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THE SPECTROHELIOSCOPE AND ITS WORK[1]

PART IV. METHODS OF RECORDING OBSERVATIONS[2]

By GEORGE E. HALE

ABSTRACT

A summary statement of methods of recording observations with the spectrohelioscope and of calibrating the circle of its "line-shifter" is given. A photographic attachment is also described.

Hydrogen flocculi on the sun's disk and prominences at the limb are of two principal types, quiescent and active. The former change slowly in outline and intensity, and as their radial velocities are low, they are best recorded by the spectroheliograph. Active phenomena often appear so suddenly, change so rapidly, and offer such a wide range of radial velocity that they call for the greater flexibility of the spectrohelioscope. This will be appreciated by anyone who has seen the rapid development of an eruption on the disk, and watched the remarkable changes of its intensity and structure revealed by moving the $H\alpha$ line back and forth across the second slit with the line-shifter.

It should be remembered, however, that flocculi which have been quiescent for several days may suddenly develop great velocity, either radial or tangential, with consequent rapid changes in form or position. Possibilities of this kind, which have been described in previous papers, call for special vigilance on the part of observers.

VISUAL OBSERVATIONS

Unfortunately, however, the active phenomena of the solar atmosphere are much more easily seen than adequately recorded. In many cases only a skilled and agile draftsman could hope to depict more than a fraction of the complex series of images, which vary

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 434.

[2] For previous articles in this series see Part I, "History, Instruments, Adjustments, and Methods of Observation," *Mt. Wilson Contr.*, No. 388; *Astrophysical Journal*, **70**, 265, 1929; Part II, "The Motions of the Hydrogen Flocculi near Sun-Spots," *Mt. Wilson Contr.*, No. 393; *Astrophysical Journal*, **71**, 55, 1930; and Part III, "Solar Eruptions and Their Apparent Terrestrial Effects," *Mt. Wilson Contr.*, No. 425; *Astrophysical Journal*, **73**, 379, 1931.

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both with wave-length and with time. Again and again I have been forced to content myself by watching transformations occurring within a few minutes, without being able to obtain a faithful series of drawings. The radial velocities of the various approaching or receding parts, it is true, can instantly be read on the circle of the line-shifter, and with their aid one can determine what is happening. But to put on paper the many successive events, differing for every wave-length, is another matter. It will therefore be understood why in Part II of this series of papers I attempted no more than to record schematically the general changes in character of a few significant flocculi, omitting all others and making no effort to show intricate details of structure.

The fact remains, however, that the most necessary data for similar partial analyses of the flocculi can be obtained by anyone. These data should include (1) the times of sudden changes or other critical events; (2) the approximate heliographic position of the object under observation; (3) the approximate forms of its various parts; (4) the reading of the circle of the line-shifter when each part is shown at maximum intensity, giving its radial velocity at that moment; (5) at least an estimate of the observed maximum intensities, especially in the case of exceptional eruptive phenomena likely to be associated with terrestrial magnetic storms.

1. *Time.*—As a rule, it will suffice to give the time of observations to the nearest minute, expressed in Greenwich Civil Time.

2. *Heliographic position.*—Most of the active flocculi occur near sun-spots, in which case the identification of the spot in question (from the Greenwich publications) will greatly aid in giving the approximate heliographic position. The correct orientation of every drawing, showing the direction of the sun's equator and the true cardinal points, is also needed.[1]

[1] The simplest method of determining the position (heliocentric latitude and longitude) of any point on the sun is with the aid of a set of the Stonyhurst cardboard disks, ruled with meridians and parallels, obtainable at low cost from Casella & Co., Parliament Street, London, S.W. 1. An excellent account of the use of these disks was given by the late Father Cortie in the *Memoirs of the British Astronomical Association*, **23**, Part II, 1921. To meet the needs of the simple telescope used with the spectrohelioscope, the disks may be photographed down to the diameter of the solar image, when focused on the first slit through a piece of deep-red glass.

