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THE VARIATION IN AREA OF HYDROGEN ABSORPTION MARKINGS WITH LONGITUDE

BY

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Abstract.—The results in this paper are based upon the Hα spectroheliograms taken at Kodaikanal Observatory during the years 1926—1930.

The areas of the Hα absorption markings lying longitudinally on the surface of the sun were measured and compared with those of the respective ones at the central meridian. The areas were found to be least at the central meridian increasing with longitude towards the limb. The ratio of the area of a marking at any longitude λ to its area at the central meridian is found to fit the formula $\cos\lambda + \left(\frac{h}{b}\sin\lambda - \frac{\cos\lambda}{2}\right)$ where b is the breadth and h the height of the marking above the chromosphere. The factor $\frac{h}{b}$ was found to be about 1·8 for markings at all latitudes and 1·9 for the equatorial ones alone.

The breadths of the Hα dark markings at the central meridian were measured for the two years 1926 and 1930. The mean breadth was found to be 17″·3 for markings at all latitudes and 15″·4 for the equatorial markings alone. The respective heights deduced were 31″·1 and 29″·2.

Introduction.—The areas of Hα dark markings were originally regarded to behave in the same way as sunspot areas, varying as the cosine of their angular distances from the centre of the sun's disc, due to the curvature of the sun's surface. It was under this assumption that the measured areas of the Hα dark markings were corrected for foreshortening, before incorporating the results in the Kodaikanal Observatory Bulletins. This practice is still continued though it has long been known that the areas do not vary according to this law. This can be seen from the accompanying plate where a longitudinal Hα marking is followed from the eastern limb of the sun to the western, and it is quite evident that the area near the limb is actually larger than that near the central meridian. Since the areas of dark markings do not actually vary according to the foreshortening factor, the uncorrected areas have been given in Kodaikanal Observatory Bulletin No. XC and onwards, the areas corrected for foreshortening being continued for the purpose of comparison with the previous bulletins.

To find out some empirical law according to which the areas of Hα markings vary with longitude, a detailed study of a number of markings is required, and on the suggestion of Dr. T. Royds the present work was undertaken.

Method and Results.—The Hα dark markings selected for the purpose of this investigation were those that lay longitudinally or only slightly inclined to a meridian of the sun and that also persisted at least for a quarter rotation of the sun on the visible hemisphere. If a marking extended through more than 5° of latitude, the portion of the marking in each belt of 5° of latitude was treated as an individual marking. The areas of the markings were measured on successive days on which the Hα spectroheliograms were available and tabulated according to their observed longitudes from the central meridian in columns of 5 each The ratios of these areas to those of the respective markings at the central meridian were calculated For this purpose the mean area of a marking between 15 east and 15 west of the central meridian was taken to be its area at the central meridian The same procedure was adopted for all the available markings during the years 1926—1930

These results are shown in table I below The ratios for east and west are shown separately for each year together with their means The numbers within brackets indicate the number of markings measured in each zone of longitude

