CHARACTERISTIC RADIAL MOTIONS OF $H\alpha$ ABSORPTION MARKINGS SEEN WITH BRIGHT ERUPTIONS ON THE SUN'S DISC

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1. One of the chief uses of the spectrohelioscope is to locate short-lived phenomena on the Sun's disc. Notable among these are the bright chromospheric eruptions which have been linked up with certain ionospheric disturbances. Whilst attention has been concentrated on the flares themselves—their sudden origin, brightness and other features—it has been difficult for the observer to follow in any detail the life-history of transient absorption markings which often appear in close association. In the spectrohelioscope observations made at Greenwich, absorption markings have been observed in association with about 80 per cent. of the brightest eruptions (intensity = 3); for bright eruptions of intensity = 2, the observed association was 70 per cent., and for those of smallest intensity (= 1) 50 per cent. These are minimum values, because, to give one reason, whilst bright flares are nearly always best seen in the middle of $H\alpha$, indicating the absence of Doppler shifts, the observer must "hunt" with the line-shifter for the presence of absorption markings with medium or large radial velocities. If photometer measures are being made on the bright emission itself, only infrequent scouting with the line-shifter is possible.

In *M.N.*, 95, 650, 1935, attention was drawn to the occurrence of outward velocities followed by inward velocities, which seemed to characterize dark markings found in close association with bright eruptions. These absorption markings evidently represent prominences (in many cases, rising and falling in nearly the same place) seen in plan on the Sun's disc. In the simplest cases, the plan picture appears as a small blob 10″ to 30″ in diameter; in others, as a short dark streak, curved or straight. The observer then feels some confidence that he is following the same mass of absorbing $H\alpha$, or at least related masses from the same point of origin in the chromosphere. Direct measures of the components of radial velocity of prominences seen thus in plan are obviously a valuable addition to the time-height measures made at the Sun's limb.

The collecting of satisfactory disc data has, however, been slow, owing to the rapidity of the phenomena and to the priority given to observations of the initial bright eruptions, for which data were primarily sought on account of the associated ionospheric effects brought to light by observations at Greenwich and elsewhere in 1935–38. Although it was hoped to collect fuller data than has been possible at Greenwich up to the present, certain features have emerged which seem worth stating now for guidance in planning future observations with the spectrohelioscope.

It may be noted that if the phenomena described in this paper were recorded by cinematography and projected with the usual time-scale compression of recent prominence films of 1/600, they would go through their life-history on the screen within 2 or 3 seconds.

2. *Instrument and Observing Methods.*—The essentials to be given here are :—

(*a*) The Hale spectrohelioscope * lent to Greenwich in 1929 by the Mount Wilson Observatory is used with a Rowland grating ruled with 14,438 lines to the inch. The width of the selecting slit generally used is 0·10 mm., which in the first order spectrum at $H\alpha$ would include a range of 0·44 A., equivalent to a Doppler-shift range of 20 km./sec.

* *Ap. J.*, 70, 265, 1929.

(*b*) To make a radial velocity measure of a dark *Hα* marking, the line-shifter is turned until the marking appears at maximum density. The line-shifter reading converted into angstroms or km./sec. is differenced from the zero reading, similarly converted, which corresponds to the centre, or bottom of the contour, of the *Hα* line. An alternative method, sometimes used, is to take the line-shifter readings when the chromospheric marking just comes into visibility on each side of its maximum intensity position. The mean of these two readings converted into km./sec. and differenced from the zero value gives the required measure. The Greenwich measures of quiescent dark markings give the average total range of visibility as 1·2 A. For several markings with a mean component of radial velocity of 44 km./sec. the measured range was 1·8 A. In one case included in this paper the range was 4·5 A., the mean Doppler displacement being equivalent to -100 km./sec.

(*c*) The probable error of a single radial velocity measure made on the average quiescent marking is about 3 km./sec. including the p.e. of the zero determination. In the case of large and rapidly changing velocities such as are included in this paper, the probable error must be larger, probably about 5 km./sec.

