THE SPECTROHELIOGRAPH AND THE SPECTROHELISCOPE

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The spectroheliograph was invented independently by George Ellery Hale (1868-1938) (Figure 1) and Henri-Alexandre Deslandres (1853-1948) (Figure 2) in 1890/1891. Robert Raynolds McMath /1891-1962) extended its functionality (1932) in order to take motions pictures of the Sun. G.H. Hale also invented the spectrohelioscope in 1924-1929.

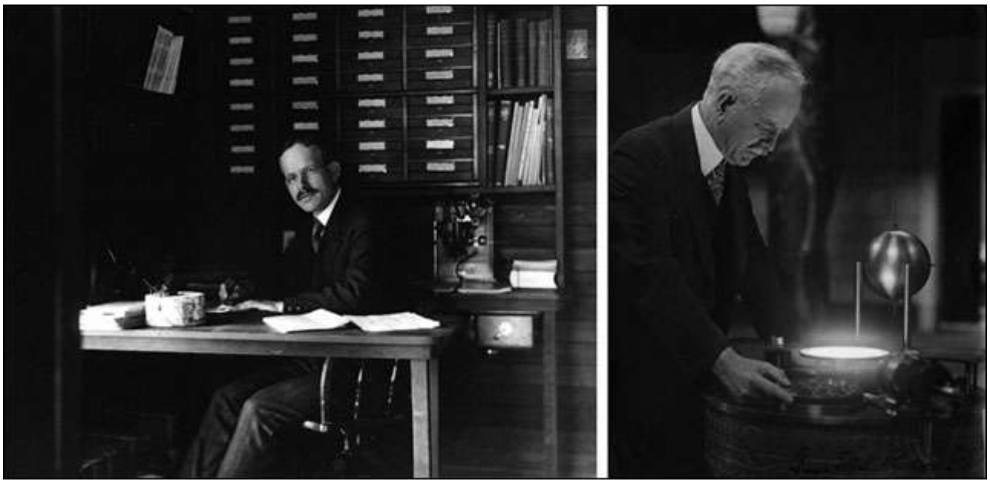

Figure 1- George Ellery Hale (1868-1938).

Figure 2- Henri-Alexandre Deslandres (1853-1948) (left) and the Meudon Observatory Spectroheliograph (right).

The principle of both the spectrohelioscope and spectroheliograph was described for the first time by Jules Jansen (1824-1907). Jansen observed for the first time the spectra of solar prominences in full sunlight during the total solar eclipse of August 18, 1868. A few months later, Jansen addressed the Paris Academy of Sciences describing its methods[1].

"Cette méthode consiste, dans son principe, à isoler dans le champ spectral un des faisceaux lumineux émis par la protuberance, faisceau qui est déficient dans la lumière solaire, et à transformer ensuite les elements linéaires des images protubérantielles dans les images elles-mêmes, par un movement rotatif assez rapide imprimé au spectroscope".

G.H. Hale invented the spectroheligraph very early in his scientific life, according to a letter that he wrote on August 5, 1889[2]:

"Of scientific work I have accomplished but one thing this summer, and even that did not involve much labor. It is the scheme for photographing the prominences, and after a good deal of thought I can see no reason why it will not work. The idea occurred to me when I was coming home from uptown the other day and it amounts to this. Stop the clock of the equatorial and let the sun transit across the slit, which is placed radial do the limb. Bring H into the field of the observing telescope, and replace the eyepiece by a plate-holder held in a suitable frame, and drawn by clockwork across the field at the same rate as the sun crosses the slit. As the H line lengthens and shortens – as it will do with the variable height of the prominence, the plate will photograph its varying lengths side by side and thus produce and image of a prominence. That is the idea in the rough, but I have studied it out in detail, and designed a travelling plate holder, which I will have Brashear make. I have also got an arrangement by which all fog is avoided and I have great hopes that the thing will be a success. It is is, new changes for work of the prominences will be opened, and in this way the changes during short intervals of time can be noted with much greater accuracy than in drawings".

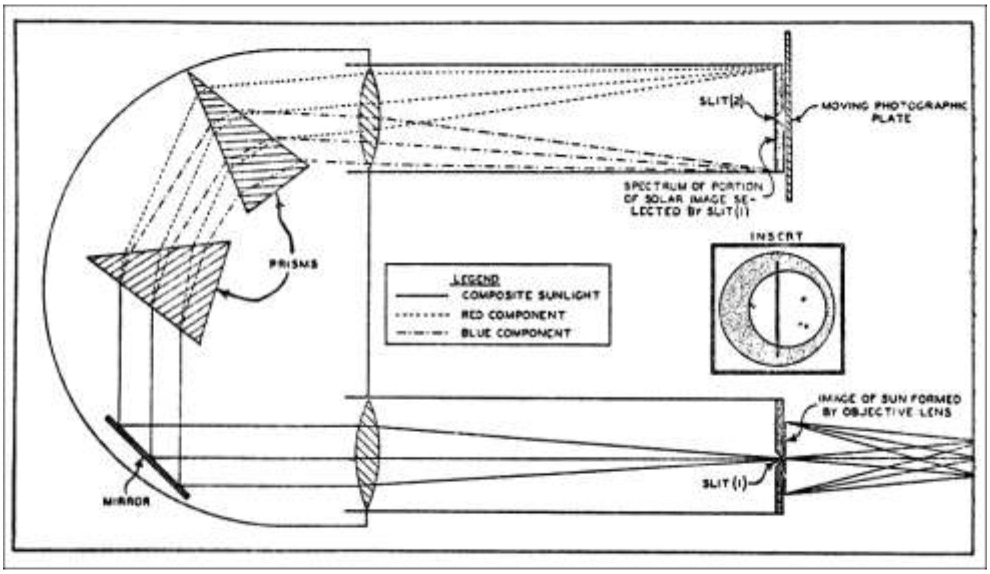

Figure 3- Principle of the spectroheliograph: Slit (1) selects a particular segment of the solar image; Slit (2) isolates a particular wevelenth in the spectrum of that segment and allows it to impress its image on the photographic plate. As the sun's image is made to move across the slit (1), the photographic plate moves in synchronism with the second slit (2). In this way a photographic image of the sun, in a particular wavelength, is composed segment by segment.

