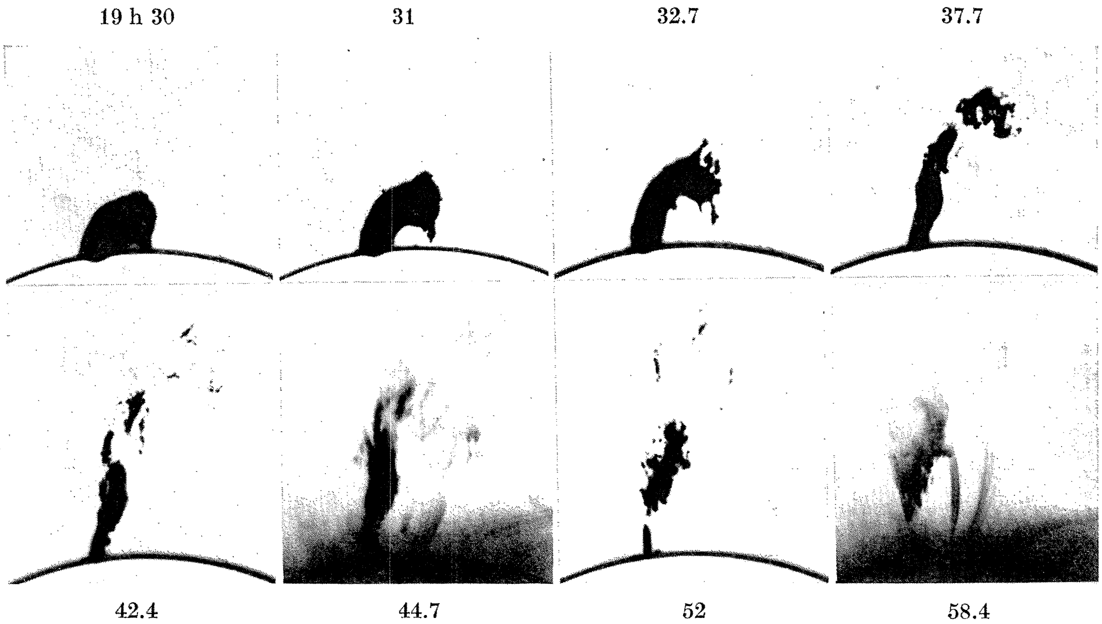

FIGURE 3. The eruptive prominence of 17 January 1974 as photographed in Hα by R. T. Hansen of the Mauna Loa station of the High Altitude Observatory of NCAR, and in He II 304 Å by N.R.L.'s extreme ultraviolet spectroheliograph on A.t.m. of N.A.S.A.'s Skylab.

