Kodaikanal Observatory.

BULLETIN No. LXIII.

SOME FEATURES OF Hα DARK MARKINGS ON THE SUN,

BY T. ROYDS, D.Sc.

The dark markings seen in spectroheliograms of the sun taken with the Hα line form one of the most interesting features of the solar surface and one that has been least studied. Since the Hα spectroheliograph of the Kodaikanal Observatory was first constructed by Mr. Evershed he has carried out many minor improvements which enable a higher average quality of photographs to be obtained, resulting in a more perfect and more continuous series of Hα spectroheliograms than in the earlier days. Experience has also been gained in the preparation of red sensitive plates. It therefore seemed appropriate to undertake a detailed study of the Hα records now available at the Kodaikanal Observatory, and a commencement has been made on the photographs taken during the half-year January—June 1918. A still earlier period might have been taken, but it was thought advisable to begin with a period when there was considerable prominence activity in the polar regions (see Kodaikanal Observatory Bulletin No. LIX).

Even a casual inspection of Hα spectroheliograms reveals certain features which can hardly escape notice, and the present paper confines itself to these more obvious features of the markings as exemplified in the spectroheliograms obtained during the half-year January--June 1918, leaving for another occasion those features requiring a more closely detailed examination. The remarks in this paper are therefore concerned only with the following three points which have not, so far as I am aware, been previously referred to by other workers :—

I. The mean directions of Hα dark markings in different latitudes.*

II. The bright margins of Hα dark markings.

III. Absorption near the bases of prominences.

I. —THE MEAN DIRECTION OF DARK MARKINGS IN DIFFERENT LATITUDES.

Almost every spectroheliogram shows that nearly all dark markings have a more or less linear character, this feature having led M. Deslandres to call them " filaments ".† Consequently it is not difficult to assign a definite direction to each marking or at any rate to different sections of its length. The tendency of Hα markings to lie along a parallel of latitude in latitudes higher than about 35° and to lie along a meridian in the equatorial regions can be gathered after a slight familiarity with the spectroheliograms. For a closer study, the average direction of the dark markings for each belt of 5° of latitude for the northern and southern hemispheres has been derived in the following way. In the course of the ordinary routine of the Observatory the dark markings are copied by hand on to 8 inch charts on which are printed the lines of latitude and longitude referred to the central meridian at 5° intervals. From each of these charts of the first half of 1918 the direction of the Hα markings in each belt of 5° latitude was read off, the areas having been previously measured on the photographs and corrected for foreshortening. For consistency, the direction was reckoned from that end of the marking which was nearer the equator ; thus one lying along a meridian was called N if in the northern

* The direction of Hα markings is treated of in Kodaikanal Observatory Memoirs, Vol. I, part II, page 119.

† Annales de l'Observatoire d'Astronomie physique, Meudon, Tome IV.

hemisphere and S if in the southern. In the northern hemisphere, the markings were classified as E, ENE, NE, NNE, N, NNW, NW, WNW or W by estimation from the charts; in the southern hemisphere similarly from E to W by S. The only point of difficulty is whether a marking which lies exactly along a parallel of latitude shall be called E or W. In this discussion such a marking has been called E as if its eastern end had been slightly nearer the pole than its western end; this may not be strictly accurate but it is more accurate than dividing them equally between E and W, for it will be seen that there is a large preponderance of markings which incline themselves towards the east over those inclining towards the west. For example in the northern hemisphere the total area of markings during the half-year which were classified as ENE, NE, and NNE was 1,447 tenths of a square minute, whilst that of markings WNW, NW, NNW was 410 only; similarly in the southern hemisphere those ESE, SE, and SSE totalled 1024 tenths of a square minute whilst those WSW, SW, and SSW were only 420. Markings whose direction was indeterminate owing to their appearing as dots or as irregular patches were omitted, as also a number of markings of insignificant size as well as those in the highest latitudes where markings are so infrequent that their average directions during a period of only six months cannot be relied on. The area of markings omitted on all accounts was, however, only 15 per cent of the total.

Briefly, what has been done is, in effect, to place the Hα markings in each belt of 5° end to end so as to form one long irregular marking and to draw a line from the beginning of this long marking to the end: this only differs from what was actually done in that the areas of the markings were taken and not their lengths.