[1] Hale, G.H. (1929). The spectroshelioscope and its works. Part I. History, instruments, adjustments, and methods of observation. The Astrophysical Journal, Volume LXX, number 5: 265-327.

[2] Wright, H. (1966). Explorer of the Universe. A biography of George Ellery Hale. Clarke, Irwin & Company Limited, Toronto and Vancouver.

The principle of the spectroheliograph is very simple according to Hale's own words[3]:

"Its object is to build up to a photographic plate a picture of the solar flames, by recording side by side images of the bright spectral lines which characterize the luminous gases. In the first place, an image of the sun is formed by a telescope on the slit of the spectroscope. The light of the sun, after transmission thought the spectroscope, is spread out into a long band of color, crossed by lines representing the various elements. At points where the slit of the spectroscope happens to intersect a gaseous prominence, the bright lines of hydrogen may be seen extending from the base of the prominence to the outer boundary. If a series of such lines, corresponding to different positions of the slit on the image of the prominence, were registered side by side on a photographic plate, it is obvious that they would give a representation of the form of the prominence itself. To accomplish this result, it is necessary to cause the solar image to move at a uniform rate across the first slit of the spectroscope, and, with the aid of a second slit (which occupies the place of the ordinary eyepiece of the spectroscope), to isolate one of the lines, permitting the light from this line, and from no other portion of the spectrum to pass through the second slit to a photographic plate. The principle of this instrument thus lies in photographing the prominence through a narrow slit, from which all light is excluded except that which is characteristic of the prominence itself. It is evidently immaterial whether the solar image and photographic plate are moved with respect to the spectroheliograph slits, or the slits with respect to the fixed solar image and plate" (Figure 3).

The subject of Hale's graduation thesis at the Massachusetts Institute of Technology was "The Photography of Solar Prominences". While preparing this thesis, Hale spent every available moment at Harvard observatory. The director of the observatory, Edward Charles Pickering (1846-1919) was very much interested in Hale's invention. He offered the use of the 15-inch refractor but it turned out that the spectroheliograph build by Brashear was too heavy to be attached to the end of the wooden tube. It was decided to adapt it to a 12-inch horizontal refractor without much progress being made due mainly to bad weather. Finally in 1890, Hale obtained some interesting first results. He wrote in his thesis:

"On April 14 a cool breeze was blowing, making the seeing fair in spite of a little whiteness in the sky. A hasty examination of the limb discovered a prominence in a good position for the work, and a photograph was made through F, the slit being about 0.0005 inch wide. On developing the plate, the outlines of two prominences could be seen rising above the limb. As only one prominence had been noticed in observing the point in question, I returned to the telescope, and found that there were in fact two prominences in the exact position shown in the photograph (…) Given a good refracting equatorial and a plate very sensitive to the longer waves of light, I am confident that the spectroscope and attachments described in this paper will be sufficient to produce prominence photographs of real value for study and measurement".

[3] Wright, H. (1966). Explorer of the Universe. A biography of George Ellery Hale. Clarke, Irwin & Compary Limited, Toronto and Vancouver.

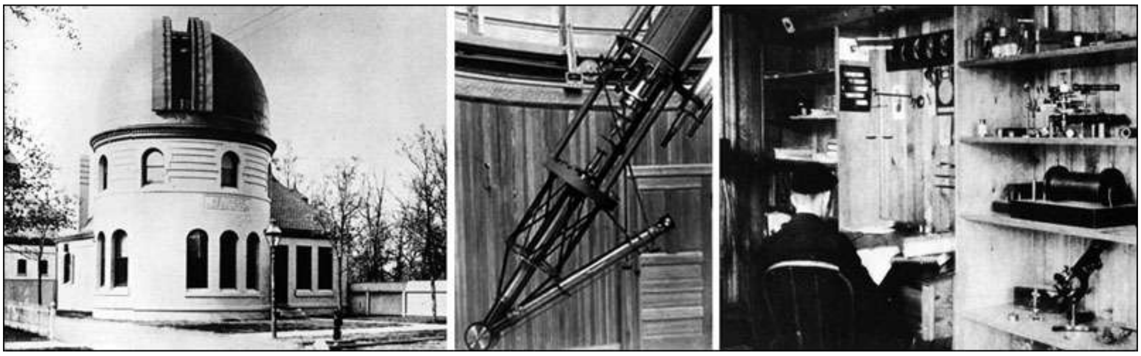

Figure 4- Kenwood observatory (left), spectroheliograph attached to the 12-in refractor (center), G.E. Hale in the Kenwood laboratory (left).

