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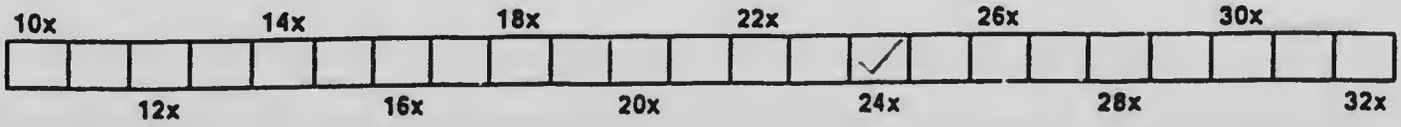

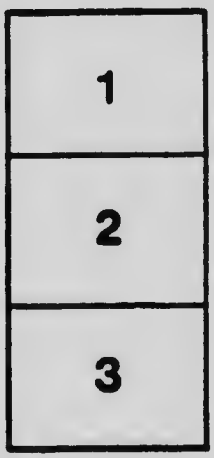

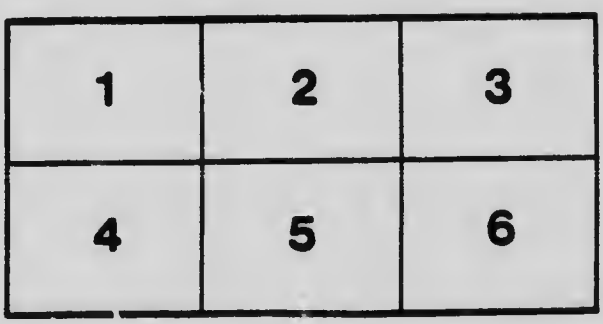

THE EFFECT OF HAZE ON SPECTROSCOPIC MEASURES OF THE SOLAR ROTATION

NOTE ON A SUPPOSED VARIATION IN THE SOLAR ROTATION

RALPH E. DE LURY

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THE EFFECT OF HAZE ON SPECTROSCOPIC MEASURES OF THE SOLAR ROTATION

By RALPH E. De LURY

Spectroscopic determinations of the rate of the sun's rotation by different observers at various times present remarkable and puzzling differences. Certain sources of error have been proved to be present; but other explanations of some of the differences are of a hypothetical nature and are veiled in doubt. It is the object of this note to present with supporting evidence a new interpretation which seems to clear up much of the uncertainty attached to the problem of the solar rotation.

DIFFERENCES IN MEASURES OF SOLAR ROTATION

Notable observed differences are:

(1) *The measurements of the solar rotation made by different observers exhibit a large range of values.*—For example, the values of the equatorial solar velocity, derived from about twenty groups of determinations, range from 2.11 to 1.86 km per sec. Furthermore, *measurements by the same observer of a series of plates taken over a short interval of time frequently show a considerable range in their values.*

(2) *Some observers have found a difference in velocity for different spectral lines, while others have not.*—The determinations by Adams and Miss Lasby at Mount Wilson in 1906–1908 show such differences,[1] and this is confirmed[2] in 1915 by St. John, Adams, and Miss Ware, and also in Ottawa by the writer in 1915, a summary of these measurements being given later in this paper. On the other hand, all other observers (the writer included) find no serious difference for different lines in the interval 1909–1913. Hence

[1] Adams, *Mt. Wilson Contr.*, Nos. 20, 24, 29; *Astrophysical Journal*, **26**, 203, 1907; **27**, 113, 1908; **29**, 110, 1909; Adams and Lasby, *Publication No. 38, Carnegie Institution of Washington.*

[2] St. John, Adams, and Ware, *Popular Astronomy*, **23**, 641, 1915.

the conclusion: *The difference in velocity for different spectral lines is a variable, being present in some observations and apparently absent from others.*

(3) *One observer found that the northern and southern hemispheres of the sun rotated at different rates.*—The observations of Hubrecht at Cambridge[1] alone give information on this point. In 1911 the writer suggested the method of using simultaneous exposures from the center of the solar disk and from the limbs for determining the rates of rotation in the two hemispheres independently,[2] and since the apparatus was received in 1913 he has been making such observations; in 1915 a similar method was started at Mount Wilson,[3] so that more evidence on this point will soon be at hand.

