Kodaikanal Observatory

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AN ANALYSIS OF ERUPTIVE PROMINENCE MOTIONS

By

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Abstract

The motions characterising the eruption of eight prominences have been studied. It is found that all parts of a prominence adhere to a general pattern of motion, on which are superposed small, but significant individual deviations. Sky-plane components of the trajectories tend to fall broadly into two types; one type showing strong curvature and large accelerations transverse to the direction of solar gravity, while trajectories of the second type are long and curved slightly, showing large accelerations away from the sun. It is suggested that an eruptive prominence has a compound magnetic field, consisting of a stable weak field and a momentary strong component; and that the type of trajectory of erupting material is primarily decided by whether the equilibrium in the active prominence is destroyed, by the kinetic energy exceeding the magnetic energy or *vice-versa*.

Introduction

The study of eruptive prominences has a history of well over half a century. One of the earliest attempts at the measurements of their velocities and accelerations in a two-coordinate system is due to Evershed (1908, 1917). Later, comprehensive time-height analyses by Pettit (1925, 1936) yielded a large amount of data, from which Pettit obtained his two laws of prominence motion. The subsequent introduction of cinematographic techniques has completely revolutionised concepts of prominence motion, while facilities for obtaining line of sight velocities (McMath) (1940) have helped to formulate three dimensional models. Modern analyses that utilise either or both of these techniques have contributed to the following developments :

(a) The limitations of Pettit's first and second laws of prominence motion have been examined.

(b) It has come to be realised that light pressure, gravity, hydrodynamic forces etc alone as agencies of support and movement of prominence material are inadequate by several orders of magnitude.

(c) The role of electromagnetic forces has received increased recognition.

(d) High speed rotatory and circulatory movement of prominence material, as revealed by motion pictures, has led to the concept of trajectories of prominence material following magnetic lines of force.

1—3 D.A.B. Kodi./62

While the above developments have been very significant in themselves, no analyses of sequences of different eruptive prominences in the light of more recent findings seem to have been undertaken, since Pettit's classic contribution. The Kodaikanal collection of Calcium prominence plates provides material for just such a study. The 57 year collection consists of conventional prominence pictures taken with a spectroheliograph, the second slit of which is centred on the $K_{2,3}$ line. The frequency of exposure of the plates available for analysis is usually about one in four minutes during the eruptive phase of the prominence. Although cine-techniques provide more frequent pictures, those obtained at the rate of one in four minutes would be adequate for studying the gross features of prominence fields and their changes, as these force fields have been shown to be stabel over a period of at least 45 minutes (1953).

Selection and Measurement of Plates :

For the purpose of the present investigation sequences of eruptive prominence plates taken under conditions of good to average seeing and showing striking changes in shape and structure were chosen. The origin of a rectangular coordinate system similar to that used by Dodson (1948), was located on the limb, with reference to stable features on the chromosphere. The 60 mm (diameter) image of the original plate was enlarged nearly three-fold The radial Y reference axis passing through the origin was superimposed on it. The final print on which measures were made with a millimetre grid had, therefore, a scale of 7541 Km/mm. The grid was read upto 0.25 mm so that the smallest distance measured was 1900 Kilometres. The choice of features in a prominence sequence was governed firstly by the possibility of unambiguous identification over the entire sequence, and secondly, by their ability to be representative of the structure and behaviour of the prominence. The latter is important for understanding the general nature of prominence eruption. Therefore, constrictions in structure, points of bifurcation of two streamers and knots located at sharp changes in the boundary were selected. The features chosen were as well distributed over the prominence as possible.

Besides the errors inherent in such an analysis (1955), the reliability of the position measurements obtained depends on :

(i) The accuracy of identification of the same feature of the prominence on different plates,

(ii) The identical location of the origin on the various plates,

and (iii) Correct orientation of reference axes.

In the present analysis (i) was ensured, to a large extent, by independent confirmation of each identification The location of the origin and orientation of reference axes were checked at the final print stage, against a stable feature other than the one selected originally. The error on these counts is thus limited to within the smallest distance measured.

Analysis of Measurements :

The X, Y position measurements of each feature of a prominence were plotted against time, and mean curves were visually fitted. From these plots, X and Y were read off at equal intervals of time and accelerations derived from these by numerical differentiation. It must be emphasised, in this connection, that these accelerations can only give a broad idea of the changes in force fields, since differentiation vastly accentuates small irregularities in smoothing.

To obtain the overall spatial traverse of the various features in relation to each other, complete trajectories in the plane of the sky — X, Y plots— were drawn. Along these trajectories resultant acceleration vectors were drawn at equal time intervals These time intervals range from 5 to 30 minutes for the different prominences as is appropriate to each of them.

The values of positions and accelerations of individual features for the eight prominences studied are given in Tables I—VIII (Appendix A). Column I refers to time in U.T., column II indicates position angle of the origin of the coordinate system, columns III and IV give X and $\ddot{X}$ expressed in units of 10^3 Kilometres and 10^{-3} Kms/sec^2 respectively and columns V and VI furnish data on Y and $\ddot{Y}$ in similar units.

Prominence of February 18, 1908 :

This prominence has been analysed by Evershed (1908). He has calculated the velocities and accelerations to which parts of this prominence were subjected.

On February 18, the observations of the prominence on limb extend from 0408 U.T. to 1211 U.T., covering the active and eruptive phases. At 0408 it is seen as a large 'hedgerow' prominence the base of which extends over 30° With reference to the origin of the coordinate system the highest part of the prominence is approximately 110,000 Km. The prominence shows detailed internal structure with sharply defined regions of high intensity embedded in a less distinct, filamentary background. The entire prominence has a sharp boundary. Knots A, B, C, D and E are located as shown in Figure 1 (a). The overall structure remains the same with slight changes in detail till 0535, when the well defined structure demarcated by C, D, E, B tends to rise. The southern edge streams down to the limb (point F in figure) At 1142 the rise is more striking and the prominence is completely detached from the chromosphere except for point F. By 1147 the prominence has become diffuse and the northern tip is no longer visible The last picture at 1211 shows a dome shaped floating cloud having no apparent connection with the chromosphere. The point B which is the highest visible part of the prominence, is at a height of 200,000 Km above the origin.

The X versus time curves are shown in Figure 1(b). It is seen that during the active phase of the prominence, all the X-T plots are nearly identical. At 1035 the plots show a tendency to either curve up or down. Knots E, D and B curve down while knots C and A curve up, implying clearly, an expansion in the X direction.

The Y versus time plots— Figure 1 (c)— are also very similar for the different knots of this prominence, showing a steady increase with time, although individual knots do so at slightly different rates This confirms Dodson's (1948) findings that every part of the prominence is characterised by the same group motion, while individual distinctions remain.

The resultant of the computed $\ddot{X}$ and $\ddot{Y}$ acceleration vectors in Km/sec^2 for the prominence have been plotted in Figure 1(d). The acceleration vectors have been determined at half-hour intervals and plotted along the respective X—Y trajectories of the knots. The directions and magnitudes of vectors at particular instants of time for the different knots indicate no definite relationship. Again, no similarity between vectors situated in particular space regions is evident. The acceleration vectors show a definite tendency to change direction and reverse several times along the trajectory. The highest acceleration recorded is by feature B, approximately 1/3rd of g. and almost transverse to it. Accelerations at instants later than 0930 would be much higher, but the slow convergence of the numerical differentiation formula does not yield accurate acceleration values in the later phases of the observation.

The X-Y trajectories themselves are very instructive. The trajectories are highly curved, each having slightly different curvature from the other. There is a gradation in the curvature in the direction of increasing X, with trajectory E at one end tending to be definitely anticlockwise and A at the other end decidedly clockwise. These trajectories emphasize, that, while the general motion of the five features is similar, there is a strong guiding factor present, the spatial configuration of which controls the details of individual knot motion.

