An atlas of representative stellar spectra from 4870 to 3300

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Chapter IV.

CHAPTER IV

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DESCRIPTION OF THE SPECTROSCOPES IN USE IN THE OBSERVATORY

THE two principal telescopes in the Observatory, as has been stated in the chapter on the "History of the Observatory," consist of a refractor of 15 inches aperture, and a Cassegrain reflector with metal specula of 18 inches aperture; both instruments carried together on the same mounting in Right Ascension, by the clockwork, but moving independently in Declination.

Each instrument is provided with its own spectroscope.

THE 15-INCH REFRACTOR.

The illustration represents the principal spectroscope, furnished with its micrometer for use by eye, and rigidly attached by means of three steel tubes to the eye-end of the telescope.

We borrow the description of this spectroscope which I wrote for *Astronomy and Astrophysics* (No. 117) in 1893:

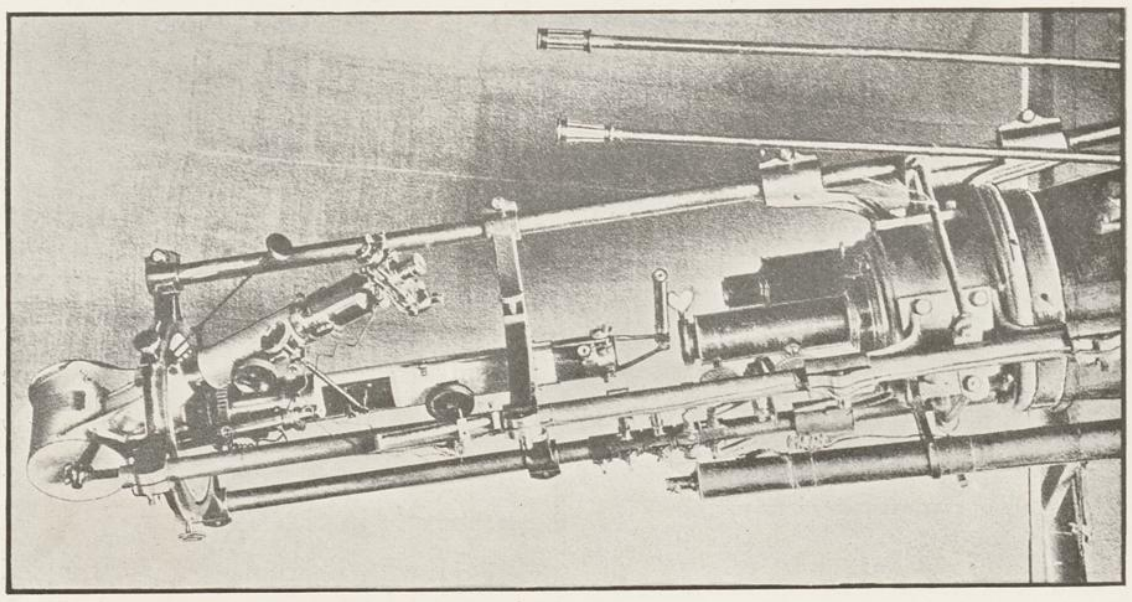
This instrument was designed primarily for the purpose of mounting, upon

Initial.—The border is reduced with slight adaptation from the title-page of the *Kalendarium* of Regiomontanus, printed by Ratdolt at Venice, 1476. The earliest known ornamental title-page. Designed by Lady Huggins.

the 15-inch Refractor belonging to the Royal Society, a fine 4-inch Rowland grating which was furnished to me by Mr. Brashear.

A condition of fundamental importance in the adaptation of the spectroscope to the telescope is that the instrument shall remain perfectly rigid in all its parts relatively to each other, and also to the optical axis of the telescope, in all positions of the telescope. It appeared to me that this condition would be most certainly secured by making the spectroscope complete and rigid in itself, independently of its attachment to the steel tubes, by which it is supported. The spectroscope if removed from the telescope would remain a complete and rigid instrument.