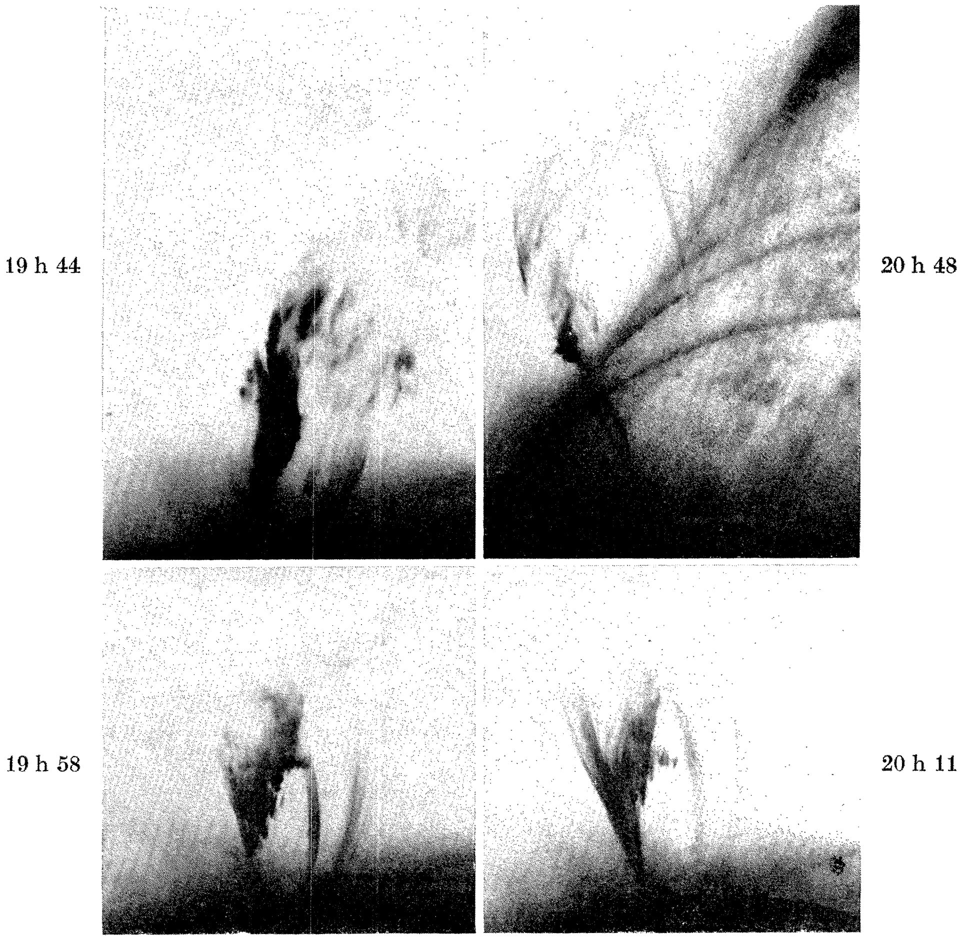

FIGURE 4. The four He II 304 Å images of the 17 January 1974 eruptive prominence obtained by the N.R.L. spectroheliograph. The images are oriented alike (west up; north to the left).

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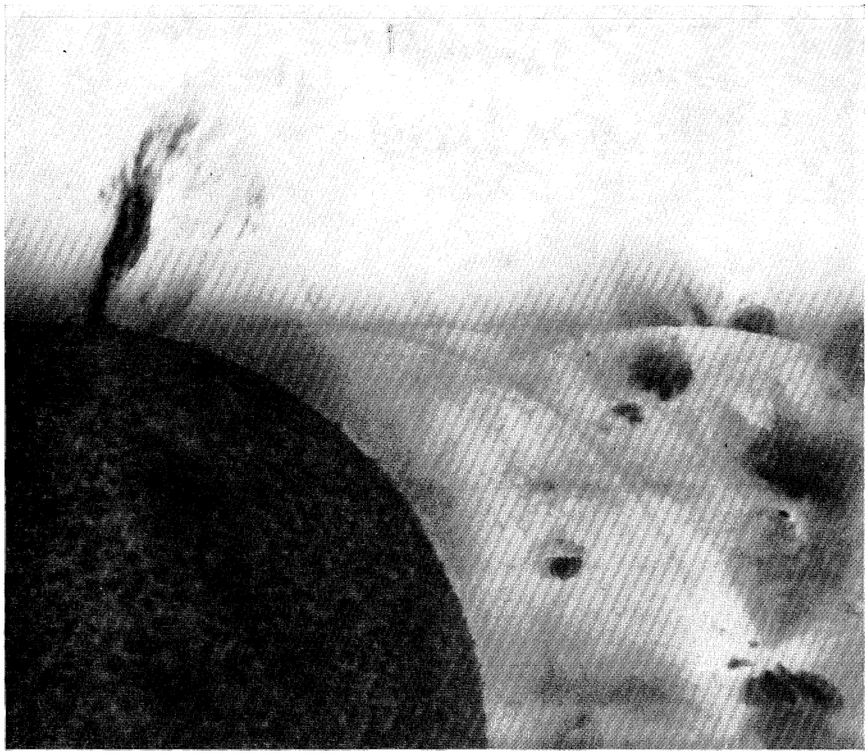

FIGURE 5. A large section of the exposure on 17 January 1974 at 19 h 45 U.T. showing the eruptive prominence in He II 304 Å, left, and Fe XV 284 Å, right. Between them the eruptive prominence can be seen in Si IX, 296.2 Å, 292.8 Å, and perhaps 290.9 Å. The bright limb rings for these lines are conspicuous, as is the 'shadow' produced by the limb in Si XI 303.4 Å.

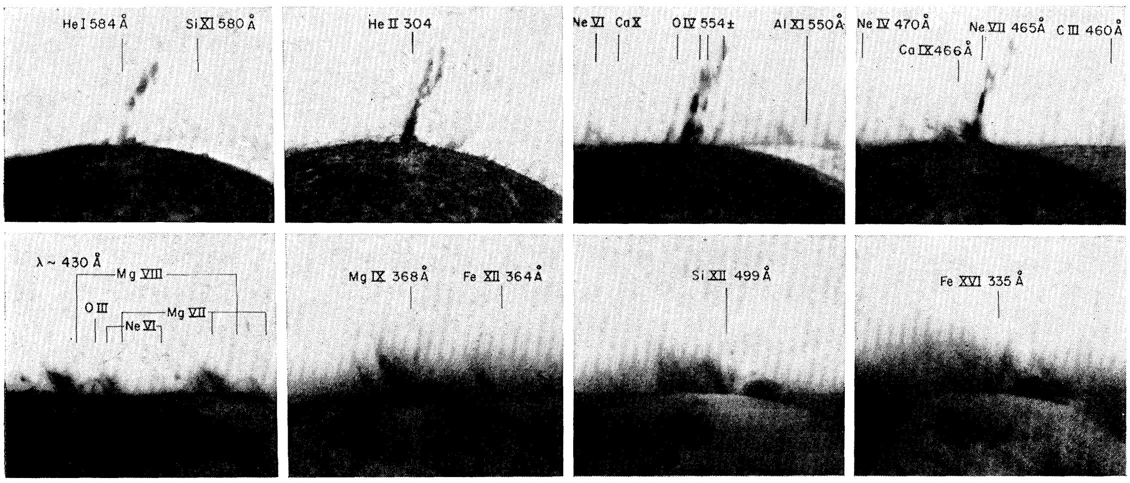

FIGURE 6. Enlarged sections of figure 1, showing sections of the eruptive prominence of 17 January 1974 in emission lines from ions ranging from the chromosphere to the corona. The indicated lines are listed in table 1 together with the temperatures at which they reach maximum density.