(4) *Some observations show a value of the rate of rotation progressively increasing with wave-length over the small range of wave-lengths covered by a plate; a great many more observations do not exhibit this effect.*—The 1906–1907 series[4] of Mount Wilson measurements show this effect, while the 1908 series[5] does not. Some measurements by Schlesinger in 1909, and those by Hubrecht[6] in 1911 show the effect. All other observations appear to be free from this effect.

MECHANICAL EXPLANATION OF DIFFERENCES

The following explanations of the foregoing results have been or may be offered:

(*a*) *Instrumental errors.*—Such instrumental errors as would be caused by uneven illumination of the prism or grating, combined with observations of the spectrum out of focus, may account for part of results (1), (3), and (4).

(*b*) *Observational errors.*—Small inaccuracies in determining the points observed are possible, but it is unlikely that these could ever equal 0.5 per cent.

[1] Hubrecht, *Monthly Notices*, **73**, 5, 1912.

[2] De Lury, *Report of the Chief Astronomer, Ottawa*, 1911, p. 290.

[3] St. John, Adams, and Ware, *loc. cit.*

[4] See footnote 1, p. 177.

[5] *Ibid.*

[6] Hubrecht, *loc. cit.*

(*c*) *Errors of measurement.*—In 1910 the writer suggested that errors of measurement might account for (1) and (2). He tested this explanation of (2) by mechanically introducing displacements of the spectral lines the same for all lines and of configurations and magnitudes of displacement similar to actual observations; a slight tendency to systematic difference for different lines was found in a series of twelve of these "imitation" rotation plates, as well as a systematic difference depending on the direction of the plate.[1] These plates were taken in the region of λ 4250, where Adams and Miss Lasby found the differences for different lines,[2] and the plates were sent to them in the hope that their measures of the same lines mechanically shifted would settle the question as to whether the differences for different lines in their original measurements were due to personal errors. Unfortunately they did not have time for the measurements, hence the part played by systematic error of measurement in their 1906–1908 determinations remained unsettled. This explanation of (1) was tested by having various observers measure the same lines on the same plates. J. S. Plaskett kindly offered to co-operate with the writer in measuring the above-mentioned twelve plates of the mechanical shifts, with the result that a systematic difference between the two measures of about 2 per cent was discovered. This difference persisted throughout the measurements of the solar rotation in 1910–1913. These suggestions of the writer followed by the comparative measurements led to these recommendations made at the meeting of the International Solar Union held at Bonn, in 1913: "It is highly desirable to trace to their source the systematic differences that are found in the values of the solar rotation by different observers. . . . . Investigation should also be made into the personal differences that are found in measures of the same plates by different observers." (In this connection it would seem advisable to have a series of plates, say one or two from each observer, measured by the automicrophotometer at Mount Wilson, and then passed around among the various observers for measurement.)

[1] De Lury, *op. cit.*, p. 264; *Journal of the Royal Astronomical Society of Canada*, 5, 384, 1911.

[2] See footnote 1, p. 177.

PHYSICAL EXPLANATIONS OF DIFFERENCES

The foregoing explanations are based upon the possibility of instrumental, observational, or personal errors; those which follow are based on physical considerations:

(*d*) *Convection in the solar atmosphere.*—Local convection currents undoubtedly account for some of the differences obtained by the same observer under apparently similar conditions (1), and it is quite possible that in small series of observations the mean may be considerably distorted by this cause. Adams found instances of such local motions in the neighborhood of spots.[1] The writer found in one case a difference of 8 per cent between the top and bottom of a spectrum 1 mm wide, the lines being quite visibly bent from their normal straightness.