The firm attachment of this spectroscope to the telescope is carried out



SPECTROSCOPE MOUNTED ON THE EYE-END OF THE 15-INCH REFRACTOR.

by means of three steel tubes $1\frac{3}{8}$ inch external diameter, which slide in three long brackets strongly bolted to the iron eye-end of the steel tube of the telescope. These tubes, as can be seen in the photograph, are further held together and formed into a stiff supporting cage by two iron ring brackets through which they pass. The ring-bracket near the ends of the tubes supports the heavy part of the spectroscope, consisting of the grating and prism box; the other ring-bracket supports the collimator near the slit end, and strengthens the tube-cage near the middle of its length.

By means of adjusting screws in these ring-brackets the axis of the collimator can be brought into line with the optical axis of the telescope. The other necessary adjustments are also provided for. By the large milled head on the top of the collimator, the spectroscope, as a whole, can be moved so as to bring the slit to the focal plane of the object-glass for the part of spectrum under observation; and a fine graduation on the sliding tube enables this adjustment, and also any similar adjustment that may be required for changes of temperature, to be found at once after the necessary data have been obtained. The adjustment of the collimator lens can be made by a smaller milled head. By an arrangement, which explains itself in the photograph, the collimator and telescope can be focussed simultaneously.

The collimator, and the telescope, fixed at an angle of 25°, are firmly attached to the grating-box, and are further secured from relative flexure by a gun-metal collar fitting into the iron ring-bracket.

The grating is mounted in an air-tight metal case, provided with shutters to open when it is in use. This case slides into the box against a fixed point, so as to secure the grating always taking up the same position. A prism of 37°, silvered on one face, similarly mounted, can take the place of the grating when small dispersion is required.

The grating, or prism, is movable about the axis of the box, by a rod which is placed conveniently for the hand of the observer. At the top of the box, which is strengthened internally by metal compartments, a sector is fixed on the movable axis, which is graduated on silver, and is read by a small telescope. The graduated edge of the sector, which can be illuminated by a small incandescent lamp, is divided into spaces of 5′, and reads by the aid of the vernier to 10″.

The telescope of the spectroscope is provided with a micrometer by Troughton and Simms, the fine webs of which are very successfully illuminated simultaneously from both sides from one small incandescent lamp, on an original plan devised by them. The amount of illumination can be varied by means of a small resistance coil to suit the object under observation. With the feeble illumination which is necessary for most celestial spectra, it is not easy to read the number of whole revolutions of the micrometer screw, in the usual way, from the teeth of the comb. A simple form of a revolution-counter is geared into the outer rim of the micrometer head, and turns with it without sensible friction. The micrometer heads and their revolution-counters can be illuminated at pleasure by means of two small movable incandescent lamps suitably placed above them. The micrometer-screw has 100 threads to the inch; and when the second order of the grating, ruled to 14,438 to the inch, is in use, about $\frac{23}{100}$ of a revolution are equal to one-tenth metre.

The collimator and telescope have thin cemented lenses of $2\frac{1}{4}$ inches diameter; that of the collimator is provided with a diaphragm reducing it to 2 inches, which is its effective aperture; as the collimator has a focal length of 24 inches, and the object-glass of the telescope a ratio of $\frac{f}{12}$. The telescope of the spectroscope has a focal length of 18 inches, and is provided with four eye-pieces magnifying respectively 12, 18, 22 and 29 diameters.

For photography the eye-part of the telescope can be replaced by a camera, and the whole instrument rotated through 90°, so as to bring the length of the slit in the direction of the star's motion.

The grating-box can be uncoupled from the collimator and removed from the supporting iron ring, and replaced by a battery of glass prisms, the same telescope and micrometer, or photographic lens and camera, being then attached.

A novelty in this instrument, which will be seen at once to be one of great practical importance, consists of a simple but very effective arrangement by which a star can be brought at once, and kept steadily, within the jaws of the slit. For my primary photographic work on the spectra of the brighter stars, I devised in 1875 a method of bringing and keeping a star within the slit, which is figured and described in my paper "On the Photographic Spectra of the Stars" (*Phil. Trans.* 1880, p. 673):—

"A round thin plate of polished silver, 1½ inch in diameter, with a narrow opening in the middle rather longer and wider than the slit itself, was fixed over the slit of the spectroscope. This forms a plane mirror, and when the telescope has been brought approximately into position by its finders, the bright image of a star is seen somewhere upon the plate by looking into a Galilean telescope fixed in the place of the eyepiece of the Cassegrain telescope. Now, if at the same time artificial light is thrown upon the plate, it becomes itself visible, and thus the opening in it, and the slit within the opening, can be distinctly seen at the same time as the image of the star as a bright point upon it. By the aid of this arrangement there is no difficulty in bringing the star's image by the slow-motion handles of the equatorial readily and with precision upon any part of the slit. As the position of the star's image even upon the slit itself can be seen, the image being somewhat wider than the slit and therefore not wholly lost within it, it is possible to keep the star in view upon the slit during the whole time the photograph is being taken; and to correct instantly by hand any small departure of the star's image from its proper place upon the slit."