The average direction of the Hα markings in each belt is shown in figure I and in table I, the lengths of the lines in the figure being proportional to the vector sum of the areas. The total areas in each belt quite independent of their direction is given also in table I and it will be seen by comparing this total with the vector sum that the markings deviating from the average direction do not form a large proportion.

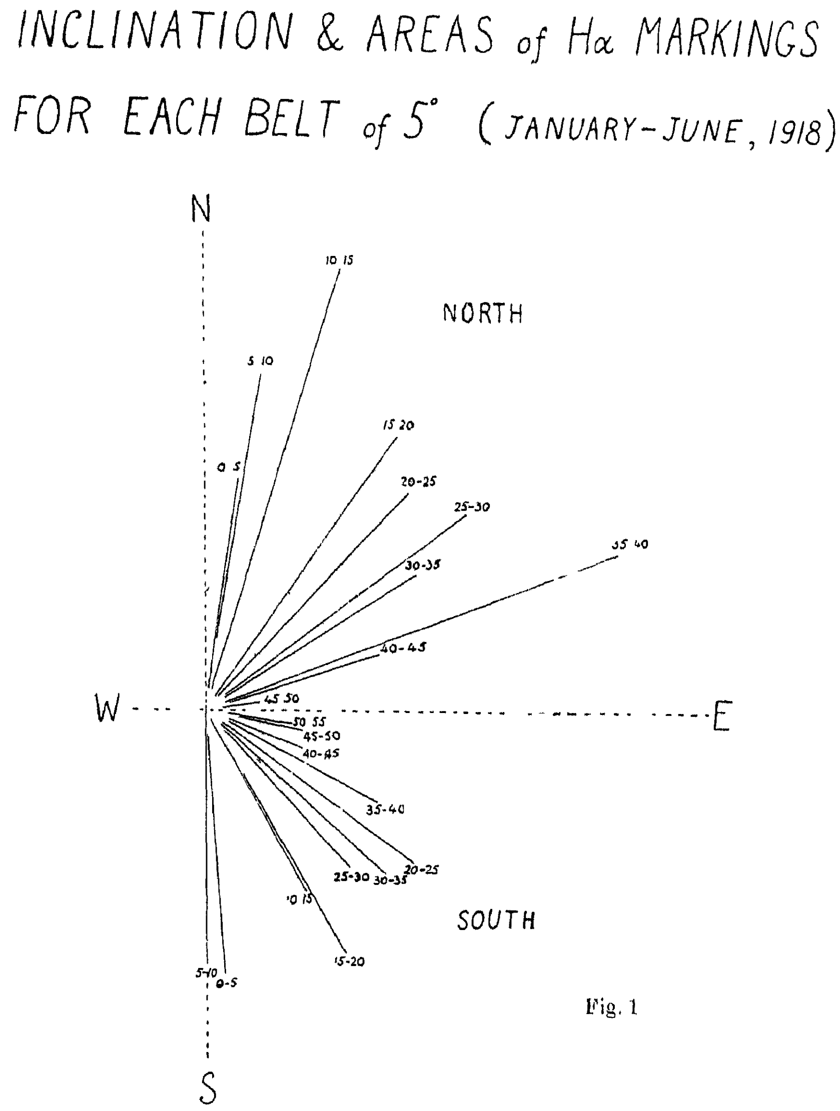

Fig. 1

TABLE I.—Mean direction of dark markings in different latitudes.

North Latitudes	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	25°–30°	30°–35°	35°–40°	40°–45°	45°–50°	50°–55°	55°–60°	
Total areas in $\frac{\square}{10}$	319	478	634	513	400	444	378	577	225	63	30	11	
Vector sum	257	373	505	365	327	356	275	482	200	60	27	9	
Mean direction (north of east)	82°	81°	73°	55°	47°	37°	33°	21°	18°	8°	15°	0°	
South latitudes	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	25°–30°	30°–35°	35°–40°	40°–45°	45°–50°	50°–55°	55°–60°	60°–65°
Total areas in $\frac{\square}{10}$	388	384	323	141	356	266	324	268	152	132	130	18	10
Vector sum	290	279	228	307	281	233	267	212	111	110	95	11	10
Mean direction (south of east)	86°	90°	61°	60°	36°	47°	42°	28°	21°	12°	9°	1°	0°