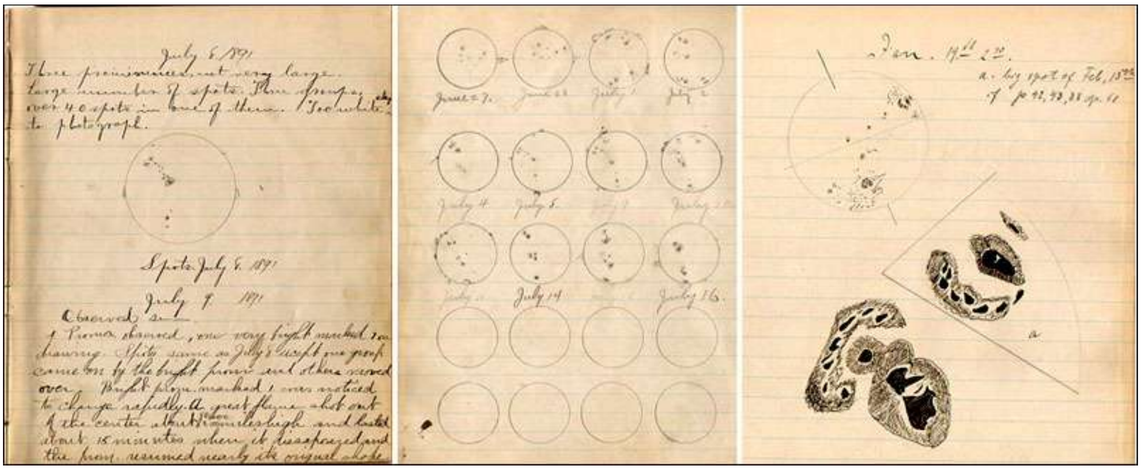

Figure 5- Sunspot drawings by G.H. Hale "Kenwood Astro-Physical Observatory" notebook, June 22, 1891 to January 2, 1893.

Hale used extensively the spectroheliograph at the Kenwood observatory[4]. Kenwood's principal instrument was a 12-inch refractor which was used with the spectroheliograph (Figure 4, Figure 5). Hale hired Ferdinand Ellerman as an assistant; years later, the two would work together again at the Mount Wilson Observatory.

Several years later, Hale designed a large horizontal refractor, the Snow telescope that was to be installed at the Mount Wilson observatory. The Snow telescope had a 24-inch mirror with a 60-foot focal length. This instrument, provided with a high-dispersion spectrograph, was built by George Willis Ritchey (1864-1945). It was tested in October 1903 at the Yerkes observatory and mounted at Mount Wilson in 1905 (Figure 6, Figure 7).

[4] The Kenwood Astrophysical Observatory was the personal observatory of George Ellery Hale, constructed by his father, William E. Hale, in 1890 at the family home in the Kenwood section of Chicago.

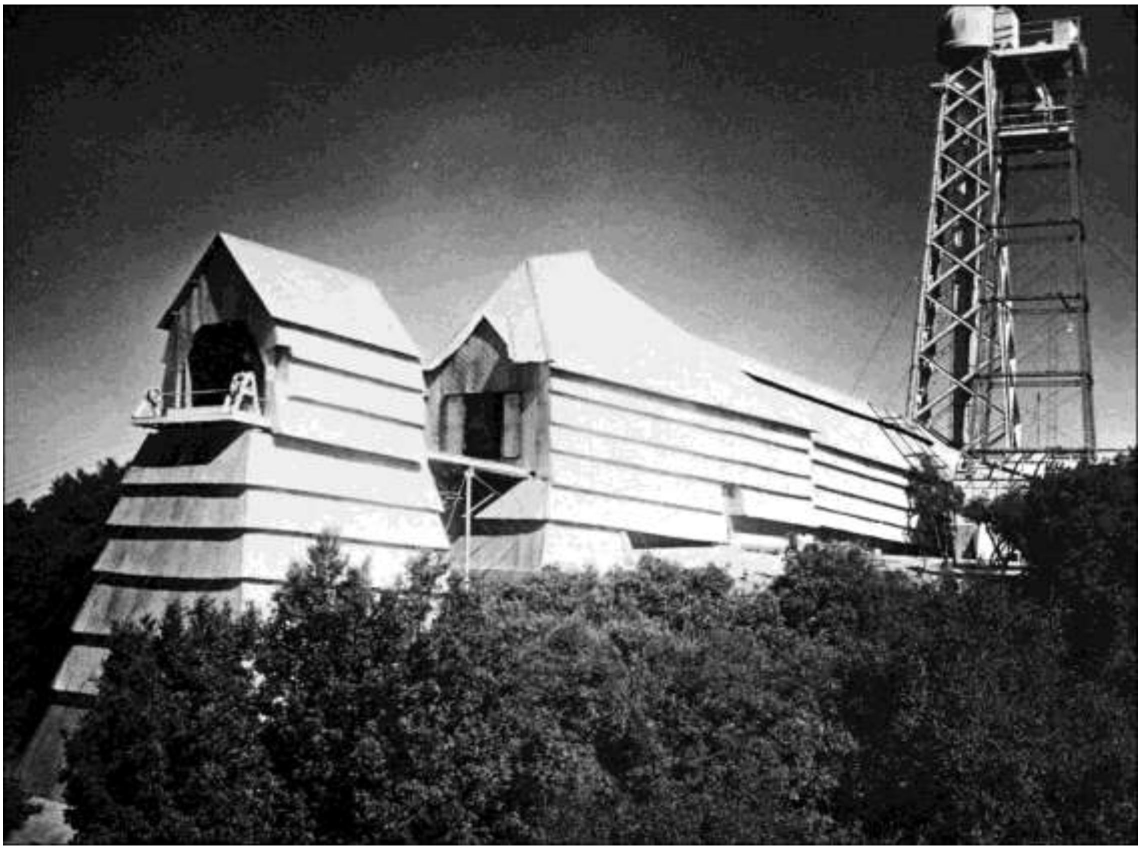

Figure 6- Snow telescope at Mount Wilson observatory (*ca.* 1905). The 60-foot tower telescope is seen in the background.