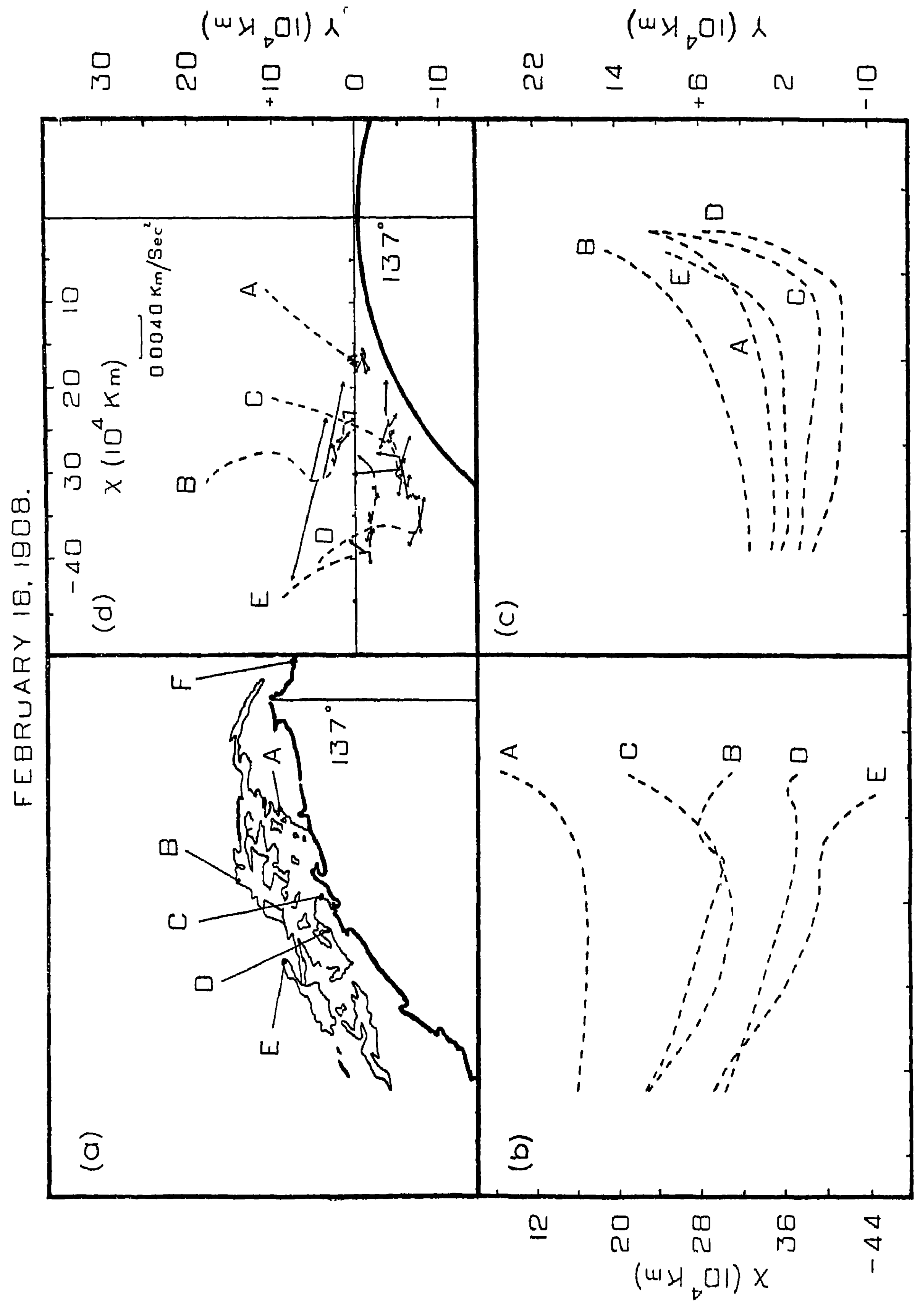
FEBRUARY 16, 1908.
(a)
(b)
(c)
(d)
A
B
C
D
E
F
137°
X (10⁴ Km)
Y (10⁴ Km)
TIME (U.T.)
0500
0900
1300
00040 Km/Sec²

FIG.I.

This prominence erupted on the east limb and to find any related disc phenomenon on the west of the prominence in question, Ca^+ plage plates of 17th and 18th were examined The disc plates indicated no special features in the concerned region. The Ca^+ plage plates of the following day bring into view a plage region with a small spot in it. With respect to this region, the erupted prominence would have been placed to the west and along the poleward fringe.

Prominence of December 31, 1920 :

This is a fairly large and strikingly filamentary prominence. It erupted on the west limb.

Ca^+ plage plates of December 31 show that the prominence is located to the west of the plage region, on the poleward side of it. This region with a spot in it (Greenwich gr. No. 9277) can be traced back upto December 20. No activity in the form of flares is traceable from December 20 to December 31.

The prominence when first observed at 0237 U.T. is already undergoing eruption. Formed like an arch approximately 200,000 Km in height, it spans a region of 45° around the limb. The southern tip of the arch does not reach the limb until later, at 0312. From the first observation at 0237 the whole prominence rises almost as one unit, with end F [See Figure 2(a)] rooted to the chromosphere. The most striking feature during this ascending phase is the change in detail noticed around the region R. At the beginning of the observation, several diffuse filamentary strands are seen. In the next picture at 0249, these strands have come closer together. At 0312 they have come very close to each other and have become compact and bright. At 0323 these join together to form a bright streamer. Thereafter it remains a single streamer and ascends along with the rest of the prominence becoming fainter and fainter. Following the prominence right through the eruption, it is noticed that certain sharp patterns persist. The longest enduring among these is the feature C, D which is seen even in the last picture when other features, visible earlier, of the prominence remain unidentifiable. Feature C rises particularly high above the chromosphere, almost to a height of 620,000 Km above the origin. There does not seem to be any extension of the prominence on to the disc, which has withstood eruption.

The X-T curves of the four knots A, B, C and D are shown in Figure 2(b). Here also, as noticed in the previous prominence, there is the same general trend in the X—T plots of the four knots. Even so there are obvious differences. Knot A shows an increase in X, till 0307, decreasing thereafter fairly rapidly. Knot B on the other hand, only shows very slight increase in X till 0250, after which it decreases in X less rapidly. Knots D and C show no substantial increase in X at all. They remain constant in X till 0310 and then decrease slowly with time.

The individual differences between Y-T plots shown in Figure 2(c) are few. Knots B, C and D have nearly identical curves in the Y-T plots. The curve for knot A has a more gradual slope

These variations are brought out in a significant manner in Figure 2(d), where X-Y trajectories are drawn A shows a fairly pronounced curvature. This curvature decreases for B and C and is least for D.

The resultant acceleration vectors at 10 minute time intervals are also represented in Figure 2(d); the length of the vector gives the magnitude, and its orientation gives the direction of the sky plane component of the space acceleration. The chaotic changes in magnitude and direction of these vectors is very evident, showing frequent reversal in direction.

The outstanding difference between the prominence of February 18, 1908 and this one is that the X-Y trajectories for the former show strong curvature, within a short path length, while in respect of the latter the trajectories are long and slightly curved.

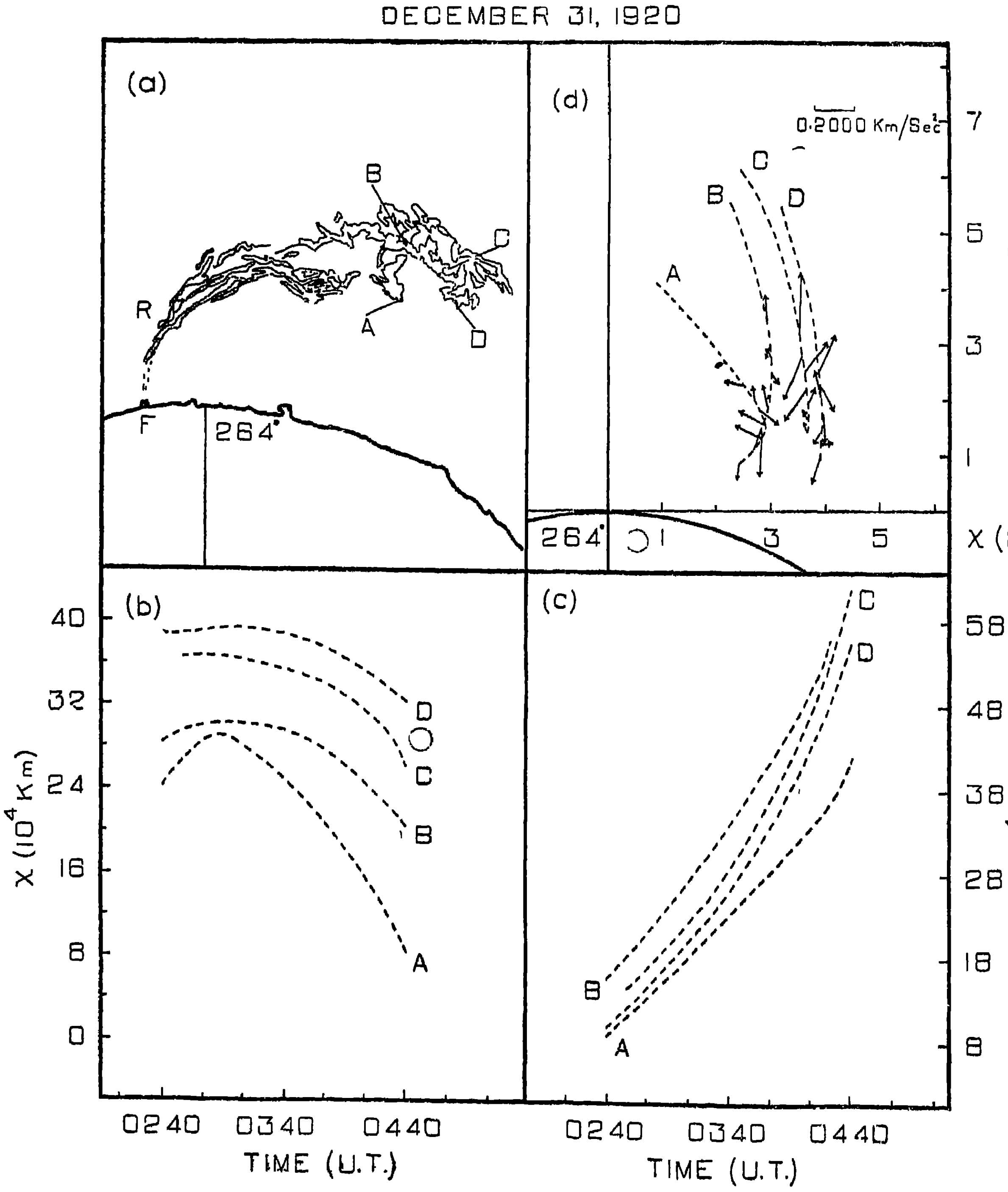
DECEMBER 31, 1920
(a)
B
C
R
A
D
F
264°
(d)
0.2000 Km/Sec²
C
B
D
A
7
5
3
1
Y (10⁵ Km)
264°
1
3
5
X (10⁵ Km)
(b)
40
32
24
16
8
0
X (10⁴ Km)
D
C
B
A
(c)
C
D
B
A
58
48
38
28
18
8
Y (10⁴ Km)
0240
0340
0440
TIME (U.T.)
0240
0340
0440
TIME (U.T.)