Some improvements, and modifications of the original plan, have been made to suit the conditions of a spectroscope applied to a refracting telescope. Slit-jaws of speculum metal have been substituted for the silver plate used in 1875. This metal answers the purpose admirably, as it receives and maintains a high polish, and can be fashioned to take very smooth and true edges for the slit.

If the polished surfaces of the jaw-plates were in a plane perpendicular to the optical axis of the telescope, the light after reflection would return upon its path. The plane in which these surfaces lie is, therefore, slightly inclined so as to throw the reflected light sufficiently to one side of its original direction to be caught by a suitably formed reflecting prism placed just outside the converging rays from the object-glass. This prism is provided with a suitable optical arrangement of some magnifying power, and is shown in the photograph in position for use.

At night, when the telescope is directed to the heavens, if the eye is placed at this reflecting eyepiece, a field of stars of about 5′ in diameter is seen together with the slit crossing it. Very often the faint illumination of the sky is sufficient to enable the slit to be seen; but if necessary, a feeble artificial light can be thrown upon the polished surfaces, so as to make the slit visible, but without interfering with the visibility of the images of even faint stars. It is obvious that by means of this arrangement it is quite easy to bring, and also to keep steadily, a star image upon any part of the slit. In the case of suitable double stars wider than about 3″, the component images are seen well apart, and either of them can with ease be brought and kept within the slit-jaws. So also in the case of planets and nebulæ there is no difficulty in selecting any small part of one of these objects for separate spectroscopic examination.

This reflecting eyepiece is hinged, and when not in use can be turned down out of the way to give room for a large diagonal eyepiece for viewing celestial objects directly, without removing the spectroscope from the steel tubes.

The slit is also provided with the usual reflecting eyepiece, which can be pushed in behind it. I pointed out in my paper of 1879 (*loc. cit.*) that in photographing the spectra of the stars the necessary breadth can be most conveniently obtained by the plan now universally employed, of giving a small motion to the star's image in the direction of the length of the slit. For eye observations it is still necessary to have recourse to cylindrical lenses. For a great number of years I have minimised the inconveniences which such lenses introduce by using the plano-concave instead of the usual plano-convex form.

Perhaps the least objectionable way of using them, is to have three, or more, of different cylindrical curvatures fitted into a small brass slide, which goes immediately in front of the eye-lens, and fits equally the different eyepieces. The lens giving the most suitable breadth can be brought into use, and if it be of concave form, without in the least disturbing the focal adjustment of the eyepiece.

If it be preferred to place the cylindrical lens before the slit, the advantage in respect of light will be seen to be in favour of the plano-concave form.

The arrangement for comparison spectra is attached to one of the tubes, a reflecting prism of 90°, sending the light upon the small movable prism immediately in front of the slit. The optical arrangement is such as to completely fill the lens of the collimator with the light which furnishes the spectrum for comparison.

I cannot refrain from expressing my admiration of the great rigidness of every part of the apparatus, as well as of the extremely fine definition both when the prism and the grating are in use; for which the highest credit is due to Messrs. Troughton and Simms; and also to Mr. Brashear for the high qualities of the grating.

The 18-inch Cassegrain Reflector.

The spectroscopes provided for this telescope have been designed for obtaining photographs of stellar spectra, which include the ultra-violet region. Their optical parts, therefore, consist exclusively of substances transparent for ultra-violet light—namely, Iceland spar and quartz.

It is scarcely necessary to say that it was with these spectroscopes, attached to the reflector, that the photographs of stellar spectra reproduced upon the Plates of this volume have been obtained.

We may again quote from the *Astrophysical Journal* (May 1895, p. 359), for which Journal I wrote a description of the principal ultra-violet spectroscope in 1895.

