# GREENWICH PHOTO-HELIOGRAPHIC RESULTS.

1901.

# RESULTS

OF THE

# PHOTO-HELIOGRAPHIC OBSERVATIONS

MADE AT THE

# ROYAL OBSERVATORY, GREENWICH,

IN THE YEAR

# 1901:

UNDER THE DIRECTION OF

W. H. M. CHRISTIE, C.B., M.A., F.R.S.
ASTRONOMER ROYAL.

(EXTRACTED FROM THE GREENWICH OBSERVATIONS, 1901.)

EDINBURGH:
PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE,
BY NEILL & COMPANY, LTD., BELLEVUE.

1902.

# GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1901.

## INTRODUCTION.

§ 1. *Measures of Positions and Areas of Sun Spots and Faculæ on Photographs taken at the Royal Observatory, Greenwich, at Dehra Dûn in India, and at the Royal Alfred Observatory, Mauritius, in the year* 1901 ; *with the deduced Heliographic Longitudes and Latitudes.*

The photographs from which these measures were made were taken either at Greenwich; at Dehra Dûn, North-West Provinces, India; or at the Royal Alfred Observatory, Mauritius.

The photographs of the Greenwich series were taken either with the Thompson or with the Dallmeyer Photoheliograph. The Thompson Photoheliograph, which was in regular use at the beginning of the year, is a photographic refractor of 9 inches aperture, presented to the Royal Observatory by Sir Henry Thompson, which has been fitted with an enlarging doublet by Ross, and with a camera and shutter for rapid exposure so as to take photographs of the Sun on a scale of about 7·5 inches to the solar diameter. The Dallmeyer, which was substituted for the Thompson while the former was in use for the Eclipse expedition to Sumatra, from 1901 February 15 to 1901 September 19, is an instrument used in the Transit of Venus expedition to New Zealand, which, as now adapted, gives a solar image of 8 inches diameter on the photographic plate.

The photographs, have been taken throughout the year on gelatine dry plates, "Lantern" plates supplied by R. W. Thomas and Co. being used, with hydroquinone development.

The Indian photographs, which have been forwarded by the Solar Physics Committee to fill the gaps in the Greenwich series, were taken under the superintendence of the Deputy Surveyor-General, Trigonometrical Survey of India, with a Dallmeyer Photoheliograph giving an image of the Sun nearly 8 inches in diameter. In the process adopted at Dehra Dûn, bromo-iodized collodion wet-plates have been generally used in connexion with iron development; but several "Lantern" dry-plates have also been taken.

The Mauritius photographs were taken under the superintendence of Mr. T. F. Claxton, Director of the Royal Alfred Observatory, Mauritius, with a Dallmeyer Photoheliograph, giving an image of the Sun about 8 inches in diameter. At the Mauritius Observatory bromo-iodized gelatine dry plates have been used with alkaline development.

Photographs of the Sun were taken at Greenwich on 149 days, and Indian photographs on 189 days with Mauritius photographs on 21 days have been received from the Solar Physics Committee to complete the total of 359 days for which there are either Greenwich, Indian, or Mauritius photographs of the Sun available for measurement in 1901.

The *first* column on each page contains the Greenwich civil time at which each photograph was taken, expressed by the day of the year and decimals of a day, reckoning from Greenwich mean midnight January 1d. 0h., and also by the day of the month (civil reckoning), which latter is placed opposite the total area of Spots and Faculæ for the day. The photographs taken in India are distinguished by the letter I., and those taken in Mauritius by the letter M.

The *second* column contains the initials of the two persons measuring the photograph; the initial on the left being that of the person who measured the photograph on the left of the centre of the measuring instrument, and that on the right being that of the person who measured on the right of the centre.

The following are the signatures of those persons who measured the photographs for the year 1901:—

| | | | |
|---|---|---|---|
| P. H. Cowell | - - C | T. G. Staples | - - TS |
| E. W. Maunder | - - M | R. Fowler | - - RF |

The *third* column gives the No. of the group, and the letter for the spot. The groups are numbered in order of their appearance.