(*e*) *Periodic variation in the rate of the solar rotation.*—From variations in the visual measurements of Dunér (at Upsala, 1887–1889 and 1899–1901) and of Halm (Edinburgh, 1901–1906), the latter suggested that there was a periodic change in the sun's rate of rotation. If such is the case (1) could be accounted for, partially at least; and since there is periodicity in sun-spots and asymmetry in the spottedness of the northern and southern hemispheres, (3) might result from such periodic variation; and possibly result (2) could be explained by such periodicity, for the evidence on this point seems to bear some relation to the sun-spot variation.

(*f*) *Variation in the angular rate of rotation depending on level in the solar atmosphere.*—When Adams discovered differences in angular velocity for different lines of the spectrum (2), he suggested[2] that it was due to the fact that the gases producing the different lines existed at different levels (an assumption apparently supported by other lines of evidence) and that the angular rate of rotation increased with elevation. To account for the additional facts mentioned in (2) above, this explanation would have to be modified by adding: *and such variation in the angular rate of rotation varies periodically.*

[1] See footnote, 1, p. 177.

[2] *Ibid.*

(*g*) *Sky spectrum.*—Hale noted the possibility of error caused by the sky spectrum blending with the displaced spectrum of the limb, and observers have for the most part been careful to select the clearest days for observation. However, there seems to be error due to this source in some of the observations. The writer made, in 1911, some tests of the effect of sky spectrum in lessening the rotation displacement, with the result that for the very clearest days there seemed to be little error from this source.[1] This work led to the consideration of the general question of blended spectra, and in 1912 measurements of blends of spectra of limb and center were made which showed a striking, though predicted, relationship between measured displacements and line-intensity, owing to the fact that the difference in intensity for a line at limb and at center increases in general with decrease in intensity of the line.[2] These results led to the following explanation which, though mentioned previously, presented only now because recent results in the measurement of the solar rotation at Ottawa by the writer, and at Mount Wilson[3] by St. John, Adams, and Miss Ware are strikingly well explained by it.

(*h*) *Spectrum of haze.*—It has been shown[4] (see also later) that a variable haze, between the observer and the sun, causing to be blended on the spectrum of the limb a spectrum of variable intensity and of character somewhat similar to that of the center of the solar disk in regard to intensity and wave-length of the spectral lines, causes: (i) the spectroscopic determinations of the solar rotation to vary, and (ii) the velocities of rotation from the different lines to decrease in general with decrease in intensity of the lines, the amount of the decrease in velocity for a given line depending on the strength of the continuous spectrum due to the haze relative to the continuous spectrum of the limb and on the ratio of the intensities of the line in the spectrum of the haze and in the spectrum of the limb. Observations already made make it seem probable that the variable terrestrial atmosphere and its

[1] De Lury, *Report of the Chief Astronomer, Ottawa*, 1911, p. 281

[2] De Lury, *Journal of the Royal Astronomical Society of Canada*, **10**, 201, 1916.

[3] St. John, Adams, and Ware, *loc. cit.*

[4] See footnote 2.

clouds and hazes are sufficient to account for differences (1) and (2), after eliminating the systematic and accidental errors mentioned above. But if in any series of observations the spectrum of terrestrial haze can be proved of insufficient strength, then we may introduce the idea of haze existing between the earth and the sun, near the sun, or even in the solar atmosphere (such as produced by matter falling in variable amounts into the sun and requiring an interval of time before being swept along in the general rotation). Such a variable haze possibly could account for the differences in the solar radiation observed by Abbot and others; it would be interesting to make simultaneous observations of solar rotation and radiation to see whether the changes in their values synchronize.

That explanation (*h*) is the true explanation of the residual differences in (1) and (2) above, after due allowance has been made for the other known sources of error, seems established from the similarity of the following three series of results, dealing with measurements of blended spectra, measurements of the solar rotation at Ottawa on plates made through different amounts of haze, and measurements of the solar rotation made at Mount Wilson.