TABLE I

Mean Ratios for all Latitudes

Longitudes	15—20	20—25	25—30	30—35	35—40°	40—45	45—50	50—55	55—60	60—65	65—70°	70°—75	75°—80°	[illegible]
1926														
E	0 98	1 03	1 15	0 95	0 96	1 36	1 03	1 63	1 13	1 20	1 94	2 08	0 70	[illegible]
	(26)	(18)	(31)	(21)	(14)	(32)	(18)	(23)	(23)	(15)	(17)	(10)	(6)	
W	1 35	1 28	1 58	1 62	1 54	1 95	1 99	1 93	2 15	2 70	2 09	2 50	2 29	[illegible]
	(18)	(28)	(28)	(28)	(17)	(21)	(25)	(16)	(13)	(22)	(7)	(2)	(1)	
Mean.	1 16	1 12	1 36	1 29	1 25	1 65	1 51	1 78	1 64	1 85	2 01	2 29	1 50	[illegible]
1927														
E	1 09	1 40	1 15	1 40	1 58	1 19	1 81	1 76	1 14	1 72	1 73	1 47	1 05	[illegible]
	(33)	(35)	(27)	(22)	(44)	(31)	(32)	(30)	(22)	(13)	(29)	(22)	(6)	[illegible]
W	1 23	1 26	1 45	1 64	1 78	1 48	1 56	2 13	2 18	2 22	2 37	1 74	2 56	[illegible]
	(21)	(1)	(18)	(20)	(17)	(26)	(14)	(17)	(24)	(15)	(11)	(15)	(4)	[illegible]
Mean.	1 16	1 33	1 30	1 52	1 68	1 34	1 69	1 94	1 66	1 97	2 05	1 61	1 81	[illegible]
1928														
E	1 24	0 84	1 16	1 18	1 12	1 60	1 47	1 21	1 88	1 23	2 10	1 99	1 65	[illegible]
	(36)	(28)	(39)	(27)	(28)	(28)	(28)	(21)	(38)	(23)	(16)	(23)	(12)	[illegible]
W	1 16	1 38	1 26	1 21	1 49	1 22	1 30	2 02	1 54	1 68	2 01	1 88	1 56	[illegible]
	(27)	(35)	(31)	(25)	(36)	(26)	(22)	(27)	(20)	(22)	(26)	(16)	(11)	[illegible]
Mean	1 20	1 11	1·21	1 20	1 30	1 41	1 39	1 61	1 71	1 46	2 05	1 94	1 60	[illegible]
1929														
E	0 99	1 07	0 65	1 22	1 10	1 30	1 27	1 06	1 32	1 27	0 83	1 09	0 94	[illegible]
	(23)	(15)	(11)	(6)	(9)	(18)	(13)	(11)	(13)	(8)	(7)	(9)	(7)	[illegible]
W	1 06	1 51	1 41	1 51	1 39	1 52	1 63	1 45	2 09	2 21	2 02	1 95	1 58	[illegible]
	(16)	(16)	(23)	(22)	(18)	(19)	(22)	(15)	(15)	(16)	(6)	(6)	(12)	[illegible]
Mean	1 03	1·29	1 03	1 36	1 25	1 41	1 45	1 26	1 70	1·74	1 43	1 52	1 26	[illegible]
1930														
E	1·21	0 80	1 93	1 50	1 44	1·63	1 40	1 36	1 77	1 88	2 02	1 05	1 59	[illegible]
	(16)	(10)	(12)	(15)	(7)	(9)	(15)	(4)	(10)	(7)	(3)	(2)	(4)	[illegible]
W	1 43	1 59	2 14	1 46	1 70	2 28	2 04	2 27	1 87	2 89	1 86	2 09	[illegible]	[illegible]
	(14)	(16)	(7)	(10)	(15)	(13)	(12)	(7)	(12)	(5)	(5)	(5)	(1)	[illegible]
Mean.	1 32	1 20	2 03	1 48	1 57	1 95	1 72	1 81	1 82	2 38	1 94	1·57	1 46	[illegible]
1926 to 1930														
E	1·10	1 09	1·19	1 26	1 32	1 38	1 46	1 49	1 48	1 39	1 79	1 68	[illegible]	[illegible]
	(134)	(106)	(120)	(101)	(102)	(118)	(106)	(89)	(106)	(66)	(72)	(66)	[illegible]	[illegible]
W	1 23	1 38	1 46	1·49	1 56	1 61	1 69	1 94	1 96	2 24	2·08	1 89	[illegible]	[illegible]
	(96)	(116)	(107)	(105)	(103)	(105)	(95)	(82)	(84)	(80)	(55)	(44)	(29)	[illegible]
Mean	1 16	1 23	1 32	1 38	1 44	1 50	1 58	1 72	1 72	1 82	1 93	1·79	1 48	[illegible]

The numbers of markings measured in different latitudes are given in table II. These include markings both north and south of the equator It will be seen from the table that not many markings are available beyond latitude 40 and none beyond 50 as the markings at higher latitudes are almost parallel to the equator

TABLE II.

Number of Markings measured in each Belt of Latitude.

