HISTORY OF THE TELESCOPE

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JOSEPH VON FRAUNHOFER (1787 - 1826) AND THE GREAT DORPAT REFRACTOR

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The great Dorpat refractor was built in 1824 by Joseph von Fraunhofer (1787-1826). It was the first modern, achromatic refractor and the largest in the world. The 9.5-inch, 14 foot focal length refractor was noted for his high quality lens but also for its mounting, the first example of what became known as the “German equatorial mount”. This refractor was installed by Friedrich Georg Wilhelm Struve (1793-1864) at the Dorpat Observatory and extensively used in pioneering observations of double stars and parallax measurements of several stars (Figure 1).

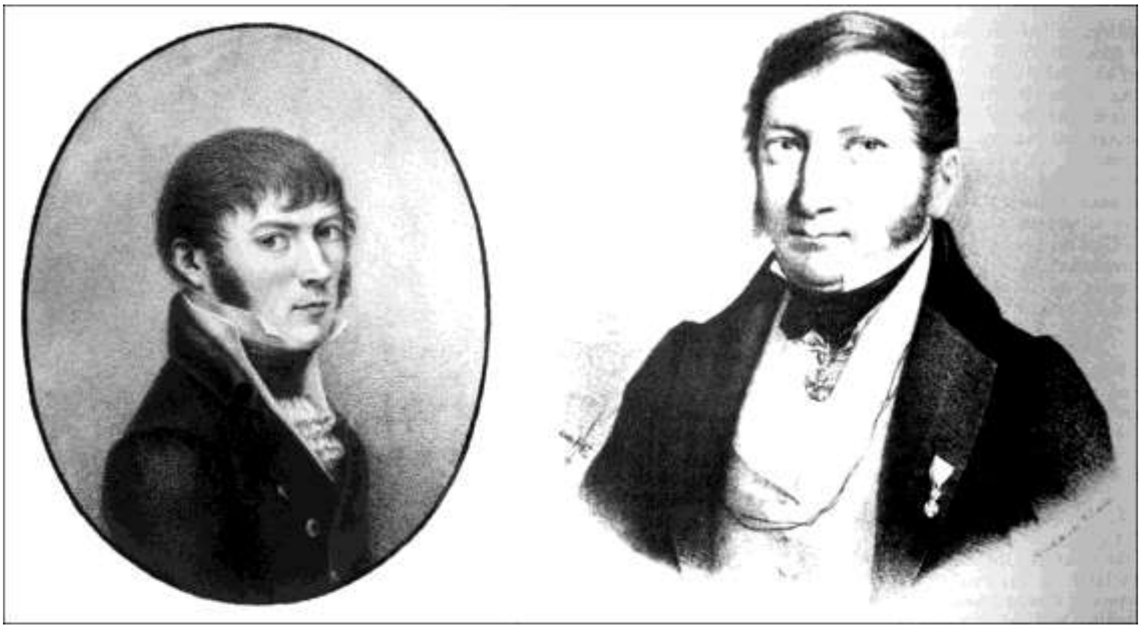

Figure 1- Joseph von Fraunhofer (1787-1826) (left) and Friedrich Georg Wilhelm Struve (1793-1864) (right).

Fraunhofer was born in Staubing (Bavaria, Germany) on March 6, 1787, the eleventh and last child of Xaver Fraunhofer, a glazier and builder of decorative glass. The young Fraunhofer lost his mother at the age of eleven and his father a year later. With only twelve he became an apprentice to a mirror maker and ornamental glass cutter in Munich (P.A. Weichselberger). After only two years the apprenticeship ended abruptly when Weichselberger house collapsed. Fraunhofer was protected by a cross-beam and escaped injured, but alive. In 1806 Fraunhofer was offered a junior post at the Munich Institute by Joseph Utzschneider, a politician and entrepreneur that left his posts to concentrate on the making of fine instruments and optics. Within a year, he was grinding and polishing lenses and soon after took charge of a workshop and several apprentices. Utzschneider moved his business to Benediktbeuern where he had founded a glass melting workshop. It was there that Fraunhofer met the Swiss Pierre Louis Guinand (a specialist in melting high quality crown and flint glass). Fraunhofer and Guinand did not get on well together. Utzschneider instructed Guinand to introduce Fraunhofer to the secrets of glass melting. After 1809, Fraunhofer was already a partner of the firm and in charge of building optical instruments: microscopes, opera glasses and astronomical telescopes of different apertures including an heliometer. The firm produced almost everything related to telescope building: optical parts, mountings, clockwork mechanisms, precision shafts, tubes…

At Benediktbeuern, Fraunhofer produced achromatic doublets of excellent quality. Surface imperfections were corrected and the best quality glass was used. Glass melting was also improved along the way. A 7-inch object-glass was produced and plans were made for a 10-inch. Newton rings were used for the first time as well as special spherometers and micrometers to test lens surfaces.

These new techniques enabled Fraunhofer to design and build a giant 9.5-inch refractor (the largest aperture refractor made up to that time). This instrument was to be installed at the Dorpat Observatory and entrusted to F.G. Wilhelm Struve (Figure 2).

The giant refractor arrived in Dorpat in November 10, 1824. Upon arrival, F.G. Wilhelm Struve inspected the instrument and made a special report (published in *Astronomische Nachrichten*):

On the 10th November last this immense telescope arrived here, packed up in twenty-two boxes, weighting altogether 5000 pounds, Russian weight. On opening the boxes, it was found that the land carriage of more than 3000 German miles (close to 1500 English miles), had not produced the smallest injury to the instrument, the parts of which were most excellently secured. All the bolts and stops, for instance, which served to secure the different parts, were lined or covered with velvet; and the most expensive part (the object-glass) occupied a large box itself; in the center of which it was so sustained by springs, that even a fall of the box from considerable height could not have injured it.

Considering the great number of small pieces, the putting together again of the instrument seemed to be no easy task, and the difficulty was increased by the great weight of some of them; and unfortunately the maker had forgotten to send the direction for doing it. However, after some consideration of the parts, and guided by a drawing in my possession, I set to work on the 11th, and was so fortunate as to accomplish the putting up of the instrument by the 15th; and on the 16th (being a clear morning) I had the satisfaction of having the first look through it at the Moon and some double stars.

I stood astonished before this beautiful instrument, undetermined which to admire most, the beauty and elegance of the workmanship in its minute parts, the propriety of its construction, the ingenious mechanism for moving it, or the incomparable optical power of the telescope and the precision with which objects are defined.

The instrument now stands in a temporary position, in the western apartment of the observatory, where observations maybe made for an hour and a half in the vicinity of the meridian to about 45°altitude. Next summer it will be placed in its proper position, in the tower of the observatory, under a rotatory cupola, where it may be used for observations in every position of the heavens.

Wilhelm Struve later compared the performance of this telescope to the best refractors he had used until that date:

What a difference is seen there! A mountain peak illuminated on the dark side of the Moon, which offers me noting remarkable in the Troughton (refractor), I recognize, by means of the Giant Refractor as consisting of 6 peaks well separated from each other. One of the most difficult of Herschel's double stars I recognize immediately.

I believe this telescope can be boldly placed alongside the giant reflecting telescope of a Herschel, for if the latter has a greater light-gathering power, our achromat surpasses by far any reflecting telescope in the precision of the images (…) By clockwork the telescope can be given a uniform motion similar to the velocity of the fixed stars, so that the star remains in the field of view. This is here, notwithstanding that the famous astronomer Bode has now for several years explained that it is impossible…

Fraunhofer described the instrument in a paper entitled (*On the Construction of the just finished Great Refractor*) published in *Astronomische Nachrichten*, No. 74 (1826), 17-24 (Read at the public meeting of the Royal Bavarian Academy of Sciences on July, 10 1824):

(…)

The instrument, about which I have the honor to speak, is for the Imperial Observatory at Dorpat. It is the largest of its kind and new in respect to the important parts of the mounting.

The largest viewing tools existing so far are the telescopes with metal mirrors. Since even the most perfect metal mirror reflects only a small part of the incoming light, the larger part being absorbed, reflectors have to be very large to have a positive result, thus the intensity of the light reaching the eye of the observer will remain low. In addition, with reflectors, the aberration of the light rays due to the spherical form of the reflecting surfaces, which is very prominent, cannot be corrected. For this and several other reasons the reflectors could not be used to advance of the mathematical-astronomical observations, and the reflector was never used as a meridian instrument.

Since almost all light is passed through the glass, and with a telescope constructed from Crown and Flint not only the aberration by chromatic dispersion is compensated, but also that from the spherical glass surfaces, the effect of an achromatic telescope, compared to that of a reflector, is unequally larger. Partly to this reason, in part because their construction makes them suitable for all kinds of observations, almost all astronomical observations are made with achromatic telescopes.

Although the achromatic telescopes used so far, being small compared to the reflectors, the first have achieved more in several fields than the latter. The most rigorous test of a telescope is, as is common knowledge, the observation of double stars, and here the impact of the newer achromatic telescopes is much greater than from the reflectors. Discovered by Bessel in Koenigsberg, for example, with an achromatic telescope from here (Fraunhofer's workshop), with an aperture of 48 lines, that the double star 4th class Zeta Bootis, discovered by Herschel with his telescope, is also one of the 1st class, i.e. he saw that there is another star close to the main star, which was not seen by Herschel. Likewise several other fixed stars, which were observed often with telescopes in the past, were recognized as double stars by the use of achromatic telescopes.