MEASUREMENTS OF BLENDED SPECTRA

In the paper cited, it has been shown that the measured rotational displacements of the lines from the limb when blended with the lines—undisplaced by rotation—from the center of the solar disk decrease progressively with decrease in the intensity of the lines; and this was explained as due to the fact that the difference in intensity between lines in the spectra of center and limb decreases, in general, with increase in intensity of the lines. There are exceptions to this latter generalization which serve to test the various theories (see later). The accompanying summary (Table I) of the first table in the paper quoted will suffice to illustrate the general results. It is thus seen that the lessening of the displacement due to rotation in the blend with the spectrum of the center is greater progressively with decrease in intensity of the line, which, in turn, is accompanied by steadily increasing values

of the ratio of intensity from center to limb, and decreasing values of the ratio of width at center to limb. (Thus decreasing intensity at the limb seems to be accompanied by increasing width. To explain this the writer has advanced the hypothesis that the

TABLE I

BLENDED SPECTRA, λ 5600

Mean displacements of equatorial limb lines blended with five different blends with center spectrum in . ich the ratios of the densities of deposit on the photographic plate from the continuous spectrum of the limb to the total of continuous spectrum were 0.89, 0.83, 0.74, 0.62 and 0.54; mean ratio, 0.72.

Plate, L854, September 20, 19 . 1

Line-intensity, center...	1	2	3	4	5	6	8	
Line-intensity, limb....	0	1–	2	3	5–	6–	7	
Line-width, center.....	4.8	4.2	5.4	6.8	7.8	7.2	9.2	km per sec.
Line-width, limb.....	6.2	5.6	5 8	6.6	8.2	8 0	8 6	" "
No. of lines.....	3	6	5	2	1	1	1	
Mean velocity from blends.....	1.553	1.573	1.575	1.594	1 633	1.648	1.651	" "
Equatorial velocity not blended.....	2.020	2.053	2.014	2 053	2 085	2.085	1 978	" "
Mean.....							2.042	

widening and weakening of the lines at the limb are due to convections similar to those in the penumbral regions of spots. Other factors come in to play and account for many exceptions. The question will be discussed soon in another communication.)

MEASUREMENTS OF THE SOLAR ROTATION AT OTTAWA ON HAZY DAYS

The results from the measurements of the solar rotation on hazy days for varying degrees of haze show a striking similarity to those from the measures of the artificial blends as shown in Tables II, III, and IV. It will be thus seen that the differences of percentage between the values for intensity 1 and 22 are: Table II, 1.2; Table III, 4.6; Table IV, 8.2. After the observations of Table IV were made, a photographic comparison of the intensity of the spectrum of the haze relatively to the spectrum of the limb was secured; however, the haze was continually varying so that only a rough approximation could be arrived at, and from this it would seem that the average ratio of intensity of the continuous

spectrum of the haze to the continuous spectrum of limb and haze for the observations of Table IV was 12± per cent. This would involve the assumption that the haze in Table II was about 2 per cent, while the haze for observations of Table III was about 7 per

TABLE II

SOLAR ROTATION, λ 5200

March 11, 1:30 P.M., 1916, very slightly hazy, 6 *double* observations, i.e., 2 strips of spectrum from each limb

	Mean	Mean	Mean	Mean	Mean
Intensity	1	2	5.3	22	5.3
Number of lines	3	11	7	3	24
Equatorial velocity	1.956	1.972	1.972	1.968	1.967

TABLE III

SOLAR ROTATION, λ 5200

June 16, 4:15 P.M., 1915, slightly hazy, 6 double observations

	Mean	Mean	Mean	Mean	Mean
Intensity	1	2	5.3	22	5.3
Number of lines	3	11	7	3	24
Equatorial velocity	1.808	1.842	1.845	1.883	1.843