FIG. 2.

Prominence of October 20, 1925 :

This prominence erupted on the west limb and has no detectable active region associated with it. Hα disc pictures show the prominence as a filament from October 7 onwards. As it traverses the disc, the filament stretches itself, with a new segment added to its eastern tip. It attains its greatest length on October 14. The orientation all along is very nearly east-west. After October 14 the newly acquired eastern section starts separating out into independent segments. This process is more evident on subsequent days. On October 19, the western tip is projected beyond the limb and it is this portion that erupts on the following day. The fact that the process of fragmentation sets in almost a week before the observed eruption is worth noting.

As for the eruption itself the first observation at 0232 U.T. indicates two bright strands presenting a twisted appearance. At 0309 one strand is seen to move relative to the other. At 0326 the whole structure rises preserving the relative orientation. Thereafter the rise is rapid and the strands become diffuse. Here again, some patterns like that demarcated by E, D, C in Figure 3(a) are long enduring. Feature E reaches a height of over 500,000 Km.

The X-T graphs for the five knots A, B, C, D and E—Figure 3(b)—show that all the plots tend to converge to a point with X coordinate around 250,000 Km, at 0407. All the knots follow nearly similar trajectories having small slopes till 0310. After 0310 the plots rise up steeply with the different curves tending to cross each other.

Y-T curves, *vide* Figure 3(c), are all identical. The X-Y trajectories shown in Figure 3(d) display different curvatures. This is to be expected in view of the crossing of the knots evidenced in the X-T graphs. Figure 3(d) also gives the resultant acceleration vectors in the plane of the sky, computed for 10 minute intervals. For feature D these give consistently large values comparable in magnitude to solar gravity. The acceleration vector reverses direction almost alternately. In regard to feature E the acceleration changes in magnitude from about 1/2 solar gravity at 0240 to approximately solar gravity at 0320. The majority of the acceleration vectors drawn are almost transverse to the direction of acceleration due to gravity.

This prominence of October 20, 1925 is similar to that of December 31, 1920 in that the X-Y curves only show small curvatures. The common feature of similar general motion with variation in detail is evident once again.

Prominence of December 10, 1926 :

This prominence erupted on the west limb and is very close to the south pole. The presence of several filaments around this region makes an unambiguous identification of the particular filament concerned difficult.

In contrast to the fairly broad structures of the preceding prominences, this is a narrow long prominence. The prominence consists, for most part, of a very intense region, with a narrow, less intense region along side. The first picture at 0248 U.T shows the highest tip of the prominence as being approximately 270,000 Km above the origin of the coordinates. At 0347 the prominence breaks off at A [Figure 4(a)] and ascends rapidly. The entire structure comprising of A, B, C, D and E rises together with no observable relative motion between the different parts. Around 0430 the prominence becomes broad and diffuse and disappears out of view at 0507. At 0450 the visible tip reaches over 600,000 Km above the chromosphere

The curves—Figure 4(b)—show the changes in X with T. The X-T plots are nearly identical upto 0410 and thereafter tend to diverge. This is indicative of the fact that the prominence becomes broad at the later stages of eruption.

OCTOBER 20, 1925

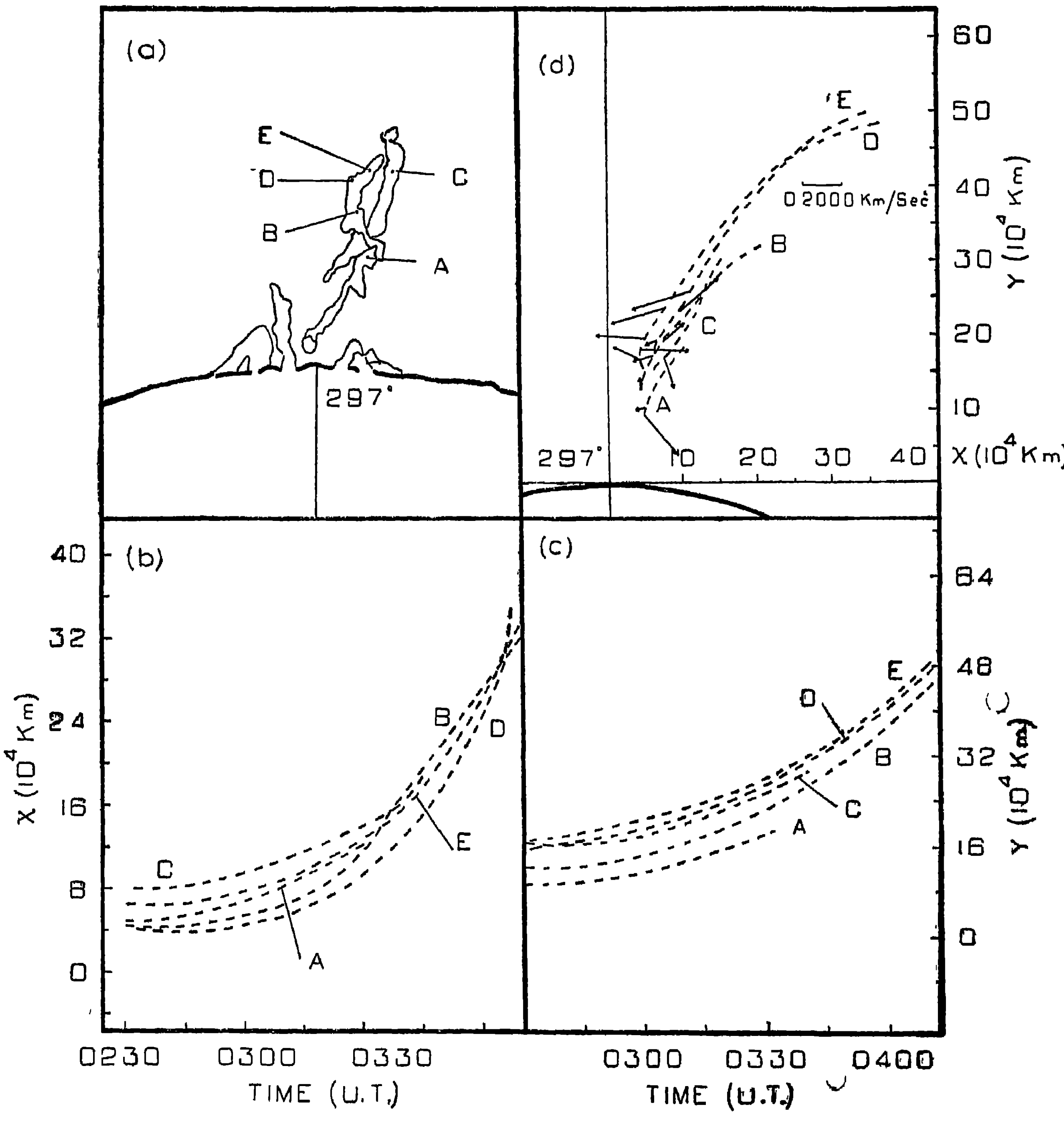

FIG.3.

Y versus T plots in Figure 4(c) further confirm the great similarity of motion for the different parts of prominence Also, the persistent narrowness of the structure is brought out by the fact that the various trajectories are confined to a very narrow region along the X axis. Acceleration vectors also shown in Figure 4(d) [here the X-Y plots for features B, C, D and E have been shifted by 2500, 5000, 7500, and 10,000 Km respectively, along the X-axis, from their true positions to show the acceleration vectors more clearly] once again point out the lack of a general pattern in their magnitude and orientation. Of the five features, C shows consistently large accelerations reaching as much solar gravity in magnitude. The directions of the acceleration vectors bear no relationship to that of gravity. Again alternate reversals of the direction of these acceleration vectors, drawn along the respective trajectories are in evidence.

In regard to the general shape of the X-Y trajectories this prominence would seem to belong to the same class as the prominences of December 31, 1920 and October 20, 1925 *i.e.*, the trajectories are long and curved slightly

Prominence of March 14, 1927 :

The western portion of the prominence extends as a filament on the disc and seems to point to the following spot in a plage region. The eruption took place on the east limb

At 0310 U.T. there is no sign of any activity whatsoever. At 0324 a short streamer is seen at P.A. 40° The next picture at 0348 brings into view a broad column of luminous material Subsequent pictures show this material resolved into a system of well defined knots and streamers. These have a distinct tendency to arch down into the chromosphere. From 0439 onwards all features show a tendency to twist around while descending. At 0544 the prominence is hardly seen above the chromoshpere. The extension of the prominence on the disc survives eruption and traverses the disc with no substantial changes in structure. The filament retains its orientation in relation to the spot group *i.e.* points to the following spot right through its traverse

X-T graphs in Figure 5(b) show that the identity in the plots for the different features exist only in so for as the knots are moving towards regions of increasing or decreasing X, with time. Apart from this, there is hardly any other feature characteristic of all the X-T plots.

The above statement applies equally to Y-T plots in Figure 5(c). In fact the Y-T plots exhibit more individual variations than the X-T plots.

It is the X-Y trajectories shown in Figure 5(d) that highlight the interesting aspects of eruption. Knots A, E and F show trajectories which twist in the anticlockwise direction. Knots, B, C and D twist around in the clockwise direction. The axis of twist is the same for both the right handed and left handed twists. Neither the right nor the left handed twists is confined to any particular part of the sky.