This eruptive prominence was recorded in Hα from the ground by Ramey AFB, and also by HAO-Mauna Loa of NCAR. It is compared in Hα and He II 204 Å in figure 3. Thanks are extended to R. T. Hansen of the Mauna Loa Station for permission to reproduce the Hα images. First detection of Hα was at 19 h 25 U.T. The upper series showed the development prior to the first images in the X u.v. A thick loop emerged over the limb, became detached at the right (south), straightened up and rotated about the point at the left, as if hinged. In the lower series Hα and He II images were recorded in the same time frame. Unfolding is nearly complete at 19 h 38 and in the image at 19 h 42 the top part is detached and moving up, matching the He II image at 19 h 45. In the last Hα at 19 h 53, as in He II at 19 h 58, the prominence has faded and the motion appears reduced; also in He II the prominence seems to have a complete break near the limb.

Radio bursts were recorded by Harvard and by Boulder during the early period of the eruption. Type II emission was reported as early as 19 h 31 U.T., 6 min after the first observation in Hα, and terminated at 19 h 48, 4 min after the first X u.v. images were obtained. Type III bursts as reported by Harvard extended from 17 h 01 to 19 h 26, and a short type III burst, 19 h 33.4–19 h 35.7, was recorded by Boulder. A small X-ray enhancement was recorded by Solrad 9, beginning at 19 h 44 when it came into sunlight, and decreasing slowly until 20 h 50 when it went into darkness. These observations, together with the highly energetic character of the eruptive prominence, seem to make quite certain that a flare in the active region gave rise to the eruption. Further evidence comes from severe disturbances in the white light corona in the form of a coronal spray, observed in progress at 19 h 44, when operation of the HAO S052 instrument in A.t.m. started (R. M. MacQueen *et al.* 1975, personal communication).

Four excellent images of the eruptive prominence were obtained by S082A in the short wavelength configuration. They are reproduced in figure 4, oriented alike as indicated. The total time spanned 64 min from the first He II image, or 83 min from the first Hα. In the last exposure the A.t.m. had been rolled so that the dispersion is 54.9° to the horizontal, rather than 12.6° in the first three. The exposure times were 78 s for the last and 39 s for the others.

The eruptive prominence, as recorded in He II 304 Å, consists of several parts of different character and several special features. The principal part, of course, is the great, intense, ragged plume; it is composed of seemingly independent bits and pieces. The upper part is still moving out; blobs of emission are visible in the first and second images to $1.8R_S$, and to $2.2R_S$ in the last. Less dense prints show more clearly that there is a special position, which is present in each exposure; it is located approximately 2′ above the limb. In the first, third, and last images the prominence forks at this point; in the second it is actually detached. For the first image this point can be seen better in figure 6. This fork point does not change position even though the prominence as a whole changes greatly and appears to move to the left, as if in a continued rotation.

Completely separate from the main prominence are the smooth, uniformly curved rays, each consisting of threads, some of diameter no greater than 1500 km, the instrumental resolution. These rays may be loop prominences, but if so they must extend to three or more R_S, in order to bend around and come back to join the limb on the left side of the prominence. This seems most plausible in the third image, where there are well defined rays on the left. In the last image, however, the rays are seen far out, and cannot easily be extrapolated to return. Not to be confused with rays are several bright limb rings within the disk spectrum.

The sequence of changes during the more than an hour of observation suggests two main processes. The first is the material ejection in the form of clouds, last seen in the X u.v. at 20 h 48 U.T. and 2.2 R_S, but followed farther with the white light coronagraph of HAO. The speed of this material can only be crudely estimated because the clouds lose identity, suggesting that there is no single value of velocity. The speed is estimated to lie between one and several hundred kilometres per second.

The second process relates to the intense portion of the eruptive prominence from the limb to approximately 5′ above, and to the rays. These emissions, although appearing to change position, contain many elements that remain approximately stationary, hence show little evidence of mass motion. Rather, the distribution of intensity becomes changed; emission on the right weakens and disappears, while new emission makes its appearance to the left. This is true also of the rays, but here the region of maximum intensity along the ray moves outward. Although rays of this type are known in Hα and seem to form high loops, it is not easy to visualize these He II rays as complete loops, because of their rapidly changing character, and because their directions and curvatures indicate that they must extend to great heights.

Another indication of the relatively stationary character of the He ions is the arc of small clouds at 19h 58 U.T., concentric with the limb. At 20h 11 only one part of this arc remains, but its height and detailed structure are unchanged.

