Kodaikanal Observatory

BULLETIN No CXI

A PROGRESSIVE CHANGE IN THE INCLINATION OF HYDROGEN DARK MARKINGS TO THE MERIDIAN OF THE SUN

BY

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SUMMARY

The nclinat on of hydrogen dark m l ng to the s la m d an has been measur d at eacl ucc s ve otat n of the fo wh h the ma k ig nay e dure The study mprises all su table dark markings in th years 1923—1933 e f a complet 11 year y le a recorded in tle Meudon cha t It s found that th polar end f a da k ma king drifts m d no e a te ly of tl e equatorial end t a h su cess e otat n f the sun the average hange f n linat on of a da k mark g n e otat on of tl e un am unt g t 0 47 f r tl change in the c tang nt of the angle whi h the dark ma king m kes w th a par ll l of latitude

The nly ad j t explanat on fo tl p ogress e change f linat on is that it s due to the polar reta d t n f tl te f th s rotat n The an unt t be expected f om this theory is 0 51 a 6 pa d w th the abo e alu of 0 47 l h e g l l a b g n t sfa t ry agreeme t

Sin tl p og l a g s rega ded as be ng ad quately explain d by the p la retardat on t se ms p ob bl that th icl nat o t l (w th the polar end n ore a d more to tl e t t i increase of lat tude in the sun a f l Kod kanal Ob at ry B ll t n N 63) are also l e to the pola retardation In this case w are dri n to a ume th t e pe ally n l ghe l t t les the solar d turbance n wh ch the hydrogen marking originates has already been in exis te e s m cons de abl t n e l fo tl e dark ma king appears on the surface of the sun the only alternat e to this hypo th seems to be tl at tl s so onst t te l that the f rmat on f dark markings in direction othe than those pref rred (a l ng t ol t) l ff ult

In Kodaikanal Observatory Bulletin No 63[1] it was shown that hydrogen dark markings do not lie arbitrarily oriented on the surface of the sun but have a tendency to lie with their polar ends to the east of their equatorial ends Their mean inclination towards the east varies with latitude It was suggested that the easterly drift of the polar end of dark markings was caused by the polar retardation of the sun s rotation which makes the more slowly rotating higher latitude drift to the east of the lower latitude If the polar retardation of the sun s rotation is the sole cause of the inclination of hydrogen dark markings to the east it follows that the age of the dark marking must be sufficiently long for the observed inclination to the east to develop and it was pointed out in the bulletin referred to that the time required for the dark markings to develop the observed inclination in the higher latitudes was much greater than the observed ages of the markings

It is the purpose of the present bulletin to investigate another possible effect of polar retardation on dark markings If the polar retardation of the sun s rotation is the cause of the easterly inclinations of dark markings it is to be expected that at each successive rotation of the sun the easterly inclination of any dark marking which persists should increase by an appreciable amount An example of this is illustrated in Kodaikanal Observatory Bulletin No 89[2] figures 2 and 3 which show the change in inclination of a dark marking after one complete rotation of the sun namely from 40 between the meridian and the marking to 30

In order to study a reasonable number of markings a period extending over a complete 11 year solar cycle has been taken The study of so long a period has become amenable through the facilities afforded by the charts

(1) Royds Kodaikanal Observatory Bulletin No 63 p 289
(2) Royds Kodaikanal Observatory Bulletin No 89

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of dark markings published by the Meudon Observatory, Paris,[1] with the assistance of grants from the International Astronomical Union. On these charts, the dark markings are presented for each rotation of the sun, so that it becomes a practicable proposition to study from them the inclinations of persistent markings at each successive rotation of the sun for a long period. The method adopted has been to lay a transparent protractor over the charts and to read off the inclinations of those dark markings which last for a complete rotation or more. A separate measure was made for each zone of 10° of latitude over which a dark marking might stretch. The method of representation of the sun in Mercator's projection in the Meudon charts does not affect the inclinations to the sun which are measured in this way. Those markings with inclinations to the meridian[2] greater than 70° have been neglected because the tangent of the inclinations, which (as will be seen later) is the factor to be studied, then increases so rapidly that any inaccuracy in the measurement of the inclinations (or rather small irregularities in the inclinations) becomes of considerable effect. This elimination has also had the effect of confining the latitudes studied to those between ±40°, for the dark markings in higher latitudes are almost invariably nearly parallel to the equator.