The Ultra-Violet Spectroscope.

The spectroscope which I designed and had constructed during the seventies for my original work on photographing the spectra of stars,* was arranged to include the whole of the ultra-violet region of the light from the heavenly bodies which reaches the earth.

I had at my command a refractor of 15 inches aperture, and a Cassegrain telescope of 18 inches aperture, both belonging to the Royal Society. I chose the latter instrument for my work, notwithstanding the drawback of some want of permanency of the collimation of the mirrors, on account of the freedom of a reflector from the outstanding chromatic aberrations of a refractor, and also because by the employment of Iceland spar for the prism and quartz for the lenses, the whole of the more refrangible part of the spectrum could be photographed, at least as far as the absorption of our atmosphere allows rays of small wave-length to pass.

The Cassegrain telescope, which has mirrors of speculum metal of very fine defining power, was made by Sir H. Grubb. In 1882 it was mounted, by the novel device of a double declination axis, one axis moving within the other, as a twin telescope, together with the 15-inch refractor, upon the same equatorial stand. This instrument has been used chiefly for spectroscopic work, but last year advantage was taken of the fine definition of the specula to make some crucial observations of the character of the image of Nova Aurigæ.†

The early arrangement employed in 1876-79 consisted essentially of a small

* "On the Photographic Spectra of the Stars." *Phil. Trans.* 1880, Part ii., p. 669.

† In this instrument, which is of course free from chromatic aberration, the images of Nova Aurigæ and of the star near it were indistinguishable in character under a magnifying power of 700 diameters. Both appeared equally stellar. *A. N.* 3211. *A. and A.*, April 1894, p. 314.

spectroscope containing a single prism of Iceland spar, and lenses of quartz, the slit of which was placed in the principal focus of the great speculum, 18 inches in diameter, of the Cassegrain telescope, the small convex speculum having been removed.

In this instrument the plan was adopted for the first time of turning the jaw plates of the slit into mirrors, in which the objects to which the instrument was directed could be seen by reflection at the same time as the slit itself. In the first instance polished silver was used for the reflecting substance; afterwards very thin plates of quartz, silvered at the back, the edges of which formed the slit; and finally, in the new spectroscope attached to the refractor,* speculum metal was found to fulfil very satisfactorily the necessary conditions of giving a permanently reflecting surface, and furnishing true edges for the slit. In this early instrument the images of celestial objects reflected from the mirror-jaw plates were observed through the hole in the great speculum by means of a small telescope fixed in the place of the eyepiece.

The advantage which this form of spectroscopic arrangement possessed of reducing the loss of light by reflection to that at the surface of one speculum only, was accompanied by some drawbacks. The spectroscope, though made as small as possible, was larger than the 4-inch hole in the speculum, and blocked out some light. The adjustments of the spectroscope itself, and also of its relation to the speculum, could only be made with some inconvenience, at the top of the tube. For the same reason, unless the telescope was directed to an object very low down, it was necessary, at some loss of time, to unclamp it in declination and bring the spectroscope-end within reach in order to insert or to change the photographic plate.

There was the further disadvantage that, in consequence of the large ratio of aperture to focal length of the great speculum, namely, $\frac{f}{7\frac{1}{2}}$, the collimator had to be made very short. Consequently, with one prism, to which the spectroscope was necessarily restricted on account of size, either light or the necessary purity of the spectrum had to be sacrificed. If the slit were opened wide enough to just include, or even nearly so, the image of a star, its angular magnitude relatively to the dispersion was too great for the needful resolution of lines, and therefore, as a matter of fact, the slit was always used too narrow to receive more than a part of the light of a star, with the great disadvantage of long exposures.

The new instrument is free from these disadvantages; though in one respect it comes short of the earlier arrangement, since there is additional loss of light from reflection at the second speculum. The Cassegrain telescope is restored to its original form, and, the collimator of the new spectroscope passing up through the hole in the large speculum, the slit is placed within the

* See the description of the spectroscope attached to the refractor, pp. 48, 49.