As it is known, the effect of a telescope is not dependent on its length, but on the aperture of its object glass, so that with equal perfection that telescope, which has double the size of a comparable one, has twice the effect. The difficulties which are to be faced when making larger, equally good telescopes as smaller ones, do not grow by the relation of the diameter, but even more, with the relation of the cubes of those. Since it has not been possible to overcome those difficulties until now, those larger achromatic telescopes, with objective apertures of over 48 lines, which were tried to be made, were not of equal perfection as smaller ones, and with even larger (apertures) it (perfection) was reduced. One of the difficulties was that the glass, which was to be used to manufacture the objectives, could not be made in that perfect way that is necessary for larger telescopes. Namely the English Flint glass has wave-like streaks which disperse the passing light in an irregular way. Since there are more streaks in a larger and thicker glass than in a smaller one, which must, if an increase in impact is desired, be the other way round, the effect was reduced with objectives of larger diameter. In addition, the English Crown glass, as any other glass which was used so far, has these wave-like streaks, which, although not always visible to the naked eye, giving the light rays, by uneven refraction, a wrong direction. The Bavarian Flint as the Crown glass is free of these streaks and of equal density (within the glass). Since the Flint glass differs from regular glass only by the stronger color dispersion, and this dispersion of English Flint relates to normal glass as 3 : 2, but with Bavarian Flint as 4 : 2, therefore the latter is also better in this regard.

Until now the achromatic objectives were not completely made following certain theoretical principles, one had to rely on good luck within reasonable limits, therefore a great number of glasses were ground and mated as pairs (by trial and error) until the errors almost compensated. Since the probability of such a chance is much smaller with large objectives than with smaller ones, also objectives of medium size are rarely perfect, and even with good Flint glass no thought would be spent on large achromatic objectives. The main causes for this procedure were: in part, the theory of achromatic objectives is not fully understood; in part, that the refractive and color dispersing characteristic of the glass used, which must be known exactly when calculating, was determined not exactly enough by the means employed earlier; in part, finally, that the methods, which were used to grind and polish the glass, did not follow the theory as predicted, if no observable deterioration should be observed.

The objective of the here discussed great refractor has 108 Parisien Line[1]s aperture and 160 inch focal length. The effect of a telescope is best shown when comparing with another one, pointed at the same object. While observing with large telescopes, the largest obstacle is the imperfect air, and here mainly the apparent undulating of it. These disadvantages grow with larger telescopes with the square of their diameter, but the effect grows only with the (linear) relation of the diameter; therefore, even when the sky seem to be clear and the air is only a bit imperfect in the mentioned sense, observations are not possible with larger telescopes. Since the air, everywhere in space, is perfect in this sense only on a few days per year, to learn about the relative effect of this large telescope, a special object for this purpose was placed (on the earth); because in this case a shorter layer of air has to be passed, and its imperfections would be less harmful. The experiments, executed as described, showed that the effect of the large

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[1] In the nineteen century telescope apertures were measures in Parisien lines: one Parisien line equals 2.234 mm or 0.08795 inch.

refractor increases in relation to its diameter, fulfilling the maximum expectations. - It would be too much to mention the means which were employed to, for example, adjust the centers of the lenses onto a common line, remove the effects of expansion and contraction of the metal lens cell at different temperatures etc., what had to be considered to make sure that the best effect is achieved with this instrument.

One of the largest obstacles that was encountered when using large telescopes on celestial objects, is the apparent daily movement of the stars, which is magnified in the same relation as the telescope magnifies; so that stars close to the equator remain only a short time within the field of view of a high magnifying telescope, and pass quickly through the same. Even with the smoothest movement of the telescope by hand with screws, small oscillations will be introduced, which will be magnified in relation to the magnification of the telescope. Before the telescopes comes to rest, the star will have passed the field of view, making it possible almost only by pure chance to see it for a short moment under good conditions. These favorable conditions are even rarer since a star can only be seen with the highest precision when being located in the middle of the field of view. The mentioned difficulties can only be met if the telescope would move like the observed star without the interference of a human hand. This had to be with the same precision for all stars, regardless of the ones apparently slower close to the pole, or those located near the equator moving very fast.

For this reason the large telescope was mounted paralactic in its own way, that is, one of the main axes around which it rotates, is elevated against the horizon in such a way, that its angle equals the polar altitude and is pointing at the pole. The second axis, named the declination axis, is mounted on the hour axis exactly vertical (at right angle). If the telescope, mounted in this way, is pointed at any star, then only the hour axis needs to be turned with such a speed that it would turn once in 24 hours, like the Earth's axis, in which case the star, whichever it might be, remains within the field of view of the telescope as long as it is above the horizon. This movement is applied to the hour axis by an apparatus similar to a clock, consisting of two works. The force of one work overcomes the friction and the weight of the moving mass of several Zentner (a unit of mass, 50 kg); the other mechanism regulates the movement. To regulate the movement neither a pendulum nor a balance spring could be used; because in this case the telescope would not move uninterrupted, but only in steps.

The regulator in this work is a centrifugal mechanism, which rotates uninterrupted in a conic housing in one direction. Also, when cranking up the weights the telescope moves with the same speed. The telescope may, while the clock moves on, be stopped at any time and set to move again equally fast. In addition, it may be moved by hand or by means of a bolt in any direction. The clock may be, at any time, adjusted to faster or slower, only by setting a spiral formed disk to another degree of its division. This is to advantage, because, if a star is not at the desired location in the field of view, it may be set to that place by using the clock, which is of great use with micrometer observations, and not advisable by other means, because of the dead travel etc. This spiral disk has also the advantage that the telescope can be set to a movement equaling that of the Moon.

To assure this uniform movement of the large telescope, it must be in all positions, as different as they may be, balanced in relation to both main axes, and these balances may not disturb the *telescope from being pointed to any part of the sky. In relation to the declination axis, the eccentric mounted telescope is balanced by two weights close to the eyepiece, mounted on individual conical brass tubes, each of which has two axes in the centre of gravity, at right angles, so that in this relation the telescope is equally balanced in any position. In relation to the hour axis this telescope is balanced by two weights, of which one is mounted directly to the declination axis. The second weight is attached to a rod of an individual form, which is bent in the direction of the hour axis to form a ring; this ring touches, by two opposing axes, a second smaller; this second ring is attached to two axes, which are perpendicular to the first, a third even smaller; and this finally turns at a bushing in which the declination axis is located, so that in relation to the hour axis the telescope is balanced in all positions. To eliminate the friction of the hour axis, and remove any pressure down or up, another special weight is attached which exerts a force on the bearing of two friction rollers. It is due to this installation that the telescope, regardless of the extraordinary weight, may be moved with one finger.*

The pier of the instrument has a form that, although its position may never be altered, will never hinder the telescope from being pointed to any location in the sky. Although it seems that there are positions of the telescope in which the pier may prevent following a star; this instrument is constructed in such a manner that the telescope may be directed to an object in two ways, only by turning the hour axis by 180°; if the pier is hindering in one way, it cannot in the other, and the telescope is free in this case.

As it is, with a telescope of high magnification, very difficult to point to an object and bring it into the field of view, usually a second smaller one is mounted with the axis exactly parallel to the larger one. The finder of the large refractor has 29 lines aperture and 30 inch focal length.

Each of the two main axes has an individual divided circle, named the hour and declination circle. These are fixed to their axes and turn with these. The division of the hour circle is 4 time seconds, the division of the declination circle 10 arc seconds. With these one can (adjust) the telescope to stars which are off the meridian, and find and observe them by day, which, especially with stars of the 1st magnitude, may not be observed with advantage by night.

(…)

Fraunhofer’s design of the Great Dorpat refractor may have influenced the appearance of modern observatories. The German equatorial mounting could be pointed to any part of the sky above the horizon. Some regions of the sky are only accessible after performing a meridian flip of the mount (by reversing the telescope about its polar axis).

Movement by clockwork was virtually a novelty when it was adapted by Fraunhofer in 1824. Clockwork movement was first proposed by Robert Hooke (1635-1703) in 1674. Several astronomers used telescopes with clockwork control during the eighteenth century but these apparatus were not very elaborate.

As mentioned before, when the telescope arrived in Dorpat, the refractor had to be used at an open window. Later it was mounted under a dome (“rotatory cupola”) at the top of the main tower of the Observatory. The Dorpat dome was a forerunner of modern domes (Figure 3).

Fraunhofer is better known today for his invention of the spectroscope (1814) and the diffraction grating. He placed a flint glass prism in front of the objective of a small theodolite and fed both with sunlight from a vertical slit. In this way he noticed that the sun’s spectrum was crossed by a series of vertical, dark lines of different intensity that always kept the same position. Fraunhofer selected eight of these lines (A, B, C, … H) and used them as marks to test the refractive index of glass for different colors. Between the lines B and H he counted 574 lines (still called Fraunhofer lines in his honour) (Figure 4).

Fraunhofer's success made his name synonymous with progress. Astronomers considered it a privilege to have their orders accepted by him. The famous refractor he made for the Dorpat Observatory and the heliometer for the Berlin Observatory gave both institutions positions of leadership for several decades.

Joseph Fraunhofer died on June 7, 1826 at the early age of thirty nine years. The privations of youth and his delicate constitution and signs of tuberculosis ended a very promising scientific career.