It is worth noting that the eruptive prominence still meets the limb at 20h 48, 83 min after the first Hα image. It can be seen as a fine thread, not greater than 1500 km across, against the 0.5′ wide 'shadow' cast by the limb of Si XI, 303.4 Å. Presumably it continued on to connect with the active region beyond the limb.

The unique character of this eruptive prominence is illustrated most dramatically by figure 5, a greatly enlarged section of He II 304 Å and Fe XV 284 Å. Shown is a 28 Å long portion of the western half of the first spectroheliogram. Contrastingly, Fe XV shows only the slightest trace of the He II main prominence. The stubby spur in Fe XV, directed left, is the most intense feature. Next is the mound to the right. Probably emitting the most total radiation is the broad, structured region to the left.

Also to be seen midway between He II and Fe XV are three spurs and bright limb rings. These lines are Si IX; 296.19, 292.83, and 290.63 Å, the latter extremely faint, in approximate agreement with the laboratory intensity values 150, 80, and 20, respectively (g ^3P–$^3P^0$). In these lines of 1.2×10^6 K ionization temperature, the prominence images are faint replicas of the most intense parts of Mg IX, of the same temperature. Both the spur and the mound of Fe XV show as loops in Si IX. Curiously, the He II ray lying between the main prominence and the rays to the right is cut off sharply at the position where the top of the mound would intercept it, but the other rays are not.

Active region McMath 12686, from which the eruptive prominence is believed to have arisen, would be expected to be similar to the active region seen in Fe XV some 4′ inside the limb, or to the active region near the lower corner of the print. It can, of course, be seen in figure 2 on 14 January, quite close to the limb.

The most interesting aspect of this event is the change in character with increasing temperature at which the line in which it is observed is formed. This is shown in the series of 8 images, reproduced in figure 6. The lines indicated are listed in table 1, together with ionization temperatures mainly from Jordan (1969). These are far from all the lines present, and comments will be made about the most intense of them only.

The main eruptive prominence is taken as typical in He II, in which it is most intense near the limb, with the two parts above the fork less intense but equal. He I, however, does not show the left branch above the fork, and is less intense below the fork than above. From the HAO images, it appears that Hα resembles He II, not He I. No lines except He II 304 Å show the rays. C III, like

He II is more intense near the limb, whereas in O III the two parts are equal. Beginning with O IV the section near the fork becomes more intense, while that near the limb remains broad. (The print is not perfect in its reproduction of these tones.) This becomes most apparent in Ne VII, approaching the top of the transition region, and in this line coronal type emission first makes its appearance around the base of the prominence. With Mg VIII, Mg IX, Si XII, and Fe XV and XVI the He II type prominence becomes progressively weaker. Nevertheless, in the coronal lines it is still present below the forked point. In many ways the prominence in Ne VII is unique. It is complete, sharpest, narrowest, and has the highest contrasts. It is also smooth, unlike He II, and sharply angular. But it does fit the He II prominence when they are superimposed.

Table 1. Electron temperature for maximum ion abundance (for lines indicated in figure 6)

Species	Wavelength/Å	$T_e/(10^6$ K)
He I	584.33	0.02
He II	303.78	0.08
C III	459.46, 0.52, 0.63	0.055
O III	434.97	0.065
O IV	553.33, 4.07, 4.51, 5.26	0.13
Ne IV	469.87	0.20
Ne VI	433.18, 435.65, 558.59	0.5
Ne VII	465.22	0.6
Mg VII	429.1, 431.3, 434.9	0.65
Mg VIII	430.47, 434.73	0.9
Mg IX	368.69	1.1
Al XI	550.01	1.8
Si IX	290.63, 292.83, 296.19	1.2
Si XI	580.85	1.9
Si XII	499.37	2.3
Ca IX	466.23	0.9
Ca X	557.74	1.3
Fe XII	364.48	1.4
Fe XV	284.15	2.3
Fe XVI	335.41	3.0

The coronal eruptive emission commences with Ne VII (0.6×10^6 K) in the form of loops coming from the base of the prominence. (Note the faint duplicate of the most intense parts of Ne VII, in Ca IX, 1.0 Å to the blue.) There is a nice arch-like loop to the left, an extremely faint one to the right, and irregular emission features to the left that develop into more loops at higher temperatures.

In Mg VIII (0.9×10^6 K) the He II prominence is weak; the loop on the right now equals that on the left. The other emission to the left has gained intensity. This trend continues with Mg IX (1.1×10^6 K). The most intense feature is now the emission from the base, which is a filled in, extended loop, hardly recognizable as a loop in Ne VII. In addition, the emission spot farther left has become a loop. The right arch-loop is now the only one visible.

With Si XII, Fe XV and Fe XVI the coronal emission pattern continues to change. Now the left-most emission takes over, and the loop to the right becomes an intense mound. The spur of Fe XV is reduced in Fe XVI, while the mound is more intense. Nevertheless, in the position of the He II prominence, there remains a feature that is similar, but it is greatly reduced in size, form and intensity.