The Snow telescope consisted of a heavy cast-iron platform mounted on four steel balls which run in V guides of hardened steel. Most of the weight of the instrument was floated on mercury contained in three troughs which formed part of the cast-iron base. The platform carried the two slits, the collimator and camera objectives and the prism-train. An image of the sun, about 6.7-inches in diameter, was formed by the Snow telescope on the collimator slit. This slit was long enough to extend entirely across the solar image and most prominences. After passing through the slit the diverging rays fall upon the 8-inch collimator objective. With the new spectroheliograph designed specifically for this telescope, Hale was able to photograph the distribution of the white-hot clouds of individual gases that float above the sun's surface. Using a high-speed shutter, Hale recorded most of the features of the chromosphere, with great detail. The results surpassed his "greatest expectations" and were far superior with he had attained with the 40-inch Yerkes refractor (with an attached spectroheliograph). With this telescope Hale published some of the first papers related to solar research performed at Mount Wilson.

In 1924/1929, Hale invented the spectrohelisocope. According to Hale[5], this instrument permitted:

"The visual observation and analysis of the forms and motions of prominences at the sun's limb and of bright and dark flocculi on the disk".

[5] Hale, G.H. (1929). The spectroshelioscope and its works. Part I. History, instruments, adjustments, and methods of observation. The Astrophysical Journal, Volume LXX, number 5: 265-327.

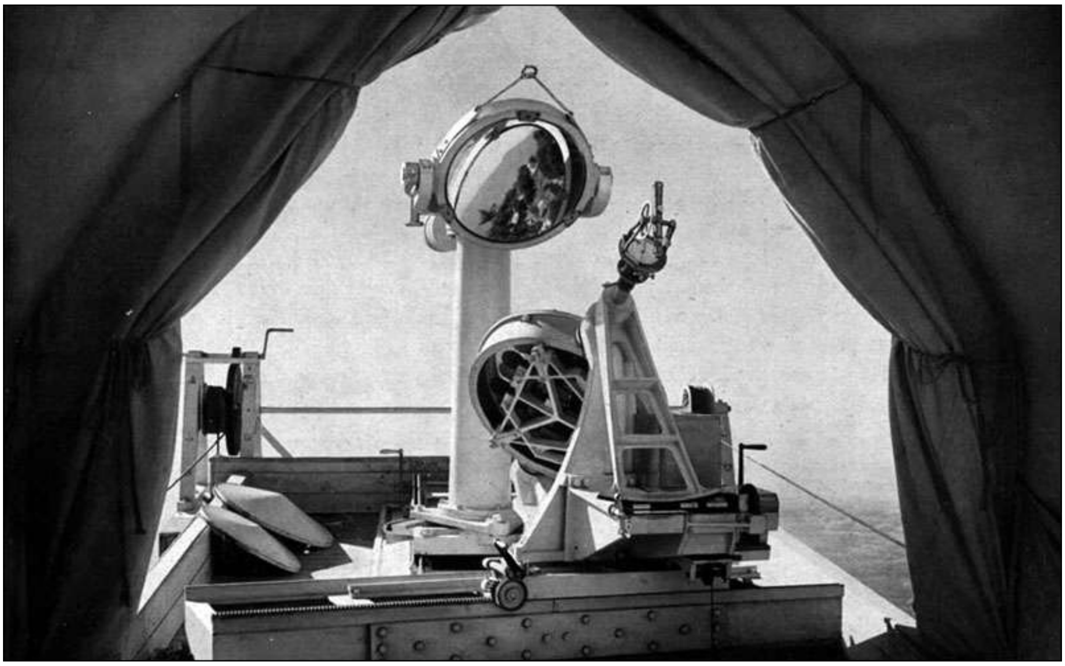

Figure 7- Coelostat of the Snow horizontal telescope.

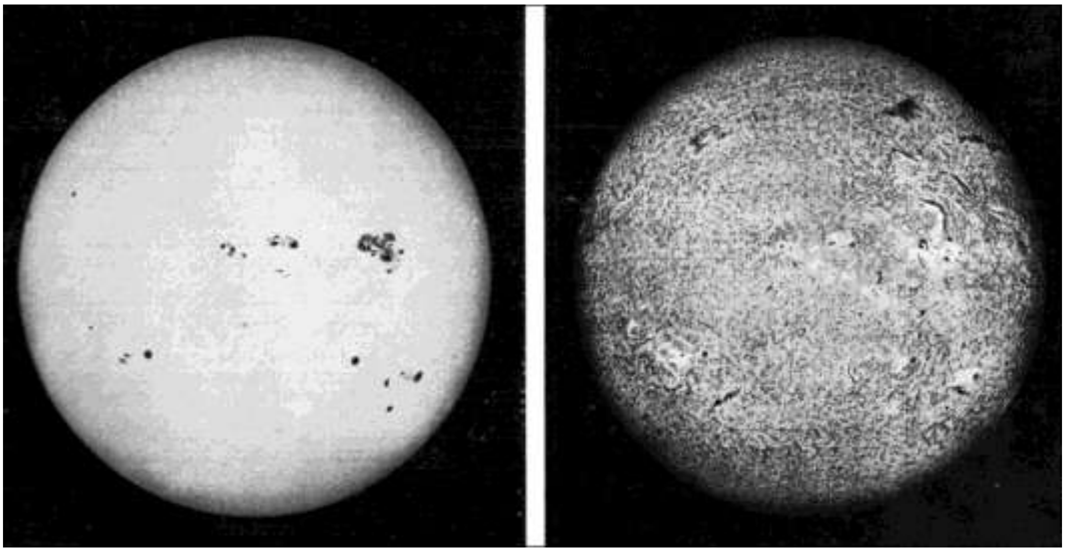

Figure 8- The sun in visible light (left) and in H-alpha (right). Mount Wilson observatory, August 12, 1917.