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3. *Form.*—Sketches, even if merely schematic, should be drawn to scale. All the spots of the group, as seen on the continuous spectrum beyond the edge of $H\alpha$, should first be quickly sketched with a blue pencil; the most significant parts of the dark flocculi should then be added in black and the more important bright flocculi in red. Several such sketches of active flocculi may be needed for different positions of the line-shifter, followed by other sets of sketches made as the flocculi change in form and radial velocity. A small transparent glass scale,[1] mounted so that it can be turned into position close to the plane of the second slit, may be employed for measuring the areas of flocculi and their distance from spots, but during most of the observations it should be swung out of the way, as it interferes with the perception of the more delicate details.

4. *Radial velocity.*—This is given (with a probable error of 2 or 3 km/sec.) by the circle of the line-shifter, after it has been calibrated by determining the displacement in angstroms of any narrow sharp line near $H\alpha$ corresponding to each interval of 10° on both sides of the zero. For moderate circle readings the relationship will be linear, but a reduction table or curve will be needed to interpret the larger readings.[2]

[1] I have used with oscillating slits a linear scale 10 mm long, each millimeter divided into tenths, and a 7-mm square divided into smaller squares, made by the Leitz Co. for microscopes, on thin glass disks 15 mm in diameter. Either can be swung into place beneath the eyepiece, and rotated in position angle. The squares serve for the measurement of the areas of flocculi.

[2] To experienced spectroscopists, provided with wave-length tables and large-scale maps of the solar spectrum, the calibration of the circle will offer no difficulties. In several cases, however, the observers in our long chain of co-operating stations are not thus equipped. It may therefore be a convenience to provide here a photograph of the $H\alpha$ region, with the wave-lengths of the lines used in the calibration of my own instrument and an outline of the process. (Plate X*a*, *b*)

The wide $H\alpha$ line, in the deep red of the solar spectrum, occupies a region where the telluric lines caused by the gases of the earth's atmosphere are both numerous and variable. Their intensity and number change greatly with the altitude of the sun and the state of the atmosphere, so that the spectrum sometimes becomes almost unrecognizable. For determining the scale it is convenient to use two solar lines a short distance from $H\alpha$ toward the red, at wave-lengths 6569.460 and 6574.468. The linear distance between these lines in my spectrohelioscope, using the first order of the grating, is 1.21 mm. As the lines differ in wave-length by almost exactly 5 A, this means that 1 mm equals 4.13 A.

The distance between the lines can be measured with sufficient precision by means

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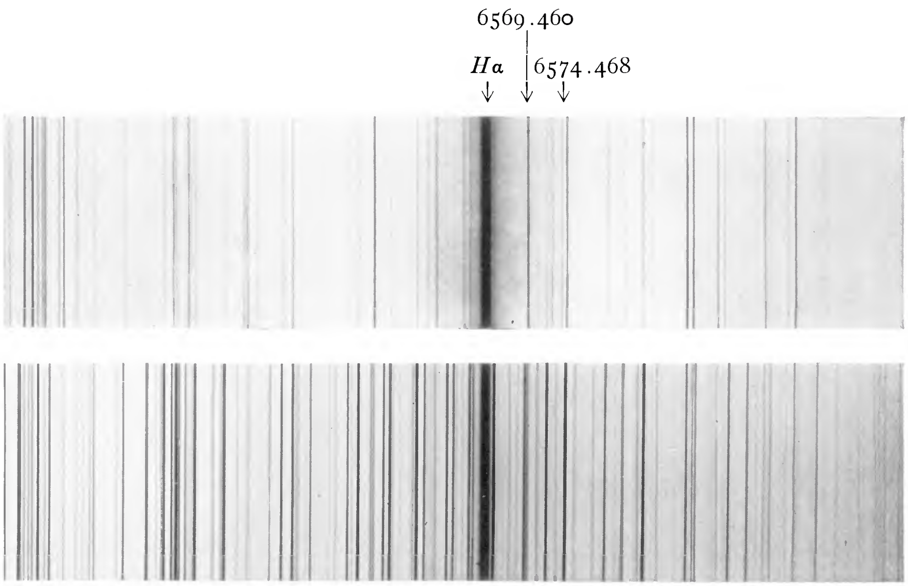
PLATE X