In this way, we have measured the inclinations of all suitable dark markings in the years from 1923 to 1933 inclusive. All markings lasting for one rotation or more have, as far as possible, been measured, but some markings are too irregular in shape to have a definite direction assigned to them. In all, 66 dark markings have been measured, yielding 257 values of the change of inclination after one complete rotation of the sun. A progressively greater inclination with each rotation of the sun is clearly seen in the majority of markings (see, for example, the marking illustrated in Kodaikanal Observatory Bulletin No. 89 already referred to) but naturally there are many irregularities in different markings. Occasionally it happens that the inclination of a marking may, at a certain rotation, have made a sudden jump (backwards or forwards) compared with the normal tendency. Such jumps have been neglected whenever the life of the dark marking has been interrupted between the successive rotations as recorded on the Meudon charts. Naturally interruptions may, without our knowledge have occurred whilst on the side of sun turned away from the earth. Such possibilities cannot be taken into account.

In a study of this character where the quantity to be measured is subject to many irregularities, if not exceptions to the general rule, it is desirable to avoid, as far as possible, prejudices due to preconceived ideas of what general behaviour should be expected. In order to avoid any such biassed judgment all measurements of inclinations were made and completed before considering whether they were in accordance with the effect of the solar rotation on the variation of the inclination of markings with each successive rotation. But for a logical presentation of the treatment of the data which has been adopted in this bulletin, it is necessary to discuss first the effect of solar rotation. According to d'Azambuja[3] the speed of rotation of hydrogen dark markings varies with latitude according to the following law:

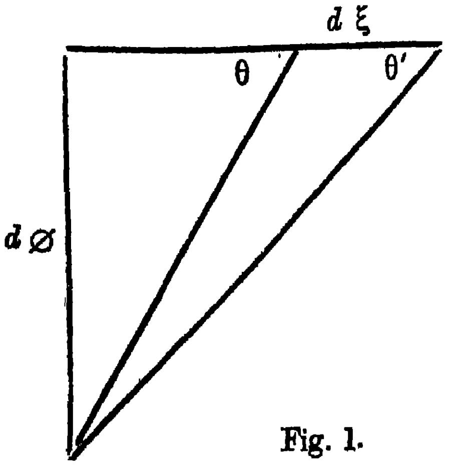

Fig. 1.

$$\xi = 14^\circ{\cdot}44 - 1^\circ{\cdot}60 \sin^2 \varnothing$$

where ξ is the angular rotation per siderial day. The change of inclination to be expected from the polar retardation of rotation is therefore given by $\frac{d\xi}{d\varnothing} = \cot\theta' - \cot\theta$, as seen in fig. 1, θ and θ' being the inclinations of the dark markings to a parallel of latitude (complement of the inclination to the meridian) for successive days. For a difference of one solar rotation as represented on the Meudon charts, the change in inclination due to polar retardation will be

$$\text{Cot}\,\theta' - \cot\theta = 1{\cdot}523 \sin\varnothing \cos\varnothing.$$

(1) d'Azambuja, Cartes synoptiques.

(2) Footnote. For brevity, the expression "inclination to the meridian" is often used whereas there are many conveniences in using the complement of this angle, namely the inclination to a parallel of latitude. When the former convention is used it is the tangent of the inclination which is to be studied and when the latter convention the cotangent of the inclination.

(3) d'Azambuja, Cartes synoptiques, Vol. I, Fasc. 1. 1934.

Consequently we see that to correlate the progressive change in the inclination of the markings with the effect of polar retardation we have to study the change in the cotangent of the inclination of the marking An example is given below —

TABLE I —EXAMPLE OF MARKING No 3246 *et seq* LATITUDE 20 —30°N

Rotation No	966	967	968	969	970	971
Inclination	60	50	47	42°	32°	26°
Cot θ	577	839	932	1 111	1 600	2 050
Change in Cot θ	262	093	179	489	450	

The mean value of the change in cotθ for this marking is 0 295 but the mean for all markings in latitude 20 —30 is 0 508 as seen in table II and the value to be expected from d Azambuja s law of solar rotation for latitude 25 is 0 583

A summary of all our results is given below in Table II

TABLE II —AVERAGE CHANGE IN THE COTANGENT OF THE ANGLE OF INCLINATION TO A PARALLEL OF LATITUDE FOR ONE SOLAR ROTATION

Latitude	0 —10	10 —20°	20 —30°	30°—40°
Average change in Cot θ	0 424	0 364	0 508	0 591
No of markings	3	79	108	47
Average change for all latitudes 0 —40	0 471			

The average change of cot θ for one rotation of the sun for all markings studied between latitudes 0 and 40 in the years 1923 to 1933 is 0 471 Their mean latitude is about 22½ and the polar retardation of rotation would give for this latitude the value 0 539 which is in agreement as close as one would expect The solar retardation would give the value 0 471 in agreement with observation, for latitude 19