To interpret these changes is diffi ult until intensity contours have been determined. Even then, lacking the ability to separate features in the line of sight, a fully satisfactory explanation may not be possible. At least it should be possible to interpret the changing structure of the He II-type eruptive prominence. Of all the features this changes the most rapidly with time.

On 18 January at 14h 05 U.T. the next exposure was made. Almost nothing of the activity was left. There was only a 20″ wide 10″ high bit of emission on the limb, exactly where the mound had been 17h earlier.

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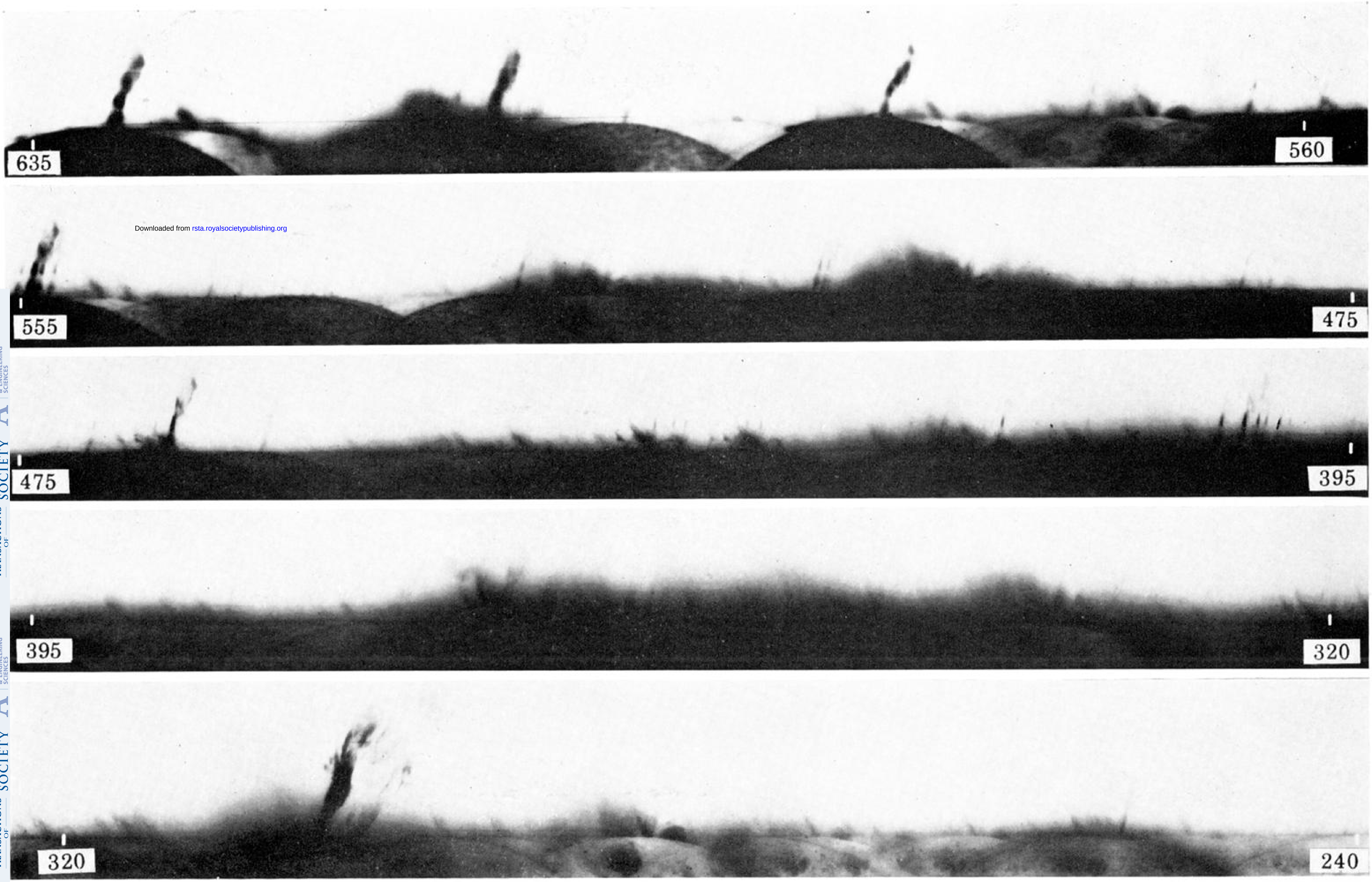

FIGURE 1. The spectroheliogram of the eruptive prominence of 17 January 1974 showing the west limb at 19 h 44 U.T. in the section at the bottom and at 19 h 45–19 h 48 in the others. Approximate wavelengths (Å) are indicated.