The *next two* columns give the distance from the centre of the Sun in terms of the Sun's radius, and the position-angle from the Sun's axis, reckoned from the

Sun's north pole in the direction *n, f, s, p,* both results being corrected for the effects of astronomical refraction.

The measures of the photographs were made with a large position-micrometer specially constructed by Messrs. Troughton and Simms for the measurement of photographs of the Sun up to 12 inches in diameter. In this micrometer the photograph is held with its film-side uppermost on three pillars fixed on a circular plate, which can be turned through a small angle, about a pivot in its circumference, by means of a screw and antagonistic spring acting at the opposite extremity of the diameter. The pivot of this plate is mounted on the circumference of another circular plate, which can be turned by screw-action about a pivot in its circumference, 90° distant from that of the upper plate, this pivot being mounted on a circular plate with position-circle which rotates about its centre. By this means small movements in two directions at right angles to each other can be readily given, and the photograph can be accurately centred with respect to the position-circle. When this has been done, a positive eyepiece, having at its focus a glass diaphragm ruled with cross-lines into squares, with sides of one-hundredth of an inch (for measurement of areas), is moved along a slide diametrically across the photograph, the diaphragm being nearly in contact with the photographic film, so that parallax is avoided. The distance of a spot or facula from the centre of the Sun is read off by means of a scale and vernier to 1-250th of an inch (corresponding to 0·001 of the Sun's radius for photographs having a solar diameter of 8 inches). The position-angle is read off on a large position-circle which rotates with the photographic plate. The photograph is illuminated by diffused light reflected from white paper placed at an angle of 45° between the photograph and the plate below.

The following is the process of measurement of a photograph:—By means of the screws attached to the circular plates carrying the pillars which hold the photograph, the image of the Sun is centred as accurately as possible by rotation. The position-circle is then set to the readings 0°, 90°, 180°, and 270° in succession, and the scale readings taken for the two limbs. The scale being so adjusted that its zero coincides with the centre of rotation of the position-circle, the mean of the eight readings for the limb gives the mean radius of the Sun directly.

At the principal focus of the photoheliograph are two cross-spider-lines which serve to determine the zero of position-angles on the photograph.

The zero of position-angles for the Thompson and Dallmeyer Photoheliographs, employed at Greenwich has been determined by the measurement of a plate which has been exposed to the Sun's rays twice, with an interval of about 100 seconds between the two exposures, the instrument being firmly clamped. Two images of the Sun, overlapping each other by about a fifth part of the Sun's diameter, were therefore produced upon the plate, and the exposures having been so given that the line joining the cusps passed approximately through the centre of the plate, the inclination of the wires of the photoheliograph to this line was measured with the position-micrometer, and a small correction for the inclination of the Sun's path was then applied. The following tables give the correction for zero of position for the mean of the two wires as thus determined:—

Thompson Photoheliograph, to 1901 February 15.

| Date, Greenwich Civil Time. | | Correction for Zero. |
|---|---|---|
| | d h | ° ′ |
| 1900 December | 14. 10 | − 0. 28 |
| | 29. 11 | − 0. 19 |
| 1901 January | 15. 11 | − 0. 13 |
| February | 15. 11 | − 0. 8 |

A correction of $-0^{\circ}\cdot3$ for zero of position has been applied to all photographs taken with the Thompson Photoheliograph up to 1901 February 15.

Dallmeyer Photoheliograph, 1901 February 15 to September 19.

| Date, Greenwich Civil Time. | | Correction for Zero. |
|---|---|---|
| | d h | ° ′ |
| 1901 March | 1. 11 | + 0. 24 |
| 1901 May | 3. 11 | + 0. 22 |
| June | 8. 10 | + 0. 26 |
| August | 13. 12 | + 0. 40 |
| September | 3. 12 | + 0. 36 |
| | 18. 11 | + 0. 30 |

The wires were taken out, adjusted to centre, and replaced, on 1901 May 3, before any photographs were taken.