All the X-Y trajectories show pronounced curvature so that they are more like the trajectories of the prominence of February 18, 1908, than those of December 31, 1920, October 20, 1925 or December 10, 1926.

Prominence of November 19, 1928 :

This prominence has been reported by Royds (1928) as one of the highest ever recorded

The prominence erupted on the west limb and was close to the south pole. There are a number of small filaments in the region concerned. Therefore the particular filament on the disc corresponding to this prominence on the limb could not be identified. Part of the prominence is seen projected beyond the limb even on November 18.

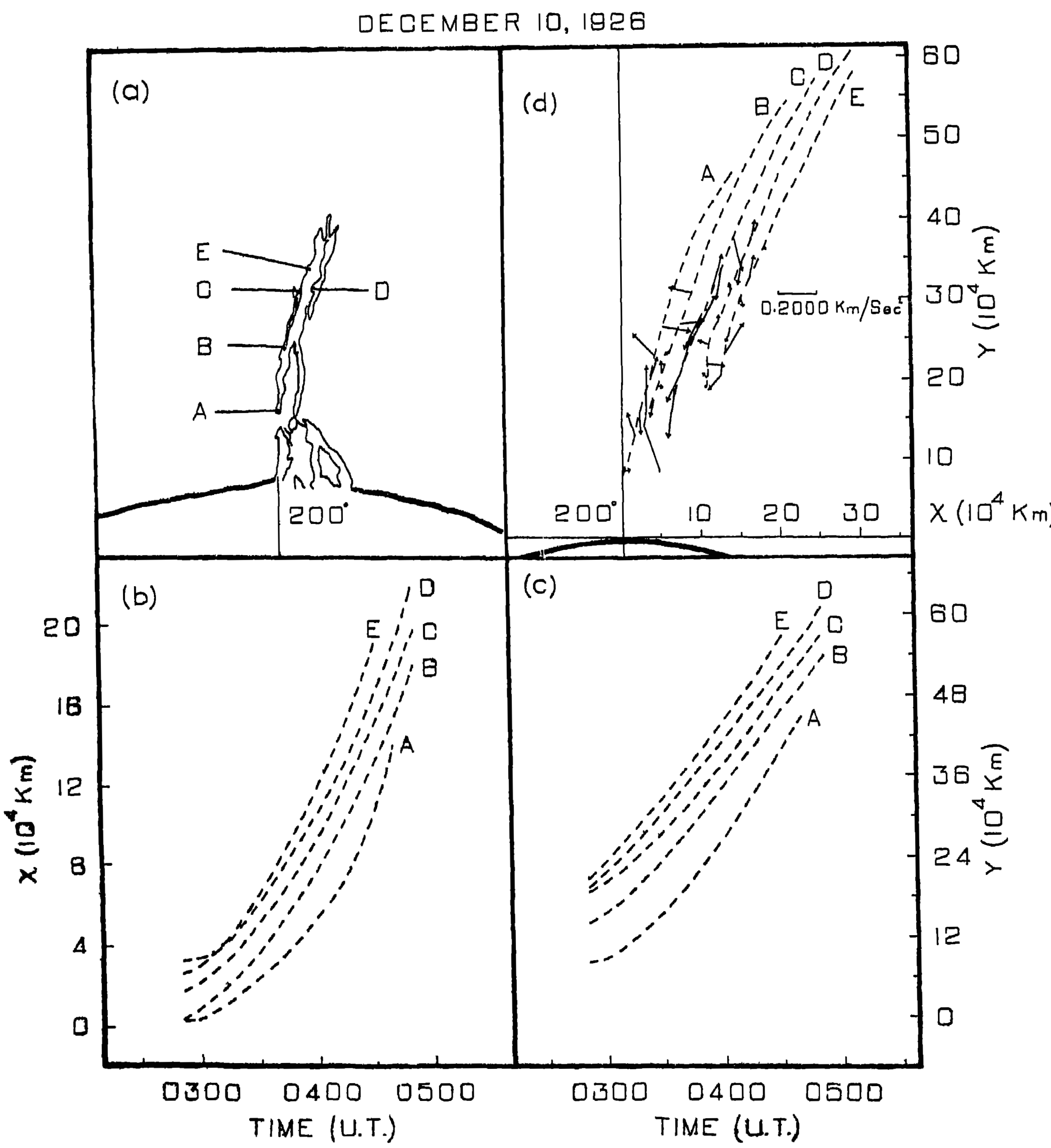
DECEMBER 10, 1926
(a)
E
C
D
B
A
200°
(d)
A
B
C
D
E
60
50
40
30
20
10
Y (10^4 Km)
0.2000 Km/Sec
200°
10
20
30
X (10^4 Km)
(b)
D
E
C
B
A
20
16
12
8
4
0
X (10^4 Km)
0300
0400
0500
TIME (U.T.)
(c)
D
E
C
B
A
60
48
36
24
12
0
Y (10^4 Km)
0300
0400
0500
TIME (U.T.)

FIG. 4.

MARCH 14, 1927.

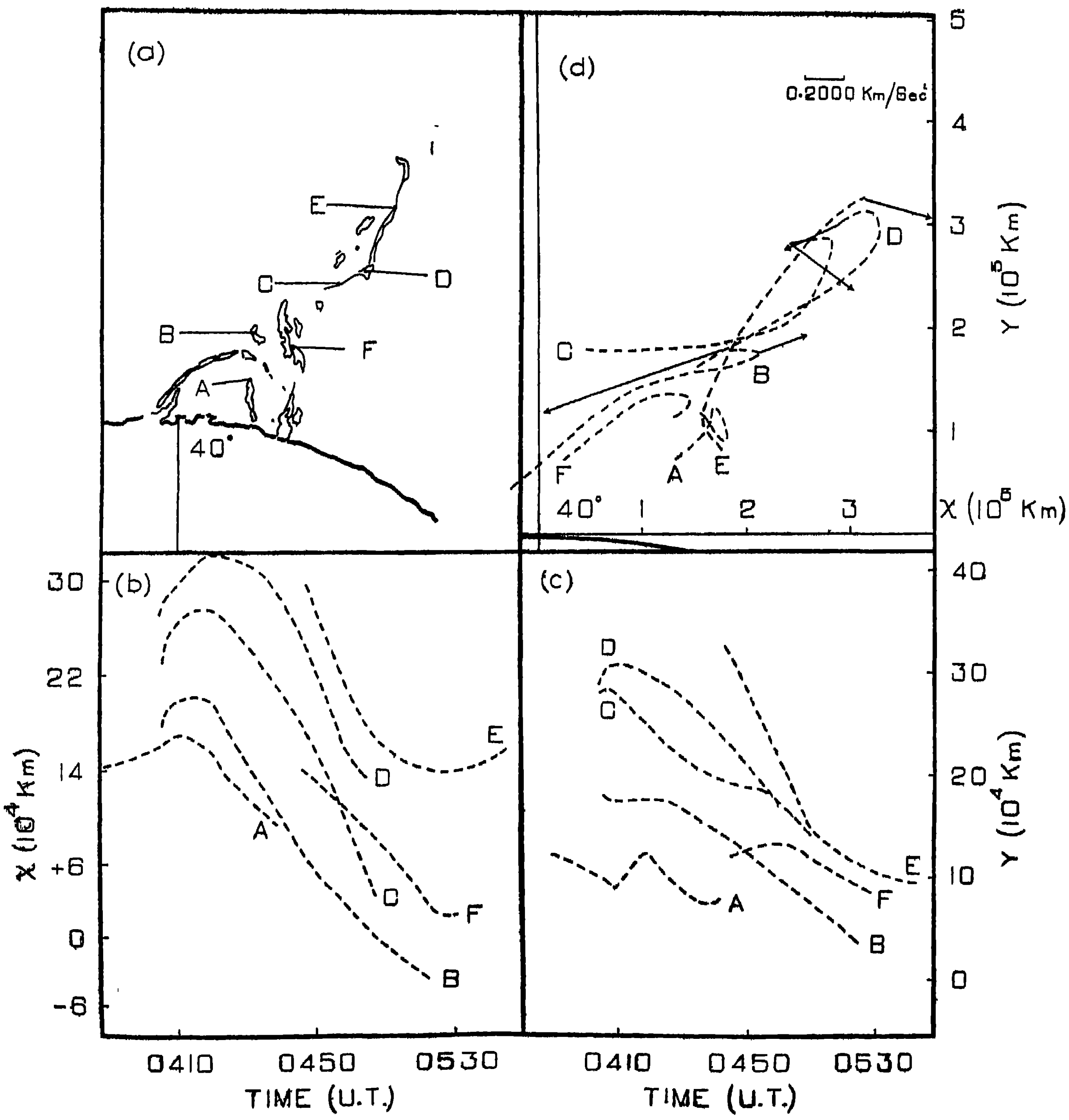

FIG. 5.

The first picture, at 0256 U.T. shows the prominence poised high above the chromosphere. The prominence consists of many fine filaments grouped in two bundles twisting around each other. The region around C—Figure 6(a)—is particularly bright. The whole prominence rises as one unit with small changes in structure. As it ascends the filaments separate out and become diffuse. At 0342, in the last picture of the eruption, the tip E reaches a height of over 900,000 Km. As pointed out by Royds if clouds had not prevented further observation it could have been tracked to greater heights

The X-T graphs—Figure 6(b)—for the knots, A, C and D reveal a tendency to converge while the plot for E diverges.

The X-T plots—Figure 6(d)—show long, slightly curved trajectories. For each of the features the direction of ascent of the knot is at a small angle to the Y axis and then it turns off at a certain point along the trajectory. The turn-off point corresponds, as is evident, to the point of large change in slope noticed in the Y-T plots.