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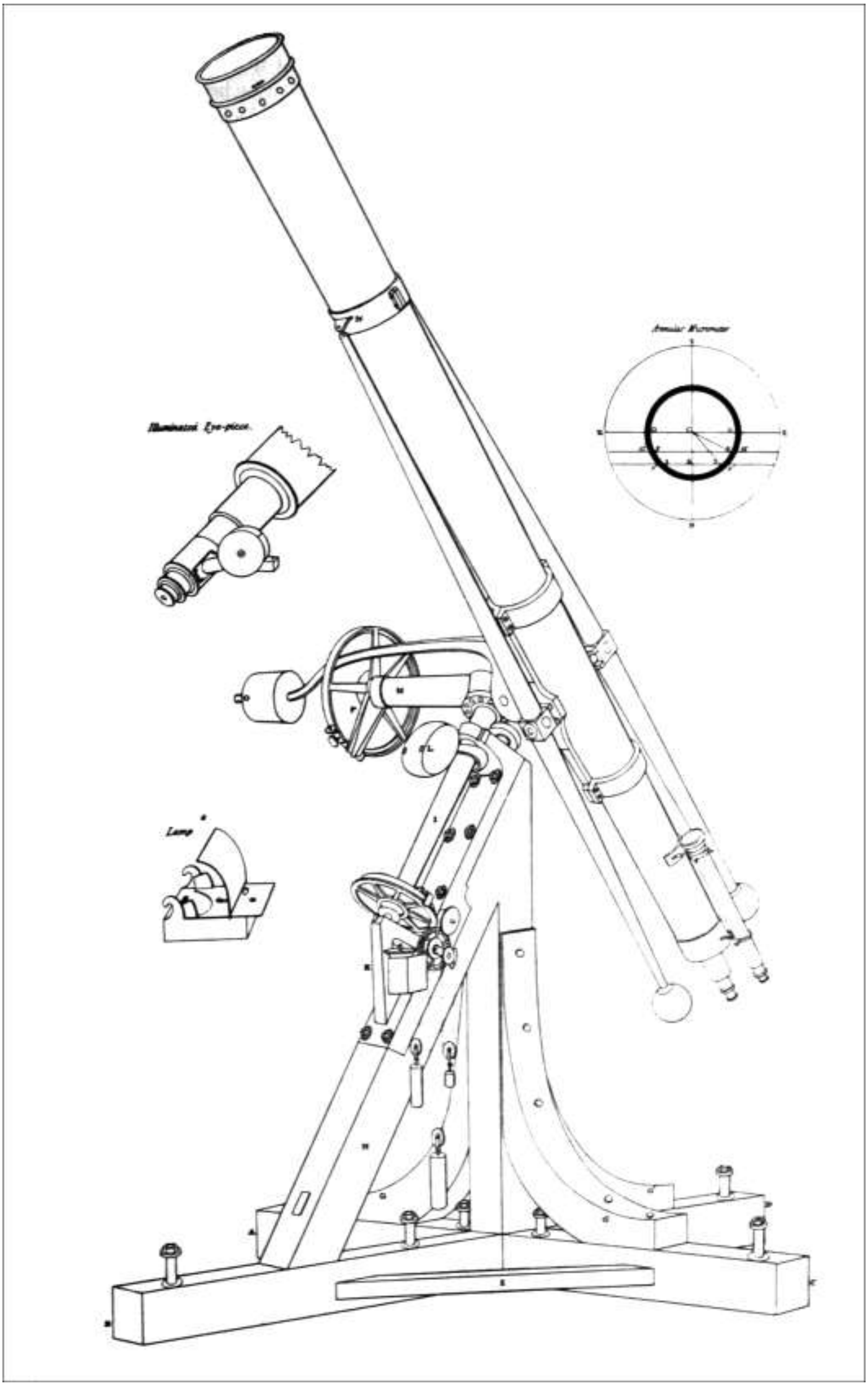

Figure 2- The great Dorpat refractor.

Figure 3- Dorpat Observatory main building (left) and cutaway drawing of the main tower with the great Dorpat refractor installed under the rotatory cupola (right).

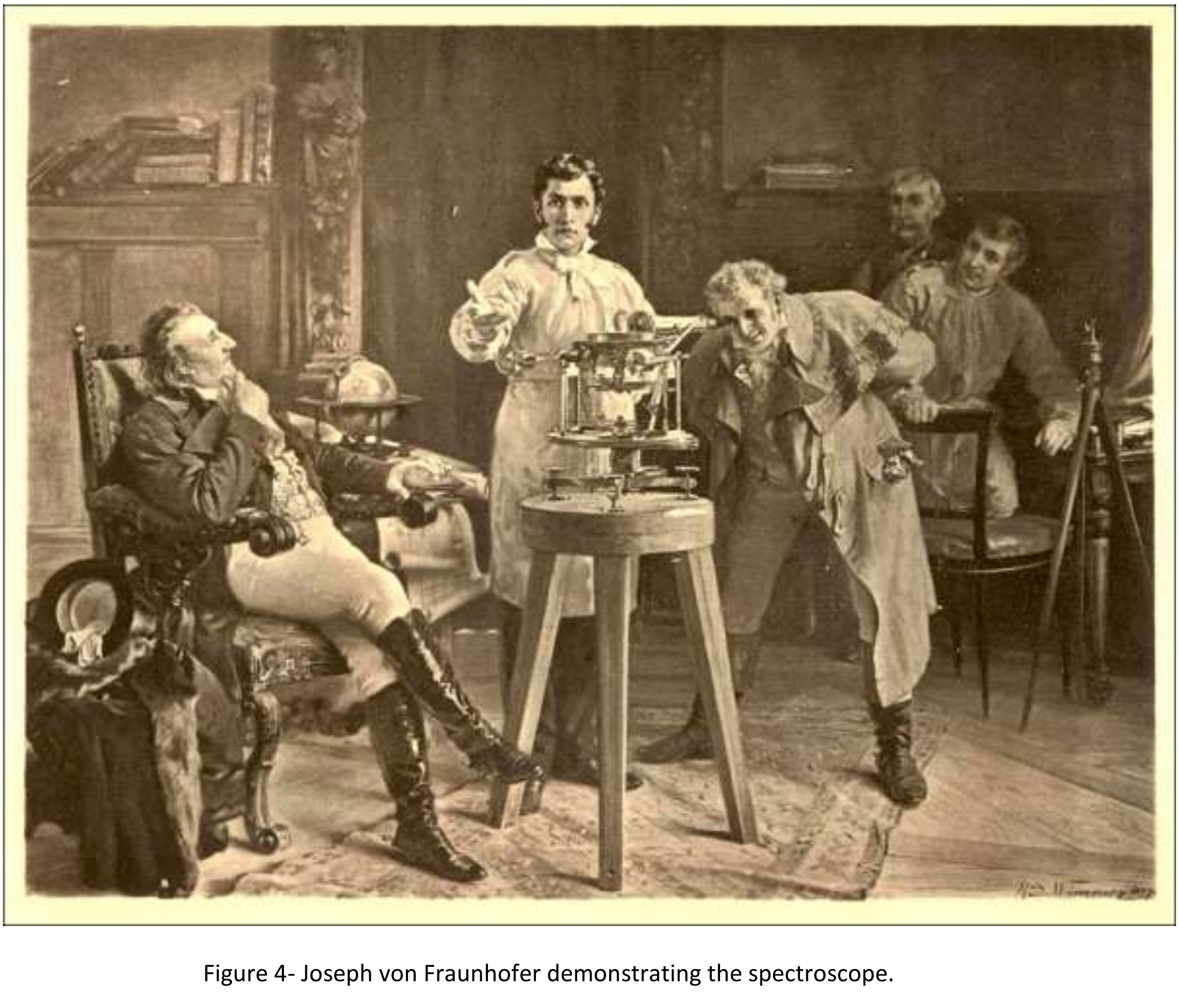

Figure 4- Joseph von Fraunhofer demonstrating the spectroscope.

ALVAN CLARK (1804-1887), GEORGE BASSETT CLARK (1827-1891) AND ALVAN GRAHAM CLARK (1832-1897): AMERICAN MAKERS OF TELESCOPE OPTICS.

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Alvan Clark and his sons, George Bassett Clark and Alvan Graham Clark (Figure 1), were the main makers of large refracting telescopes in the late ninetieth century. The firm Alvan Clark & Sons was founded in 1846 in Cambridgeport, Massachusetts. For five times the Clarks made the objectives for the largest refracting telescopes in the world: (i) The 18.5-inch (470 mm) Dearborn telescope was commissioned in 1856 by the University of Mississippi; (ii) In 1873 they built the 26-inch (660 mm) objective lens for the United States Naval Observatory; (iii) In 1883, they finished the 30-inch (760 mm) telescope for the Pulkovo Observatory in Russia; (iv) The 36-inch (910 mm) objective for the Lick Observatory refractor was made in 1887 and finally (v) The 40-inch (102 cm) lens for the Yerkes Observatory refractor, in 1897, the largest ever built still in operation (Figure 2 and 3).

Figure 1- Alvan Clark (center) and his sons, Alvan Graham Clark (left) and George Basset Clark (right). Lick Observatories photograph.

