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## ON THE ANGULAR SPEED OF ROTATION OF A LONG-ENDURING PROMINENCE

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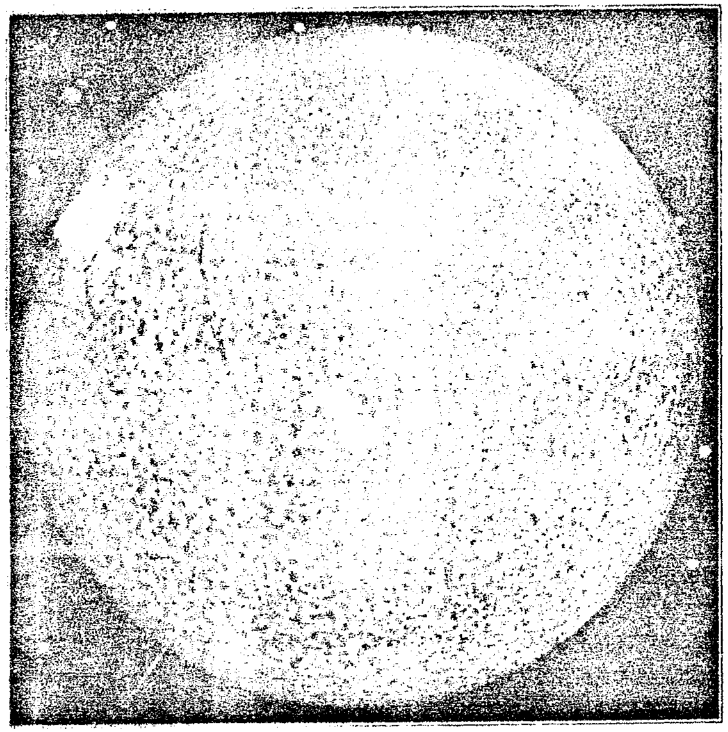
The prominence described by Dr. Slocum in the *Astrophysical Journal* for September 1910 (**32**, 125), and figured in Plate XII, was photographed with the Kodaikánal spectroheliograph at each successive appearance on the sun's limb. Our photographs are very similar to those taken at the Yerkes Observatory, but, contrary to Dr. Slocum's experience, our $K_2$ flocculi plates show the prominence also as an absorption marking on the disk of the sun at three successive meridian transits. On the three days following March 22 the prominence is such a conspicuous and remarkable object on the disk that it is difficult to understand Dr. Slocum's failure to photograph it.

Taking advantage of the exceptional opportunity afforded by the disk photographs for determining the speed of angular rotation of the prominence, I have made a series of measures of a well-defined portion of the absorption marking, and the results of these measures, together with a spectrographic determination of rotation speed, are, I think, of sufficient interest to give in some detail.

As the spring months at Kodaikánal are the most favorable for solar work, our series of photographs is very complete, and they show that the prominence endured in a more or less compact form for at least 82 days, and the region of longitude in which it

PLATE I

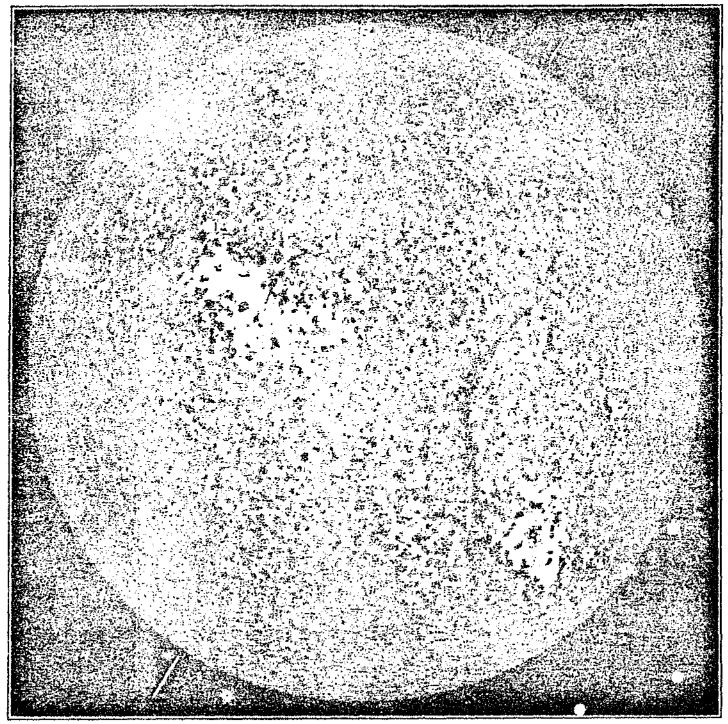
North Pole



February [illegible]