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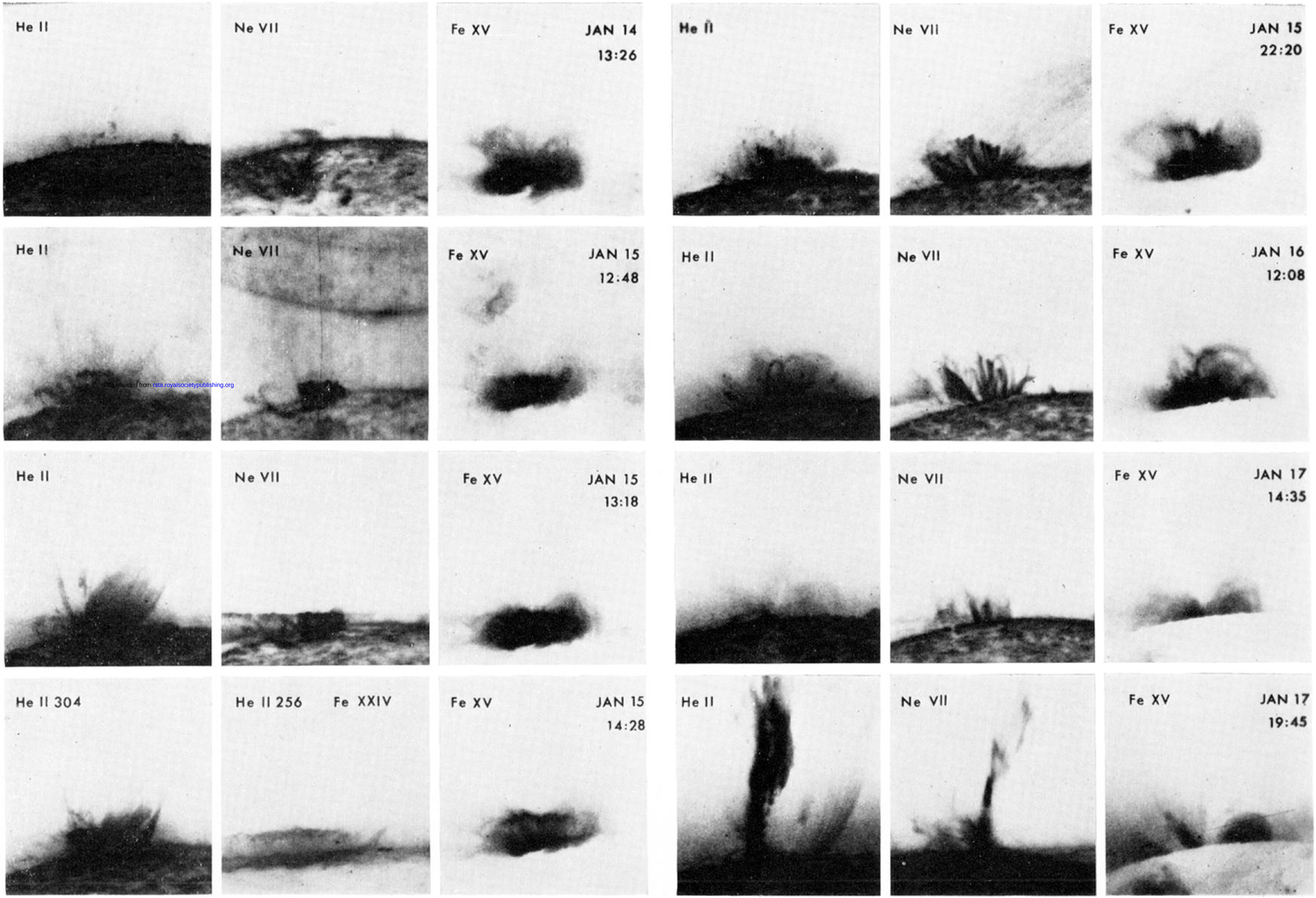