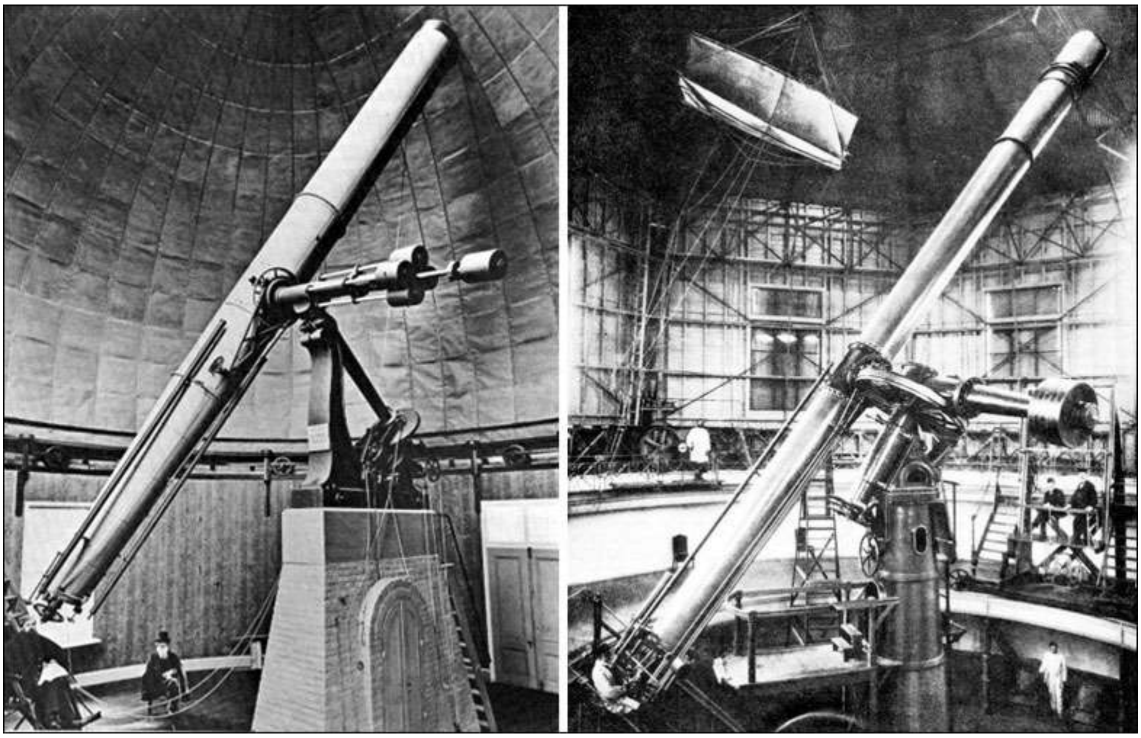

Figure 2- The 26-inch U.S. Naval Observatory refractor (left) and the 30-inch Pulkovo Observatory refractor (right).

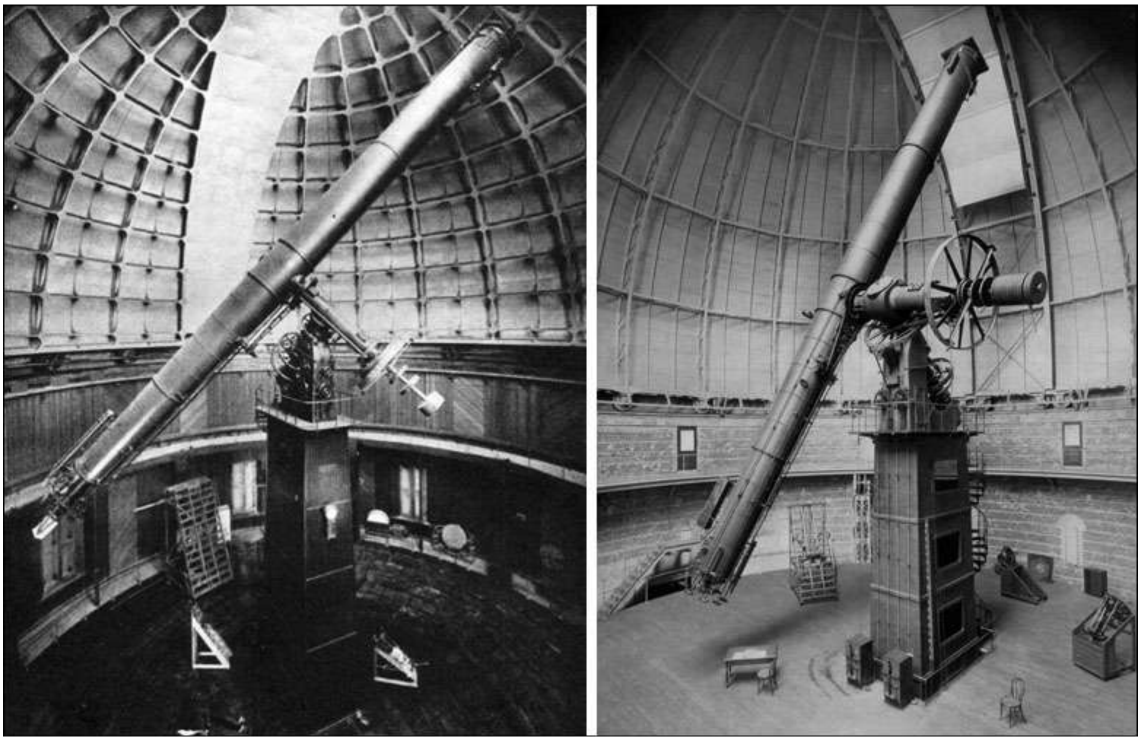

Figure 3- The 36-inch Lick Observatory refractor (left) and the 40-inch Yerkes Observatory refractor (right).

Alvan Clark was born in Ashfield, Massachusetts on March 8, 1804. He was the fifth of ten chidren of Abram (a descendant of Thomas Clark, one of the early pilgrins of the Mayflower) and Mary (Pease) Clark. Before turning to astronomy, Alvan was noted for his work in other fields, namely drawing and engraving. Towards the end of his life Alvan wrote an autobiography that is often quoted. This is the reason why the life and work of Alvan Clark is better known than that of his two sons.

Both Alvan Graham Clark and George Graham Clark devoted their entire careers to building fine astronomical telescopes. Alvan Graham did the optical work and George did the mechanical work. It is very difficult to identify who was responsible for a particular telescope built by the Clarks. Taking this into account all three Clarks are responsible for the achievements of the firm Alvan Clark & Sons that later became simply Alvan Clark.

Abram Clark (Alvan Clarks father) owned and operated a rocky farm, a sawmill and a gristmill in Ashfield leaving his son a patrimony of fifty dollars. Alvan received a formal education at a local small grammar school and began to work with his older brother in a wagon maker's shop. Soon he turned to other interests. On March 25, 1826 Alvan married Maria Pease and they became parents of four children (Maria Louisa and Caroline Amelia, as well as George Bassett and Alvan Graham). Alvan earned his living as an engraver and later by painting small portraits of exceptional quality in ink and watercolor (Figure 4). Sometimes he used a prism and a camera lucida to outline the main features of the people in his portraits and miniatures.

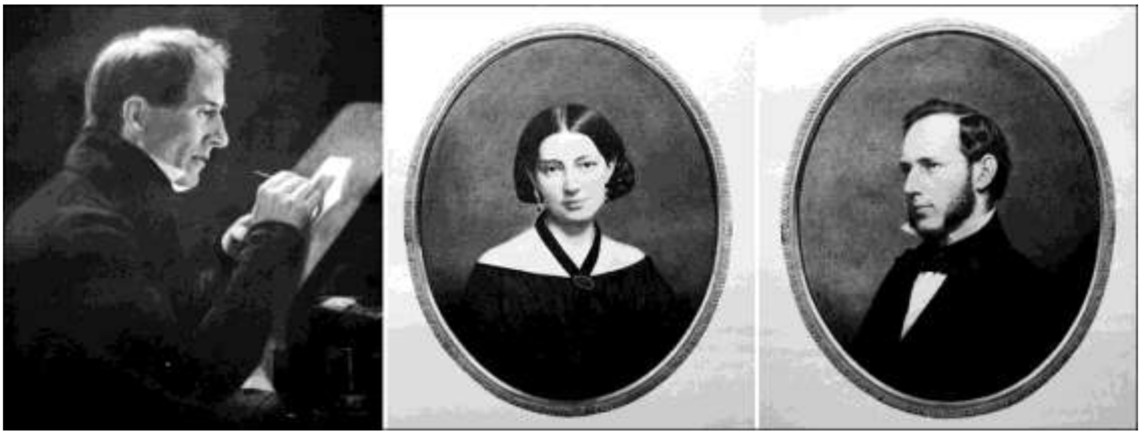

Figure 4- Alvan Clark portrait as an artist in his studio (left), center and right two of A.Clark paintings (Mrs. And Mr. Charles Henry Cummings).

Clark maintained the studio until 1860 when the firm Alvan Clark & Sons became lucrative. It seems that Alvan Clark turned to telescope making almost by accident. His eldest son, George Basset, while a student at Andover (Phillips Academy), melted down a metal bell in order to make a reflecting telescope. Alvan attention was caught and by 1850 the firm Alvan Clark & Sons was founded. The firm grew out of a small shop in East Cambridge used by George Basset to repair optical instruments.

In 1850 the largest refractors were the 15-inch (38 cm) instruments at Pulkovo and Harvard Observatories both made by the Merz & Mahler in Munich (Germany). The largest reflector was the 72-inch (182 cm) "Levithan" erected in 1845 by the Third Earl of Rosse, William Parsons, at the Birr Castle in Ireland. In the middle of the nineteen century refractors were regarded as precision instruments while reflectors were considered much more crude and difficult to use. For this reason refractors were the preferred instruments for astronomical work at observatories worldwide.

Alvan Clark started by building metal reflectors with aperture as large as 8-inch. In 1847-48 Alvan using a 7.5 inch reflector build by himself made a drawing of the Orion nebula. William Cranch Bond, director of the Harvard Observatory, was very impressed with this sketch (the drawing was more complete than the sketch made by William Herschel using his 20-foot reflector).

Clark soon realized that refractors had better light gathering power and definition than metal reflectors and started building objective lenses around 1846. The first lenses he made were similar to ones built by the only contemporary American lens maker, Henry Fitz (1808-1863).

William Rutter Dawes (1799-1868) an English amateur bought several Clark objectives, one of which was used from 1869 to 1869 by William Huggins (1824-1910) for his monumental work in spectroscopy. A trip to England in 1859 (the only time Alvan Clark left the United States) was very important for establishing Clark’s reputation as a maker of telescope optics both abroad and in the U.S. Soon after, Clark was asked to make a refractor with an aperture of 19 inches (48 cm) for the University of Mississippi. The firm Alvan Clark & Sons had only built objectives of apertures up to 8 inches. After examining the 15-inch lens of the Harvard Observatory and recognizing its imperfections, Clark offered to make a 15-inch. The University wanted the largest telescope of the world and Clark agreed to make an 18.5-inch (47 cm) objective.