PLATE II

North Pole



March 23, 1910

SPECTROHELIOGRAMS SHOWING DARK FLOCCULUS

Taken with calcium line $K_3$. Kodaikánal Observatory

PLATE III

North Pole

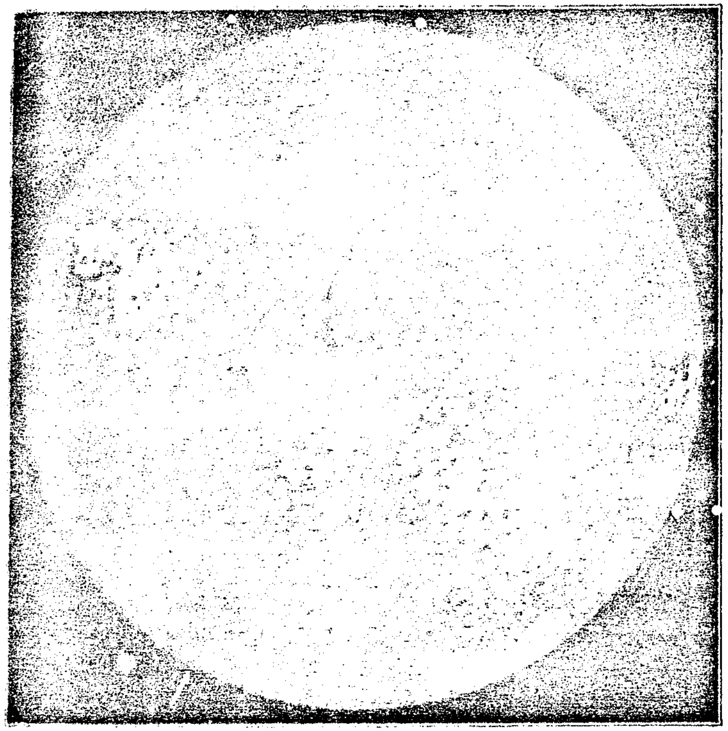
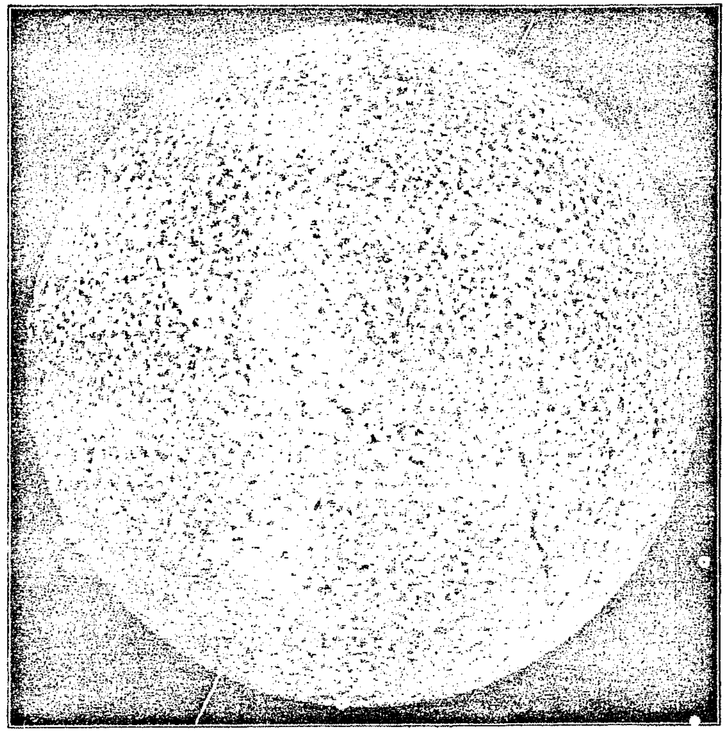


PLATE IV

North Pole



April 18, 1910

SPECTROHELIOGRAMS SHOWING DARK FLOCCULUS

Taken with calcium line $K_2$. Kodaikánal Observatory the locality of origin of the prominence rotates with the normal speed of the photosphere.

If we take the interval of 82 days between February 5 and April 28 to represent three synodical revolutions of the prominence, we get a rotation speed of $13^\circ.2$ per diem, or a sidereal speed, $\xi = 14^\circ.2$ per diem. This corresponds closely with the angular speed of spots in latitude $10^\circ$ to $15^\circ$. The mean latitude of the prominence at its western apparitions is $-13^\circ$.

