RESULTS

OF THE

SPECTROSCOPIC AND PHOTOGRAPHIC OBSERVATIONS

MADE AT THE

ROYAL OBSERVATORY, GREENWICH,

IN THE YEAR

1889:

UNDER THE DIRECTION OF

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

(EXTRACTED FROM THE GREENWICH OBSERVATIONS 1889.)

LONDON:
PRINTED FOR HER MAJESTY'S STATIONERY OFFICE,
BY DARLING & SON, LTD., 1-3, GREAT ST. THOMAS APOSTLE, E.C.

1890.

GREENWICH SPECTROSCOPIC AND PHOTOGRAPHIC RESULTS, 1889.

INTRODUCTION.

§ 1. *Spectroscopic Observations in the Year* 1889.

The spectroscope used for these observations was mounted on the South-east equatorial, the object-glass of which (made by Merz and Son of Munich) has a clear aperture of 12·8 inches, with a focal length of about $17^{ft.}\ 10^{in.}$

This section contains :—Measures of Displacement of Lines in the Spectra of Stars, Sun, Moon, and Planets; Collected Results for Motions of Stars in the line of Sight; and Observations of the Spectra of χ Cygni, Uranus, R Andromedæ, and of Comet *e* 1889.

The measures of displacement of lines in the spectra of stars were made with a micrometer in the viewing telescope of the "Half-prism" Spectroscope. The eye-piece used gives a magnifying power of 14. Estimations of the displacement, in terms of the apparent breadth of the bright comparison-line, were also made; the breadth corresponding to any given width of slit being determined by a careful observation under similar conditions. $1^{rev.}$ of the screw for opening the slit corresponds to 0·01 inch, or 10″. It has not been thought necessary to give in detail all these particulars of the reductions. The values used in each case may be inferred from the observed motion, which is the algebraic sum of the concluded motion and of the Earth's motion. A displacement of one tenth-metre corresponds at D to a motion of 31·7 miles per second, at *b* to a motion of 36·1 miles, and at F to a motion of 38·4 miles. For comparison with the spectrum of hydrogen or other chemical element, an image of the vacuum tube or electrodes is formed on the slit, by means of a transparent plate of glass placed at an angle of 45° with the axis of the collimator, in connexion with a collimating lens, so that the cone of rays from the comparison-light fills the whole of the object-glass of the collimator.

Whenever the star-line was sufficiently distinct to allow of its being seen at the same time as the bright comparison-line, a direct comparison of the two was made; in other cases the bright line was compared with the pointer of the micrometer which had just previously been placed on the star-line, giving an indirect comparison.

The reading of the position-circle is given, as it is conceivable that the results might be affected by the position of the spectroscope. The slit lies north and south when the reading is 6°.

With regard to the observations of the spectra of χ Cygni, Uranus, and R Andromedæ, it is sufficient to remark that a curve has been laid down in the usual manner, connecting micrometer readings and wave-lengths for the Single-prism Spectroscope, and that a correction for index-error has been deduced from observations of comparison-lines, and applied to the observed readings to reduce them to the standard curve from which the corresponding wave-lengths have been read off. The tabular wave-lengths of comparison-lines have been taken from Ångström's *Spectre Normal du Soleil.*

§ 2. *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* 1889; *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 with the Dallmeyer Photo-heliograph returned from the Transit of Venus expedition to New Zealand, which, as now adapted, gives a solar image of 8 inches diameter on the photographic plate.

Bromo-iodized gelatine dry plates with alkaline development have been regularly used throughout the year.

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 has been used in connexion with iron development.

The Mauritius photographs were taken under the superintendence of Dr. C. Meldrum, 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 178 days, and Indian photographs on 166 days with Mauritius photographs on 16 days have been received from the Solar Physics Committee to complete the total of 360 days for which there are either Greenwich, Indian, or Mauritius photographs of the Sun available for measurement in 1889.

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 1889 :—

E. W. Maunder - - M   S. J. Temple - - - ST

The *third* column gives the No. of the group, and the letter for the spot. The groups are numbered in the 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 eye-piece, 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 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-wires which serve to determine the zero of position-angles on the photograph.

The zero of position-angles for the Dallmeyer Photoheliograph, employed at Greenwich, has generally been determined throughout 1889 by the measurement of a plate which had 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 a little more than the 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 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 table gives the correction for zero of position for the mean of the two wires as thus determined :—

Date, Greenwich Civil Time.			Correction for Zero.
		h	° ′
1888	December	7. 13	− 2. 3
1889	February	2. 2	+ 0. 4
		26. 9	+ 0. 32
	April	4. 12	+ 0. 33
	June	6. 13	+ 0. 46
	August	1. 12	+ 1. 47
		24. 13	− 0. 3
	September	11. 11	+ 0. 52
		25. 12	+ 0. 14
	October	25. 11	+ 0. 4
	November	12. 12	+ 0. 3
	December	3. 11	+ 0. 39
		23. 12	+ 0. 39
1890	January	29. 12	+ 0. 48
	February	10. 12	+ 0. 48

The zero of position has also been determined on several occasions by allowing the diurnal motion to carry a spot or the Sun's limb along the equatorial wire, a correction for the inclination of the Sun's path being applied to the reading of the position-circle so obtained, and also by running the image along the wire by the use of the R. A. slow motion, the mean of the two determinations, further corrected for the error of the perpendicularity of the wires, being then taken.