3. *Data.*—Between 1936 March and 1939 August, sets of measures were made on 25 absorption markings associated with chromospheric patches of abnormal enhancement near sunspots. Nineteen of these bright patches were classified as bright eruptions, nine being of intensity 1, eight of intensity 2 and two of major intensity 3. In the six other cases, the enhanced emission was not quite bright enough nor quite typical in light fluctuation to be classified as a bright eruption. These cases are designated as of intensity < 1.

Identification of the above 25 *Hα* absorption markings may be made by referring to the *Greenwich Photoheliographic Results* for the years 1936–39, in which are or will be published the range of measured radial velocity, data of the associated sunspot, etc. For 1936 the reference numbers are (*loc. cit.*, p. 153) : 46, 96, 100, 109 *, 122, 125, 175, 200, 252. More recent Greenwich *Results* have not yet been published, but identification will be possible later with the help of the following dates :—

1937. Jan 7: Oct. 2. (For 109 * above, refer also to 1937.)
1938. Mar. 15, 18: Apr. 12, 13: May 6, 8: June 10: Sept. 23: Nov. 11, 12.
1939. Mar. 24: May 4: June 29: Aug. 18.

4. *Characteristics of a Recognized Type.*—Of the 25 absorption markings, the life-histories of six were incompletely observed, but their partial evidence is useful. Of the remaining 19, twelve show a distinct similarity in their time-velocity graphs, and their characteristics are presented in fig. 1. This diagram gives, in point of fact, the mean numerical values obtained from the collective observations. The average duration of the associated bright eruptions is indicated by the thick horizontal line at zero velocity.

The distribution curve of measured radial velocities of bright flocculi in general corresponds essentially to that of a probable error of 2 km./sec. Velocities exceeding 10 km./sec. are rare and tend to be found near the Sun's limb.

The life-history of the associated absorption marking falls into three phases.

Phase I: The marking is usually discovered within two or three minutes of the first appearance of the bright eruption. The average measured radial velocity is of the order -50 km./sec., *i.e.* outwards from the Sun, and is caught on a very rapid rise in the measured velocity to a peak value exceeding -100 km./sec. or even -200 km./sec. This peak is near in time to the intensity peak of the bright emission. A rapid decline in outward velocity at once follows, half the peak value being measured within the next two or three minutes.

Then for several minutes (Phase II) the measured outward velocity continues to fall towards zero, usually with a mean retardation less than that due to solar gravity ($2{\cdot}74 \times 10^4$ cm. sec.$^{-2}$). But the absorbing *Hα* cloud is not apparently visible at the top of its trajectory, for the dark blob which had become dense in appearance now begins to fade rapidly and is usually lost to view at a measured velocity of about −30 km./sec.*

About two minutes before this disappearance occurs, a second dark marking (Phase III), often very close in position to the first, is faintly discernible with a measured component of radial velocity of about 35 km./sec. *inwards* to the chromosphere. At this stage, by oscillating the line-shifter, the pair of markings with − and + velocities