The estimate of the time when a prominence is at the limb or $90^\circ$ from the central meridian is very uncertain, however, and the whole interval may well be subject to an error of $\pm 1$ day, so that the above value may be over 1 per cent in error.

A much more accurate estimate is obtained by measuring the absorption marking due to the prominence projected on the disk, and deducing the times of passing the central meridian at the successive transits. The marking was photographed on February 25, 26, 27, and 28; on March 22, 23, 24, and 25; and again less distinctly every day from April 16 to 26 inclusive. In the two earlier apparitions it is shown as a bow-shaped dark streak, crossing the equator (see Plates I and II), the center of the bow lying on the equator. During February the bow was narrower than in March, and more sharply bent at the center, forming an obtuse angle; this definite point, which was in latitude $+0^\circ.4$, was measured on the successive days, giving a good value of the daily motion, as well as the time of meridian passage. The three plates of March were similarly measured, but in this case a point had to be chosen $8^\circ$ north of the equator, where the marking contracted to a narrow line, nearly perpendicular to the equator. In April only the southern arm of the bow can be seen, highly inclined to the equator, and accurate measures of the daily motion are not possible; but from measures of the western end of the marking in the plates of April 20, 22, and 23 I have estimated the time of meridian passage of a point in latitude $-3^\circ$.

The times of meridian transit deduced from these measures are

| | | | | |
|---|---|---|---|---|
| 1910 February | 25, | $9^h$ | $12^m$ | Greenwich Civil Time |
| March | 24, | 7 | 20 | Greenwich Civil Time |
| April | 20, | 3 | | Greenwich Civil Time |

The first interval of 26.92 days, representing a complete synodical revolution, is equal to a mean daily sidereal motion, $\xi = 14^\circ.37$; and the second interval of 26.84 days is equal to a mean motion of $14^\circ.40$. The first interval is not likely to be in error by an amount exceeding one part in 400, but the second is less trustworthy. These values may be taken to represent the equatorial velocity, notwithstanding the fact that the measures for March refer to a point in latitude $+8^\circ$.

It is assumed, of course, that the marking photographed in February is identical with those obtained in March and April; this is probably true only in the same sense that the prominence photographed on the west limb on February 5 is identical with those photographed on later dates; that is to say, the angular velocity obtained is the velocity of the origin of the marking, not that of the absorbing gas itself. It is in quite remarkable agreement with the equatorial speed of the photosphere as determined from spots.

The measures of angular motion from day to day give quite a different result, as the following determinations of longitude measured from the central meridian clearly indicate.

DAILY MOTION IN LONGITUDE OF ABSORPTION MARKING SITUATED IN LATITUDE $+0^\circ.4$

| Date | G.C.T. | Longitude | Motion in 24 Hours | $\xi$ |
|---|---|---|---|---|
| 1910 Feb. 25 .......... | $2^h 40^m$ | $3^\circ.8$ East | | |
| Feb. 26 .......... | 2 42 | 10.2 West | $14^\circ.00$ | $15^\circ.00$ |
| Feb. 27 .......... | 2 45 | 24.4 West | 14.12 | 15.12 |
| Feb. 28 .......... | 3 01 | 38.7 West | 14.14 | 15.14 |

Mean daily sidereal motion = $15^\circ.09$

DAILY MOTION IN LONGITUDE OF ABSORPTION MARKING SITUATED IN LATITUDE $+8^\circ$

| Date | G.C.T. | Longitude | Motion in 24 Hours | $\xi$ |
|---|---|---|---|---|
| 1910 March 23 .......... | $2^h 31^m$ | $18^\circ.3$ East | | |
| March 24 .......... | 2 42 | 2.6 East | $15^\circ.3$ | $16^\circ.3$ |
| March 25 .......... | 2 21 | 11.7 West | 14.8 | 15.8 |

Mean daily sidereal motion = $16^\circ.05$

As a check on these results I measured at the same time a small bright flocculus, which could be identified in successive plates during four days; the results are as follows:

DAILY MOTION IN LONGITUDE OF A CALCIUM FLOCCULUS SITUATED IN LATITUDE −8°

| Date | G.C.T. | Longitude | Motion in 24 Hours | ξ |
|---|---|---|---|---|
| 1910 March 23........ | $2^h 31^m$ | 41°.2 East | | |
| March 24........ | 2 42 | 28.2 East | 12°.9 | 13°.9 |
| March 25........ | 2 21 | 14.3 East | 14.1 | 15.1 |
| March 26........ | 2 24 | 1.0 East | 13.3 | 14.3 |

Mean daily sidereal motion = 14°.43

The above result, although somewhat rough, is in substantial agreement with Hale's determination of mean motion of the flocculi,[1] and shows that the absorption marking was drifting westward with respect to the flocculus.