TABLE IV

SOLAR ROTATION, λ 5200

March 3, 12:55 P.M., 1916, very hazy, haze varying, 3 double observations

	Mean	Mean	Mean	Mean	Mean
Intensity	1	2	5.3	22	5.3
Number of lines	3	11	7	3	24
Equatorial velocity	1.738	1.760	1.814	1.887	1.816

cent. These are of course only rough estimates, but they serve to point out the necessity of very accurate measures of the relative strengths of the spectrum of the haze and the spectrum of the limb. When such are made and accurately correlated with measurements of solar rotation for groups of lines of different intensities, it will be possible to eliminate the effect of the spectrum of the haze from any similar series of measurements of rotation. Such being the

case, it should be possible to estimate the strength of haze present during the Mount Wilson observations.[1]

MEASUREMENTS OF THE SOLAR ROTATION AT MOUNT WILSON

TABLE V

SOLAR ROTATION, λ 5200

1914–1915 measurements (St. John, Adams, and Ware, *Popular Astronomy*, **23**, 641, 1915)

	Mean	Mean	Mean	Mean	Mean
Intensity	1	2	4.9	22	6.4
Number of lines	2	5	9	3	19
Equatorial velocity	1.924	1.933	1.945	2.043	1.950

It is seen from Table V that the difference between the values for lines of intensity 1 and 22 is 6.1 per cent. It would seem that, if this is altogether ascribable to haze, there was an overlapping spectrum of the haze of about 9± per cent in these observations. The three lines of average intensity 22 were the same as in the Ottawa observations, namely, the three strong Mg lines in the *b* group, λ 5167 to λ 5184, but the lines of intensity 1 could easily yield different results in the two series, 3 in the Ottawa observations and 2 in the Mount Wilson observations. However, it seems likely that there must have been a considerable effect of haze during the latter observations. The large difference between the values of the rotation in the two series is probably accounted for by some of the other sources of error, though the Ottawa values in Table II (very slight haze) are nearly the same in the mean, the strongest lines being, however, exceptionally high in the Mount Wilson measures. That is a question which can best be attacked after the influence of the spectrum of light scattered from haze or optical parts has been accurately eliminated.

MEASUREMENTS TO TEST THE LEVEL HYPOTHESIS

The measurements of the solar rotation given in Tables VI and VII seem to support the haze explanation and to disprove the level hypothesis, unless the latter be assumed to be variable, as pointed out above.

[1] St. John, Adams, and Ware, *loc. cit.*

In Table VI are given the measurements of 6 lines of intensities 0 and 1 paired off with 6 lines of intensities 4–15, giving a great difference in penumbral displacements in spots, interpreted as

TABLE VI

SOLAR ROTATION, λ 4500

Ottawa, June 30-July 25, 1910, 32 observations

	Mean	Mean	Mean
Intensity	0.7	8.5	4.6
Number of lines	6	6	12
Penumbral displacement	+0.028 A	−0.001 A	+0.015
Equatorial velocity	1.968±0.003	1.972±0.007	1.970±0.004 (lines) ±0.010 (plates)

Seven of the foregoing plates taken on cloudy or hazy days, yield:

Equatorial velocity	1.909	1.939	1.924 km per sec.

TABLE VII

SOLAR ROTATION, λ 5600

Ottawa, December 6–12, 1910, 32 observations

	Mean	Mean	Mean
Intensity	1.6	6.2	3.9
Number of lines	5	5	10
Equatorial velocity	1.930±0.006	1.936±0.002	1.933±0.003 (lines) ±0.005 (plates)

indicating range in level in the reversing layer (Evershed and St. John).[1] If Adams' hypothesis of increasing angular velocity for increasing elevation in the sun be true, there should be a considerable difference between the velocities of rotation from these two groups of lines. There is no appreciable difference, however, and the results of Table VII show this also. We are thus forced to abandon the level hypothesis, or else to modify it by adding the idea of variability. From the seven plates of Table VI taken on days when the spectrum of the haze was stronger than for the other

[1] Evershed, *Kodaikanal Observatory Bulletin*, 15, 1909.