The firm moved to a new location with larger facilities near Harvard to work on this lens. The two crown and flint discs (ordered from the Chance Brothers Company of Birmingham) were finished in 1862. Alvan Graham Clark while testing this lens discovered the companion of Sirius on January 31 1862. By this time the American Civil War had began and the University of Mississippi was unable to fulfill the agreement with the Clark firm. The Chicago Astronomical Society bought the lens and the telescope was installed in the Dearborn Observatory of the University of Chicago in 1866.

The 18.5-inch refractor did not remain the largest refractor in the world for a long time. Robert Stirling Newall (1812-1889) a wealthy Scottish engineer and amateur astronomer, commissioned Thomas Cooke (1807-1868) to build a telescope for his private observatory at Ferndene. The discs for a 25-inch (64 cm) refractor were ordered from the Chance Brothers Company in 1863. The lens had a focal length of 9.1 m and a combined weight of 66 kg. Altogether the Newall refractor took seven years to build. It was for a few years the largest in the world. Newall erected this telescope in 1871 on his estate, a very unfavorable site: during a period of fifteen years he had only one night in which he could use its full aperture (Figure 5).

In 1871, Clark agreed to make an instrument that surpassed the Newall refractor. By this time Alvan Clark & Sons had already refigured the lenses of several telescopes of the U.S. Naval Observatory with excellent results. The 26-inch (66 cm) crown and flint discs weighting 50 kg were again commissioned from the Chance Brothers Company. The lenses were finished in two years (1873). The objective was mounted on a metal tube (previous Clark instruments were provided with a wooden tube. With this instrument (installed by late 1873) Asaph Hall (1829-1907) discovered the two satellites of Mars (Phobos and Deimos) in 1877) (Figure 2).

In 1872 Karl Ludwig von Littrow (1811-1877), director of the Vienna Observatory, made plans for a large refractor and the contract went to Howard Grubb (1844-1931) of Dublin. The young Grubb together with his father Thomas Grubb (1800-1878) were mainly specialized in building reflectors with heavy equatorial mountings. For this project H. Grubb designed a German equatorial mounting that was a great improvement over the mountings supplied by the Clarks in such a way that it became a model for all future mountings of large refractors (Figure 5).

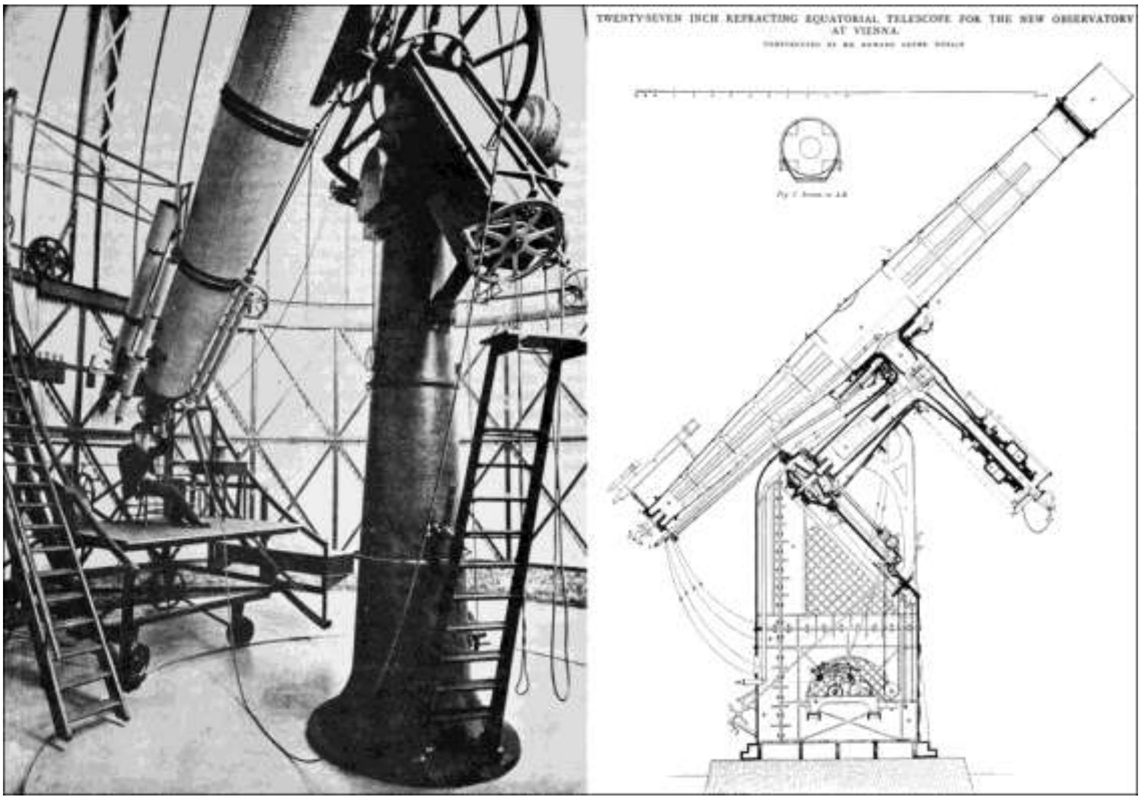

Figure 5- The 26-inch Newall refractor (left) and the 27-inch Grubb refractor of the Vienna Observatory (right). The 27-inch surpassed the 26-inch Clark of the U.S. Naval Observatory becoming the model of all mountings for subsequent large refractors.

Otto W. Struve (1819-1905) director of the Pulkovo Observatory ordered a 30-inch (76 cm) objective from the Clarks in 1879. The lens was not completed until 1884. The mount was finished on the same year by Repsold (Hamburg) (Figure 2). This refractor (then the world largest) went into operation at Pulkovo in 1885. It was extensively used in the study of double and proper motion of stars.

In 1880 the Clark firm was again given a contract to build a 36-inch (91 cm) objective and photographic corrector. The blanks were ordered from the firm Field in Paris. The lens with a focal length of 17.6 m was finished in 1885 but the photographic corrector (33-inch, 84 cm) was only completed in 1887. The mount for this refractor was built by the firm Warner & Swasey and erected on Mount Hamilton (Lick Observatory) in 1887. The Lick refractor was one of the most productive instruments in the history of astronomy (Figure 3).

With the completion of this instrument the representatives of the University of Southern California asked the Clarks to make an objective for a larger telescope. In 1889 they agreed to built a 40-inch (102 cm) lens and the blanks were ordered from the firm Mantois in Paris. When the disks arrived the University was unable to pay the bill and the opportunity to obtain the largest refractor in the world went to another Institution. George Ellery Hale (1868-1938) that had just been appointed Associate Professor at the University of Chicago was able to raise the necessary sum to buy the lens by convincing the Magnate Charles Tyson Yerkes (1837-1905). Yerkes contributed with $300.000 to establish what would become known as the Yerkes Observatory, located in Williams Bay, Wisconsin.

Alvan Graham Clark, the last surviving member of the Clark family began figuring the lenses and Warner & Swasey were asked to supply the equatorial mount. The mount was finished in

1893 being displayed at the Columbia Exhibition in Chicago that same year (Figure 6). The 40-inch refractor (19.3 m focal length) went into operation only in 1897 after the foundation of the Yerkes Observatory in 1895 (Figure 3). This refractor is still the largest in the world today. The combined weight of the two components of the 40-inch objective was 225 kg (Figure 7). James Edward Keeler (1857-1900) that examined the lens in 1896 wrote in a paper published in the *Astrophysical Journal*:

"From these tests it appears that the character of the image varies with the position of the lenses relative to each other, and, to a less extent, with the position of the objective as a whole relatively to its cell. It is probable that flexure of the lenses is the principal cause of the observed changes, and it is interesting to note that there is here evidence, for the first time, that we are approaching the limit of size in the construction of great objectives".

Figure 6- Mounting of the 40-inch Yerkes refractor on display at the Columbia Exposition in Chicago (1893).

Before his death in 1897, Alvan Graham Clark declared his intention to make a 60-inch (152 cm) lens. In the twentieth century several attempts were made to build larger refractors without any success (Figure 8). By this time reflectors were the main instruments used for spectroscopy and astrophotography.

Figure 7- Alvan Graham Clark and Carl Lundin with the 40-inch object glass.