The ascent of this prominence is characterised by the tremendously large accelerations noted. Acceleration vectors in Figure 6(d) give an idea of the change in acceleration vectors at 5 minute intervals along the respective trajectories. Magnitudes of these vectors for the various features reach particularly high values at 0310, ranging from over 10 times solar gravity to 4 times solar gravity. There is, however, no discernible correspondence in the directions of the acceleration vectors for the various features.

The prominence is included in one of Pettit's (1932) analyses of prominence motion. He finds that there are distinclty two velocities of uniform motion, 81 Km/sec. and 200 Km/sec. The change from 81 Km/sec to 200 Km/sec is shown to take place at about 0320. This is almost exactly the time at which the abrupt change in Y corresponds to the turn off point in the X—Y plot Further Pettit finds that the change in slope results in an increase in the velocity while the slope of Y-T plot here, decreases after 0320 The contradiction could be removed if the difference in the coordinate systems used for measuring the positions of the knots is taken into account Pettit's measures give the height above the chromosphere, measured along a radius, every time. A two coordinate system is used in this study and hence the Y coordinate is the projection of the radial distance on the Y axis. Consider the trajectory of a knot which rises up first almost radially and then turns off. In this case it is evident that Pettit's system of measurement would give larger increases in heights than the rectangular coordinate system. Therefore it seems that the abrupt change noticed is merely the result of the trajectory turning off from the original course and the X-Y plot clarifies the situation. But the existence of a turn-off point has to be explained. Since every part of the prominence shows this turn-off at the same interval of time, this might be associated with the time variation of the local configuration of the controlling agency. No accurate values of acceleration could be computed for instants later than 0315 and therefore, clues regarding the quantitative nature of the 'turn-off point' could not be obtained.

September 5, 1929 :

This prominence erupted on the west limb. It is seen as a prominence on August 25 on the east limb The western tip is pointing to the leading half of a plage region without any spots. As the prominence crosses the disc it does not show any large changes in shape. It attains the sharpest outline on September 1. From September 2 onwards it becomes diffuse and fuzzy, and on September 4 the curved eastern tip is only very faintly connected to the rest of the prominence. On September 5, Hα disc picture taken before the eruption shows the eastern tip still on disc. Hα pictures of September 6, however, do not show any trace of it. Again, it is evident that the process of dissolution has set in earlier than the observed eruption.

In overall shape this prominence is similar to those of February 18, 1908 and December 31, 1920. This prominence has complicated ultrafine filament structure. At 0256 U.T. the prominence rises from L and M—Figure 7(a). The rise is more rapid later on. Around 0436 the connection with the chromosphere is identifiable, and the prominence gradually becomes diffuse. Nevertheless, the structure outlined by C, D, E, F persists right up to the last picture at 0505.

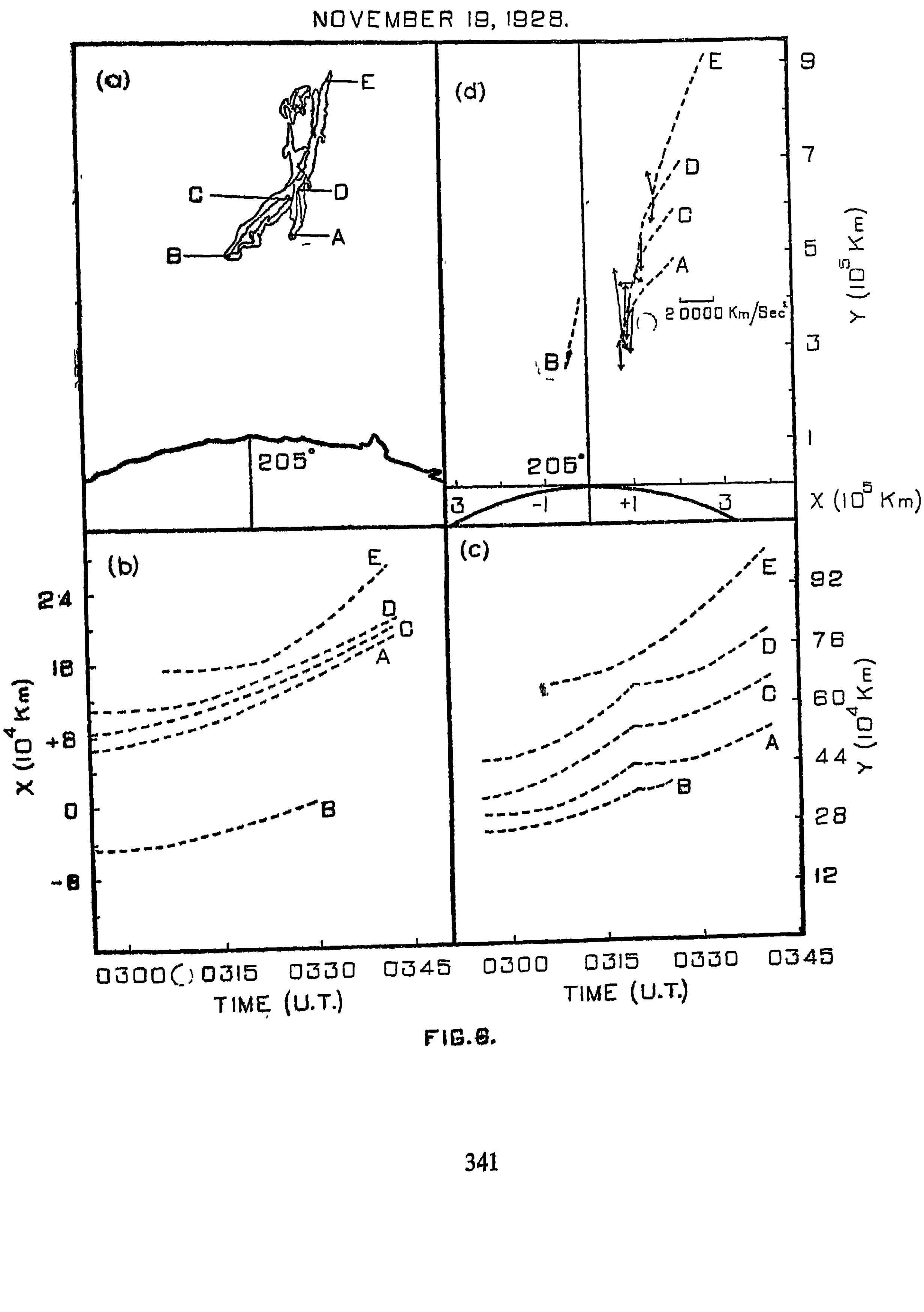
NOVEMBER 19, 1928.
(a)
(b)
(c)
(d)
A
B
C
D
E
205°
X (10^4 Km)
Y (10^4 Km)
Y (10^5 Km)
X (10^5 Km)
20000 Km/Sec
TIME (U.T.)
0300
0315
0330
0345

FIG.6.

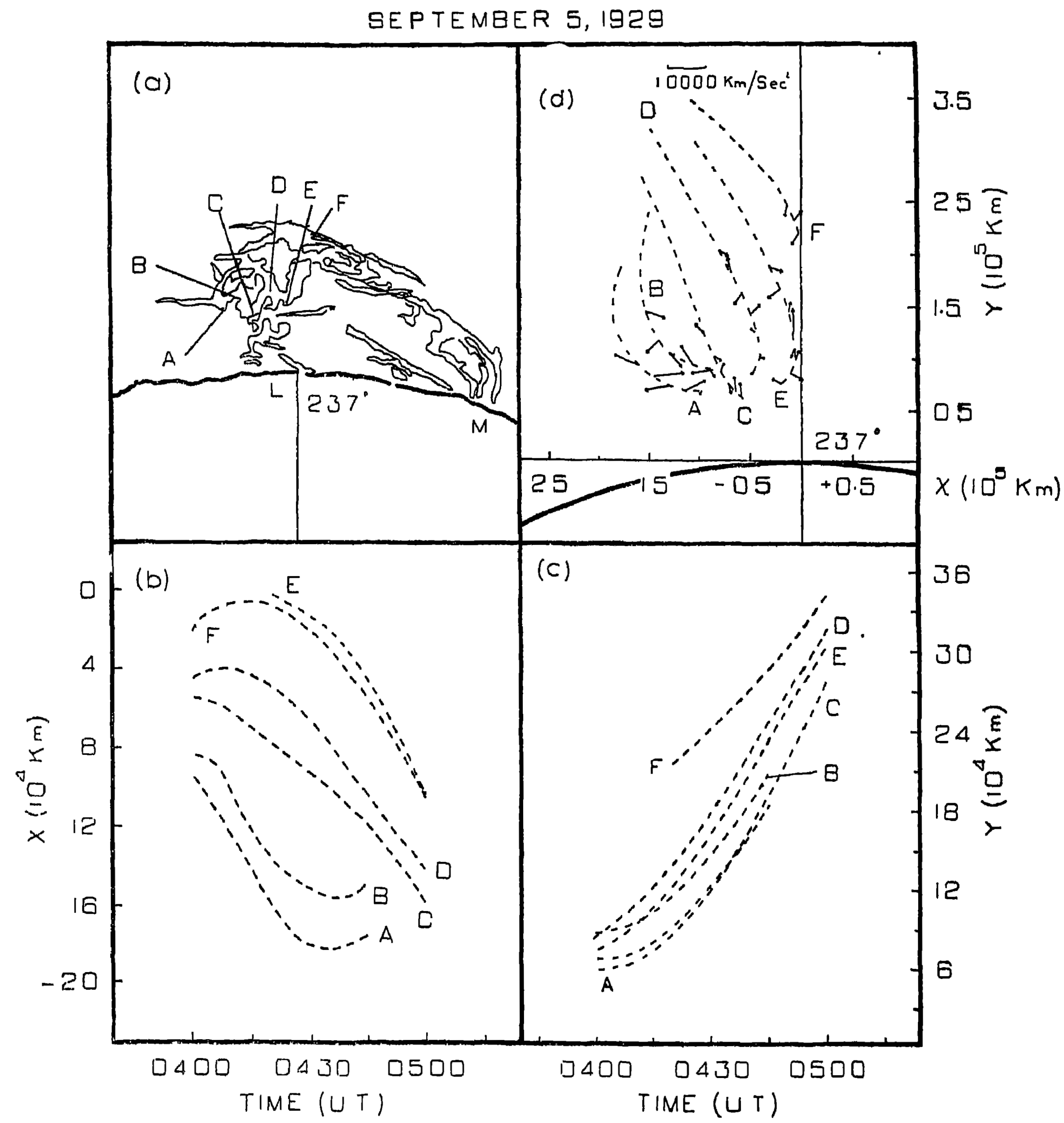
SEPTEMBER 5, 1929
(a)
A
B
C
D
E
F
L
M
237°
(d)
10000 Km/Sec
3.5
2.5
1.5
0.5
Y (10^5 Km)
237°
X (10^5 Km)
(b)
X (10^4 Km)
TIME (U T)
0400
0430
0500
(c)
Y (10^4 Km)
TIME (U T)