Year.		0°–5°.	5°–10°.	10°–15°.	15°–20°.	20°–25°.	25°–30°.	30°–35°.	35°–40°.	40°–45°.	45°–50°.	Total.
1926 ...	...	6	5	6	16	21	17	9	3	..	..	83
1927 ...	...	7	10	14	21	15	13	15	9	...	...	104
1928 ...	...	8	12	18	25	21	12	11	4	1	1	113
1929 ..	...	8	7	13	13	13	7	8	2	1	...	72
1930 ...	...	8	7	10	5	5	5	2	...	...	...	42
1926–30	...	37	41	61	80	75	54	45	18	2	1	414

It was desired to know whether the equatorial markings differ in any way from those at higher latitudes in their behaviour with regard to area. For this purpose the markings lying between 15° north and south of the equator were sorted out and their ratios calculated as before. The results are given in the following table :—

TABLE III.

Mean Ratios for Latitudes + 15° *to* − 15° *only.*

1926—30.

Longitudes.	15°—20°.	20°—25°.	25°—30°.	30°—35°.	35°—40°.	40°—45°.	45°—50°.	50°—55°.	55°—60°.	60°—65°.	65°—70°.	70°—75°.	75°—80°.	80°—90°.
E ...	1·17	1·09	1·28	1·34	1·64	1·49	1·52	1·93	1·55	1·72	2·04	1·67	1 66	1·13
	(41)	(32)	(37)	(40)	(31)	(38)	(35)	(26)	(34)	(21)	(23)	(21)	(11)	(3)
W ...	1·22	1·36	1·41	1·47	1·36	1·72	1·93	1·79	2·19	2·32	2·19	2·11	1·94	1·39
	(30)	(35)	(28)	(35)	(33)	(34)	(29)	(27)	(28)	(27)	(19)	(14)	(14)	(4)
Mean.	1·19	1·23	1·35	1·41	1·50	1·60	1·72	1·86	1·87	2·02	2·11	1·89	1·80	1·26

The results in tables I and II are represented graphically in diagrams 1 and 2, the ordinates representing the mean ratios for the years 1926—1930 and the abscissæ the mean longitudes from the central meridian. These longitudes are the observed longitudes which are slightly higher than the real longitudes on account of the height of the markings above the chromosphere. But the difference between the measured and the true longitudes is small being only about 0°·5 at 45° longitude, and about 1° at 60° longitude, assuming the base and height of the marking to be on the average 15″ and 30″ respectively. Therefore, this difference was not taken into account in measuring the longitudes of the markings. Moreover, as the markings were grouped together in zones of 5° of longitude and as the mean longitude of each zone was taken to represent the mean longitude of all the markings in that zone, the majority of the markings would not be affected. Only a few of the markings would fall into the next lower zones. The effect of this would be to just shift the curves given below towards the left without seriously distorting their shapes.