A correction of $+0^{\circ}\cdot 4$ for zero of position has been applied to all photographs taken with the Dallmeyer Photoheliograph from 1901 February 15 to 1901 May 2, and a correction of $+0^{\circ}\cdot 5$ to all photographs taken with that instrument from 1901 May 3 to 1901 September 19.

Thompson Photoheliograph, from 1901 September 19.

| Date, Greenwich Civil Time. | | | Correction for Zero. |
|---|---|---|---|
| | | d h | ° ′ |
| 1901 | September | 26. 12 | + 0. 35 |
| | October | 10. 11 | + 0. 23 |
| | | 28. 11 | + 0. 11 |
| | November | 2. 11 | + 0. 23 |
| | | 28. 12 | + 0. 36 |
| 1902 | January | 25. 12 | + 0. 25 |
| | February | 5. 13 | + 0. 23 |

A correction of $+0^{\circ}\cdot 4$ for zero of position has been applied to all photographs taken with the Thompson Photoheliograph since 1901 September 19.

The Thompson Photoheliograph was mounted on the tube of the 26-inch Thompson Photographic refractor throughout the year, excepting during the period 1901 February 15, to September 19, when it was dismounted for use in the observation of the total solar eclipse of 1901 May 18, at Aoer Gadang, near Sumatra. The Thompson Photoheliograph is not fitted with a position-circle, and the position-angle of the wires, which are approximately parallel and perpendicular to the circle of declination cannot be altered.

The Dallmeyer Photoheliograph was mounted on the tube of the 26-inch Thompson Photographic refractor, during the period 1901 February 15 to September 19, when the Thompson Photoheliograph was removed. The Dallmeyer Photoheliograph was dismounted on 1901 September 19, and placed in the upper floor of the Museum.

In the use at Greenwich of the Dallmeyer Photoheliograph the position circle has usually been set to some convenient reading near that for zero, so that the wires are respectively very nearly parallel and perpendicular to the circle of declination, and a correction for zero of position of the photoheliograph for the mean of the two wires has been applied to the zero of the position-circle of the micrometer. The position-circle was set to the reading $354^{\circ}\cdot 0$ throughout 1901.

The zero of the position-circle of the micrometer has been determined from the readings of the position-circle for the four extremities of the two wires. The resulting combined correction is applied to all position-circle readings for spots and faculæ, so as to give true position-angles.

In the use of the photoheliographs at Dehra Dûn and in Mauritius the position circle has always been set to the zero as determined by allowing the diurnal motion to carry a spot or the Sun's limb along the horizontal wire, and the accuracy of the adjustment has been tested at short intervals. No correction for zero of position of the wires has therefore been applied for the reduction of the photographs taken in India or in Mauritius.

The uncorrected distance from the Sun's centre for spots and faculæ is read off directly to 1-250th of an inch by means of a scale and vernier, the zero of the scale of the new micrometer being adjusted to coincide with the centre of the instrument.

Two sets of measures of the Sun's limb and of spots and faculæ on each photograph have been taken, and the mean of the two sets adopted.

No correction has been applied to the photographs on account of distortion.

The correction for the effect of refraction has been thus found, the Sun's image being assumed to be sensibly an ellipse. The refraction being sensibly $c \tan z$ where $c = \sin 57''\cdot5 = \frac{1}{3600}$ nearly, and $z$ is the apparent zenith-distance, we shall have—

$$\frac{\text{Vertical Diameter}}{\text{Horizontal Diameter}} = \frac{1 - c \sec^2 z}{1 - c} = 1 - c \tan^2 z\,;$$

and thus the effect of refraction will be to diminish any vertical ordinate $y$ by the quantity $c \tan^2 z$. Resolving this along and perpendicular to the radius vector $r$, and putting $v$ for the position-angle of the vertex, we have for $\delta r$ and $\delta \theta$, the corrections to radius vector and position-angle for the effect of refraction—

$$\delta r = +c \,.\, \tan^2 z \times r \,.\, \cos^2(\theta - v) = +c \,.\, \tan^2 z \times r \times \frac{1 + \cos 2(\theta - v)}{2},$$

$$\delta \theta = -c \,.\, \tan^2 z \,.\, \sin(\theta - v) \,.\, \cos(\theta - v) = -c \,.\, \tan^2 z \,\frac{\sin 2(\theta - v)}{2}.$$