The chief features of the results shown in figure 1 are (i) that in both hemispheres the markings incline themselves to the east and (ii) that as one passes from the equator the average direction of markings changes from a position along a meridian by inclining more and more towards the east until in the higher latitudes they lie practically along a parallel of latitude. These features of $H\alpha$ markings seeming to prefer one direction varying with latitude over another, and that always to the east can be accounted for by the polar retardation of the angular velocity of rotation of the sun; but this by itself is not sufficient for it requires that the age of the marking in different latitudes is equal to that required to produce the easterly drift of its polar end which is indicated in figure 1. If $H\alpha$ markings are of short duration they will have disappeared before the end nearer the poles have acquired any appreciable easterly drift; if, however, they are of considerable duration it is easy to see that as the age of the marking increases the end which is in a higher latitude and consequently rotating more slowly, will gradually drift towards the east relative to the end in the lower latitude. It should however be stipulated that the age of the marking in this sense does not necessarily mean the length of time the marking is visible, for if the origin of an $H\alpha$ marking is operating invisibly for a considerable time before the $H\alpha$ marking becomes visible at the surface the eastern tendency of $H\alpha$ markings would still be produced.

Let us examine what must be the "age" of $H\alpha$ markings (in the above sense) in different latitudes to produce the inclinations observed in figure 1. These are given in table II. The polar retardation operating has been supposed to that given by Adams for the reversing layer[1]; the ages deduced vary from about 8 days in the belt 0°—10° to about 116 days in the belt 45°—65°. If the polar retardation had been taken from Adams' values for the $H\alpha$ line, the ages deduced would have ranged from 22 to 290 days.

TABLE II.

Latitude	0°—10°	10°—20°	20°—35°	35°—45°	45°—65°
Mean directions N and S	84°·5	63°·5	40°	22°	9°
Easterly longitudinal drift per diem	0°·11	0°·30	0°·74	0°·60	1°·12
"Age" of $H\alpha$ markings in days	7·9 days	16·6	24·1	41·0	116

[1] Adams, Papers of the Mt. Wilson Observatory, Vol. I, Part I.

The question now arises as to whether the "ages" shown in table II correspond with any exactitude with the duration of Hα markings as observed in the daily spectroheliograms. It is not, however, easy to determine exactly the average duration of Hα markings for several reasons, chief among which are (1) the fact that there are sometimes gaps of several days in the Hα record owing to bad weather, (2) the fact that it is often difficult to decide whether a marking which has reappeared at the eastern limb is identical with one which disappeared at the western limb or a new birth in approximately the same position, for seldom does a marking reappear with characteristics which can be definitely correlated with its features when it disappeared at the western limb and (3) the fact that many markings are born on the invisible side of the sun before they appear at the eastern limb, and many die there also after disappearing at the western limb. The spectroheliograms for the half-year have however been examined in order to ascertain whether the duration of Hα markings is consistent with the "age" deduced in table II. In the northern hemisphere an average duration of 25 days was found and in the southern, 10 days. These values are not so consistent with each other as, possibly, they might have been if a longer period had been taken, but at any rate it suffices for the present to have found no appearance of any tendency for markings in high latitudes to last longer than those in low latitudes. Consequently if polar retardation of the sun's rotation is the sole cause of the easterly tendency of Hα markings, the logical conclusion seems to be that in high latitudes the disturbance which finally appears as a dark marking is operating long before the marking becomes visible.