This instrument, described by Hale in 1929[6], consisting of a horizontal coelostat telescope and a spectrohelioscope, could be used in a wide variety of observations. Two oscillating slits of variable amplitude or a pair of square prisms rotating before the fixed slits were used to give a monochromatic image of a portion of the sun, usually with H-alpha line:

"Soon after we obtained on Mount Wilson the first spectroheliograms of the hydrogen flocculi with the H-alpha line, it occurred to me to try to observe their forms visually with the 30-foot spectroscope of the 60-foot tower telescope. This vertical spectroscope was of the Littrow type, with the slit in the optical axis of the tower telescope and an opening for a photographic plate at one side.

[6] Hale, G.H. (1929). The spectroshelioscope and its works. Part I. History, instruments, adjustments, and methods of observation. The Astrophysical Journal, Volume LXX, number 5: 265-327.

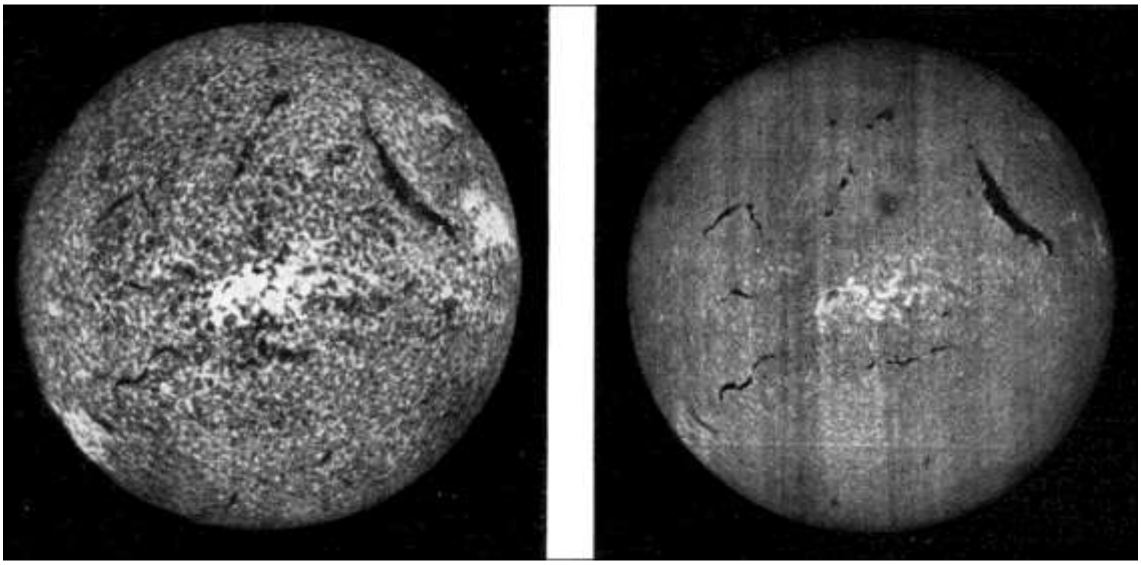

Figure 9- Spectroheliographs obtained at Meudon observatory: Calcium (left) and H-alpha (right). March, 21, 1910.