The quantity $\delta r$ thus found is the correction, on the supposition that a horizontal diameter of the Sun is taken as the scale. But, as the mean of two diameters at right angles has been used, the scale itself requires the correction $\delta R = +c \,.\, \tan^2 z \times R \times \frac{1}{2}\left\{\frac{1 + \cos 2(\theta_0 - v)}{2} + \frac{1 + \cos 2(\theta_0 + 90^\circ - v)}{2}\right\} = +\frac{1}{2} c R \,.\, \tan^2 z$, where R is the Sun's mean radius and $\theta_0$, $\theta_0 + 90^\circ$ the position-angles of the two diameters measured. Thus the final correction to $r$ becomes—

$$\delta r = +c \,.\, \tan^2 z \times r \times \frac{\cos 2(\theta - v)}{2}.$$

The quantities $c \tan^2 z$, $-\frac{\sin 2(\theta - v)}{2}$, and $\frac{\cos 2(\theta - v)}{2}$ have been tabulated for use as follows, $c \tan^2 z$ being expressed in circular measure and in arc for application to distances and position-angles respectively :—

$c \tan^2 z$.

| z. | In Circular Measure. | In Arc. | z. | In Circular Measure. | In Arc. | z. | In Circular Measure. | In Arc. |
|---|---|---|---|---|---|---|---|---|
| ° | | ′ | ° | | ′ | ° | | ′ |
| 80 | ·0089 | 31 | 70 | ·0021 | 7 | 60 | ·0008 | 3 |
| 79 | ·0073 | 25 | 69 | ·0019 | 6½ | 58 | ·0007 | 2 |
| 78 | ·0061 | 21 | 68 | ·0017 | 6 | 56 | ·0006 | 2 |
| 77 | ·0052 | 18 | 67 | ·0015 | 5½ | 54 | ·0005 | 2 |
| 76 | ·0045 | 15 | 66 | ·0014 | 5 | 52 | ·0005 | 2 |
| 75 | ·0039 | 13 | 65 | ·0013 | 4½ | 50 | ·0004 | 1 |
| 74 | ·0034 | 11½ | 64 | ·0012 | 4 | 45 | ·0003 | 1 |
| 73 | ·0030 | 10 | 63 | ·0011 | 4 | 40 | ·0002 | 1 |
| 72 | ·0026 | 9 | 62 | ·0010 | 3 | 30 | ·0001 | 0 |
| 71 | ·0023 | 8 | 61 | ·0009 | 3 | | | |

Factors for Refraction.