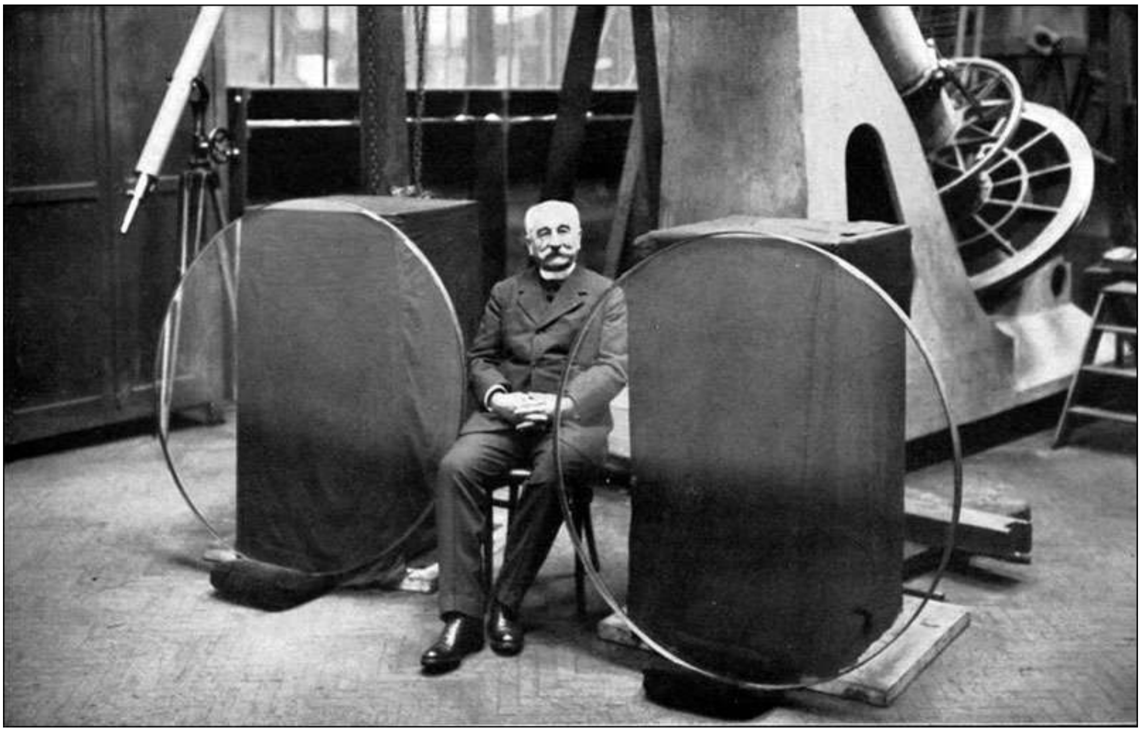

Figure 8- 50-inch optical disks made by the Mantoins firm (Paris).

Very little is known regarding the Clark methods for grinding lenses. The Clark left no records of these procedures. Many people visited the Clark factory and were shown every detail of the process. One visitor wrote that the methods employed were crude and inferior to those used by European optical makers. The success of Clark's lenses was attributed to skilful manipulation and supervision rather than the use of precise mechanisms. It seems that the techniques used were nothing extraordinaire. Great care was taken in the grinding and polishing of a lens. The blank disk was always tested for purity and evenness (glasses with evident striation were discarded). Grinding and preliminary polishing was done with rudimentary machines which consisted of horizontal tables rotated by a steam engine. Early Clark lenses were ground with emery, but later (1887) cast iron sand was used as an abrasive. When grinding was finished the metal lap used for this purpose was changed for one made of grooved pitch fed with water and rouge for polishing. The Clarks never used cloth polishers. The process of correcting and perfecting the lenses was always performed. Local correction was suggested to the Clarks Henry Fitz. Fitz only retouched one surface whilst the Clarks regularly retouched all four surfaces of each objective. This maybe the explanation for the superior quality of the Clarks object glasses.

Local corrections were used to remove small errors after grinding and polishing. To locate this errors the Clarks developed a test similar (but prior) to the one described as the Foucault knife-edge test for mirrors. This test was performed either on a star or on an artificial star (inside a horizontal tunnel with almost 70 m of length). Tests on photographic lenses involved photographing a star several times in focus and out of focus in order to examine the images obtained. A perfect lens would form even images.

Once the irregularities were found these were marked and the lens had to be retouched several times until a perfect shape was reached. Alvan Clark seemed to have a special sense of touch in such a way that he could detect irregularities with his fingers. He repeatedly used his bare thumbs to make local corrections.

Most of the Clarks objectives are similar to Fraunhofer lenses consisting of an equiconvex crown (R1 = R2) and a meniscus flint in which R3 is made a few percent shorter in radius than R2. R4 (closer to the eyepiece) becomes a long radius convex surface being almost flat. There are mainly two drawbacks in this type of lenses. It is an airspaced design, similar to the Fraunhofer, but with weaker curves. R1, R2, and R3 are all close in radius to one another. Spherical aberration can be canceled (corrected) just as in the Fraunhofer design. In addition, if R1 and R2 become reversed during cleaning, there is no apparent change in performance.

Most of the Clark objectives are corrected for visual use. However two methods were developed for adapting the lenses for photographic applications. The Lick refractor was provided with a third (smaller) photographic lens. In 1887, with the assistance of Edward C. Pickering (1846-1919) the Clarks developed a clever combination of two lenses that could be used for either visual or photographic observations. Is this design the Crown component is more convex on one side than the other. For visual applications the flatter side was put in contact with the flint and for photography the crown lens was reversed and separated from the flint.

The Clarks were great opticians, perhaps the most skillful ever. The excellence of their achromatic objectives is recognized even today in an era where apochromatic refractors are readily available.

WILLIAM PARSONS (1800-1867) E O LEVIATÃ DE PARSONSTOWN

PEDRO RÉ
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William Parsons (3° Conde de Parsonstown, Lord Rosse) nasceu em York no Reino Unido em 17 de Junho de 1800. Estudou em Dublin e em Oxford (Magdalen College) onde completou com distinção os seus estudos graduados em matemática (1822) (Figura 1).

Figura 1- William Parsons (Lord Rosse).

Após o falecimento do pai, foi membro do parlamento entre os anos de 1841 e 1834 e a partir de 1845 representante irlandês no parlamento. Foi igualmente presidente da “Royal Society” (1848-1854) e chanceler do Trinity College (Dublin) (1862-1867). Em 1841, herda o Castelo de Birr e torna-se no 3° Conde de Parsonstown. Lord Rosse aliou os seus conhecimentos de engenharia a um elevado interesse que evidenciou desde cedo pela astronomia e pela construção de telescópios. Construiu diversos telescópios a partir de 1827 nas oficinas que fundou no condado de Parsonstown. Efectuou diversas experiências com espelhos metálicos (“specula”) construidos inicialmente a partir de um mosaico de peças distintas. O primeiro espelho composto tinha um diâmetro de 15” (38 cm) e uma distância focal de 12 pés (360 cm). Com o auxílio deste instrumento efectua as primeiras observações da Lua e de estrêlas duplas usando amplificações que variaram entre 80 a 600x. Ao espelho de 15” seguiram-se dois espelhos de 24” e de 36” (1839), este último constituído por 16 segmentos distintos. Em 1840 Rosse consegue finalmente construir um espelho metálico sólido de 36” que foi instalado numa montagem azimutal semelhante às utilizadas por William Herschel (1738-1822) (Figura 2).

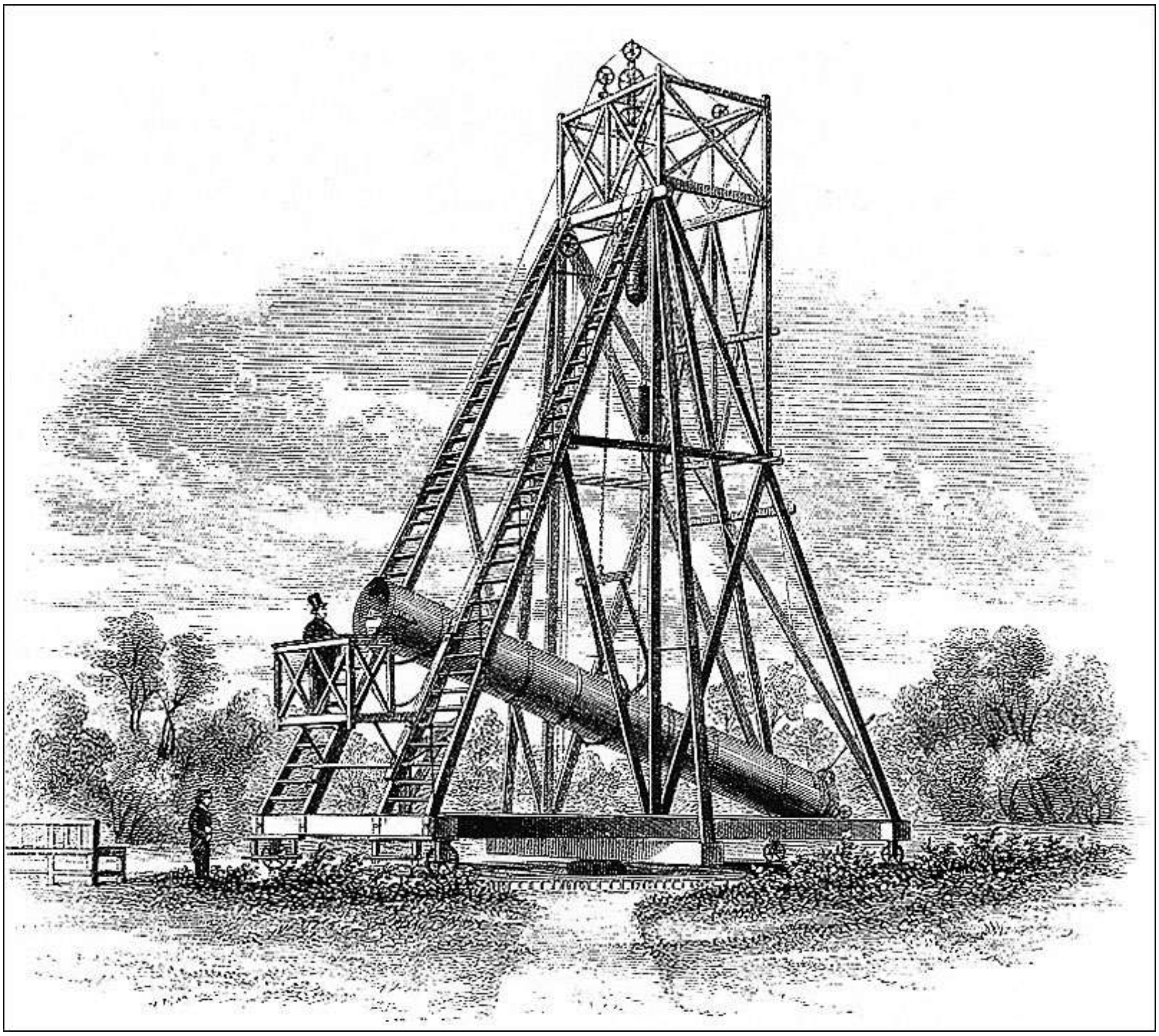

Figura 2- Telescopio de 3 pés (91 cm) construído por Lord Rosse em 1839/1840.

