THE TOWER TELESCOPE OF THE MOUNT WILSON
SOLAR OBSERVATORY

BY GEORGE E. HALE

In a previous paper\textsuperscript{2} I have outlined some of the conditions to be
met in designing a fixed telescope for solar research. The change of
figure of the mirrors on exposure to the sun, and the disturbance of
the definition caused by heated currents of air rising from the ground,
are the principal difficulties encountered. Since exposure to sunlight
ordinarily produces actual bending of the mirrors, the use of very
thick disks is naturally suggested. Again, since currents of warm air
rising from the earth rapidly become mixed with cooler air at higher
levels, a point of observation even 50 or 60 feet above the ground
offers very definite advantages. Accordingly, the design adopted and
described in my paper consists of a coelostat with very thick mirrors,
mounted at the summit of a skeleton steel tower about 65 feet in height.
The second mirror used with the coelostat stands near the center of
the tower and sends the beam vertically downward through a 12-inch
(30.5 cm) visual objective, by Brashear, of 60 feet (18.29 m) focal
length (Fig. 1). The image of the sun is thus formed by this objective
at a point about 5 feet (1.5 m) above the level of the ground, within a
small building standing at the base of the tower.

It will be seen that the arrangement described comprises the follow-
ing points of advantage: (1) great thickness of mirrors, to reduce
astigmatism and rapid change of focal length; (2) the use of an objec-
tive, instead of a concave mirror (as employed in the Snow telescope),
giving the shortest possible path between the coelostat and the focal
plane and greatly decreasing the change of focal length experienced
with a concave mirror; (3) the use of a vertical beam of light, with
less probability of disturbance across the wave-front than in the case
of a horizontal beam. Moreover, this type of telescope is well adapted
for use in connection with an underground laboratory, in which power-

\textsuperscript{1} Contributions from the Mount Wilson Solar Observatory, No. 23.
\textsuperscript{2} Contributions from the Solar Observatory, No. 14; Astrophysical Journal, 25,
68–74, 1907.
Fig. 1.—Section through upper end of Tower
PLATE XXIV

THE TOWER TELESCOPE
The Snow Telescope appears in the background
ful spectrographs and other instruments requiring constancy of temperature and freedom from vibration can be mounted.

Soon after the publication of the paper cited, a special grant from the Carnegie Institution permitted the construction of the "tower" telescope to be undertaken. On account of the great pressure of work in our own instrument shop, it was not feasible to construct here the coelostat and the mounting for the second mirror and objective, or the Littrow spectrograph. Accordingly, the former were built by Brashear, and the spectrograph by Gaertner, from our working drawings. The steel tower, purchased from the Aermoter Company of Chicago, was set up on Mount Wilson last July. The coelostat mirror, 17 inches (43.2 cm) in diameter and 12 inches (30.5 cm) thick, and the elliptical mirror, also 12 inches thick, with major axis of $22\frac{1}{2}$ inches (56.5 cm) and minor axis of $12\frac{1}{2}$ inches (32.4 cm), were both made in our optical shop under the direction of Mr. Ritchey. All of the other parts of the instrument, including the platform at the summit of the tower, the rails on which the coelostat carriage slides, the vertical shaft and driving mechanism for moving the 12-inch objective (when the instrument is used with a spectroheliograph), the house at the foot of the tower, supports for the spectrograph, etc., were built by our own workmen.

Plate XXIV is reproduced from a photograph of the tower telescope. In the original design an outer tower, covered with canvas louver, was provided to protect the inner one from the wind. However, on account of the importance of avoiding convection currents, which might result from heating of the outer tower, it was thought best to try the experiment of using the inner tower alone, without wind protection. This has proved so satisfactory that it is hardly likely the outer tower will be added. In a windy country a single tower would not be stable enough, but on Mount Wilson, where the average wind velocity during the best observing hours, especially in summer, is very low, the present arrangement seems likely to suffice. The use of a number of steel guy ropes is of course essential.

* This photograph was taken from a point northeast of the tower, and shows the Snow telescope house in the background. The small shelter standing on the south side of the platform at the summit of the tower is placed over the coelostat when the telescope is not in use.
Fig. 1 shows, in general outline (from the north), the arrangement of the apparatus at the summit of the tower. The coelostat carriage stands on rails, which permit it to be moved north and south. As the best definition is obtained with the low morning or afternoon sun, the apparatus is designed to give the greatest efficiency at such times. When observing the morning sun, the coelostat stands on the west rails, its position in a north-and-south line being determined by the declination of the sun for the date in question. When it is to be used for afternoon observations, the coelostat is transferred, by means of a carriage rolling on east-and-west rails, to the rails east of the second mirror. The second mirror is then turned so as to face the coelostat mirror, and the beam sent vertically downward as before.