We are therefore led to the conclusion that the effect of polar retardation of rotation is a sufficiently complete explanation of the progressive change in the inclination of dark markings to the solar meridian. This conclusion strengthens the supposition that not only is the change of inclination with time due to the polar retardation but also the inclinations themselves as found on the sun are attributable to the same cause If dark markings were oriented with equal frequency in all directions the average inclination to a parallel of latitude in the procedure adopted in this and in previous bulletins referred to would be 90 for the northern and southern hemispheres taken separately It was found in Kodaikanal Observatory Bulletin No 63 that the average inclination of dark markings in the period January—June 1913 was in all latitudes, with their polar end to the east of their equatorial end the amount varying with latitude To obtain more accurate values a longer period has now been taken namely 1928 to 1930 and the inclinations have been read off by protractor more accurately than the approximate procedure adopted in Kodaikanal Observatory Bulletin No 63 The following average values have been obtained

TABLE III.—AVERAGE INCLINATION OF DARK MARKINGS (POLAR END IS EAST OF THE EQUATORIAL END).

Latitude.	0°—5°	5°—10°	10°—15°	15°—20°	20°—25°	25°—30°	30°—35°	35°—40°	40°—45°	45°—50°	50°—55°	55°—60°
Inclination to parallel of latitude.	86°	79°	73°	62°	46°	45°	32°	29°	17°	20°	23°	17°
Inclination to meridian (complement of above angle).	4°	11°	17°	28°	44°	45°	58°	61°	73°	70°	67°	73°

These values are consistent with those found in the previous bulletin, taking into account the less accurate procedure there adopted which has the greatest effect in high latitudes. It was then pointed out that if these inclinations were caused by the polar retardation, a supposition which is strengthened by the progressive change found in the present bulletin, it necessitated a certain age of the markings in order to allow the observed inclination sufficient time to develop, and it was shown that the ages so deduced[1] increased with latitude more rapidly than the actual durations of dark markings (although it is difficult, from the nature of the case, to determine the duration of markings with any accuracy). Now it is to be noted that, at any rate in the higher latitudes, the markings already present an eastward position of their polar ends when the markings first appear. Indeed in the high latitudes, they almost invariably lie along a parallel of latitude at their first appearance and do not gradually develop into this orientation. If their inclinations are due to the polar retardation, a view which is strengthened by the evidence in this bulletin, it follows that the retardation must have been operating (at least for high latitudes) before the dark marking appears at the surface of the sun, *i.e.*, the marking is already old when it first appears at the solar surface, and the origin of the dark marking must have been in existence some considerable time before its appearance at the surface with a large inclination to the meridian of the sun. It is therefore to be supposed that the solar disturbance in which the dark marking originates is operating below the surface of the sun before the marking comes up to the surface for a period which is greater in higher latitudes. There is one alternative to this supposition, namely, that the sun is so constituted that dark markings, instead of being originally distributed arbitrarily in any direction, are difficult of formation except in the preferred direction in which they are observed to lie on the surface of the sun at their first appearance.

We must not fail to mention two considerations which are, at first sight, unfavourable to the view that the progressive change of inclination is solely due to the polar retardation of the sun's rotation. The progressive change might have been investigated by comparing the average inclination of all markings at their first appearance on the sun with all markings at each successive appearance. If this is done, the evidence is not quite clearly favourable to the hypothesis. As will be seen from the following table there is a progressive change only for the first few rotations and no regular change thereafter.

TABLE IV.—INCLINATION OF ALL DARK MARKINGS CLASSIFIED AS ENDURING MORE THAN ONE ROTATION.

Rotation.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Inclination to parallel of latitude	64°	52°	51°	41°	44½°	49°	39°	50°	51°

(1) Kodaikanal Observatory Bulletin No. 63. The ages were deduced taking the polar retardation in the reversing layer. If d'Azambuja's rate of polar retardation for dark markings is taken, the ages deduced are still greater.

Apparently the reason for the failure of the inclination to decrease after a few rotations is that when all markings are considered the number of new births in the same longitude as a previous marking overbalances (specially as the order of rotation increases) the effect which is found by considering only individual dark markings that have undoubtedly continued uninterrupted. And secondly we have the fact seen from Table V that although the average change is sufficiently near the value expected from the rate of polar retardation of the umbra rotation the variation with latitude is not so near the expected variation. This is evident in the following table V.

TABLE V.—VARIATION OF PROGRESSIVE CHANGE WITH LATITUDE

Mean latitude	5	15	25*	35
Average change (from Table II)	0 424	0 364	0 506	0 591
Change according to law of polar retardation	0 132	0 381	0 563	0 715

Naturally the expected variation depends on the law of solar rotation adopted. It is not a very simple matter to determine the law of rotation of dark markings partly on account of their being often extended over a wide and varying range of solar longitude. In our procedure we have simply adopted d'Azambuja's law as the best available one and one which has been determined quite distinctly apart from its suitability to any preconception of what would suit any particular theory.

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