John Thomas Romney Robinson (1792-1882)[2], director do observatório de Armagh, descreve em 1840 algumas observações efectuadas com o auxílio deste instrumento:

Both specula, the divided and the solid, seem exactly parabolic, there being no sensible difference in the focal adjustment of the eyepiece with the whole aperture of 36 inches, or one of twelve; in the former case there is more flutter, but apparently no difference in definition, and the eyepiece comes to its place of adjustment very sharply. The solid speculum showed α Lyrae round and well defined, with powers up to 1000 inclusive, and at moments even with 1600; but the air was not fit for so high a power on any telescope. Rigel, two hours from the meridian, with 600, was round, the field quite dark, the companion, separated by more than a diameter of the star from its light, and so brilliant that it would certainly be visible before sunset (…)

Rosse utilizou o telescópio de 3 pés até 1874. A montagem azimutal de madeira foi substituída por uma montagem equatorial em metal em 1876 (Figura 3). Pouco tempo após ter completado o telescópio de 3 pés, Rosse iniciou (1839) a construção do um novo telescópio

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[2] King, H.C. (1955). *The History of the Telescope*. Dover Publications, Inc. New York.

como o dobro da abertura (6 pés, 183 cm). O Leviatã de Parsonstwon, como ficou posteriormente conhecido, foi utilizado pela primeira vez em 1845 (Figura 4).

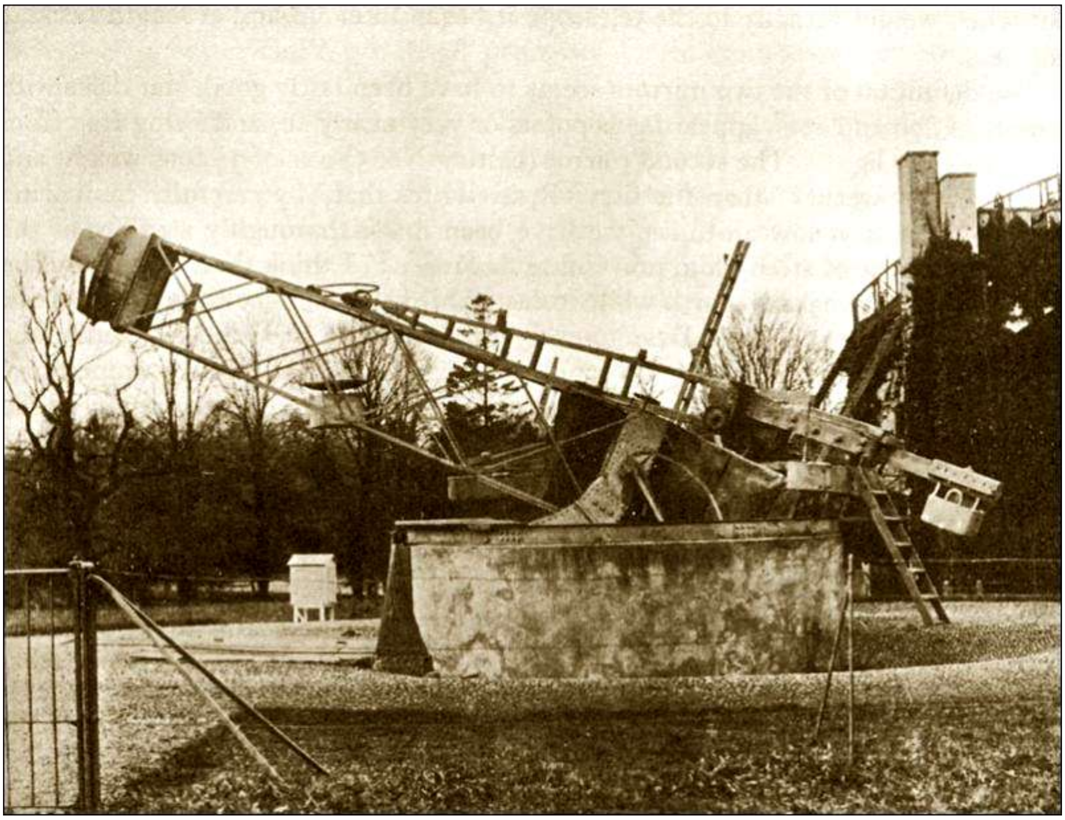

Figura 3- Telescópio de 3 pés (91 cm), montagem equatorial (*ca.* 1876).

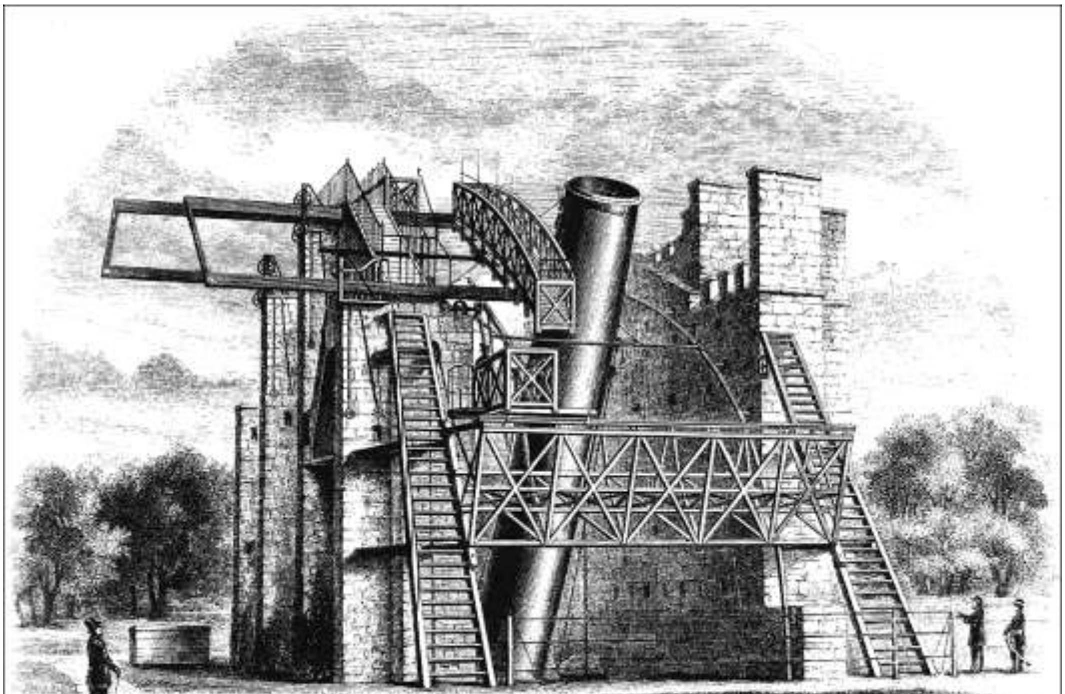

Figura 4- Leviatã de Parsonstwon (*ca.* 1845).

John Louis Emil Dreyer (1852-1926)[3], um dos últimos astrónomos a usar o Leviatã, descreve em 1914 o instrumento bem como as técnicas de observação:

Since the telescope was erected between two high walls in the direction north and south, an object on the equator could only be observed within half an hour east or west of the meridian, and after a clock movement had been applied to it in 1869 it could only pick up an object on the equator some five or ten minutes east of the meridian. The range was further limited by the fact that the telescope could not be brought much beyond the zenith, as the top gallery ended about 10° north of it. Objects within about 25° of the pole could, therefore, not be observed. When furnished with a clock movement, the instrument was certainly a most convenient and comfortable one to use. Three workmen were in attendance every night; one at the windlass in the north to raise or lower the tube, one in a little hut close east of the lower end of the tube to move it in hour-angle by turning a large wheel or to start or stop the clock, and one in the gallery to move the gallery out of the tube and gradually to move it back as the tube was driven westward by the clock. There was a slow motion in R.A., but it was rarely or never used, as two eyepieces (one a finder eyepiece of low power, the other a micrometer with bars visible without illumination) were mounted side by side on a slide movable to the extent of some 15' to 20'. The flat mirror was sufficiently large to allow this to be done with little or no loss of light. The galleries were so constructed that the observer always stood upright and looked horizontally into the eyepiece and as he had no body labor to do, observing was not more fatiguing than it would have been with quite a small instrument.