The object-glass, which stands just below the second mirror, is mounted in a support which can be moved vertically, for focusing, by a steel tape controlled by a hand-wheel near the focal plane (Plate XXV). It can also be moved in an east-and-west direction by means of a screw connected with a vertical shaft driven by an electric motor in the house at the foot of the tower. The image of the sun can thus be made to move at a uniform rate across the collimator slit of a spectroheliograph, the same motor being employed to move the photographic plate, at the same rate, across the camera slit.

Plate XXV shows the slit-end of the 30-foot spectrograph, in the house at the base of the tower. The underground chamber in which the spectrograph stands is a circular well, 8 1/4 feet (2.6 m) in diameter and 30 feet (9.1 m) deep. The walls are built of concrete and contain several layers of building paper, heavily coated with tar, to make them perfectly water-tight. Having once been thoroughly dried out, the walls have since shown no traces of moisture.

The spectrograph has proved to be an extremely satisfactory instrument. It is of the Littrow or auto-collimating type, and the construction is very simple. A slit, 2 inches (51 mm) long, is mounted at the end of a short tube at the center of the circular iron casting which forms the upper extremity of the instrument. This casting is connected with another iron casting at the bottom of the underground chamber by means of a skeleton steel tube (Fig. 2). The lower cast-

---

1 The vertical shaft appears in the drawing and photograph, but many of the details of the connections are not shown.
SLIT-END OF THE THIRTY-FOOT LITTROW SPECTROGRAPH
ing terminates in a hemispherical head, which rests on a cast-iron support mounted on a concrete pier. Thus the spectrograph can easily be rotated about a vertical axis,\(^1\) by means of a gear-and-pinion attached to the iron ring which defines the position of the upper casting (Plate XXV). A large divided circle permits the position angle of the slit to be read.

Light from the solar image, after passing through the slit, falls on a 6-inch (15.2 cm) visual objective, by Brashear, of 30 feet (9.1 m) focal length, mounted near the lower end of the skeleton tube (Fig. 2). This lens can be moved vertically for focusing, by means of a rod terminating near the slit. The grating, mounted in a support just below the objective, can also be rotated from above by a similar rod. Scales giving the position of the objective and the angle of the grating can be read with a small telescope from the upper end of the instrument by the aid of electric illumination.

\(^1\) This axis is actually inclined a few degrees from the vertical, to afford space for the 30-foot spectroheliograph, which will occupy a symmetrical position on the east side of the well.
The image of the spectrum is formed on a plate 17 inches (43 cm) long, carried in a plate-holder which can be moved parallel to itself, by rack-and-pinion, so as to permit a large number of narrow spectra to be photographed side by side. The width of the exposed portion of the plate is defined by two adjustable bars, standing a short distance in front of the plate, and independently movable by rack-and-pinion. The plate is shielded from reflected light by a bar placed across the collimating-camera objective. The plate-holder can be inclined so as to make an angle greater than 90° with the incident beam, but with the visual objective employed this is necessary only in the violet.

The spectrograph is furnished with several pieces of auxiliary apparatus, including a device for bringing to the slit light from opposite ends of a solar diameter (employed in spectrographic observations of the solar rotation); a similar device permitting spectra of the center and the limb of the sun (or some point lying between limb and center) to be photographed simultaneously; and a moving plate-holder, with two slits, which permits the spectrograph to be converted into a spectroheliograph.

The first tests of the tower telescope showed that rapid changes of focal length need not be feared. In the Snow telescope these changes are very different on different days, and frequently amount to several inches after the mirrors have been exposed ten minutes to the sun. Moreover, the focal length is increased by such exposure, which would naturally be the case if the heating caused the mirrors to become convex. A considerable part of the effect is doubtless to be attributed to the distortion of the concave mirror, but the change of figure of the two plane mirrors is also an important factor, as is demonstrated by the marked evidences of astigmatism presented by the solar image after continuous exposure of the mirrors. In the case of the tower telescope, when used in the early morning, there is no appreciable change of focal length after the mirrors have been exposed to the sun for about half an hour. Later it appears that the focal length is gradually decreasing, and by noon, after continuous use of the instrument, the change may amount to from four to six inches. In the afternoon the focal length increases, finally returning to the early morning value.