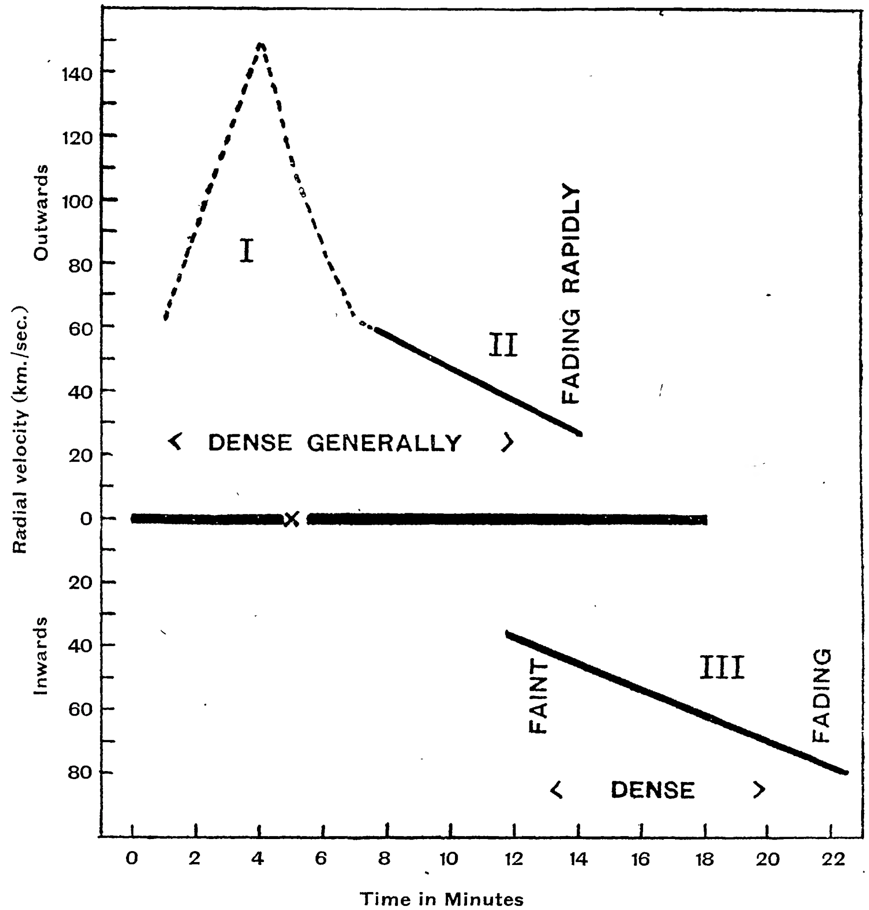

FIG. 1.—*Schematic Time-Velocity Diagram. Type of dark Hα from bright eruptions.*

respectively can usually be seen in close juxtaposition. The new marking gains rapidly in density, and for more than 10 minutes its velocity increases with an approximately constant acceleration less than that due to solar gravity. The marking beginning to fade is soon lost to view at a velocity generally exceeding 50 km./sec. and tending to larger values if the peak outward velocity of Phase I is large.

Of the above phases, the first is the most difficult to observe owing to its sudden onset and the rapidity of its changes. In several cases the peak has been missed altogether; one or two cases do in fact suggest that no marked peak ever occurred. The ending of Phase II and the whole of Phase III are much better observed, for the changes are less rapid and the observer is concentrating on a recognizable sequence of events.

* This velocity, like others given in this section, refers to the centre of maximum density of the marking. From § 2, paragraph (*a*), it follows that the setting of the line-shifter indicating 30 km./sec. may well include velocities from zero to 60 km./sec. A line-contour of an *Hα* absorption marking is given in *M.N.*, 97, 535, 1937.

The chief details are given in Table I (pp. 6–7) of the observation of each of the twelve dark $H\alpha$ markings with a typical life-history represented in fig. 1. No corrections to the observed radial velocities have been made on account of angular distances of the eruptions from the central meridian. In this preliminary survey the data are sufficient only to find out the broad features of the phenomena. Moreover, the application of a secant correction appears in practice to be of doubtful validity as applied to chromospheric phenomena in general.

The headings of the table are mostly self-explanatory. In column 8, the blanks indicate that the peak was not observed. The addition of brackets indicates that the peak was not fully observed. The 15th column gives the mean deviation of the observed velocities from a straight line, the number of points being given in brackets.

5. *Remarks on the Results.*—Phases I and II: The initial accelerating velocity outwards of absorbing $H\alpha$ within a short time of the origin of the bright eruption strongly suggests some effect of radiation pressure such as has been investigated by E. A. Milne. The observations do not determine whether (*a*) the identical mass of gas is traceable throughout Phases I and II, or (*b*) the sharp drop from the observed maximum velocity indicates a few successive ejections of decreasing initial velocity. If (*a*), then some cause of rapid retardation appreciably greater than that due to solar gravity must operate. There is, however, no corroboration of this in the time-velocity graph of the descending $H\alpha$ of Phase III, which occurs close in time and place to that of Phase I. An alternative explanation to (*b*) is that the gas cloud of the initial ejection (having ascended to greater heights where it becomes invisible to the observer, or having left the Sun altogether) has produced an upward drag on the surrounding chromospheric gases. This secondary effect, if it exists, may be represented by the sudden drop in observed velocities.