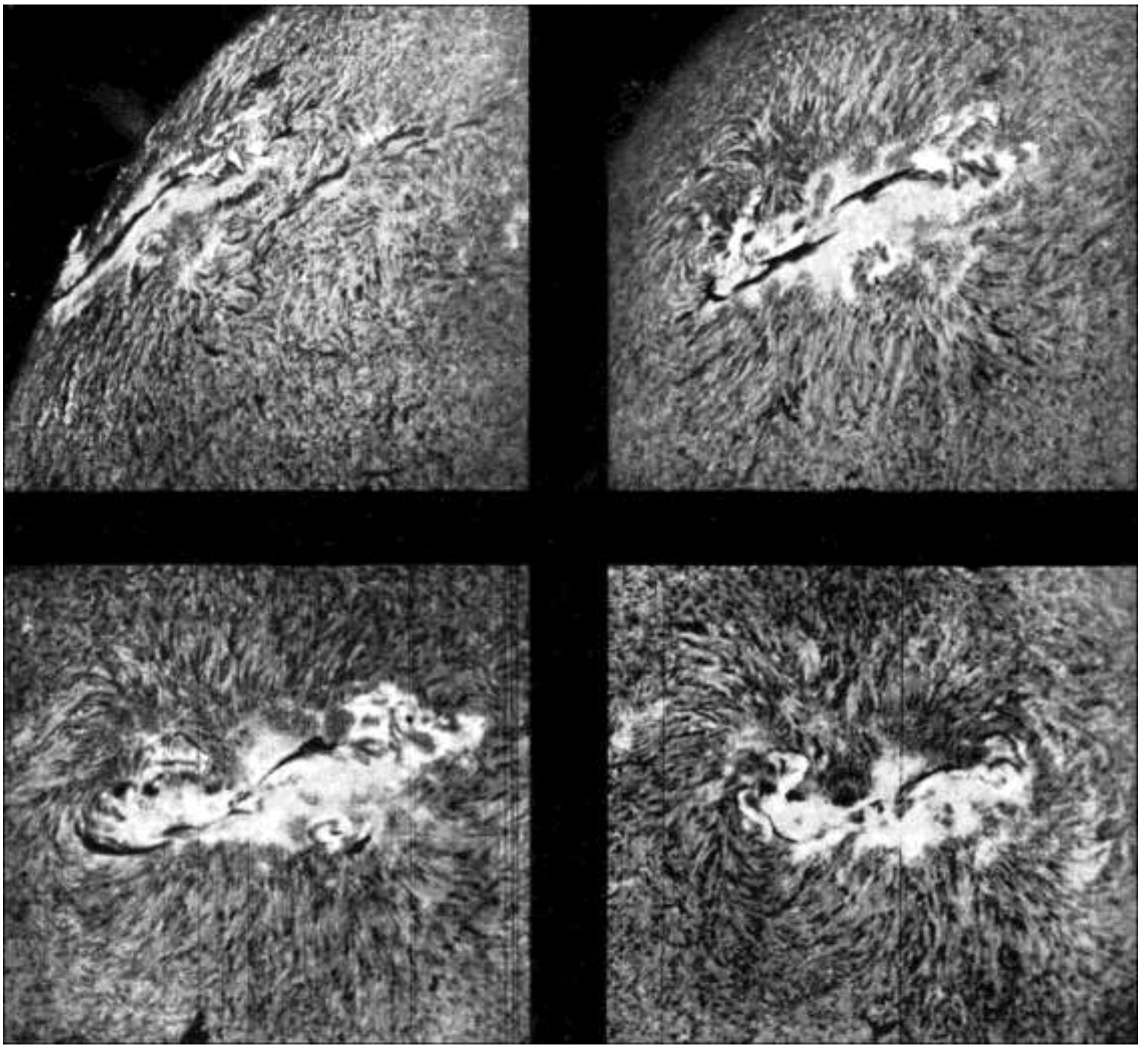

Figure 10- Spectroheliograph images (H-alpha). Mount Wilson observatory, August, 3, 5, 7 and 9, 1915.

Thus a second slit could be placed in the plate-opening in line with the first slit, an arrangement used when the instrument was employed as a spectroheliograph, either with a grating or with a large liquid prism mounted at the bottom of the 30-foot pit. The distance between the slit and centers is 6 inches, and it was a simple matter to mount in their place a circular brass disk, with its vertical bearing halfway between them. This disk was provided with a number of radial slits, which successively served in pairs as the first and second slit of a spectrohelioscope. As the first slit moved to the right, the corresponding H-alpha line moved with the opposite slit at the same speed to the left, assuming the adjustments to be properly made and the field restricted so that only one pair of slits was illuminated at any time. Thus the observer, using a low-power positive eyepiece or a single lens focused on the second slits, should see a monochromatic image of a portion of the sun.

Hale described an inexpensive spectrohelioscope that consisted of: (1) a telescope, which in its simplest and least expensive form comprises a coelostat, second mirror, and sigle lens; (2) a spectroscope, of about 13-feet focal length, of the reflecting Littrow type; (3) a pair of oscillating slits or a similar device for producing the necessary rapid motion of the slits and solar image.

The general arrangement of this spectrohelioscope is shown in Figure 11 and Figure 12.

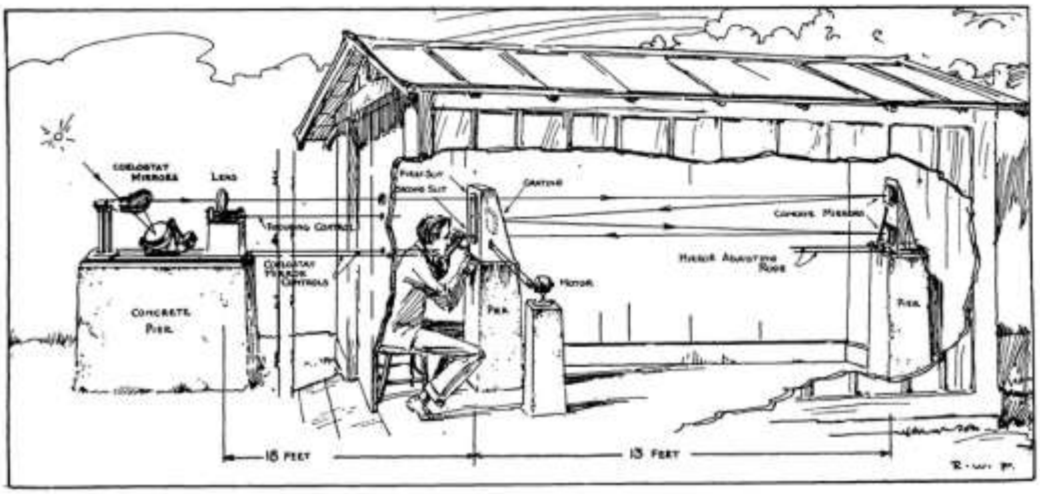

Figure 11 – Coelostat telescope and spectrohelioscope. Drawing by Russel W. Porter (1929).