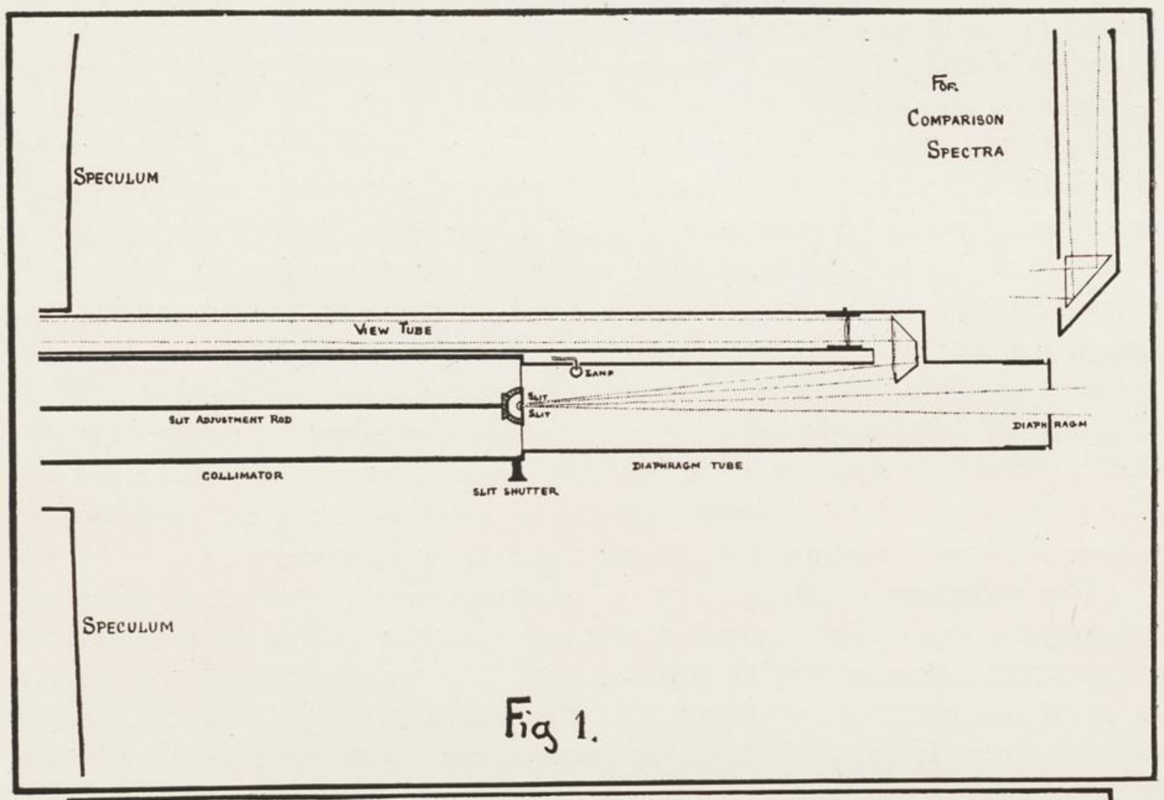


Fig 1.