Diagram 1.—Mean Ratios for Markings at all Latitudes

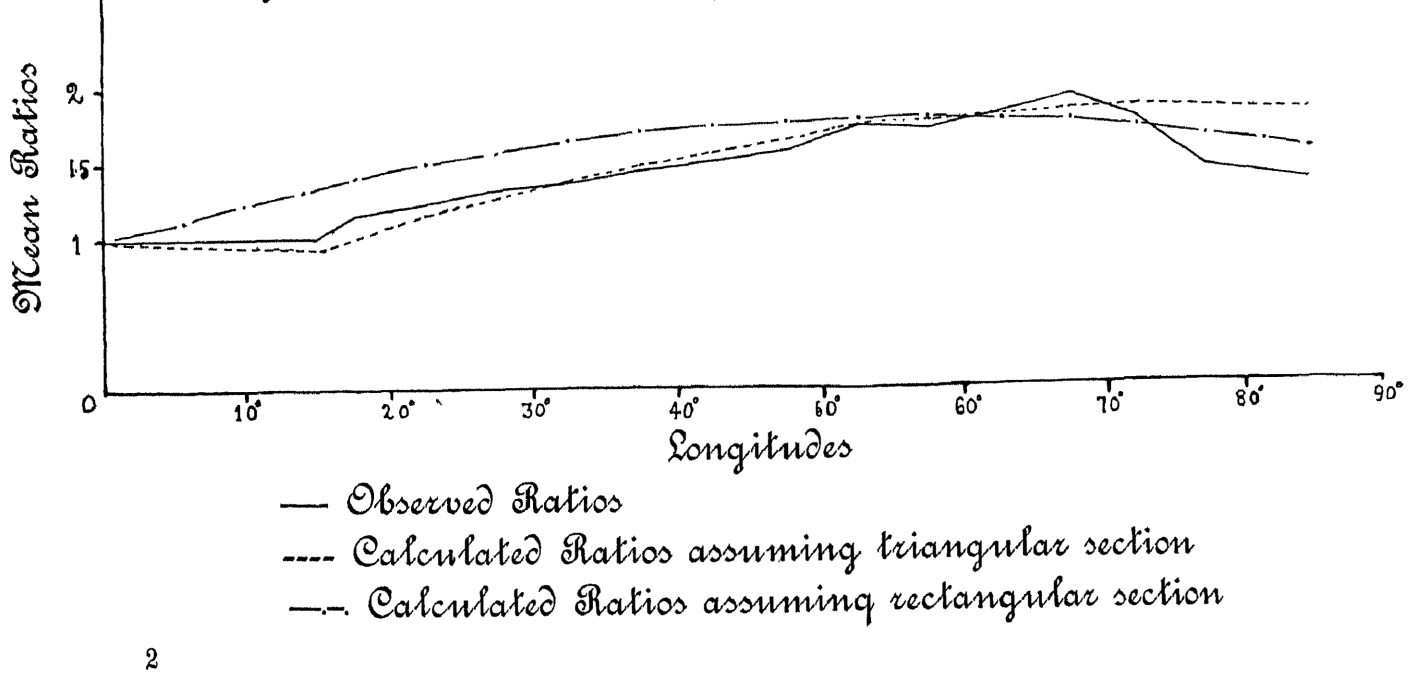
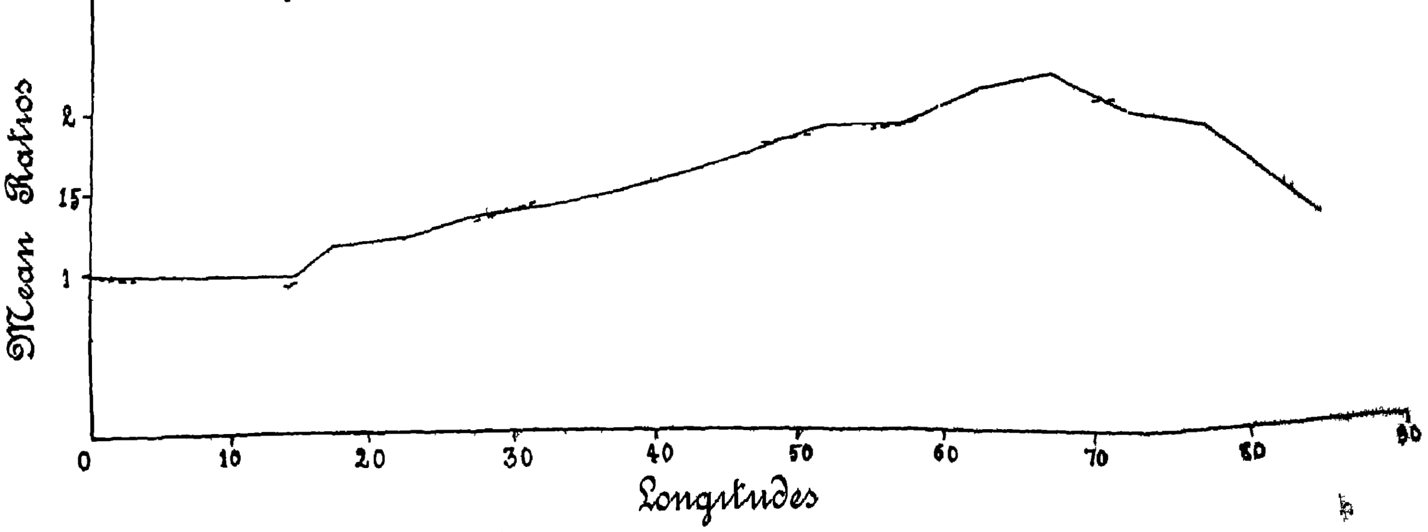