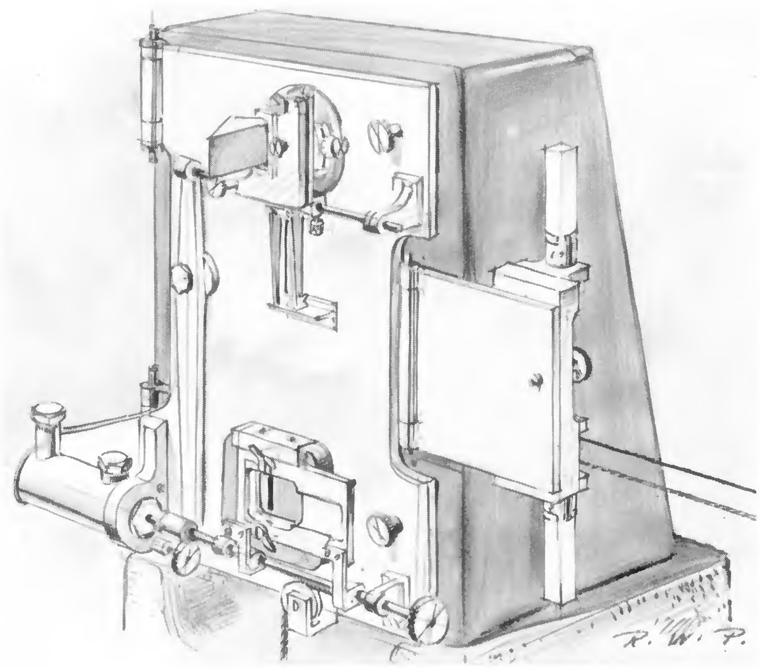


a

b

Hα region in solar spectrum: *a*, high sun; *b*, low sun, showing increased number of telluric lines.

c



Attachment for quickly transforming a spectroheliscope into a spectroheliograph.

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The circle reading giving the radial velocity is taken to be that at which the region of the flocculus in question, whether dark or bright, is of maximum intensity. An exception to this rule is occasionally shown by flocculi that exhibit maxima of intensity on both the red and violet sides of the center of $H\alpha$. In such cases the radial velocity may be uncertain. Objects especially calling for measurement are easily distinguished by turning the line-shifter back and forth and noting whether an arched flocculus, for example, shows at one extremity a maximum of intensity only on the red or the violet side of $H\alpha$, which moves toward its other extremity as the line-shifter is rotated.

5. *Intensity.*—For most purposes it will suffice to record the intensity of either bright or dark flocculi on a scale of 3, calling faint objects 1, those of moderate intensity 2, and those either very black or very bright 3. It must be remembered, however, that the intensity is determined by a great number of factors, including among others the nature and condition of the grating and the various optical parts employed, the widths of the first and second slits, and the amplitude of oscillating slits, or the size of the rotating prisms when Anderson's device is employed with fixed slits. Moreover, with a given instrument the apparent intensity of the flocculi

of the small linear scale divided to tenths of a millimeter mentioned in the last footnote. If the second slit of the spectrohelioscope cannot be opened wide enough to permit both lines to be seen at once, it may be removed altogether for this purpose. The millimeter scale is mounted in or very near the plane of the slit, and the lines and scale are observed with a positive eyepiece magnifying 8 diameters, clamped centrally above the glass scale.

It is assumed that the first slit has been narrowed sufficiently to make the solar lines very narrow and sharp, and that the circle of the line-shifter is set at zero when measuring the distance between them.

To calibrate the circle, turn the grating until the sharp iron line λ 6569.460 falls as close as possible upon the central division of the glass scale when the circle of the line-shifter reads zero. Then make two or more readings of the circle, turning it alternately to right and left, to check the coincidence and determine any necessary correction to the first approximate zero.