It is evident that the conditions here are very different from those encountered in the case of the Snow telescope. In fact, exposure to
PLATE XXVI

\[ \lambda_{5134} \quad \lambda_{5151} \quad b_1 \quad b_3 \quad b_5 \quad b_7 \]

REGION OF $b$ LINES IN SPECTRUM OF SUN AND SPOT
The scale is that of Rowland's Map
sunlight seems to have very little influence on the figure of the mirrors, which continues to change in the manner above outlined even when both mirrors are shielded from the sun. The observed change of focal length must then be due to the change in temperature of the air. With such thick mirrors, the gradual heating of the air during the morning hours would result in expansion of the edges, causing the front and rear surfaces to become concave. This would produce astigmatism which, however, has not yet been noticed before eleven o'clock in the morning, and is not serious until a later hour. Thus the changes in the image are not of such a character as to give serious trouble, since the definition holds well during several hours and the change of focal length is slow enough to permit long exposures to be given. Hence the purpose for which the telescope was built has been accomplished. Nevertheless, the evidence goes to show that the mirrors are thicker than they should be, and for this reason their thickness will probably be reduced as soon as circumstances permit.

The second point to be considered is the quality of the image as affected by the condition of the air about the telescope. To test this, simultaneous observations have been made on several occasions with the Snow and the tower telescopes. In order to make the tests as fair as possible, the aperture of the Snow telescope was stopped down to 12 inches, and the mirrors were exposed to the sun for so short a time as to obviate any such effects of poor definition as would arise from their change of figure. In all cases it has been found that the tower telescope gives a more sharply defined image, the improvement in the "seeing" being from one to two points on a scale of ten. With the Snow telescope, all of the work requiring good definition must be done within a period of about an hour in the early morning or late afternoon. With the tower telescope, the definition is excellent during a much longer period. In fact, except for an interval near noon, this instrument can be kept in active use throughout the day for observations of an exacting nature.

The great focal length of the 30-foot spectrograph has also proved highly advantageous. The only grating available for work in the higher orders is a 4-inch (10.2 cm) Rowland, formerly employed at the Kenwood and Yerkes observatories, and used on Mount Wilson in all of our observations with the 18-foot (5.49 m) Littrow spectro-
graph. In my experience in photographing sun-spot spectra, which began at the Kenwood Observatory in 1891, I have used this grating in spectrographs of 42½ inches (1.08 m), 7 feet (2.13 m), 18 feet (5.49 m), and 30 feet (9.1 m) focal length. A decided gain has invariably resulted from each increase of focal length, even in the spectra of the third and fourth orders. The grating is not a perfect one, but its definition may be called good. In the 30-foot spectrograph of the tower telescope the ruled surface, being but 53×83 mm, of course receives only a small part of the light from the 6-inch objective, which is completely filled by the solar beam. In spite of the long exposures thus required, our recent photographs of sun-spot spectra, though taken under the unfavorable atmospheric conditions of November and December last, are decidedly superior to those obtained with the 18-foot spectrograph and the Snow telescope during the best observing period last summer, when much larger spots were available. The photographs reproduced in Plate XXVI, on Rowland’s scale, were widened with a pendulum apparatus which does not retain the full sharpness of the original negatives. A more perfect device, now under construction, will be used in making the enlargements required for our new map of the spot spectrum. This is to replace the preliminary map, a few copies of which were distributed last year to observers taking part in the co-operative study of sun-spot spectra initiated by the International Solar Union.

The photographs not only show many new spot lines; some of them also bring out for the first time bright reversals similar to those observed visually by Mitchell. Since such reversals may prove of great importance in the interpretation of spot spectra, they will receive careful attention.

Besides serving for the photography of spot spectra by Mr. Adams and myself, the tower telescope has enabled us to continue and extend our comparative study of the spectra of the limb and center of the sun. Moreover, the remarkable results obtained by Mr. Adams in his spectrographic determination of the rotational motion of hydrogen in the sun¹ were derived from photographs made with the 30-foot spectrograph. As for work with the spectroheliograph, I have been confined, pending the completion of the 30-foot instrument, to preliminary

¹ Contributions from the Mount Wilson Solar Observatory, No. 24.
experiments with the spectroheliograph attachment of the 30-foot spectrograph. With the aid of a 5-inch grating, which is very bright in the first order, I have secured a few photographs of sun-spot regions with iron and hydrogen lines. These show that a long-focus spectroheliograph of the Littrow form will give excellent results. The use of two camera slits, permitting photographs of the same region to be taken simultaneously with different lines, has been tested and found to be very satisfactory. This method is indispensable for accurate comparisons of the forms and positions of the floculi of different elements, and will find many applications in our future work.

February 1908