Diagram 2 —Mean Ratios for Equatorial Markings

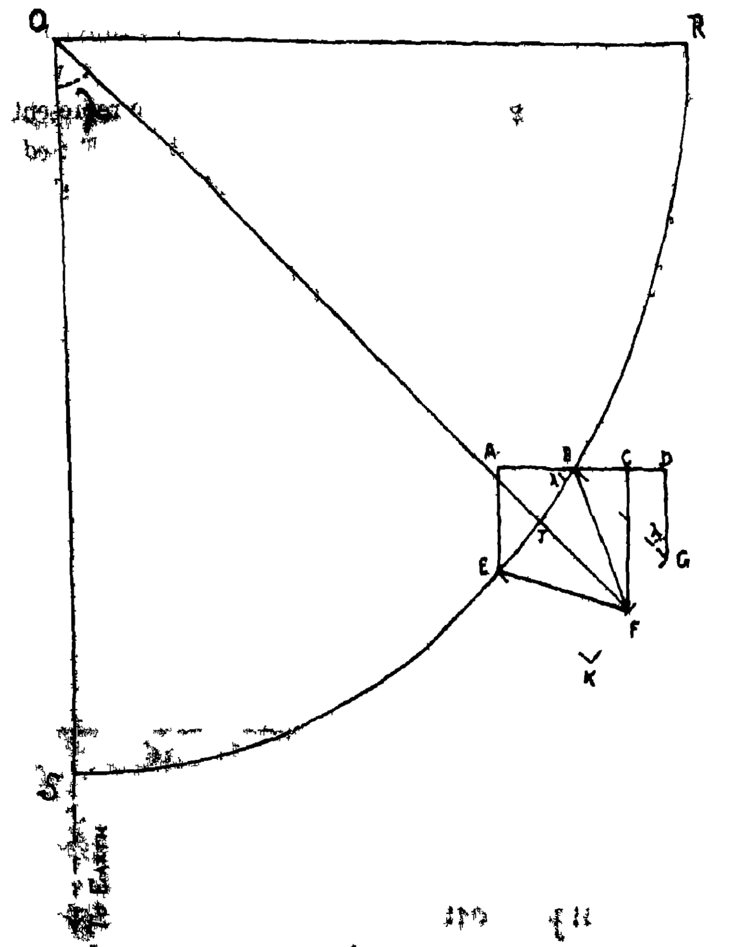


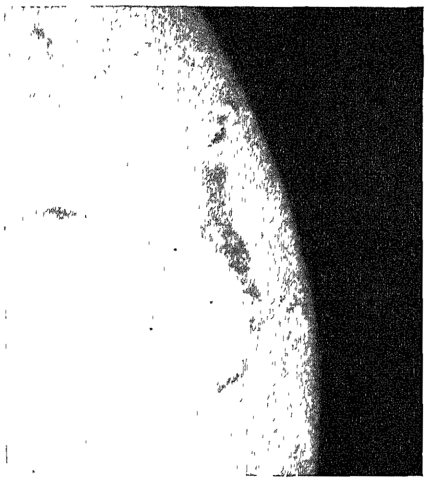
— Observed Ratios
Calculated Ratios assuming triangular section

The full line curves in the diagrams represent the observed ratios It will be seen that both the curves are similar in general shape excepting that the ordinates in diagram 2 are slightly higher than those in diagram 1 In both the curves the ratios increase from unity at the central meridian to about 2 at longitude 70 Beyond this they begin to decrease but it is doubtful whether this decrease is real on account of the difficulty of making reliable measures on markings near the limb

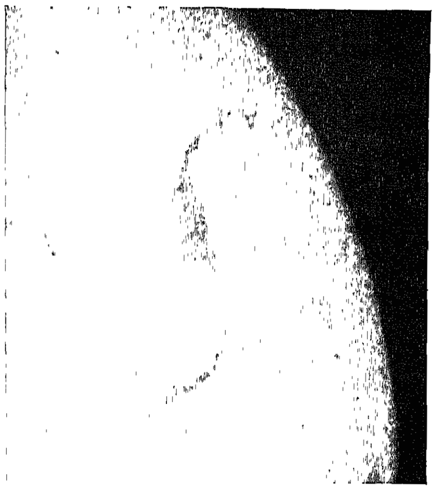
Conclusions—It should now be considered why an $H\alpha$ absorption marking should present the least area when at the central meridian and why it should increase with longitude. If we conceive of it as a flat area carried around the surface of the sun from the central meridian it should appear to decrease according to the cosine of its longitude as it moves towards the limb It is only under this assumption that the $H\alpha$ areas as given in the Kodaikanal Observatory Bulletins were corrected for foreshortening But this does not correspond with the facts An $H\alpha$ marking is not a flat area carried around the surface of the sun It should be regarded as a huge mass of hydrogen gas rising above the chromosphere to a certain height. It is probably the hydrogen prominence itself projected on the disc When an equatorial marking is at the central meridian we look directly at it and what we see is its full base the height of the marking not interfering But at any other longitude we see only its foreshortened base together with the projection of its height This projected area due to the height of the marking would increase towards the limb according to the sine of its longitude from the central meridian This can be clearly seen from diagram 3