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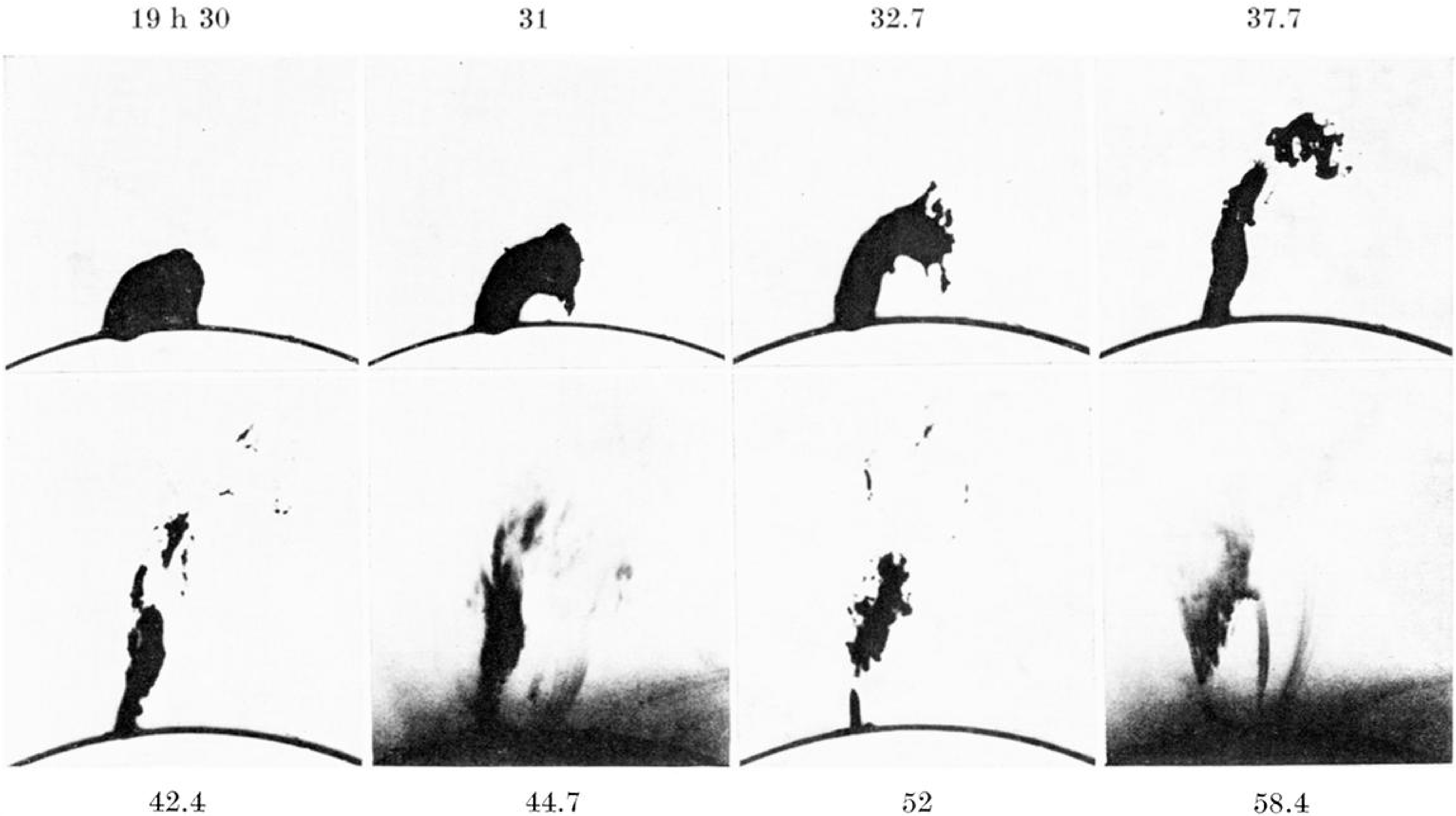

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19 h 44

20 h 48

19 h 58

20 h 11

Figure 4. The four He ii 304 Å images of the 17 January 1974 eruptive prominence obtained by the N.R.L. spectroheliograph. The images are oriented alike (west up; north to the left).

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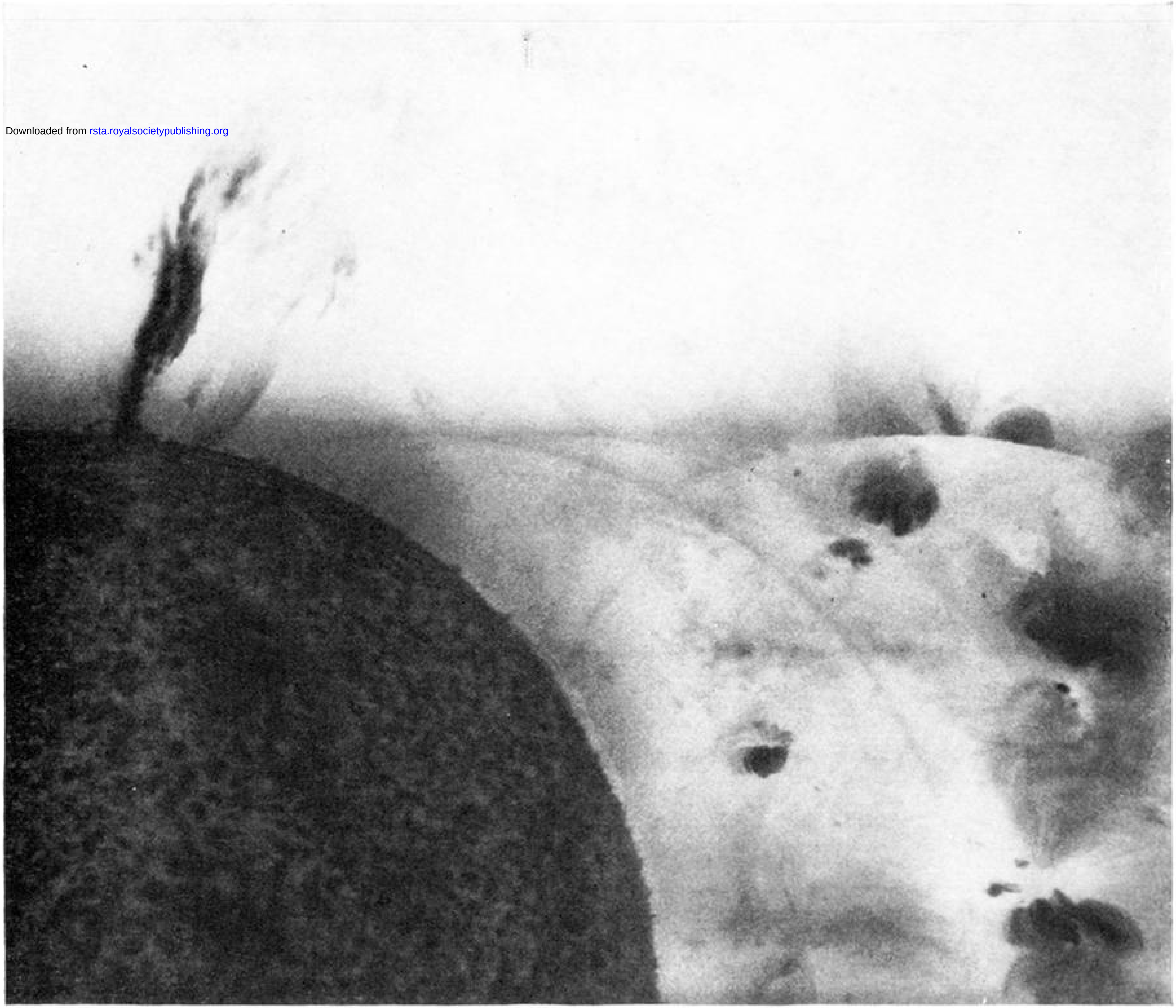