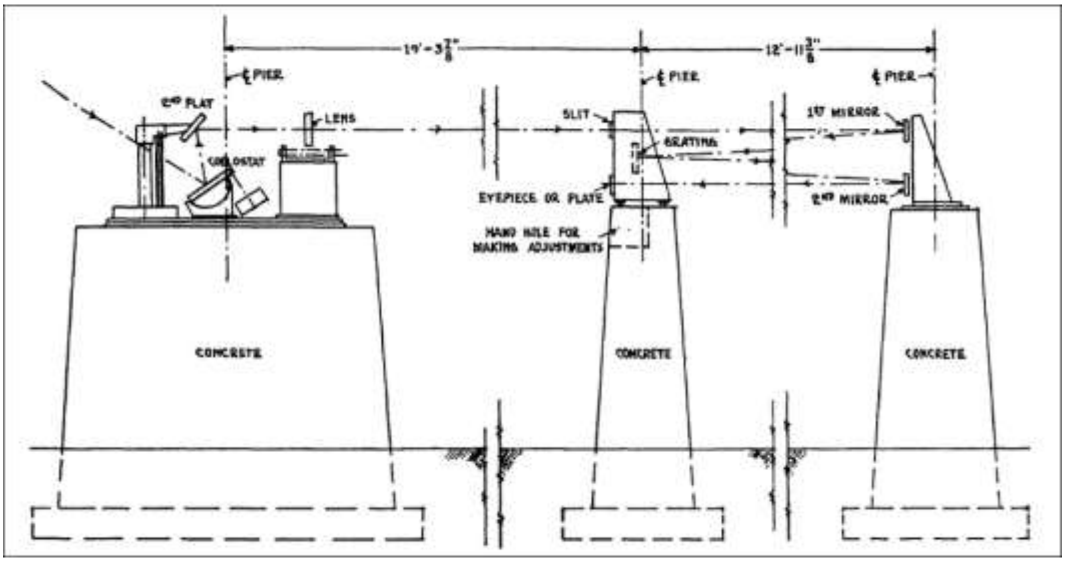

Figure 12- Concrete piers for the coelostat and spectrohelioscope.

The coelostat consisted of two mirrors of 5½-inches and 4½-inches of ordinary plate glass, ½–inch thick with silvered front surfaces plane to about a quarter of a wave (Figure 13). This coelostat was driven by clock movement and slow motions for rotating and inclining the second mirror, thus bringing any part of the solar image upon the first slit of the spectroshelioscope. The objective lens could be focused by the observer (a single lens was employed).

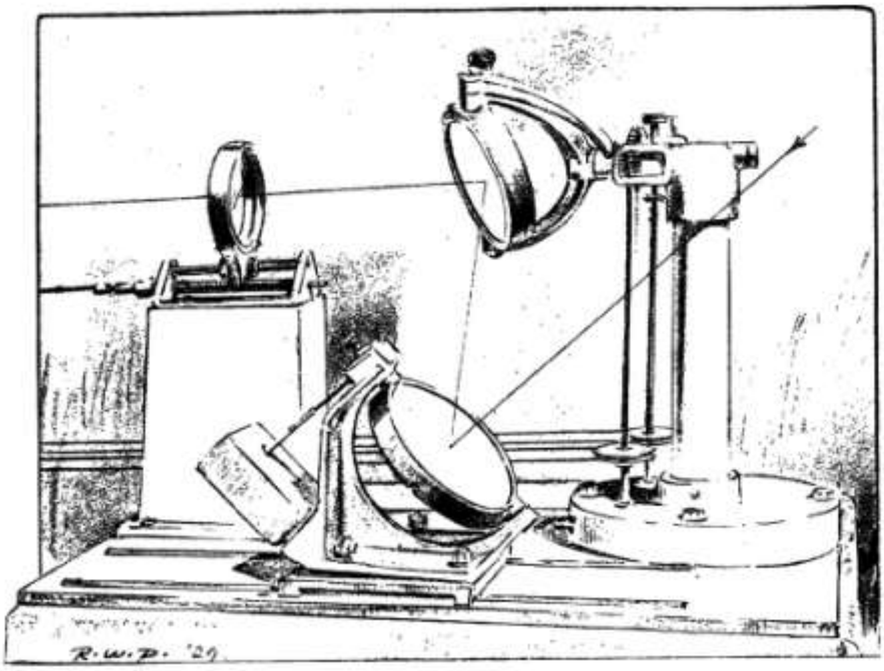

Figure 13- Coelostat, second mirror and telescope lens. Drawing by Russel W. Porter (1929).

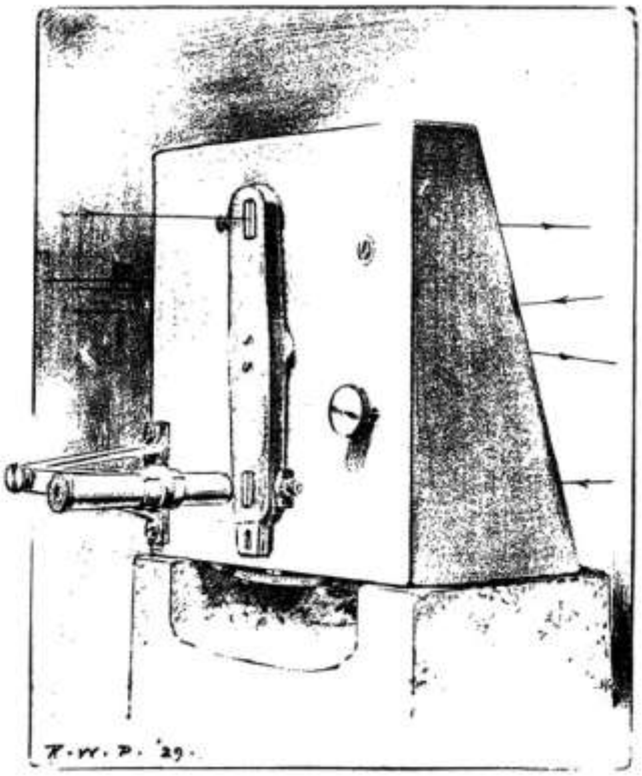

Figure 14- Oscillating slits and eyepiece of the spectrohelioscope. Drawing by Russel W. Porter (1929).