It appears, then, that the dark mass of calcium vapor (and hydrogen) near the equator had an angular rotation speed 5 per cent greater than the general surface of the photosphere during the February apparition, and as much as 11 per cent greater during the March apparition. Also that the two apparitions really represent two distinct masses of absorbing gas, emanating from a common origin approximately in solar longitude 75°. Although the February marking could be traced nearly to the western limb on March 3, it must have become dissipated subsequently, as it was not shown near the east limb on some excellent plates taken on March 19 and 20. On March 21 it reappears as a vague and ill-defined dark mass, extending across the equator, and some distance within the east limb. On the following day the bow-shape became evident.

The intermittent character of the marking is also shown in its later phases. On March 25 it had attained its greatest apparent development, extending for a distance of at least 36° of solar latitude, or 250,000 miles (400,000 km). The northern arm can indeed be faintly traced for a much greater distance in a vast circular sweep toward the eastern limb, which it nearly reaches. Notwithstand-

[1] *Astrophysical Journal*, 27, 227, 1908.

ing the prodigious length of this mass of relatively cool gas, the whole object utterly vanished during the next 24 hours. The plate of March 26 is of the best quality, and shows two small prominences as dark markings on the disk, yet not a trace can be seen of the large marking, nor is it shown on the plates of the 27th or 28th. A portion of the southern branch is seen again on the 29th, but in a more easterly position on the disk; this apparently reappears on the east limb on April 16, and continues visible until near the west limb on the 26th of the month.

From the whole inquiry it seems definitely established that there was a region on the sun, narrowly defined in longitude, and partaking of the normal rotation speed of the photosphere, which was somewhat intermittently giving rise to prominences, and that these prominences drifted westward with about the angular speed of the hydrogen of the chromosphere. The remarkable bow-shape of the absorption marking, with the center over the equator, is very suggestive of a wave surging westward over the photosphere, with a greater speed near the equator than in higher latitudes. Yet the velocity obtained in latitude $+8°$ in March is distinctly greater than that observed on the equator a month earlier. The marking is unfortunately too indefinite in higher latitudes for measures of longitude to be made. It is perhaps more probable that the bow-shape is really due to the original disposition of the prominence-forming orifices.

The mean level of the absorbing calcium vapor is difficult to determine. If the whole prominence is effective in producing absorption it may be roughly estimated at some $30''$ above the photosphere, but there is reason for supposing that only portions of the prominence are cooled sufficiently to be effective, and these portions may be in the lower and denser region not extending much above the chromosphere. When these dark markings are seen extending to the sun's limb they are found almost invariably to end in a prominence, but the latter in many cases are somewhat insignificant in height. On the other hand, many large prominences, perhaps the majority of them, seem to produce no absorption on the disk.

The rotational movement of the higher regions of a "quiet" prominence can be ascertained by spectrographic measures, and this method of investigation has for some time past been on our program of research. Only a few plates have as yet been obtained, but these fortunately include the prominence of March when on the east limb. With a radial slit placed across the limb at the sun's equator the *Hα* line was photographed in this prominence on March 17 and 18. It appears as a sharply defined bright line, about 0.5 mm wide outside the limb, and as an absorption line 1 mm wide within the limb, the scale of the plates being 1 mm = 1.2 Å. I have measured the displacement of the bright line with respect to the dark line, and the result distinctly confirms the westward movement of the prominence. In measuring the plates a single straight thread was used, placed parallel to the spectrum lines, and the error in parallelism which might seriously affect the result was carefully determined and allowed for. The mean results obtained, with the red end of the spectrum to the right and left respectively, are as follows:

| Date | Height above Photosphere | $\Delta\lambda$ | Km per Sec. |
|---|---|---|---|
| 1910 March 17... | 17″ | −0.015 Å | +0.68 |
| March 18... | 30 | −0.015 Å | +0.68 |

The absorption line may be taken to represent the normal chromosphere line, with a velocity of approach of about 2 km per second. The excess velocity of the prominence at a considerable height above the chromosphere amounts therefore to as much as 34 per cent. The consistence of the measures with the red end of the spectrum to right and left, and the undistorted character of the emission line lead me to believe that this relatively high velocity is real and permanent. It would be unsafe, however, to infer from a single instance that the law of increase in angular speed with height discovered by Adams is continued outside the limits of the chromosphere, but this may be taken as a suggestion only.

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November 29, 1910