Whatever the exact nature of the uprush represented by Phase I, Phase II appears to indicate absorbing $H\alpha$ rising towards the top of its visible trajectory. The mean retardation has now become less than that due to solar gravity, suggesting that there is a radiation-pressure effect from the now diminishing bright eruption or from the general field of normal bright flocculi. The explanation of the disappearance of the dark $H\alpha$ before reaching zero velocity at the top of its trajectory may be connected with diffusion of the cloud or the degree of ionization. The mean order of height deduced in the last column of Table I is 50,000 km.

Phase III presents three interesting features. (1) The appearance of dark $H\alpha$, not near zero velocity but at 30–40 km./sec. inwards to the chromosphere, the mean value being 36 ± 2 km./sec.; (2) the discontinuity with the outward time-velocity curve, indicating at first sight that a different cloud mass from that of Phases I and II is involved; (3) the average acceleration downwards, ranging from zero to $1{\cdot}9 \times 10^4$ cm. sec.^{2}, is definitely less than that due to solar gravity, suggesting also in this case the operation of radiation pressure.

It will be seen that the time-velocity graph for Phase III produced backwards to zero velocity intersects the time axis near in time to the initial ejection of the dark $H\alpha$. This in itself suggests that with this initial ejection a downward flow of chromospheric gas begins in a closely adjacent position, similar perhaps to the downward movement of "coronal prominences" as seen at the Sun's limb. But if this be the case, what becomes of the outward moving $H\alpha$ of Phase II, and of Phase I if the latter is not shot outwards into space?

The attention of observers is drawn to this very interesting type of absorption marking found associated with bright $H\alpha$.* Much fuller data are needed, and the characteristics summarized in fig. 1 may have to be modified in detail. Velocity measures, made by both methods if possible, as described earlier, are required at intervals of not less than 30 seconds during Phase I. The full range of the line-shifter (increased if possible by a

* Recently M. A. Ellison has independently recognized the intrinsic interest of this type and is accumulating data for publication.

subsidiary one) should be frequently used to catch any glimpse of other higher-velocity markings that may be very faint. Frequent notes and sketches are very useful later. A second spectrohelioscope, operated by an observer working in collaboration with the first observer, would be invaluable for recording the progress of the bright emission. By identifying this type of disturbance with a prominence type at the limb (see *infra*) valuable evidence is available in motion pictures which can be repeatedly studied as fresh points for examination arise.

TABLE I

Hα Absorption Markings associated with Bright Eruptions

Serial No.	Year Reference Number	Date	Distance from Central Meridian	Intensity of Bright Eruption	Observed Life of Dark *Hα*, minutes	Phase I (outwards)	
						Velocity First Seen, km./sec.	Peak Velocity, km./sec.
	1936						
1	46	Mar. 18	13° W.	< 1	15	32	...
2	100	May 26	47° W.	3	30	40	...
3	109*	June 5	28° W.	3	31	59	205
4	122	June 17	61° E.	< 1	25	37	...
5	125	June 17	60° E.	1	33	57	100
6	175	Aug. 20	13° W.	1	9	70	(70)
7	200	Sept. 23	22° E.	2	16	68	...
8	252	Nov. 8	34° E.	1	19	52	...
9	1937	Jan. 7	35° W.	< 1	18	70	(70)
10	1938	May 8	62° W.	1	17	33	...
11	1939	May 9	47° W.	2	12	200	(200)
12	1939	June 29	7° E.	1	31	55	165
	MEANS	...	...	...	21	...	−155

NOTES

No. 2. Associated with a radio fade-out.

No. 9. Before the + velocity has gone, a new eruption begins and velocities rise to −135 km./sec. The ensuing motions are complex.

No. 11. Phase III. End not observed owing to cloud.

6. *Non-Typical Cases.*—Brief reference will now be made to the remaining 13 cases of dark *Hα* markings observed in association with abnormal bright emission but whose behaviour departs from the type just described. Three examples are given:—

1936 *May* 25, *No.* 96.—$09^h\ 48^m$ to $10^h\ 22^m$ U.T.: 32° W. of C.M.: latitude 11° N.: associated eruption of intensity < 1.