FIG 7.

MAY 31, 1939.

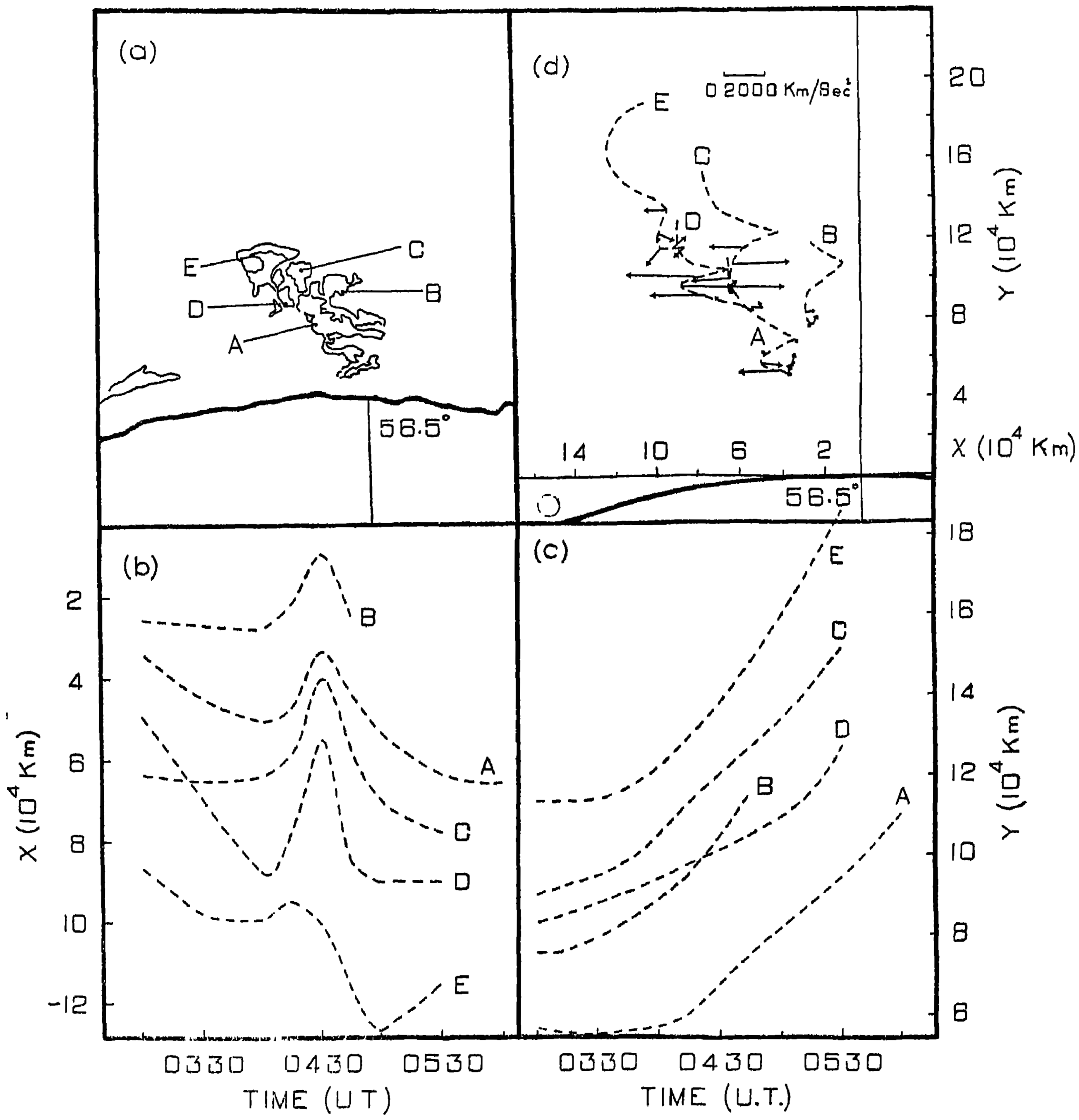

FIG 9.

The X-T plots—Figure 7(b)—for A and B are very similar, while those for C, D, E and F form another set of similar curves The difference between the two sets is that the former shows an increase in X towards the later stage of the eruption, whereas for the latter X decreases steadily after about 0410

In the Y—T graphs shown in Figure 7(c) the curves are similar Only they tend to cross each other during the early stages

X—Y plots in Figure 7(d) show the striking similarity in the overall motion upon which is superposed the equally striking range of curvatures for the individual trajectories. The curvatures of the trajectories change from being pronouncedly convex to the Y axis, to being moderately concave to it

Here again, acceleration vectors, determined at 5 minute intervals, do not fall into any definite pattern. The characteristic feature of acceleration vectors here, as before, is their almost alternate reversal in direction. As for the magnitude of accelerations, the large accelerations of the order of 4 times solar gravity is attained by feature A.

The general character of the trajectories in the X-Y plane are similar to those of prominences of December 31, 1920, October 20, 1925, December 10, 1926 and November 19, 1928.

Prominence of May 31, 1939 :

The eruption of this prominence took place on the east limb The prominence is to the east of a small plage region There is no other detectable disc phenomenon related to this prominence.

At 0255 U.T. a small prominence approximately 110,000 Km high is seen projected beyond the limb The prominence has several well defined compact knots with the material particularly concentrated near A, *vide* Figure 8(a) The whole prominence gives the impression of being tightly twisted near A. A long streamer from E streams into the chromosphere away from the direction of the plage region. Till 0438 the prominence shows no change in structure except a tendency to ascend slowly After 0438, the rise is rapid. At 0539 the pattern defined by A, D, C, becomes less curved as it rises. The tightly knit impression of the original structure is lost during ascent. The orientation achieved by A. D C at 0539 is preserved during the subsequent stages of eruption. It is interesting to note that the prominence structure from feature A and above rises up and dissolves in the background, while below A (*i.e.* 50,000 Km) the material arches down into the chromosphere.

X—T plots shown in Figure 8(b) are reasonably similar. The X coordinate seems to peak around 0430, for all the features

The Y—T graphs, on the other hand, show a gradual increase with time.

The X—Y plots throw into relief an extremely interesting aspect of the eruption Every feature studied shows unmistakable spiralling. The axes of the spirals are nearly parallel to each other and the pitch of the spiral is larger during the later phases of the eruption than at the start. Acceleration vectors drawn along the trajectories at 15 minute intervals display the usual alternation of direction. Also, many of these vectors are almost transverse to the direction of acceleration due to gravity.

The strong curvature displayed by the X—Y trajectories shows that this prominence should be considered as falling in the same class as prominences of February, 18, 1908 and March 14, 1927.

The above review of the history of the prominences and their neighbourhood, before and after the eruption, confirms that neither preferred locations nor particular types of surroundings are necessary for eruption. At least a qualitative analysis of surface details does not provide any clearcut clues.

Space-time plots show that there are large increases or decreases in distance in relatively short, but finite time intervals; rarely is there a real discontinuity, separating two uniform trajectories. As for Pettit's second law, there seems to be hardly any evidence in support of it.

The X—T, Y—T and X—Y plots clearly indicate that the fragments of the different parts of a prominence are all subject to strongly similar motions. This confirms Dodson's conclusion regarding the general overlying pattern that governs the eruption. It is very likely that the ordering agency is a magnetic field. Further, deviations from the general pattern, like the progressive change in curvature and orientation of the trajectories of the different features of a prominence, largely suggest the local configuration of the magnetic lines of force.

A comparison of the X—Y trajectories obtained in the present study for these eight different prominences show that, there are two general types of paths :

(I) Strongly curved, short ones (Prominences of February 18, 1908, March 14, 1927 and May 31, 1939).

(II) Slightly curved, long ones (Prominences of December 31, 1920, October 20, 1925, December 10, 1926, November 19, 1928 and September 5, 1929).

It is interesting to note that type I paths do not rise very high above the chromosphere while type II paths do (Prominence of November 19, 1928 rises to approximately 900,000 Km).