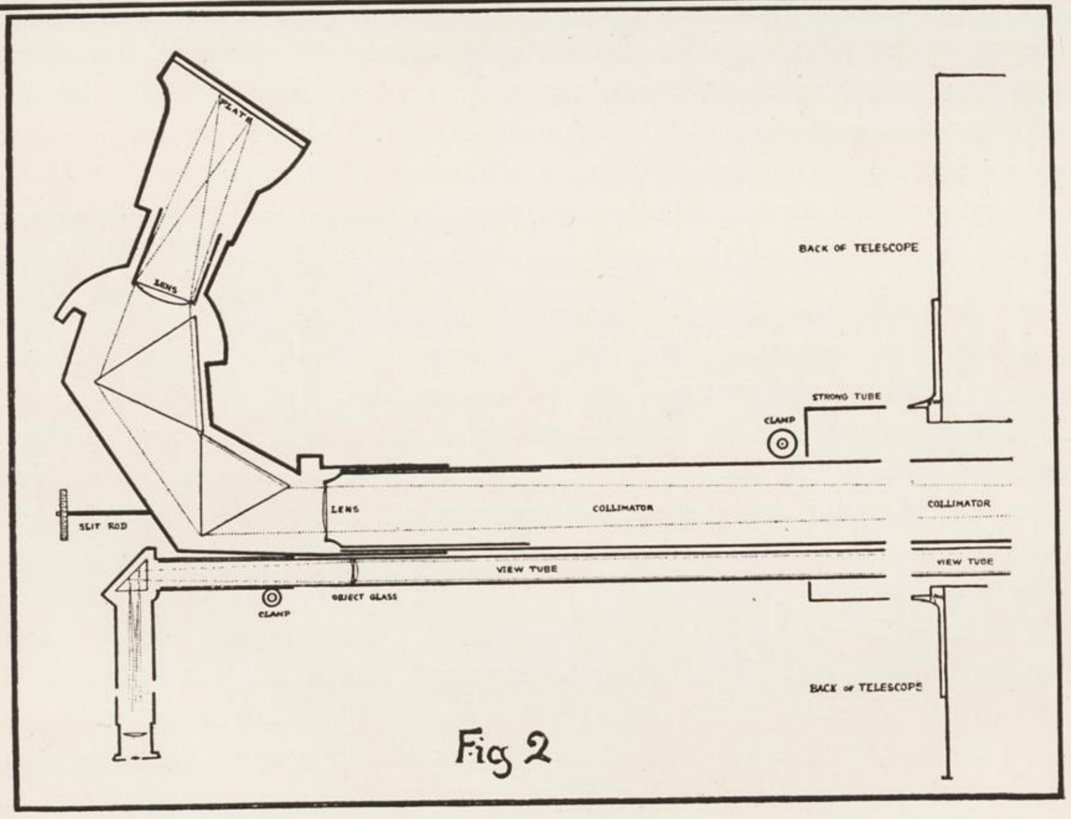


Fig 2

Ultra-violet Spectroscope.

telescope tube at the focal plane after reflection from the small convex speculum.

In Fig. 1 the collimator is seen within the telescope tube; in Fig. 2 the remaining part of the spectroscope, outside and below the telescope tube, is shown.

Returning to Fig. 1, the diagram explains itself. The slit is adjusted by means of a rod, which in Fig. 2 is seen to pass below the spectroscope and to terminate in a graduated head.

Behind the slit slides a small shutter which closes the central half of the slit, to protect the part of the plate on which the star's spectrum falls, when, either before or after exposure, narrow comparison spectra are photographed through the outer parts of the slit, above and below the star's spectrum.

In front of the slit extends a tube 12 inches long, furnished at the end with a sliding diaphragm having an opening of such a size as to exclude all light except that reflected from the small convex mirror.

A very successful arrangement of the slit-mirror method has been adopted, by which the slit, together with a small field of stars, can be conveniently seen by an observer looking into the diagonal eyepiece, shown in Fig. 2. This eyepiece, by means of the clamp, can be brought into, and then fixed, in the position which is most convenient for observation. The polished slit-plates of speculum metal are slightly inclined so that the light which does not pass on through the slit is reflected, as shown in Fig. 1, to one side of the diaphragm-tube. There it falls upon the first face of a prism of such a form that after two internal reflections it returns along the small view-tube placed by the side of the collimator. A few inches below the second surface of the prism is placed a small achromatic lens having a focal length equal to its distance from the slit. The rays after passing through it are rendered parallel, and then pass on without loss, until at a little distance from the eyepiece, Fig. 2, they encounter a second achromatic lens. This has a focal length of about six inches, and with a suitable eyepiece gives a well-defined and bright view of the small field of stars upon the slit-plates. On a dark night, or when an object of finite magnitude, as a planet or a nebula, is not upon the slit, the opening of the slit becomes lost to view. For the purpose, under these circumstances, of illuminating the slit artificially, a very small incandescent lamp made of ruby glass is inserted through the side of the diaphragm-tube a little way from the slit, Fig. 1. It is enclosed so that light passes only upon the slit-jaws. From the position of the lamp it will be seen that its light is not reflected back from the slit in the direction to pass to the observer's eye. The slit-jaws are illuminated by that small part only of the red light of the lamp which is scattered from the mirrors in consequence of imperfect polish. This feeble illumination is found in practice to be just what is needed to show the slit distinctly, without overpowering faint objects. A variable resistance is placed within reach, so as to make it easy to obtain with exactness the precise degree of illumination which is most suitable to each object. From the position of the lamp, any light which passes through the slit does not pass on to the collimator-lens, but is absorbed by the blackened inner surface of the tube. The ease with which the slit can, by this arrangement, be placed with precision upon a star, or upon a small part of a planet or of a nebula, is all that can be desired.