The outward velocities are rather irregular, showing as a whole no general increase or decrease. The mean is −21 km./sec. The inward velocities, appearing a few minutes after the outward velocities were first located, are smoother, and also show no general trend from a constant velocity. The mean value is +30 km./sec.

1938 *Sept.* 23.—$08^h\ 49^m$ to $09^h\ 47^m$ U.T. associated sunspot 29° E. of C.M.: latitude 10° S. Points of enhanced emission of intensity < 1.

Absorption marking long and curved. Very rapid increase of initial outward velocities, the observer noting that changes of velocity were apparent within 5 or 10 seconds. Individual measures are as follows:—

h m s	km./sec.	h m s	km./sec.
8 49 00	−175	8 57 30	−33
51 00	> −265	9 06 00	−55
52 00	−230	08 00	−37
52 45	−180	10 00	−33
53 45	−165 *	18 00	−30
55 00	−162	47 00	−27

* Extreme velocity: bulk of marking seen at −50 km./sec.

TABLE I

showing Characteristic Velocities as in Fig. 1

Serial No.	Phase II (outwards from Sun)			Phase III (inwards to Sun)				
	Retardation, 10^4 cm. sec.$^{-2}$	Duration, mins.	Velocity Last Seen, km./sec.	First and Last Velocity, km./sec.	Acceleration, 10^4 cm. sec.$^{-2}$	Mean Deviation, km./sec.	Duration, mins.	Distance Fallen, 10^3 km.
1	0·7	6	9	30 : 53	0·3	3·2 (10)	12	30
2	0·3	12	19	29 : 37	0·1	1·3 (8)	17	34
3	0·8	6	28	42 : 190	1·9	5·6 (9)	13	91
4	0·1	20	30	32 : 37	0·1	0·0 (4)	9	19
5	0·5	6	32	36 : 122	0·8	0·8 (9)	17	81
6	3·2	3	26	42 : 85	1·2	5·4 (7)	7	27
7	1·7	4	45	28 : 83	0·7	5·6 (7)	14	48
8	0·1	7	30	29 : 53	0·3	3·2 (10)	14	34
9	0·8	7	22	32 : 62	0·6	2·0 (8)	9	25
10	0·2	17	13	40 : 40	0·0	3·6 (5)	13	31
11	0·6	6	45	45 : 86	1·2	1·3 (3)	6	24
12	...	...	29	{48 : 63	0·2	3·5 (4)	11	36}
				51 : 109}	1·1	3·5 (6)	9	43}
	0·8	9	−27	+36 : +80	0·69 ± 0·12	3·0	12	> 41

NOTES

No. 12. Phase II is absent, the rapid retardation (4·2 . 10^4 cm. sec.$^{-2}$) continuing from the peak value. In Phase III, a marking, seen jointly from the first with that of Phase I, is represented by the upper set of values in Cols. 13–17. The lower sequence represents what appears to be the typical downward branch.

The inward velocities, first seen at $9^h\,00^m$, were irregular, none exceeding +85 km./sec. and with a general tendency to *decrease* with time.

1939 *March* 24.—$10^h\,17^m$ to $11^h\,13^m$ U.T.: 22° N.: 15° W. of C.M.

Associated bright eruption of intensity = 1 first seen at $10^h\,17^m$ and ending at $10^h\,35^m$. The individual measures are shown in fig. 2.

By $11^h\,04^m$ the marking, now dense and curved, had a measured radial velocity increasing to +65 km./sec. towards a sunspot. The mean velocity for the marking as a whole is plotted.

At $11^h\,13^m$ it was seen that a new outward velocity had appeared, but cloud interfered with further observation. There is no obvious acceleration to either the outward or inward velocities measured.