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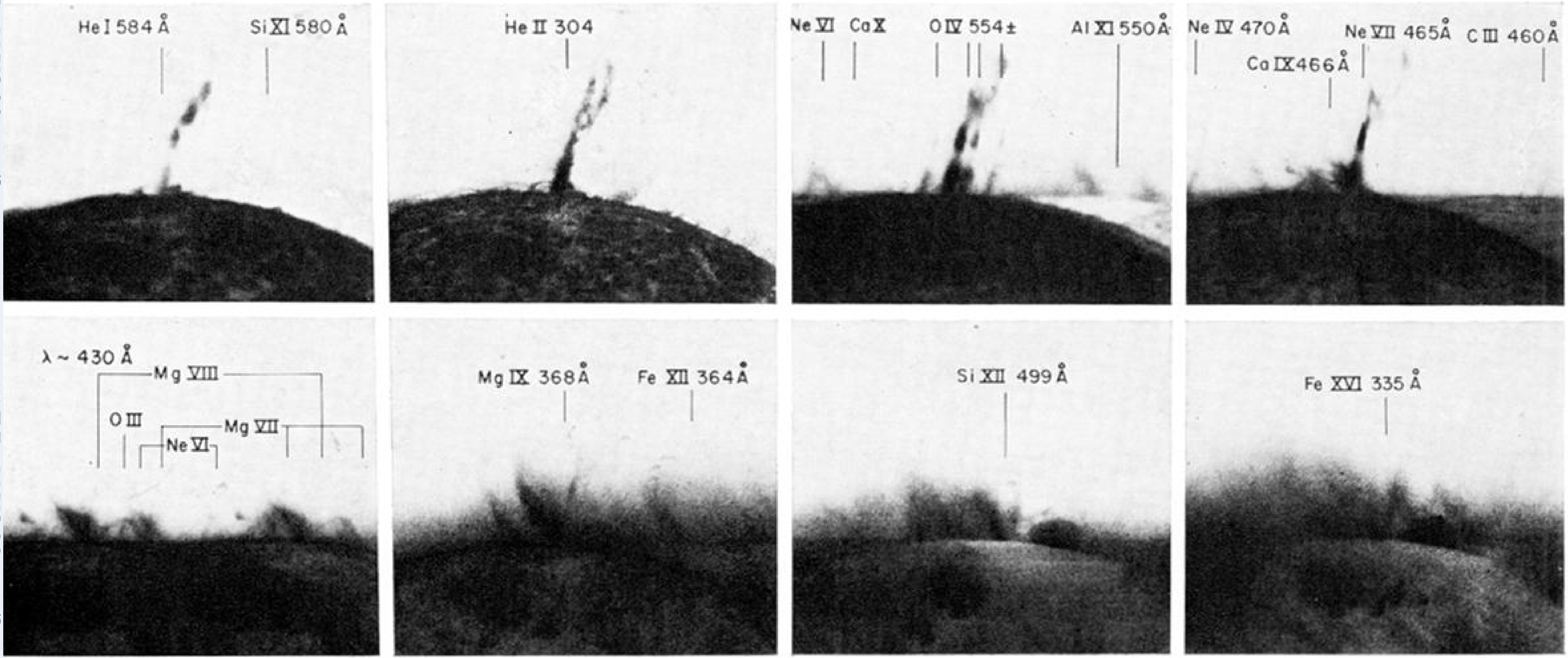

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