| $\theta - v$ | $\theta - v$ | $-\frac{\sin 2(\theta - v)}{2}$ | $\frac{\cos 2(\theta - v)}{2}$ | $\theta - v$ | $\theta - v$ | $-\frac{\sin 2(\theta - v)}{2}$ | $\frac{\cos 2(\theta - v)}{2}$ |
|---|---|---|---|---|---|---|---|
| ° | ° | | | ° | ° | | |
| 0 | 180 | ·00 | + ·50 | 90 | 180 | ·00 | − ·50 |
| 5 | 185 | − ·09 | + ·49 | 95 | 275 | + ·09 | − ·49 |
| 10 | 190 | − ·17 | + ·47 | 100 | 280 | + ·17 | − ·47 |
| 15 | 195 | − ·25 | + ·43 | 105 | 285 | + ·25 | − ·43 |
| 20 | 200 | − ·32 | + ·38 | 110 | 290 | + ·32 | − ·38 |
| 25 | 205 | − ·38 | + ·32 | 115 | 295 | + ·38 | − ·32 |
| 30 | 210 | − ·43 | + ·25 | 120 | 300 | + ·43 | − ·25 |
| 35 | 215 | − ·47 | + ·17 | 125 | 305 | + ·47 | − ·17 |
| 40 | 220 | − ·49 | + ·09 | 130 | 310 | + ·49 | − ·09 |
| 45 | 225 | − ·50 | ·00 | 135 | 315 | + ·50 | ·00 |
| 50 | 230 | − ·49 | − ·09 | 140 | 320 | + ·49 | + ·09 |
| 55 | 235 | − ·47 | − ·17 | 145 | 325 | + ·47 | + ·17 |
| 60 | 240 | − ·43 | − ·25 | 150 | 330 | + ·43 | + ·25 |
| 65 | 245 | − ·38 | − ·32 | 155 | 335 | + ·38 | + ·32 |
| 70 | 250 | − ·32 | − ·38 | 160 | 340 | + ·32 | + ·38 |
| 75 | 255 | − ·25 | − ·43 | 165 | 345 | + ·25 | + ·43 |
| 80 | 260 | − ·17 | − ·47 | 170 | 350 | + ·17 | + ·47 |
| 85 | 265 | − ·09 | − ·49 | 175 | 355 | + ·09 | + ·49 |
| 90 | 270 | ·00 | − ·50 | 180 | 360 | ·00 | + ·50 |

The position-angle of the vertex $v$ is readily taken from a globe.

The distance from centre in terms of the Sun's radius given in the *fourth* column is then readily found by dividing the measured distance $r_0$, as corrected for refraction, by the measured mean radius of the Sun, R; and the position-angle from the Sun's axis given in the *fifth* column is obtained by applying to the position-angle (from the N. point) corrected for refraction the position-angle of the Sun's axis derived from the *Auxiliary Tables for determining the Angle of Position of the Sun's Axis, and the Latitude and Longitude of the Earth referred to the Sun's Equator*, by Warren De La Rue, F.R.S.

The *sixth* and *seventh* columns give the heliographic longitude and latitude of the spot, which are thus computed.* Let $r$ be the measured distance of a spot from the centre of the Sun's apparent disk, $R$ the measured radius of the Sun on the photograph, $(R)$ the tabular semidiameter of the Sun in arc, and $\rho$, $\rho'$ the angular distances of a spot from the centre of the apparent disk as viewed from the Sun's centre and from the Earth respectively. Then we have—

$$\rho' = \frac{r}{R}(R)\text{; and } \sin(\rho+\rho') = \frac{r}{R},$$

$$\text{whence } \rho = \sin^{-1}\frac{r}{R} - \rho'.$$

Log. sin $\rho$ and log. cos $\rho$, as computed from this formula, are given in *Tables for the Reduction of Solar Observations No.* 2, by Warren De La Rue, F.R.S. Then, if D, $\lambda$ are the heliographic latitudes of the Earth and the spot respectively, referred to the Sun's equator, and L, $l$ the heliographic longitudes reckoned from the ascending node of the Sun's equator on the ecliptic, and $\chi$ the position-angle from the Sun's axis, we have by the ordinary equations of spherical trigonometry—

$$\sin\lambda = \cos\rho\sin D + \sin\rho\cos D\cos\chi$$
$$\sin(L - l) = \sin\chi\sin\rho\sec\lambda.$$

The quantities L and D are derived from Warren De La Rue's *Auxiliary Tables* before referred to, in the computation of which the following formulæ have been used—

$$\tan L = \cos I \tan(\odot - N)$$
$$\sin D = \sin I \sin(\odot - N)$$

where I is the inclination of the Sun's equator to the ecliptic, N the longitude of the ascending node, and $\odot$ the longitude of the Sun.

* "Researches on Solar Physics: Heliographical Positions and Areas of Sun Spots observed with the Kew Photoheliograph during the years 1862 and 1863," by W. De La Rue, B. Stewart, and B. Loewy. *Phil. Trans.*, 1869.