7. *Ancillary Data.*—In the *Greenwich Photoheliographic Results* for the years 1930 to 1936 there are published a number of single radial velocity measures of small dark points or blobs seen in $H\alpha$, not associated with bright eruptions but in the neighbourhood of sunspots. These markings, like those of similar appearance connected with bright

eruptions, are designated in the fourth column of the spectrohelioscopic results by an asterisk (*e.g.*, *loc. cit.*, *Results* 1933, p. 49, Nos. 5, 8, 11, 21, etc.). They are briefly considered here, because their general characteristics suggest that they are of a kindred nature to the dark markings already discussed in association with bright eruptions.

With some exceptions, when multiple observations are recorded, the duration of these small markings is not known, but the inference is that they were short-lived. In many cases only the − component of radial velocity was measured; in others only the + component, while in 38 cases both the − and the + component were seen together in close juxtaposition by rapidly oscillating the line-shifter. The mean velocities of these pairs of markings are −32·3 and +36·4 km./sec. respectively.

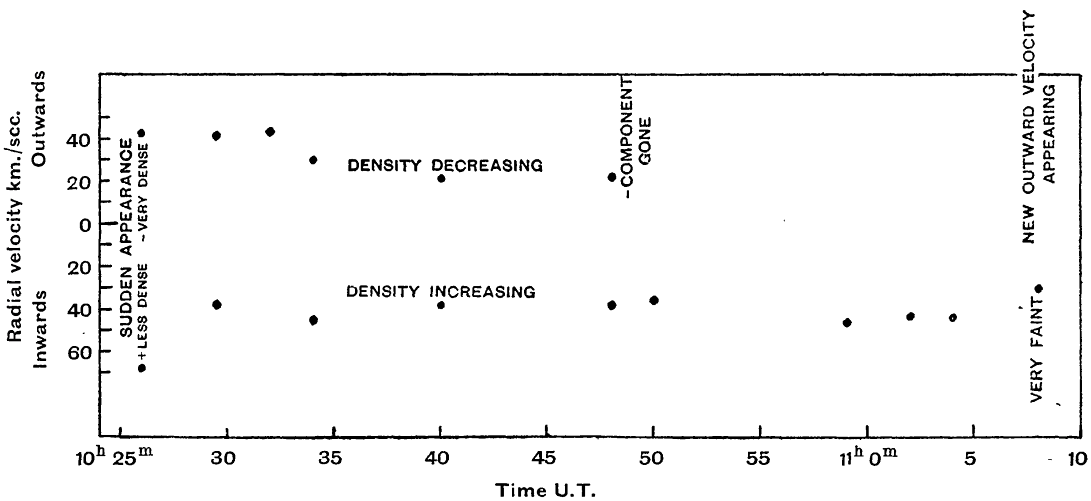

FIG. 2.—*Radial Velocity of dark Hα with bright eruption* (*non-typical case*). 1939 *March* 24.

In one case (1934, No. 8) the marking was followed for nearly half an hour. The inward velocities denote an acceleration of $0{\cdot}2 \times 10^4$ cm. sec.$^{-2}$. Another case, well observed, is that of 1936 March 17, No. 42, illustrated in fig. 3.

A velocity-frequency graph of 243 of these dark markings is given in fig. 4. The frequencies plotted for velocities 1, 4, 7 . . . km./sec. are the respective summations within each 3 km./sec. range of velocity, viz. 0–2, 3–5, 6–8 . . . km./sec. The following features * are shown:—

(1) The excess of inward to outward velocities in the ratio of nearly 3 to 1.

(2) A peak at about 34 km./sec. in both the − and + velocities, the peak being very pronounced in the case of the inward velocities. In about half the cases of inward velocities > +50 km./sec., the *Hα* marking was apparently descending into either the penumbra or the umbra of a sunspot. The peaks at about 34 km./sec. are interesting in view of S. Chandrasekhar's researches on the solar chromosphere,† from which he derived a tendency for particles of medium velocity of the order 30 km./sec. to be ejected from the chromosphere.

With respect to the marked excess of inward motions it has been noticed by prominence observers ‡ that "in the lower bright arches and loops of prominences of Classes III*b* and III*c*, the motions of *descent* are always clear, brilliant and rapid, while any corresponding *ascent* of matter where the rising side of the completed trajectory should be is either so faint that no motion can be detected or, as is more frequently the case, it is entirely absent."