The resultant accelerations drawn along the trajectories at equal time intervals do not show any clearly discernible trends. The accelerations at the same instant of time for different features of the prominence show no well defined relation between each other. Again, when resultant accelerations in regions of constant X or Y are examined, no similarity either in the direction or magnitude of the acceleration vectors is noticeable.

The most evident feature revealed by the acceleration diagrams is that the acceleration vectors change their direction, often reversing their orientation alternately along the trajectories. This is fairly consistent with the results obtained by Rothschild et al., (1955) for an eruptive prominence studied by them. They have shown that accelerations have a tendency to reverse at a certain point on the trajectory. Since most of the observations of particular features in their analysis cover only 20 minutes, the time interval between reversals should be considerably less. This would appear to be borne out by the present computations wherein accelerations calculated for 5, 10 or 15 minute time intervals alternate in direction. It should be mentioned that this reversal of direction is common, in varying degrees, to all the prominences analysed, and is not confined to only one of the two types of trajectories mentioned above.

Discussion

Investigations of the long enduring stability of prominences have shown that the magnetic fields are a necessary part of the stable configuration. Zirin (1961) has recently found that small fields in quiescent prominences are *enhanced* over ten-fold in active prominences. The d' Azambujas have shown that in two out of three cases of eruption a filament is rebuilt in the same place and with similar form after some days. This shows that the field configurations essential for filament formation withstand eruption and retain their form. Taking these findings together, it would seem that the extra energy required for the erupting prominence is provided by an enhancement of the existing magnetic field. It is proposed here that the magnetic fields involved in an erupting prominence consist of two parts : *viz.* (i) a weak but primary field, responsible for the normal prominence configuration and (ii) a strong but momentary component. The former is restored, after eruption, to its original form without any significant change in characteristics.

Also, as noticed in some of the prominences studied herein, the process of dissolution affects the other parts of the prominences even earlier than the observed eruption, probably suggestive of the impending eruption. Even so the eruption is dramatically sudden.

It was stated earlier that among the prominences investigated herein, two general types of sky-plane component trajectories are deducible. These trajectories could be explained by considering the equilibrium between magnetic energy on the one hand, and, thermal and/or turbulent energies on the other. The quiescent phase of prominence life represents equilibrium between magnetic and thermal turbulent energies. In the active phase, the equilibrium is, perhaps, dynamic; the kinetic and magnetic energies still balancing each other. At every stage, the dissipation of magnetic energy by Joule heating, and gain in magnetic energy by the stretching of the magnetic lines of force, are operative. The Joule losses would occur through the transverse slipping, across the lines of force, by the neutral atoms, while the moving plasma would cause the stretching of the lines of force. At the critical stage the momentary increase in the magnetic field might cause one form of energy to increase at the expense of the other and thereby destroy the balance. When kinetic energy exceeds magnetic energy, the resulting eruption is characterised by the kinetic motion of the material dragging the lines of force along with it. Having regard to the large amount of magnetic energy available for conversion, prior to eruption, the matter would acquire tremendous gains in kinetic energy. Therefore, the eruption will be marked by high speed movements of material, condensed originally along the lines of force and now carrying the lines of force along. This process would ensure that the original bright structures are conserved in eruption. It would also lead to long, slightly curved trajectories referred to earlier. (Prominences of December 31, 1920, October 20, 1925, December 10, 1926, November 19, 1928 and September 5, 1929 would appear to fall in this category). Estimates of acceleration made for the prominences in question show that they are subject to large accelerations, several times solar gravity.

If the enhancement of the weak field by the momentary strong one, does not result in imparting super kinetic energies to the prominence material and the balance is in favour of magnetic energy, the resulting eruption would be dominated by the magnetic field. The prominence structures would be constrained in their motion by the lines of force and spiralling along lines of force would be the feature in such a case. The type I trajectories (Prominences of February 18, 1908, March 14, 1927 and May 31, 1939), described above seem to possess characteristics remarkably akin to those explained here. It would further account for the relatively small accelerations observed in these cases.

In conclusion the preliminary nature of the foregoing speculations must be pointed out. While they give a fairly qualitative idea of the post eruption trajectories obtained in this analysis, the root cause of the enhancement of the field itself remains to be considered. Again, the restoration of the weak field after eruption to its original form has to be dealt with. In respect of type II trajectories where the conversion of the extra magnetic energy into kinetic energy results in the material carrying away some lines of force, the restoration of the original field is a natural consequence. The restoring mechanism for type II trajectories is not so clear, as the decay times of the magnetic field are long.

To check whether field conditions propitious for the reformation of filaments are achieved, the examination of Hα disc pictures of subsequent days (all three prominences in type I erupted on east limb) shows no sign of a new filament till the region in question reaches the west limb (approximately 13 days later). It is interesting to note that there are three prominences classified under type I to five under type II in approximately the same ratio obtained by the d' Azambujas for filaments that do not reappear to those that reappear, after a disappearance. It is tempting to generalise therefrom, that type I trajectories represent the class of eruptions which do not lead to the reappearance of the filament. But the near equality of the ratios referred to, could hardly be deemed more than a coincidence at the present stage.

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Kodaikanal Observatory,
October, 1962.

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APPENDIX A

TABLE I

February 18, 1908

Time	P.A. of Origin	A				B				C				D				E			
		X	$\dot{X}$	Y	Y	X	X	Y	Y	X	X	Y	$\dot{Y}$	X	X	Y	$\dot{Y}$	X	X	Y	Y
0430	137°	—158	—20	—8	—6	—226	—2	—15	—13	—224	+26	—34	0	—302	+15	—47	—9	—290	+9	—15	+11
0500		—158	+4	—9	+2	—241	+3	—15	—10	—238	—26	—38	+8	—309	—17	—53	+3	—305	—4	—23	—3
0530		—166	+10	—11	+5	—256	—5	+15	+5	—241	+9	—38	—6	—315	+12	—62	—1	—317	—7	—23	+1
0600		—166	—11	—9	—5	—272	+9	+23	—7	—256	+5	—38	—3	—324	—1	—68	+4	—332	+8	—21	—2
0630		—166	+9	—8	+1	—283	—12	+26	—2	—260	+1	—42	+5	—328	—5	—72	—3	—347	—7	—19	+3
0700		—170	—10	—8	+6	—296	+15	+26	+4	—264	—9	—43	—5	—336	—1	—74	+2	—358	+8	—19	—1
0730		—170	+10	—6	—11	—298	+5	+30	0	—272	+2	—45	+1	—344	+11	—75	0	—370	—7	—19	+1
0800		—170	—1	—4	+7	—302	—43	+38	+6	—279	+22	—49	+4	—347	—16	—75	0	—377	+10	—19	—2
0830		—166	—3	—2	0	—309	+91	+45	—19	—283	—37	—51	—5	—351	+18	—75	—4	—385	—12	—19	—2
0900		—166	+0	+6	+4	—309	—94	+53	+26	—290	+28	—53	—9	—358	—19	—75	+10	—388	.	—19	
0930		—166	+1	+11	—11	—294	+60	+62	—14	—302	—4	—55	+41	—362	+20	—75		—392		—15	
1000		—162		+15	..	—302	.	+79		—294	..	—53	..	—370	.	—75		—392		—8	
1030		—155	.	+21		—279	..	+91	..	—286	.	—49		—370		—75		—400		+8	.
1100		—143		+38		—277	.	+113	.	—270	.	—43	.	—370		—60	.	—415		+49	
1130		—124	.	+64	.	—287	..	+151	..	—241		+11	.	—362	.	—25	..	—445		+91	
1200		—83		+109	.	—309	.	+207	..	—211	.	+102	..	—370	.	+53					..

TABLE II

December 31, 1920

Time	P.A. of Origin	A				B				C				D			
		X	X	Y	Ẏ	X	X	Y	Ẏ	X	Ẋ	Y	Y	X	Ẍ	Y	Y
0240	264°	+241	—10	+83	—74	+283	—17	+147	—226					+388	—40	+91	—114
0250		+266	+46	+106	+72	+294	—21	+181	+125	+365	—14	+139	+49	+388	+62	+121	+22
0300		+285	—66	+128	—46	+300	—13	+207	—12	+368	—14	+166	+27	+390	—29	+143	—72
0310		+290	—130	+155	+64	+302	+23	+241	—33	+366	+39	+189	+81	+394	+8	+170	—129
0320		+281	+95	+179	—68	+302	—21	+272	+37	+364	—101	+217	—146	+394	—23	+196	+146
0330		+268	—10	+204	+48	+300	—19	+302	—66	+360	+116	+247	+156	+392	+63	+223	—111
0340		+249	+84	+226	+11	+294	+9	+336	+148	+357	—86	+279	—211	+388	+76	+256	+153
0350		+230	+70	+253	—89	+287	.	+373	.	+351	+11	+321	+283	+385	—23	+290	—114
0400		+207		+279	..	+277		+409		+341	..	+363	.	+381		+332	.
0410		+185		+307		+264	.	+453	.	+332		+415		+370		+375	
0420		+157		+339		+247		+505		+317		+468		+354		+430	
0430		+124	.	+370		+226		+558		+290		+539		+339		+486	..
0440		+83		+415	.			.		+241	.	+617		+324	.	+554	

TABLE III

October 20, 1925

Time	P.A. of Origin	A				B				C				D				E			
		X	X	Y	Y	X	X	Y	Y	X	X	Y	Ẏ	X	X	Y	Y	X	X	Y	Y
0230	297°	+49	—59	+90	+156	+47	+88	+123	—233	+74	—64	+162	+129	+47	+69	+151	—7	+64	+38	+170	—87
0240		+49	+150	+92	—148	+42	+1	+128	+143	+79	+71	+166	—122	+40	—146	+166	+57	+62	+105	+179	+87
0250		+52		+102		+45	+31	+132	+18	+85	—51	+173	+113	+38	+221	+181	—23	+66	—61	+190	—1
0300		+64	..	+113	..	+51	+16	+151	+17	+94		+181		+42	—258	+196	+30	+75	0	+209	—43
0310		+75		+135	.	+60	—94	—172	—18	+104	..	+200		+49	+300	+219	—21	+85	+170	+230	+104
0320		+94	.	+158	..	+77	+168	+196	—11	+117	.	+226	..	+64	—258	+241	+50	+100	—267	+256	—38
0330		+113		+181	..	+109		+230	..	+132		+264		+87		+279		+119		+290	
0340			.	.		+158	.	+279	..	+153	.	+302	..	+119	.	+317		+143	.	+328	..
0350			..		.	+207	.	+339	..		.	.		+162		+370		+192		+377	.
0400		..	.		..	+256	.	+400	..	.	..		..	+230	.	+422		+249		+437	..
0410			..	..	..	+309	..	+460	..	..	..	..	.	+308	.	+490		+321		+505	.