Repeat this process for each successive division of the glass scale. We then have a series of measures that will give the displacement in angstroms of a solar line corresponding to any reading of the circle. As a displacement of 1 A at $H\alpha$ corresponds to a radial velocity of 45.7 km/sec., the measurement of the radial motions in the solar atmosphere becomes a very quick and simple operation.

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or their parts also depends upon their distance from the center of the sun and the distance of the second slit from the center of $H\alpha$. The condition of the observer's eye is another important factor; the observing room should be as dark as possible, and the direct solar image should not be examined, at least with the same eye, just before looking at the flocculi.

For these and other reasons an exact measurement of intensity is difficult. Probably it could be obtained with the aid of a glass wedge of neutral tint, by comparing the point of extinction of the flocculus with that of a given part of the continuous spectrum not far beyond the wing of the $H\alpha$ line; or some other form of comparative photometer might be better.

When no photometer is used the value of the results will depend chiefly upon the experience of the observer, which will develop rapidly with practice.

PHOTOGRAPHIC RECORDS

The time will come, I hope, when the striking phenomena revealed by the spectrohelioscope in active regions of the solar atmosphere will be fully recorded with a suitable moving-picture attachment. The extremely rapid variations in brightness and velocity which they often exhibit, and the corresponding changes in structure shown by light of different wave-lengths, limit the possible exposures to periods too short for our present photographic plates, in spite of their sensitiveness. With more efficient instruments, giving much brighter spectra of adequate dispersion, I trust these difficulties may ultimately disappear.

Although a skilled draftsman, working rapidly, can sketch the principal phenomena, while one less skilled can at least indicate their general character, even a partial photographic record is desirable. I have accordingly devised an attachment for the standard spectrohelioscope which quickly transforms it into a spectroheliograph. This is similar in design to the moving-prism device used with the combined vertical spectroheliograph and spectrohelioscope in my Solar Laboratory in Pasadena, partially illustrated in Plates XXV, XXVI, and XXVII of the first article of this series.

The purpose of this attachment is not to give a spectroheliograph

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capable of photographing the entire solar image or its smaller details, but merely to utilize a certain type of spectrohelioscope for recording on a small scale a few striking and significant flocculi with light of various wave-lengths. The moving right-angle prism is therefore limited in dimensions, and the sensitive plate in the present case is only 1 inch square. With a 2-inch solar image this affords space for two or three successive photographs of the small part of the sun covered by an eruption on the disk. As the scale is so small, the various phenomena corresponding to any setting of the line-shifter are only roughly indicated in relative position, form, and brightness. Such a record will aid the visual observer in fixing the scale of his sketches; but if finer details of structure are desired, a larger solar image is needed, given by a coelostat telescope of larger aperture and more perfect construction than the small one described in my first paper.

Speed in operation is essential, and the apparatus shown in Plate X*c*, from a sketch kindly made by Russell W. Porter, is therefore designed to swing quickly into or out of position. The slit end of the 13-foot spectrohelioscope is assumed to be of the type shown in Plate XIX of my first paper, with fixed slits and Anderson's rotating prism. The rotating prism-support is mounted on pivots, so that it may instantly be turned out of the way when it is to be replaced by the spectroheliograph attachment. Thus when the observer detects some interesting phenomenon, such as an arch showing a wide range of radial velocity, he ascertains visually the two or three positions of the line-shifter that reveal its most characteristic features. He then turns the rotating prism to one side and swings the spectroheliograph attachment into place over the first and second slits. This permits him to photograph a strip of the solar image about a quarter of an inch wide, or large enough to include the region containing the flocculus in question. This exposure, we may assume, is made with the line-shifter set at the best position to show the approaching gases, i.e., so as to bring the necessary wave-length on the violet side of $H\alpha$ upon the second slit. Subsequent exposures may be made with light from the center of the line and then from the point on its red wing where the receding hydrogen is best shown. In practice, a larger number of photographs, corresponding to a greater

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number of wave-lengths, may be desirable. But it often happens near active spot-groups that the changes of radial velocity are so sudden that further visual observations are quickly needed to determine a new set of wave-lengths for another series of photographs which should be made without delay.