The position-angle $\chi$ is given by the formula—

$$\chi = P + G + H$$

where P is the position-angle from the north point of the Sun, and G and H two auxiliary angles given by the formulæ—

$$\tan G = \tan \omega \cos \odot$$
$$\tan H = \tan I \cos (\odot - N)$$

where $\omega$ is the obliquity of the ecliptic.

It will be seen that G is the inclination of two planes through the line joining the centres of the Earth and Sun passing through the poles of the Earth and of the ecliptic respectively, and that H is the inclination of two planes through the same line and the poles of the Sun and of the ecliptic. The values assumed for I, N, $\omega$ in the computation of the tables are $7^{\circ}.15'$, $74^{\circ}.23'$, and $23^{\circ}.27'\cdot5$ respectively.

The heliographic longitude of the spot is found from $l$, the heliographic longitude from node, by subtracting the reduction to the prime meridian, which is the longitude of the node at the epoch of the photograph, referred to the assumed prime meridian, the latter being the meridian which passed through the ascending node at mean noon, 1854 Jan. 1. The period of rotation assumed is 25·38 days.

The heliographic longitude and latitude of the centre of the Sun's disk at the time of the exposure of each photograph are also given (in brackets) in the *sixth* and *seventh* columns respectively. The longitude of the centre of the disk is found by subtracting the reduction to the prime meridian from L, the longitude of the centre from the node. The latitude of the centre is of course the same as D, the heliographic latitude of the Earth.

The measures of areas given in the *last three* columns were made with a glass diaphragm ruled into squares, with sides of one-hundredth of an inch, and placed as nearly as possible in contact with the photographic film. The integral number of squares and parts of a square contained in the area of a spot or facula was estimated by the observer, two independent sets of measures being made by two observers. The mean of the two sets of measures has been taken for each photograph. The factor for converting the areas, as measured in ten-thousandths of a square inch, into millionths of the Sun's visible hemisphere, allowing for the effect of foreshortening, has been inferred by means of a table of double entry, giving the equivalent of one square for different values of the Sun's radius, and for different distances of the spot or facula from the Sun's centre as measured by means of the position-micrometer.

The individual spots in a group have in some cases not been measured separately but combined into a cluster of two or three small spots close together, the position of the centre of gravity and the aggregate area of the cluster being given. The actual number of individual spots is usually stated in the notes.

§ 2. *Ledgers of Areas and Heliographic Positions of Groups of Sun Spots deduced from the measurement of the Solar photographs for each day in the year* 1901.

In these ledgers the daily results for each group are collected together from the measures of the individual spots and given in a condensed form. The first column gives, for each day on which the group was observed, the Greenwich civil time at which each photograph was taken, expressed by the day of the month (civil reckoning) and the decimals of a day reckoning from Greenwich mean midnight. The second and third columns give the sums, for each day, of the projected areas of all the umbræ and whole spots comprised in the group, the projected area being the area as it is measured upon the photograph, uncorrected for foreshortening, and expressed in millionths of the Sun's apparent disk. The fourth and fifth columns give the sums for each day of the areas of all the umbræ and whole spots comprised in the group, corrected for foreshortening, and expressed in millionths of the Sun's visible hemisphere. The sixth and seventh columns give the mean longitude and latitude of the group, found by multiplying the longitude and latitude of each separately measured component of the group by its area, and dividing the sum of the products by the sum of the areas. The last column gives the mean longitude of the group from the central meridian, and is found by subtracting the longitude of the centre of the disk from the mean longitude of the group. At the foot of these daily results for each group are given the mean areas of umbræ and whole spots and the mean longitude and latitude for the period of observation.

§ 3. *Total Projected Areas of Sun Spots and Faculæ for each day, and Mean Areas and Mean Heliographic Latitude of Sun Spots and Faculæ for each Rotation of the Sun, and for the year* 1901.

This section requires no further explanation.

W. H. M. CHRISTIE.

*Royal Observatory, Greenwich.*
1902, *February* 28.