The inward excess of downward motions is, however, not confined alone to these types of prominences.

* See also *M.N.*, 94, 472, 1934. † *M.N.*, 94, 25, 1933.
‡ McMath, *Proc. American Phil. Soc.*, 79, 494, 1938.

8. *Comparison with Prominences at the Limb.*—It is of primary interest to identify the outward and inward moving dark $H\alpha$ patches considered in this paper with prominence types seen in profile at the Sun's limb. From the characteristics of various prominence types described * by R. McMath and H. E. Sawyer, there appears to be a strong general resemblance in behaviour between the absorption markings considered

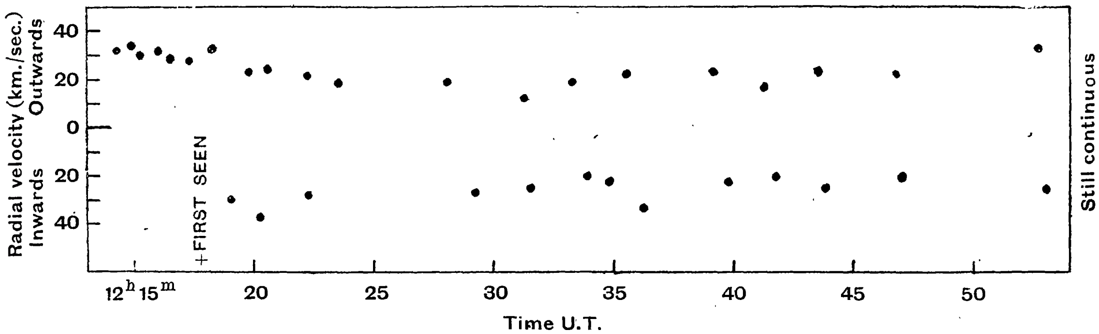

FIG. 3.—*Long-continued pair of dark $H\alpha$ markings not associated with special bright emission.* 1936 *March* 17.

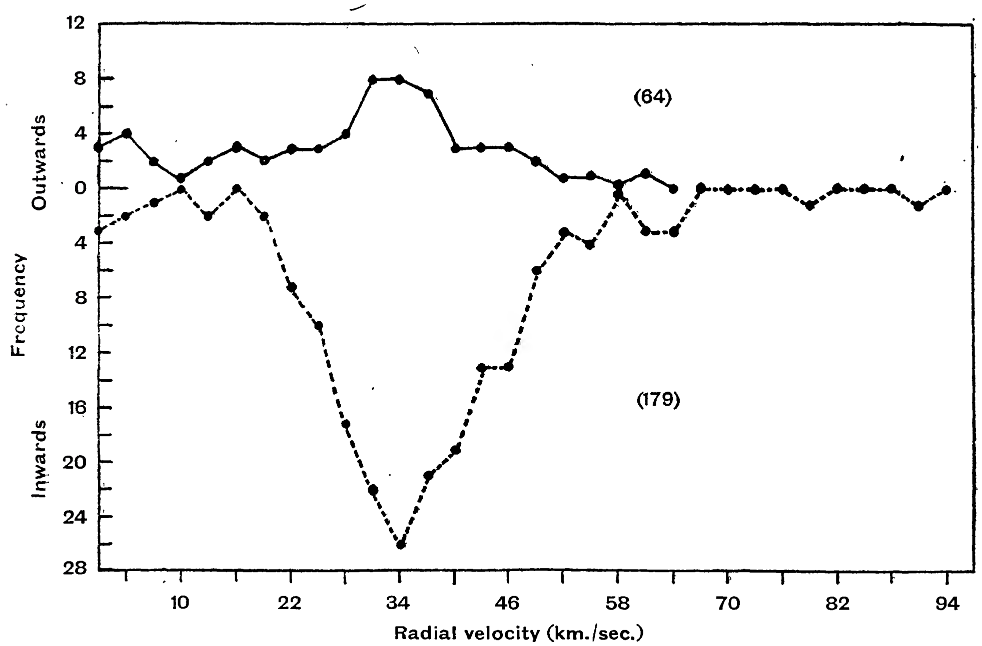

FIG. 4.—*Velocity-Frequency Diagram of* 243 *small dark $H\alpha$ markings in sunspot groups. (No special bright emission.)*