In Fig. 1 the detached tube terminated by a right-angled reflecting prism forms part of the arrangement for throwing into the slit the light from sparks or flames for comparison. When in use this tube, which slides through an outer tube furnished with the necessary adjusting screws fixed upon the outside of the telescope-tube, is pushed in until the reflecting prism comes in front of the opening at the end of the diaphragm-tube before the slit. The light from the spark, vacuum tube, or flame outside the great telescope, passes through a double quartz-combination fixed in the tube near the outer end, by which it is made to converge to a focus upon the slit, and then to diverge at a little greater angle than is necessary to completely fill the collimator-lens.

When not in use, this tube can be wholly withdrawn outside the telescope-tube, so as not to intercept any light from the great mirror.

Fig. 2 shows the prism-box, which contains two prisms of Iceland spar, each with a refracting angle of 60°. These were made for me by Mr. Hilger, and have been cut very successfully. The smaller prism, which limits the beam that can pass through them, has a length of $2\frac{1}{2}$ inches with a height of $1\frac{1}{2}$ inches.

It was decided to work with the prisms in a fixed position, though this position can be varied from time to time for different parts of the spectrum. The prisms and camera are therefore provided with clamps, by which, when all the necessary adjustments of the prism, of the camera-lens and of the plate-holder have been made, the whole apparatus can be secured rigidly in position. All the different adjustments are provided with divided scales, so that if it were necessary for any reason to dismount any part of it, the instrument could be put back again into its former position with great exactness. The instrument is furnished with a camera-lens of quartz of 15 inches focal length.*

A range of spectrum from F to a little beyond S can be obtained with good definition throughout, and also quite free from any duplication due to the double refraction of the spar. The spectrum, indeed, extends some distance beyond S, but after this point there is a little falling off in definition. The diameter of the collimator lens is $1\frac{3}{8}$ inches, that of the camera-lens being slightly greater.

* In the figure a very short camera of $5\frac{1}{2}$ inches focal length is represented. This camera is no longer in use.

For greater lightness the camera-box is made of aluminium, and as the slit is placed in the direction of the star's motion, this box stands up in a nearly vertical position when the telescope is in the meridian, which is a very favourable one for freedom from flexure.

The spectroscope, as a whole, is secured by means of strong clamps within the large tube which screws on to a plate fixed on the base of the telescope-tube behind the great speculum. It can therefore be attached and removed from the telescope without any derangement of its internal adjustments.

Through the strong supporting tube the spectroscope, as a whole, can slide a few inches for the purpose of a first rough adjustment of the slit to the focal plane; the final adjustment is then made by a fine screw which gives a slow motion to the small convex speculum.

The necessary breadth can be given to the spectra of stars in two ways: either by allowing the star's image to trail in the slit, or by means of a concavo-cylindrical lens of quartz which is mounted in a short tube, which can take the place of the sliding diaphragm-tube at the end of the tube before the slit.

The long equivalent focal length of the Cassegrain form of telescope is of advantage in many cases of modern astronomical spectroscopy, where it is desirable to have images of considerable dimensions upon the slit-mirrors. It will become, doubtless, of increasing importance to be able to photograph separately the spectra of adjacent parts of the surfaces of nebulæ, and of the planets, and to obtain, without enlargement, sufficient breadth of spectrum in the case of very small nebulæ. Further, it will be desirable to bring separately upon the slit, and to maintain there, the components of binary and multiple stars, and also the stars involved in nebulæ. The Cassegrain form furnishes the means of conveniently obtaining a long equivalent focal length, while the instrument itself, and the building covering it, remain of moderate dimensions.

For fainter stars there is a second prism-box and camera, which can be substituted for the two-prism train and the 15-inch camera. The box contains one prism of Iceland spar of 60° only, followed by a camera-lens of quartz of 12 inches focal length.

A third prism-box with one compound prism of two half-prisms of right-handed and left-handed quartz respectively, has been also provided for very faint objects. The attached camera has a focal length of nine inches.

Except when it is stated otherwise, the photographs on the Plates were taken with the most powerful of the three prism arrangements.