The design of the spectroscope is shown in Figures 15 and 16. The rays diverging from the first slit fall on a spherical concave mirror 3- inches in diameter, which renders them parallel and return them to a grating. The grating is set at such an angle as to return the spectrum to a second concave mirror identical to the first. This is illuminated only by the region centering on the line employed (usually H-alpha). The lower concave mirror forms an image of the spectrum on the second slit and the sun image can be observed through a positive eyepiece or single lens.

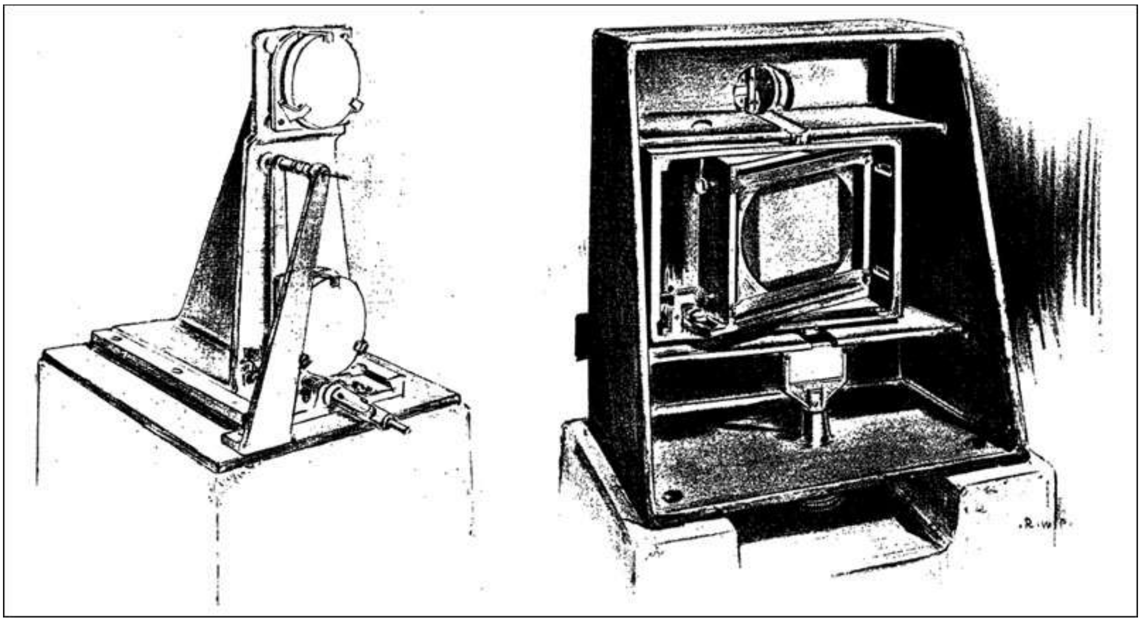

Figure 15- Concave mirrors of the spectroheliospcope (left) and grating support and line-shifter.
Drawing by Russel W. Porter (1929).

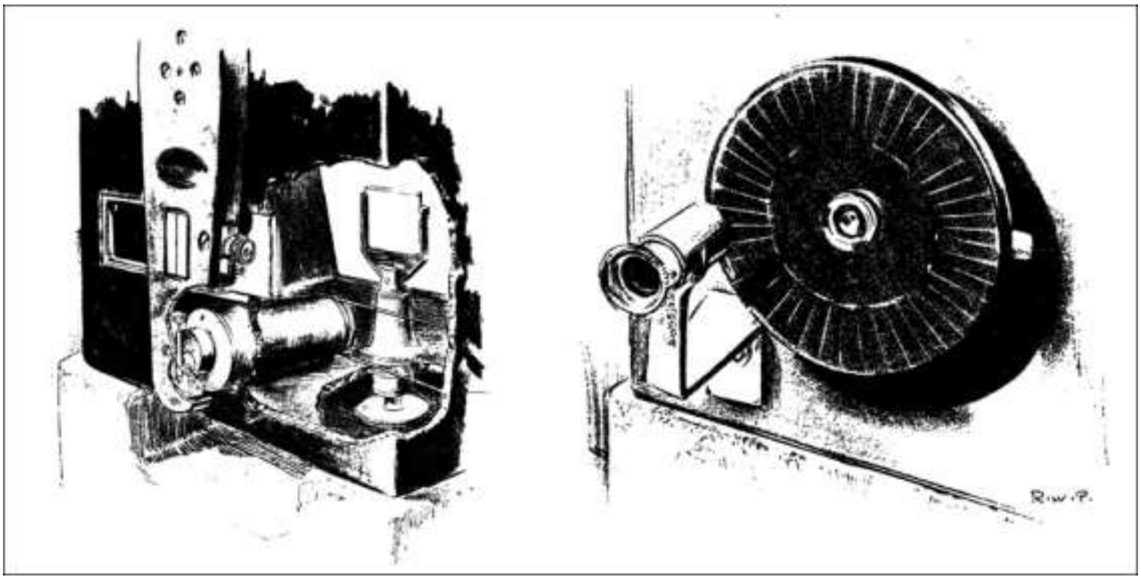

Figure 16- Second slit, driving mechanism, line-shifter (left) and spinning disk with radial slits (right).
Drawing by Russel W. Porter (1929).

Sources:

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