here and the type of short-lived prominences known as "surges" and classified as Class III*d*. Only a few time-height diagrams of surges have ever been published; the results of four are given by McMath and Pettit in *Ap. J.*, 85, 291, 1937. The heights deduced in column 17 of Table I of this paper are of the same order as those of surges; and the maximum observed velocities are also of the same order. The following description is taken from the paper, *loc. cit.*, p. 197, by McMath and Sawyer:—

"Surges are short-lived phenomena which frequently thrust upward from a spot area and subside, or in some cases apparently return to the chromosphere over the original trajectory. In general they are very bright, some examples even exceeding the brightness of the chromosphere. Small examples of their type are frequent occurrences in the

* *Publ. of the Observatory of the University of Michigan*, 7, 195, 1939; also McMath and Pettit, *Ap. J.*, 85, 296, 1937.

active region surrounding a sunspot . . . in general the velocity of ejection is greater than that of recession. . . ."

It seems likely that the small examples of frequent occurrence described by McMath and Sawyer are to be identified with the disc markings of the preceding paragraph 7. Whilst there are several points of strong similarity between the Greenwich disc observations and the Lake Angelus limb observation of surges, there remain for correlation (*a*) the discontinuity of the upward and downward motions as given by the disc observations, (*b*) the fading of the upward moving marking at about -30 km./sec. and, somewhat preceding this fading, the first signs of the downward motion at about $+35$ km./sec. A third point concerns the downward acceleration found in about half the disc markings considered herein with bright eruptions. Until quite recently, McMath and his collaborators * were unable to find from prominence limb observations any evidence for a gradual acceleration of velocities.

In a new paper †, however, on the measured space motions of prominences in *Hα*, McMath and Sawyer have found accelerating downward motions of knots in two prominences. The accelerations found are of the same general order of magnitude as those derived from disc markings in Table I of this paper.

Summary

Results are given of radial velocity measures, made at Greenwich, of *Hα* absorption markings on the Sun's disc associated with bright eruptions that occur near sunspots.

Half of the cases observed show characteristic motions summarized in the time-velocity diagram (fig. 1). The chief features are:

(1) The high initial outward velocity followed by a sudden drop.

(2) The constant acceleration downwards that occurs later; the acceleration is less than that due to solar gravity.

(3) The discontinuity in the time-velocity graphs of the outward and inward velocities, and

(4) The non-visibility of the outward moving marking when its velocity has fallen below an average value of about 30 km./sec. and the first appearance of descending *Hα* at about the same limiting velocity. These and other points are briefly discussed.

The other miscellaneous half of the observed cases, though having the general characteristic of an overlap of − and + velocities, show varying departure from the above type, including a general absence of downward acceleration.

As a whole, both classes of disc markings are to be identified with "surges" seen as limb prominences, but the correlation of detailed features as enumerated above awaits future investigation.

A large number of singly observed small *Hα* absorption markings (seen near sunspots but not with abnormal emission) may be small or incipient surges. Their velocity-frequency distribution shows a marked peak at about 34 km./sec., and inward motions greatly predominate.

Brief suggestions are made as to further observations of these interesting kindred types of *Hα* absorption markings found near sunspots.

Acknowledgments.—To the Astronomer Royal I am grateful for the opportunity given me of preparing this paper. I wish to record the helpful interest shown in these observations for some time past by Professor E. A. Milne, and recently by Dr. A. Hunter who also helped me in the final revision of the MS. Mrs. M. E. Higby of the Observatory staff has assisted me in preparing the data for publication.

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* *Proc. Am. Phil. Soc.*, **79**, 493, 1938, and *Publ. Obs. Univ. Michigan*, **7**, 199, 1939. For a theoretical aspect, see Giovanelli, *Ap. J.*, **91**, 87, 1940. † *Loc. cit.*, **8**, 123, 1941.