Diagram 3

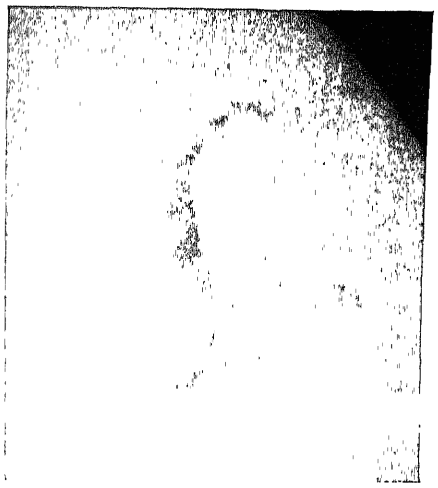




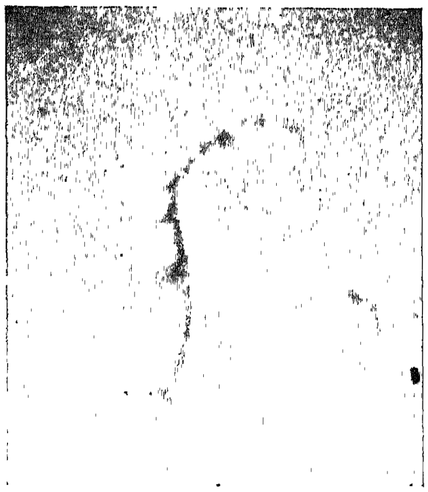
1927 March 18, 2h 28m G. C. T.
Mean longitude 58° E.



1927 March 19, 2h 42m G. C. T.
Mean longitude 45°E.



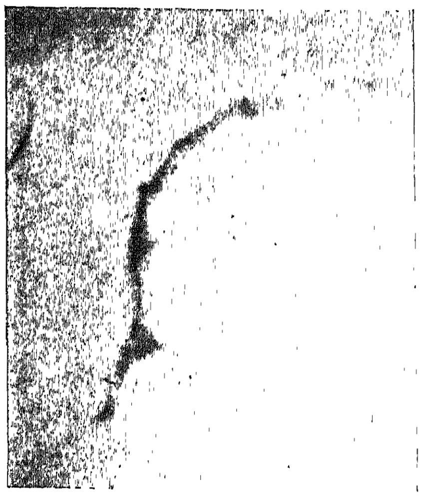
1927 March 20, 2h 35m G. C. T.
Mean longitude 32° E.



1927 March 21, 3h 24m G. C. T.
Mean longitude 18° E.

1927 March 22, 2h 27m G. C. T.
Mean longitude 5°E.

1927 March 23, 2h 49m G. C. T.
Mean longitude 8°W.



1927 March 24, 2h 32m G. C. T.
Mean longitude 22°W.

1927 March 25, 3h 10m G. C. T.
Mean longitude 36°W.

1927 March 26, 2h 26m G. C. T.
Mean longitude 50°W.

The marking lies between latitudes 7° N and 34° N. All the photographs are positives on a scale of 204 mm to the diameter of the Sun.

Before proceeding to devise the exact nature of the change in the area of the marking with longitude, some assumption regarding its cross-section is necessary. In the diagram, O R S represents the equatorial plane in the sun, O, R and S being the points on the axis, east limb and the central meridian respectively. Consider a longitudinal Hα marking at an angle λ from the central meridian. Assuming the cross-section to be a rectangle, let E B G K in the figure represent a section of the marking at right angles to its length. Let its breadth E B be equal to b, and its height J F be equal to h.