Mr. Porter's sketch is so clear that little explanation of the apparatus is necessary. The hydraulic cylinder to the left is similar to the clepsydra used to drive my original spectroheliograph at the Kenwood Observatory in 1892.[1] Its piston rod is attached to the end of the lever arm that moves the photographic plate across the fixed second slit, and a weight, hung from the cord at the bottom of the sketch, produces the motion. The upper end of the lever, half as long as the lower, moves the right-angle prism horizontally at half the speed of the plate. Under these circumstances the solar image and plate move at the same speed. The loss of light with this form of spectroheliograph is small, and the excellent contrast obtainable is shown by the series of five photographs reproduced in Plate XXIII*b–f*, in the first paper of this series.

These photographs, made with a precisely similar optical system, represent part of a 3.5-inch solar image given by a 6-inch spherical concave mirror of 30 feet focal length, used with the coelostat telescope of my Solar Laboratory. The parallel rays from the second mirror of this coelostat are sent vertically downward, and the spectroheliograph and spectrohelioscope stand parallel to each other, as illustrated in the paper just mentioned. Thus two observers can work simultaneously, one watching the rapidly changing structure of short-lived phenomena and determining the wave-lengths necessary to record them, while the other makes exposures with the spectroheliograph, which is provided with a line-shifter corresponding to that of the adjoining spectrohelioscope. In this way a greater number of photographs can be obtained in a given time, but even with the standard spectrohelioscope and smaller coelostat telescope, an attachment like that shown in Plate X*c* will enable a single observer to photograph the most significant phases of rapidly chang-

[1] A better hydraulic drive has been designed and will soon be tested. The arrangement shown here, however, will serve fairly well.

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ing flocculi sufficiently well to check the accuracy in scale of his sketches and give the relative positions, forms, and brightness of the many details involved.

If all the necessary information regarding the flocculi could be obtained from photographs taken at the center of $H\alpha$, the task of the observer would of course be greatly simplified. This, as we have seen, is not true of the active dark flocculi, which exhibit a great variety of significant changes in velocity and corresponding structure. The bright flocculi, however, usually have a very low velocity of approach, even in the case of the brilliant eruptions on the disk described in the third paper of this series.[1] Although their later stages may be accompanied by dark flocculi characterized by great velocities of approach or recession, the initial bright outburst, which usually seems to mark the critical moment needed in determining the time interval between solar and terrestrial disturbances, as well as the subsequent development of the bright flocculi, may be recorded with the second slit set on the center of the calcium (H or K) or the hydrogen lines.

If one of the calcium lines (preferably K) is used, a single-prism spectroheliograph of only 15 inches focal length will serve to photograph the bright flocculi during the various phases of such eruptions on the disk. A glance at the illustrations in Part III of this series of papers will show the importance of such a series of photographs, even if made with a small solar image and very simple apparatus. The small spectroheliograph I used on Mount Etna in 1894 in some attempts to photograph the solar corona without an eclipse[2] represents the type of instrument I have in mind. This would serve as a useful auxiliary of the spectrohelioscope, especially when bright eruptions are in progress. It would also be easy to modify it for use as an automatic instrument, to take photographs of the sun at regular intervals (say every five minutes) throughout the day for the purpose of recording all bright eruptions on the disk.

A very simple spectroheliograph of the same type, with small

[1] "Solar Eruptions and Their Apparent Terrestrial Effects," *Mt. Wilson Contr.*, No. 425; *Astrophysical Journal*, **73**, 379, 1931.

[2] *Astronomy and Astrophysics*, **13**, 662, 1894.

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coelostat telescope, both so designed that they can be made by any boy at trifling expense without the aid of machine tools, has recently been tested at my Solar Laboratory. This will be described, with full structural details, in the *Scientific American* for October, 1931. It was built by my instrument-maker, Mr. Hitchcock, who also constructed the apparatus shown in Plate X*c* and contributed in many ways to its design.

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Mount Wilson Observatory
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