St. John, *Mt. Wilson Contr.*, Nos. 69, 74; *Astrophysical Journal*, 37, 322, 1913; 38, 341, 1913.

plates, it is seen that there is a difference between the determinations of velocity of the two groups of lines, of 0.030 km per sec.—a difference explainable by the spectrum of the haze blending with the spectrum of the limb. The mean value of the December determinations (Table VII) is smaller by 2 per cent than the value from the July determinations (Table V), possibly owing to the lower declination of the sun in December and to the lower mean intensity of the lines, as well as to the probably greater relative strength of the sky spectrum in December than in July.

SOME GENERAL DISCUSSIONS

It has been mentioned that observers during 1909–1913 found little difference for different lines. Can this be due to the fact that at sun-spot minimum there is less danger from the error due to haze than during sun-spot maximum, pointing either to the presence of varying quantities of matter about the sun or to varying haziness in the terrestrial atmosphere caused by the variation in its ionization accompanying the spot-activities? In most of these 1909–1913 observations the lines were not considered in groups as to difference in intensity, but rather with regard to the element producing the line—in accordance with the recommendations of the Solar Union in 1910—the important relationship between penumbral displacements and intensity and level[1] not having been fully developed at that time. It would seem advisable to investigate the published results from this point of view. This has been done in a preliminary way by the writer. Some results show no appreciable relationship of velocity with line-intensity, some show evidence of this, and some seem to indicate the reverse of what would be expected from Adams' level hypothesis, i.e., a lower rate of rotation with increasing level, a physically possible and quite probable state of affairs. Some exceptions to the level hypothesis are readily explained on assumption of blended spectrum of haze, e.g., λ 4287.566 of intensity 1 at the center of the solar disk is strengthened and widened at the limb, and it has a penumbral displacement of 0.026 A; if this is interpreted as meaning low level, it is to be expected on the level hypothesis that this line

[1] *Ibid.*

should give a lower rotational value than the mean. Adams and Lasby find[1] in 1908 that this line has an equatorial velocity 0.004 km per sec. above the mean; this is explainable by the fact that this line is strengthened, not weakened, at the limb and therefore should yield a larger value than the mean of the other lines which are for the most part weakened at the limb, if the spectrum of the haze is of sufficient strength. In those measurements the lines that are weakened at the limb show a mean residual of −0.003, while the lines that are strengthened at the limb show a residual of +0.005 in the mean, indicating a slight effect of sky spectrum. Similar means, −0.002 and +0.005, occur in the 1906-1907 series. All published results should be discussed fully from this point of view so that a correction can be made in the absolute values. A knowledge of the behavior of the lines at the limb is essential. Is it possible that the results (4) can be due to chance selection of the lines, so that at one end of the plate the lines will yield a smaller value of the rotation than do the lines at the other end? A cursory examination of Hubrecht's results would make this seem a possible explanation. It is assuredly not a physical effect depending on wave-length, for, if it were, there should be profound differences between series taken at widely different parts of the spectrum, and this is not the case. It may possibly be due to uneven illumination of the grating and one end of the plate being slightly out of focus. It is possible, too, that Hubrecht's result (3) may also be due to blended spectrum of the haze inasmuch as the wave-lengths in the latter are not midway between those from opposite limbs, which would result in effects of blending of different magnitude for the two limbs. It seems to the writer that many of these puzzling differences will vanish when accurate determinations of the effects of the spectrum of the haze are made. A later communication will deal with the effect in various series of observations.

SUGGESTIONS FOR FUTURE OBSERVATIONS

In the meantime it is necessary for all observers to pay special attention to the influence of the spectrum of the haze; it may be eliminated by the exact correlation of changing values of the solar

[1] See footnote 1, p. 177.

rotation with differences in value for different intensities of lines, say from two groups of lines, one greatly weakened at the limb and the other not weakened at the limb. The λ 5200 region offers the best chance for such measurement, since the strongest lines there are quite measureable, and it is possible to eliminate instrumental and other errors by using when desired either iodine or chlorine comparison spectra (as suggested by the writer[1] in 1910 and 1911 and employed by him since the installation of the limb and center prism apparatus in 1913). For these reasons I would suggest that it be considered as a common region even in preference to the λ 4250 region formerly chosen.