The correction for error of perpendicularity of the wires in use up to 1889 February 25, was − 0°. 23′; for the new wires inserted 1889 February 20, it was + 0°. 6′·5; for those inserted 1889 July 12, it was − 0°. 8′; and for those inserted 1889 November 27, − 0°. 25′. The following table gives the correction for zero of position of the mean of the two wires as obtained by this method:—

Date, Greenwich Civil Time.			Corrected Zero of Position-Circle from Transit.	Zero of Position-Circle obtained when using R.A. Slow Motion.
		h	° ′	° ′
1888	December	7. 13	− 2. 31	− 2. 32
1889	February	2. 10	+ 0. 3	− 0. 3
	March	14. 13	+ 0. 28	+ 0. 30
	June	6. 13	+ 0. 33	+ 0. 31
	August	24. 14	− 0. 26	......
	September	25. 12	− 0. 2	− 0. 2
	October	25. 11	+ 0. 3	+ 0. 2
	November	12. 12	+ 0. 3	+ 0. 4
	December	3. 11	+ 0. 43	+ 0. 41
1890	February	10. 12	+ 0. 42	+ 0. 39

The mean of the values for the zero as determined by these two methods, the method of the photographs with double images of the sun, and that of running a spot or the sun's limb along the wires, has been adopted for the zero.

One or other of the wires was found to be broken on February 20, July 12, and November 27, and fresh pairs of wires were in consequence inserted on those days. The wires inserted on July 12 were re-fixed in their frame on August 14, September 2, and September 25.

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 setting of the position-circle was altered on 1888 December 7, from 356°·0 to 353°·0, and it was retained at the latter reading throughout 1889.

The correction for zero of position adopted for any date has been the mean of the determinations of that zero made next before and next after that date. 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 $c = \sin 57''\cdot 5 = \frac{1}{3600}$ 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 $\delta\, \mathrm{R} = +\, c\, .\, \tan^2 z \times \mathrm{R} \times \tfrac{1}{2} \left\{ \frac{1 + \cos 2\,(\theta_0 - v)}{2} + \frac{1 + \cos 2\,(\theta_0 + 90^\circ - v)}{2} \right\} = +\, \tfrac{1}{2}\, c\, \mathrm{R}\, .\, \tan^2 z$, where R is the Sun's mean radius and θ_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	95	275	+ ·09	− ·49
5	185	− ·09	+ ·49	100	280	+ ·17	− ·47
10	190	− ·17	+ ·47	105	285	+ ·25	− ·43
15	195	− ·25	+ ·43	110	290	+ ·32	− ·38
20	200	− ·32	+ ·38	115	295	+ ·38	− ·32
25	205	− ·38	+ ·32	120	300	+ ·43	− ·25
30	210	− ·43	+ ·25	125	305	+ ·47	− ·17
35	215	− ·47	+ ·17	130	310	+ ·49	− ·09
40	220	− ·49	+ ·09	135	315	+ ·50	·00
45	225	− ·50	·00	140	320	+ ·49	+ ·09
50	230	− ·49	− ·09	145	325	+ ·47	+ ·17
55	235	− ·47	− ·17	150	330	+ ·43	+ ·25
60	240	− ·43	− ·25	155	335	+ ·38	+ ·32
65	245	− ·38	− ·32	160	340	+ ·32	+ ·38
70	250	− ·32	− ·38	165	345	+ ·25	+ ·43
75	255	− ·25	− ·43	170	350	+ ·17	+ ·47
80	260	− ·17	− ·47	175	355	+ ·09	+ ·49
85	265	− ·09	− ·49	180	360	·00	+ ·50
90	270	·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 disc, R the measured radius of the Sun on the photograph, (R) the tabular semidiameter of the Sun in arc, and ρ, ρ' the angular distances of a

* 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

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 ρ and log cos ρ 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, λ 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 χ the position-angle from the Sun's axis, we have by the ordinary equations of spherical trigonometry—

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

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—

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

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.

The position-angle χ is given by the formula—

$$\chi = \mathrm{P} + \mathrm{G} + \mathrm{H}$$

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

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

where ω 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, ω in the computation of the Tables are 7° 15′, 74°, and 23° 27′·5 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 nearly 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.

§ 3. *Ledgers of Areas and Positions of Groups of Sun Spots deduced from the measurement of the Solar photographs for each day in the year* 1889.

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.

§ 4. *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* 1889.

This section requires no further explanation.

1890 August 14.

W. H. M. CHRISTIE.