Neglecting the effect of the inclination of the sun's equator to the ecliptic which is small, an observer from the earth always looks at the sun in a direction parallel to S O. He will not notice any appreciable change in the length of the marking, but to him A D will appear to be the breadth of the marking. But $A D = A B + B D = b \cos\lambda + h \sin\lambda$.

On this assumption the ratio of the area of any marking at longitude λ to its area at the central meridian will be $\cos\lambda + \frac{h}{b}\sin\lambda$. In diagram 1 the curve with alternate dashes and dots was drawn with the values calculated from this formula, assuming for $\frac{h}{b}$ the value 1·5. It is evident that it cannot be made to fit the actual curve on account of the too rapid increase in ratios near the central meridian.

It is therefore necessary to discard the assumption of a rectangular cross-section for the marking, and to assume a triangular cross-section instead, an assumption which is justified by the general shape of the prominences on the limb giving rise to the Hα dark markings. In the figure E B F represents a triangular cross-section of base b and height h. A C will now appear as the breadth of the marking when seen from the earth.

$$A C = A B + (B D - C D)$$
$$= b \cos\lambda + \left(h \sin\lambda - \frac{b}{2}\cos\lambda\right)$$

The length of the marking remaining the same, the ratio of its area at longitude λ to its area at the central meridian will be $\cos\lambda + \left(\frac{h}{b}\sin\lambda - \frac{1}{2}\cos\lambda\right)$.

This is true only if C falls outside A B. For small values of λ, C falls inside A B and the breadth of the marking will be only A B, so that the ratio will be represented now by $\cos\lambda$ alone.

As we have seen, this formula is derived taking into account a marking near the equator. It can be also shown that whatever be the latitude of the marking, the ratio of its area at longitude λ to its area at the central meridian remains the same to a close approximation. Moreover all the markings measured are between $\pm 40°$ of latitude.

Now if the above formula were taken to be correct, we expect hat the ratios got by measurement should compare well with the ratios calculated from the formula, the constant $\frac{h}{b}$ being properly chosen. In the diagrams 1 and 2 the broken line curves were drawn with the ratios calculated from the formula as ordinates, taking the constant to be 1·8 and 1·9 respectively. We see that these curves agree fairly well with the full line curves drawn with the observed ratios as ordinates, except near the limb where close agreement cannot be expected on account of the difficulty of obtaining reliable measures.

The fact that very few markings remain quiescent for a long time and that many of them will be undergoing sudden changes with respect to their base and height should not be also forgotten. But it is hoped that in the mean ratios for the five years given in the last row of table I, this error is greatly minimised. Besides as these are the means of ratios measured in the corresponding zones east and west of the central meridian, any abnormal change in the eastern zone may be supposed to have been compensated by a reverse change in the corresponding western zone and vice versa. This is what we notice by a comparison of the ratios east and west of the central meridian. The western ratios are slightly higher than the eastern ones. This is probably due to the fact that most of the markings measured to the west were growing ones.

Heights of the Hα Absorption Markings.

The formula derived in this paper not only explains the observed variation in the area of Hα markings with longitude, but it also gives the relation between the height and the breadth of the marking. It shows that the mean height of a marking is about 1·8 times its apparent breadth near the central meridian. For the equatorial markings, this ratio is slightly higher, viz., 1·9. Therefore, if the mean breadth of a marking near the central meridian is known, its height can be deduced. For this purpose, the breadths of 116 markings for the two years 1926 and 1930 were measured by means of a micrometer. Of these markings only 38 were within 15° north and south of the equator. Care was taken to measure the breadths only when the markings were at or near the central meridian. In each case the mean of at least two or three readings was adopted as the mean breadth. The mean breadth was found to be 0·54 mm. or 17″·3 for markings at all latitudes and 0·48 mm. or 15″·4 for markings within ± 15° of latitude. The heights deduced from these values were 31″·1 and 29″·2 respectively.

These heights correspond with the absolute heights deduced in Kodaikanal Observatory Bulletin No. LXXXIX by quite a different method. According to the arguments given there, it might have been expected here to get only about 5″ for the height of a marking, the lower portion of the marking to a height of about 28″ not showing itself by absorption. It now appears from this paper that that is not the case with all markings.

In conclusion I wish to express my gratitude to Dr. T. Royds and Dr. A. L. Narayan for their valuable guidance and many suggestions.

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