II.—Bright Margins of Hα Markings

When an Hα dark marking is near the limb the side of the marking which is nearer the centre is almost invariably bounded by a bright marking, extending for practically the whole length of that side of the dark marking. Generally there is no bright marking visible on the side nearest the limb. A good example is shown in figure 2 which is an enlargement of a portion of a spectroheliogram taken on February 6, at $8^h\ 10^m$ I.S.T. A pothook-shaped marking is near the east limb and the side nearest to the centre of the sun's disc is seen to have a wellmarked bright margin. When a dark marking is at the east limb the western side has the bright margin, when at the west limb the eastern side shows the bright margin. These bright margins are very noticeable only when the marking is near the limb but they can generally be seen in markings all over the disc, though they are much less marked and are not always there seen along the whole length of the dark marking. The ready visibility of the bright margin when the marking is near the limb is probably due to scattering in the lower layers. At a certain distance from the limb varying for different markings it can be seen that although the contrast around the bright margin is becoming less, a bright margin begins to appear also on the limb side of the dark marking. The same marking shown on figure 2 is seen again on February 12th in figure 3 when the vertical portion is near the centre of the sun's disc. Although possibly not showing in the reproduction there is now clearly visible in the original a bright margin on each side of the dark marking extending for most of the length of the dark marking but it will be seen with how much less contrast compared with figure 2. The width of the bright margins in these photographs is about equal to that of the dark marking and they are not appreciably wider than here shown even with much broader dark markings.

Since the bright margins are seen on opposite sides of the dark marking at the two limbs, and on both sides, though with reduced contrast, when near the centre of the disc, it is concluded that they are in existence on both sides all the time but that when near the limb the bright margin on the limb side is obscured by the dark marking which reaches to a higher level. Two facts go to confirm this interpretation, viz., (1) if a dark marking near the limb happens to be directed approximately radially to the centre of the disc the two sides are seen to have bright margins ; and (2) if a marking near the limb is sinuous in shape, the bright margin is seen to seek the side nearest the centre.

The height of the dark marking above its bright margins can be deduced from the distance of the marking from the centre of the disc when the bright margin on the limb side begins to be uncovered by the dark marking (when east of the central meridian) or covered (when west). For any particular marking the distance at which the bright margin on the limb side begins (or ceases) to appear cannot always be exactly determined because, firstly, as the marking approaches the centre although it may not be difficult to say when the bright margin on the limb side has become visible, the contrast is considerably reduced so that to say when the bright margin *begins* (or *ceases*) to appear is not so easy ; and secondly, even at the best, the successive spectroheliograms represent intervals of one day. A large number of markings seen during the half-year have however been examined, particularly those which lie approximately at right angles to the solar radius, and although there is considerable variation among them the bright margin on the limb side was never obscured when within about 30° of the centre of the sun's disc. The average width of the bright margins measured was about 0·22 mm, the sun's diameter being 60 mm. Taking this as being completely obscured when beyond 30° from the centre, it follows that the height to which a dark marking towers over its bright margins is equal to $0{\cdot}22 \times \sqrt{2} = {\cdot}311$ mm which is equivalent to 10″ of arc.

Having now obtained a measure of the relative heights of the dark markings and their bright margins it is important to fix their level in the sun, but there is very little evidence to settle this point. From what follows in section III of this paper it will however be seen that absorption is frequently seen at the bases only of prominences at the limb, i.e., just above the chromosphere, from which we conclude that the bright margins of the $H\alpha$ marking do not reach higher than the chromosphere for if they did they would mask this absorption. Hence although the evidence is very meagre we will take it for the present that the bright margins of $H\alpha$ markings are situated in the chromosphere and consequently that the dark markings do not generally reach higher than 10″ above the chromosphere.

It is hardly probable that the bright $H\alpha$ structure exists only at the margins of the $H\alpha$ dark marking but rather that it extends also right across, but underneath, the whole width of the dark marking forming a base on which the dark marking forms a narrower superstructure.

Perhaps a word should be said as to the relative frequency of occurrence of dark markings unaccompanied by bright margins on either side. A good deal depends of course on the quality of the photographs, for good definition, accurate focussing and good contrast in the plate are all requisite for there to be much chance of seeing the bright margins especially if the marking is not near the limb. It is estimated, however, that only in about 15 per cent of the total dark markings observed are bright margins absent when the quality of the photographs would lead one to expect them to be visible.

III—ABSORPTION AT THE BASES OF PROMINENCES.