TABLE IV

December 10, 1926

Time	P A of Origin	A				B				C				D				E			
		X	X	Y	Ẏ	X	X	Y	Ẏ	X	X	Y	Ẏ	X	X	Y	Y	X	X	Y	Y
0250	200°	+1	+7	+75	+42	+4	+72	+138	−224	+19	−36	+181	−220	+34	−11	+190	−9	+26	−68	+204	−70
0300		+4	+37	+83	+5	+8	−10	+155	+238	+23	+84	+200	+253	+36	−29	+215	+14	+32	+90	+230	+158
0310		+9	−28	+101	+111	+17	−13	+173	−87	+30	−83	+219	+204	+37	+81	+241	−12	+40	−38	+266	−89
0320		+17	+7	+128	−130	+26	+33	+206	−1	+42	+126	+249	+206	+49	−50	+272	+21	+53	+67	+294	−54
0330		+25	+54	+158	+150	+38	−6	+234	+6	+53	−86	+275	−168	+64	+3	+305	+15	+66	+29	+324	+99
0340		+34	−110	+189	+114	+51	−43	+268	−22	+68	+47	+309	+167	+79	−6	+343	+43	+83	+8	+362	−9
0350		+43	+148	+226	−30	+64	+115	+305	−1	+79	−36	+339	−179	+92	−23	+377	−12	+102	.	+403	
0400		+53	.	+264	..	+79	−109	+343	+28	+94	+31	+377	−172	+108	+14	+415	+75	+121	.	+441	
0410		+68	.	+309	..	+96	.	+383	.	+111	..	+415		+124		+451		+141	.	+481	
0420		+88		+354	..	+111	.	+423	..	+132	.	+460	.	+145	.	+486	.	+166		+526	.
0430		+109	.	+403		+134	..	+460	.	+153	..	+498	.	+168	.	+528		+190	.	+569	
0440		+143		+453		+158		+498	..	+173	.	+534	.	+192	.	+566	.	.		.	
0450				..	.	+181	.	+535	..	+198	..	+569	..	+219		+603		.			

TABLE V

March 14, 1927

Time	P.A. of Origin.	A				B				C				D				E				F			
		X	X	Y	Ÿ	X	Ẋ	Y	Ẏ	X	X	Y	Y	X	X	Y	Ẏ	X	X	Y	Y	X	Ẋ	Y	Y
0350	40°	+143	.	+119	.	.		..	.	.			.	.	..	.				.	.		.	.	
0400		+152		+106				.			.	..	.	..		.		.			.				
0410		+170		+92		+199	−499	+170	−169	+264	+174	+273	−142	+300	−131	+303	−57		.		.	.	.	.	
0420		+152	.	+154	.	+192	+139	+173	+53	+255	..	+241		+318		+291	.		.			.			
0430		+113		+112		+143	−98	+161	−25	+240		+207	.	+306	.	+272		.					.		
0440				.	.	+98		+145		+202	.	+189		+270	.	+240			.						.
0450		.	..		.	+53		+119	.	+149	.	+183	..	+204		+204		+255	+220	+315	−63	+128		+122	
0500		.	.	.	.	+21		+91		+77	..	+167		+158		+167	.	+193		+204		+101		+128	
0510		.	..	.	.	−2		+65	.		..	..		.	.		..	+155		+141		+71		+109	.
0520		.	.		..	−32	.	+41	..	.			.	.		.	.	+143		+110		+32	.	+89	
0530					..	.	.			.	.			.	.	.	.	+143	..	+110	.	+23	.	+77	
0540			.	.	.	.	.		.	.	..		.	..	.	.		+160		+86	.	..	.		

TABLE VI

November 19, 1928

Time	P.A. of Origin	A				B				C				D				E			
		X	X	Y	Y	X	Ẋ	Y	Y	X	Ẋ	Y	Y	X	Ẋ	Y	Y	X	Ẋ	Y	Y
0300	205°5	+72	—24	+294	+218	—45	+309	+256	—985	+87	+132	+343	—539	+109	—386	+422	+42				
0305		+77	+36	+302	—1504	—42		+264		+94	—75	+373	—841	+111	+369	+437	—174				
0310		+87	—42	+322	+3414	—36		+287		+104	+127	+403	+2116	+115	—40	+475	—1868	+153	—163	+590	—882
0315		+98	—171	+358	—2612	—30		+309		+113	—234	+445	—1898	+126	—34	+528	—1958	+155	—234	+611	+1395
0320		+109		+398		—19		+339		+124		+483		+138		+573		+158		+641	
0325		+128		+392		—9		+362		+138		+490		+151		+588		+173		+690	
0330		+147		+407						+155		+513		+166		+615		+200		+739	
0335		+162		+437						+170		+545		+181		+645		+226		+800	
0340		+177		+475						+187		+588		+196		+694		+256		+875	

TABLE VII

September 5, 1929

Time	P.A. of Origin	A				B				C				D				E				F			
		X	X	Y	Y	X	X	Y	Y	X	X	Y	Ẏ	X	X	Y	Y	X	Ẋ	Y	Y	X	X	Y	Y
0400	237°	—94	—332	+68	—141	—83	—531	+87	—8	—55	—45	+58	+142	—45	—66	+85	—82	—21	—128	+74	+110				
0405		—109	+494	+68	+250	—87	+126	+91	—231	—57	—79	—60	+325	—40	+100	+98	—2	—9	+171	+83	—180				
0410		—126	—684	+72	—73	—104	—237	+94	+451	—62	0	+64	+422	—40	—4	+119	—49	—6	+91	+94	+300				
0415		—141	+749	—81	+11	—121	+339	+102	—353	—70	+17	+72	—116	—43	—128	+123	+51	—6	—99	+108	—205				
0420		—158	—609	+92	+204	—136	—309	+115	—308	—77	+72	+87	+95	—49	+217	+140	+255	—8	—38	+124	+511	—2	—180	+215	—218
0425		—168		+108		—145		+128		—85	+147	+102	—155	—57	—234	+160	—319	—13	+86	+141	+220	—8	+210	+228	+316
0430		—179		+124		—153		+147		—92	—239	+121	+323	—66	—65	+181	+229	—21	—293	+162	—142	—13	—49	+241	—231
0435		—181		+141		—155		+165		—100	+330	+143	—137	—79	+224	—200	—112	—30	+335	+185	—138	—19		+256	+280
0440		—179		+162		—157		+187		—109		+170		—91		+223		—42		+207		—30		—270	
0445		—173		+185		—147		+207		—119		—194		—102		—245		—53		+234		—45		+287	
0450										—132		+221		—117		+270		—70		+258		—62		+305	
0455										—143		+249		—132		+294		—87		+283		—83		+324	
0500										—158		+279		—141		+310		—104		+305		—106		+345	

TABLE VIII

May 31, 1939

Time	P.A. of Origin	A X	A Ẋ	A Y	A Y	B X	B Ẋ	B Y	B Ÿ	C X	C X	C Y	C Ẏ	D X	D X	D Y	D Y	E X	E X	E Y	E Y
0300	56°5	−33	−36	+57	−27	−25	+14	−75	+37	−63	−1	+91	+4	−48	−18	+83	+30	−86	−48	+113	−33
0315		−39	+16	+53	+54	−26	−4	+75	−3	−65	+17	−92	−16	−59	+61	+85	−22	−92	+65	+113	+55
0330		−45	+42	−53	−26	−26	−42	+81	+10	−64	+39	−94	+19	−69	−13	+89	+9	−98	−66	+113	−77
0345		−48	−156	+57	−5	−27		+85		−63	−188	+98	−8	−79	−236	+91	0	−98	+6	+117	+86
0400		−50	+107	+57	−10	−27		−89		−63	+286	+106	+9	−88	+494	+94	−4	−99	+81	+121	−43
0415		−47	−13	+60	+12	−21		+94		−57	−175	−113	+7	−77	−380	+98	+14	−94	−108	+132	+1
0430		−32	+3	+68	−13	−8		+106		−39		−121		−54		+102		−100		+138	
0445		−43		+75		−24		+115		−59		+127		−84		+106		−118		+147	
0500		−53		+81						−69		+132		−89		+109		−124		+158	
0515		−53		+87						−74		−141		−89		+116		−121		+170	
0530		−63		+92						−77		+151		−89		+126		−115		+185	
0545		−65		+102																	
0600		−65		+109																	