In measurements of line-displacements in spots, comparisons of spectra from limb and center etc., differential effects depending on line-intensity may serve, as for rotation, in eliminating the effects of scattered light; these questions will be discussed in future communications.

CONCLUSIONS

The main conclusions from the foregoing investigation are:

1. Spectrum of haze, probably altogether terrestrial in its origin, accounts for much of the variation in the values of the solar rotation obtained by various observers at different times. Variations hitherto ascribed to the sun appear to be due to variations in scattered light.

2. Spectrum of haze, being different in character to spectrum of limb depending in general on the intensity of the line, blends with spectrum of limb in such a way as to make it appear that different spectral lines yield different values for the velocity of rotation of the sun. Such differences found in measures of the solar rotation at Mount Wilson and at Ottawa are satisfactorily explained in this manner, and it seems possible to dispense with Adams' level hypothesis.

SOLAR PHYSICS DIVISION
DOMINION OBSERVATORY, OTTAWA
April 1916

[1] De Lury, *Report of the Chief Astronomer, Ottawa*, 1910, p. 168; 1911, p. 203.

Minor Contributions and Notes

NOTE ON A SUPPOSED VARIATION IN THE SOLAR ROTATION

In a recent number of this *Journal* is published a paper entitled "A Variation in the Solar Rotation," in which the conclusion is reached[1] "that the sun, during the summer of 1915, underwent a cyclic variation in its rotation rate with a range of 0.15 km. This variation was completed in about a month." This result appeared to me to be another case showing the effect of an overlapping spectrum of haze such as was discussed in my paper (see pp. 177–179 of this number). The observations were made with the same equipment as I have been using day by day since 1913 for the purpose of investigating any changes which might occur in the positions of lines of limb and center, so it happened that I made many observations in various regions of the spectrum during the period of the observations described. The record shows that in general high values of the rotation in the observations mentioned were obtained on the brighter days and low values on the hazier days. Selecting plates at λ 4250 on July 13 (seven double observations), and on July 20 (five double observations), on which dates the measurements mentioned above show the lowest and highest values, I measured λ 4226.9, Ca, 20, strengthened at the limb, and λ 4225.6, Fe, 3, and λ 4232.8, Fe, 2, both weakened at the limb, with results and comparisons as follows:

	July 13, Hazy	July 20, Bright
	km per sec.	km per sec.
H. H. Plaskett's values for five lines of intensities 3 to 8, λ 5900	1.846	2.026
De Lury's values:		
4225.6, Fe, 3	1.712	1.966
4226.9, Ca, 20	1.794	1.983
4232.8, Fe, 2	1.711	1.972
Difference between Ca line and Fe lines	0.082	0.014

[1] H. H. Plaskett, *Astrophysical Journal*, **43**, 156, 1916.

These measurements show three results, which are all explainable by the blending of the spectrum of haze with that of the solar limb: (1) The values of the solar rotation are smaller on the hazy day than on the bright day. (2) The difference between the values for weak and strong lines is greater on the hazy day than on the bright day. (3) The values at the greater wave-length, λ 5900, are greater than those at the smaller wave-length, λ 4230, the spectrum of haze being stronger relatively to the spectrum of the limb for smaller wave-lengths than for the greater wave-lengths.

The values at λ 4230 point to a value for the equatorial velocity of about 2.03 or 2.04 km per second for a zero difference between the values for weak and for strong lines.

Measurements of the λ 5900 plates for groups of weak and strong lines will no doubt confirm the conclusion that the variation in question is due entirely to variations in the terrestrial haze.

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