The brightest of the prominences at the limb of the sun can generally be seen in $H\alpha$ spectroheliograms of the solar disc, provided the sky is clear and the plate is not underexposed. In a number of prominences seen thus, there can be seen a dark strip, suggesting absorption, near the base of the prominence, giving the appearance that the prominence, or part of it, is cut off from the disc at its base. Such cases are illustrated in figure 4, February 1, 1918, $8^h\ 13^m$; figure 5, February 1, 1918, $9^h\ 26^m$; figure 6, March 4, 1918, $8^h\ 11^m$. Considering the difficulties which may be expected in photographing a phenomenon of this kind, prominences showing this characteristic are of surprisingly frequent occurrence ; exactly how frequent is chiefly a matter of the quality of the photographs but an idea may be gained from the fact that of 103 prominences seen on $H\alpha$ plates during the three months January to March 1918, absorption was visible at the bases of 37, of which 14 were doubtful.

Certain features of the phenomenon illustrated in the above figures must be closely examined before proceeding further. Firstly, as to whether the absorption is taking place just inside the limb or is actually absorption of the prominence outside the limb. An examination of the photographs reproduced will suffice to settle the point. In figure 4, February 1, 1918, $8^h\ 13^m$ there is no doubt that the absorption near the middle of the prominence is not on the disc but on the prominence ; in this case there extends from this middle region to the southern end of the prominence a much narrower absorption line (possibly not visible in the reproduction) which also is on the prominence. In figure 5, February 1, 1918, $9^h\ 26^m$, the absorption begins on the prominence at the southern end but as it runs towards the northern end comes on to the disc. Such cases of absorption clearly on the prominence and off the disc could easily be multiplied. The differences between the two photographs on February 1 would appear to be rather changes in the prominence than due to a changed aspect on account of the rotation of the sun in the interval between them. In figure 6, March 4, 1918, the absorption is partly on the disc and partly on the prominence. There is, of course, no difficulty in finding cases in which the absorption is completely inside the limb where a prominence may be seen, and is really an absorption of light from the disc just as in any $H\alpha$ dark marking seen near the centre of the disc.

Secondly there can be no reasonable doubt that the dark strip at the base of such prominences as illustrated are produced by absorption for they frequently are continuous with absorption on the disc. It is conceivable that a prominence floating just above the chromosphere would have the same appearance as many of these cases but the occurrence is too frequent and too much alike in its general features to be due to floating prominences in every case; moreover the prominence photographs in calcium light show that the prominences under discussion are not floating. The question of the possibility of their being spurious, due, say, to the tremor of the sun's disc has been considered but no adequate reason for the unreality of the phenomenon can be conjectured.

The general features of the absorption at the bases of prominences are very similar in the different cases. There is a dark narrow strip extending along the base of the prominence and is seen never higher than just outside the sun's limb although it may be seen either partly on the disc and partly on the prominence or on the disc just inside the limb as may be expected if the base of the prominence is not exactly at the limb at the time of the photograph. It is therefore concluded that when the phenomenon is exactly at the limb the absorption is taking place just above the chromosphere The average width of the absorption strip may be taken as about ·20 mm with a 60 mm diameter of the sun, which corresponds to 6″·4 of arc, representing the height above the chromosphere to which the absorption extends.

The absorption typified in figures 4, 5 and 6 may not be of a different character from that discussed by Buss[1] who however speaks rather of absorption reaching to any level above the limb, but I would regard the latter cases as peculiar to the particular prominence whereas the absorption at the bases is typical of all prominences seen under favourable conditions.

The exact relation of an Hα dark marking with the prominence almost invariably visible when the marking reaches the limb has been an interesting question ever since the markings were first photographed. The first assumption naturally was that the dark marking on the disc and the prominence at the limb were merely different aspects of the same thing, but as it was found that prominences or parts of them do not always show as Hα markings, and vice versa, this could not be wholly true. The hypothesis that dark markings represent the cooler parts of the prominences also will not fit the facts. It has therefore been supposed, by Mr. Evershed and possibly by others also, that not all parts of prominences contain sufficient hydrogen to effect appreciable absorption of the photospheric light, and that only the denser parts of prominences will show as absorption markings.

We will now see what additional information on this question is afforded by the phenomena described in the above sections II and III. In the light of this information a typical prominence is imagined to be constituted as follows. A prominence has its base in a region of high temperature probably at the chromospheric level emitting light more strongly than the surrounding chromosphere The prominence is cooler than this base and indeed cooler than the general chromosphere When the prominence is near the centre of the disc it absorbs Hα light emerging from the chromosphere, but only in those portions where there is sufficient amount of hydrogen to effect appreciable absorption , these portions will consequently appear as a dark marking with bright margins on each side due to the emission from the base. When the prominence is seen in profile at the limb, absorption is taking place under somewhat different conditions owing to the changed aspect; instead of the denser portions of the prominence absorbing light from the chromosphere we now have the outer and cooler portions of the prominence absorbing the light from the inner and hotter region but only near the base does the light traverse sufficient thickness to suffer appreciable absorption.

I am greatly indebted to Mr. Evershed, F.R.S , for his criticism and suggestions and also to the various members of the staff who were on spectroheliograph duty during the half-year under consideration.

SUMMARY.

The average direction of Hα dark markings changes from a direction along a meridian in equatorial regions by steadily inclining more and more towards the east until in latitudes higher than about 35°, the markings lie nearly along a parallel of latitude. These features can be explained by the polar retardation of

[1] Buss, Observatory, 36, 225, 1913.

Fig. 2. H α dark marking on Feb 6, 1918 Showing bright margin on side farther from the limb

Fig. 3. The same marking near the central meridian on Feb 12, 1918. Bright margins are visible in places on both sides but with much less contrast

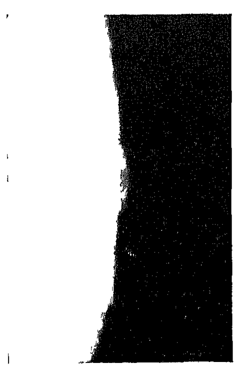

Fig. 4. Feb 1, 1918. $8^{h.}\ 13^{m.}$

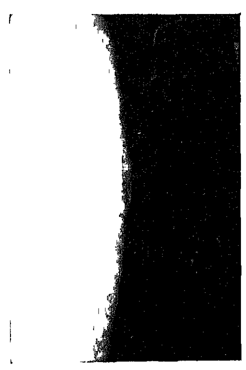

Fig. 5. Feb 1, 1918. $9^{h.}\ 26^{m.}$

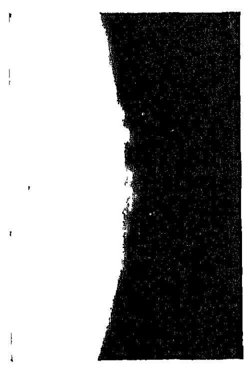

Fig 6. Mar 4, 1918

Figs 4—6 are examples of H α prominences at the limb showing absorption near their bases.

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the rotation of the sun, but this requires that the age of the dark markings should vary from about 8 days near the equator to about 116 days in latitude 55°. The observed duration of Hα markings is consistent with the above value for equatorial regions but there seems no evidence of longer duration in higher latitudes.

2. Dark markings near the limb are seen to have almost invariably a bright margin on the side nearest the centre. Since a bright margin appears on opposite sides of the dark marking at the two limbs, and on both sides, though with reduced contrast, when near the centre of the disc, it is concluded that they are in existence on both sides all the time but that when near the limb, the bright margin on the limb side is obscured by the dark marking which reaches to a higher level. From the distance from the centre of the disc at which the bright margin on the limb side becomes visible and its width when near the centre of the disc it is deduced that the dark marking reaches to a height rarely more than 10″ above the level of the bright margin, and that parts of a prominence above a height of about 10″ do not contain sufficient hydrogen to exercise appreciable absorption of the light from the disc.

3. A narrow absorption strip at the base of prominences in profile at the limb is seen in more than 25 per cent of the total number of prominences photographed in Hα light and would appear to be typical of the majority of prominences when their base is exactly at the limb. This absorption strip has a width of about 6″ and it is concluded that only up to this height is there sufficient hydrogen in the outer and cooler portions to effect absorption of light from the inner portions of the prominence

KODAIKANAL OBSERVATORY,
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T. ROYDS,
Acting Director.

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