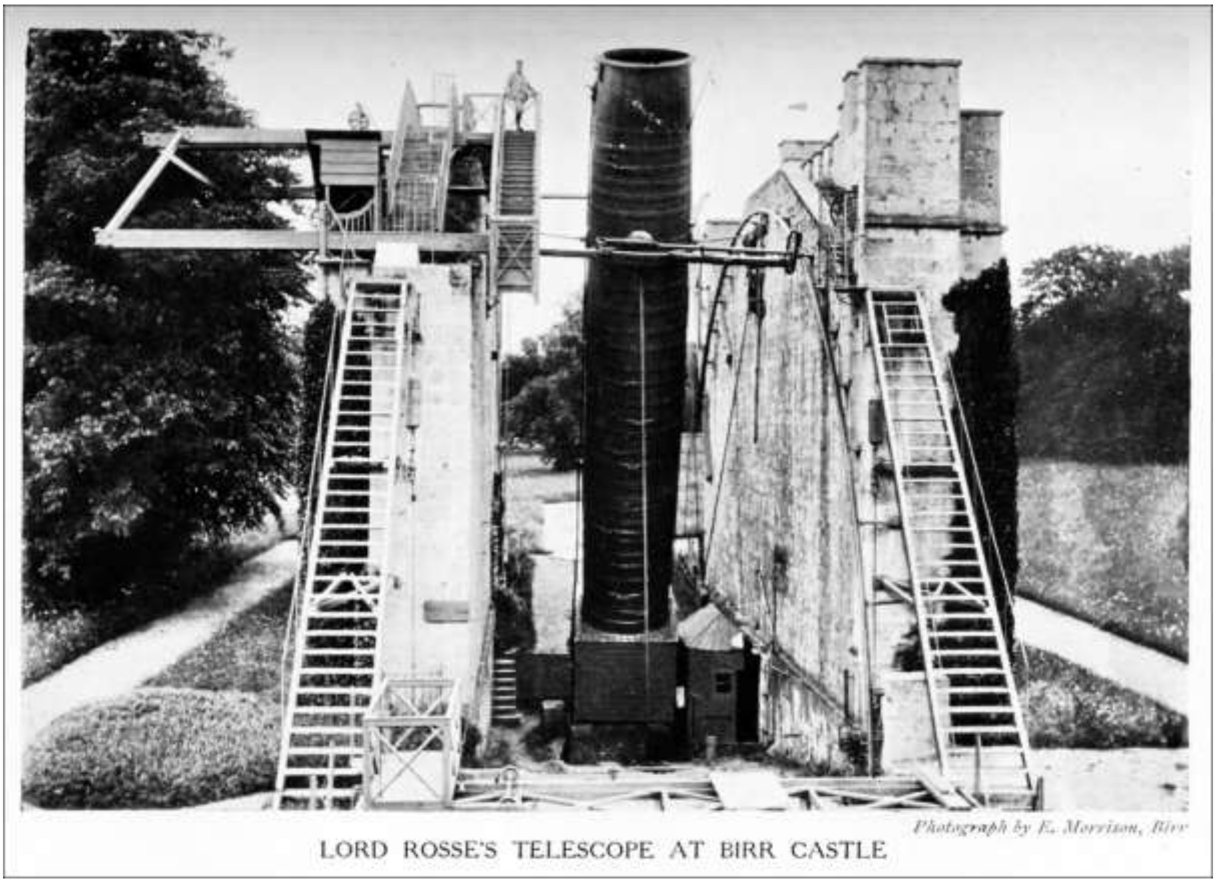

Figura 5- Fotografia vitoriana do Leviatã de Parsonstown.

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[3] Dreyer, J.L.E. (1914). Lord Rosse's Six-foot Reflector. *Observatory,* Volume XXXVII, No. 480:399-402.

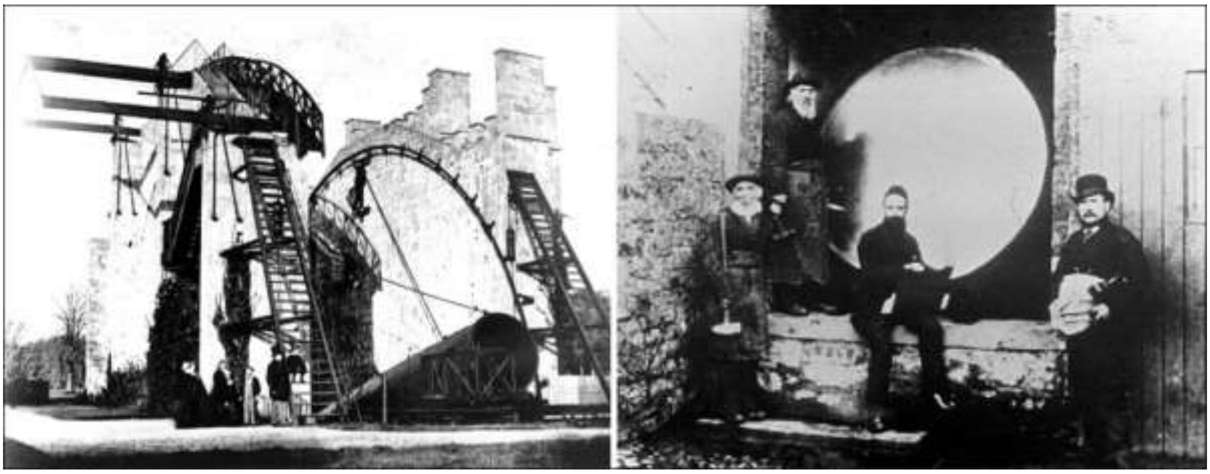


Figura 6- Telescópio de 6 pés de Lord Rosse (Fotografias da época).

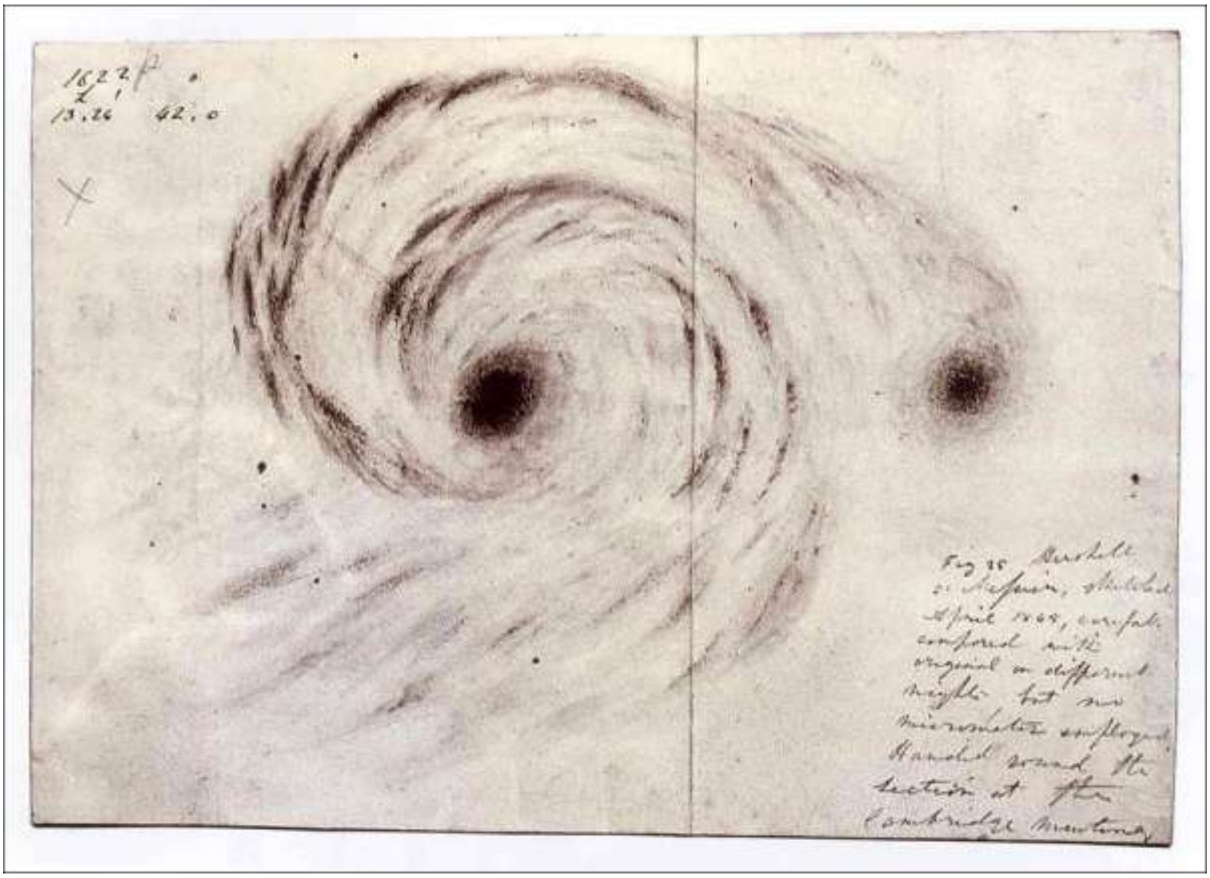


Figura 7- Desenho da estrutura espiral observada em M 51 por Lord Rosse (Abril de 1845).

O telescópio de 6 pés foi utilizado pela primeira vez no início de 1845. Em Abril do mesmo ano, Lord Rosse descreve estruturas espirais nalgumas nebulosas. A primeira nebulosa em que foi observada este tipo de estrutura foi M 51 (NGC 5194) (Figura 7). Entre os anos de 1845 e 1850, Rosse e os seus assistentes descrevem estruturas espirais em 14 nebulosas distintas. Num trabalho recente Malcom Thompson[4] refere que foram observadas com o auxílio do Leviatã estruturas espirais nas seguintes nebulosas:

NGC 108, 275, 337, 520, 598, 628, 660, 772, 877, 894/895, 941, 972, 1012, 1068, 1421, 1518, 1637, 2537, 2608, 2619, 12903/2905, 2964, 3021, 3055, 3067, 3167, 3184, 3190, 3198, 3294, 3310, 3344, 3351, 3359, 3367, 3368, 3395, 3423, 3430, 3445, 3448, 3485, 3504, 3507, 3521, 3596, 3627, 3646, 3672, 3675, 3689, 3726, 3893, 3938, 4038, 4039, 4051, 4088, 4102, 4189, 4192, 4253, 4254, 4303, 4389, 4414, 4501, 4536, 4625, 4639, 2689, 4736, 4900, 5005, 5033, 5112, 5194, 5378, 5468, 5474, 5622, 5907, 5985, 7331, 7606, 7678, 7717, 7817.

É interessante comparar as observações de M 51 efectuadas por John Herschel em 1828 com os resultados obtidos por Lord Rosse em 1845 (Figura 8). Herschel utilizou um telescópio de 20 pés de distância focal munido de um espelho com 18" (45 cm) de abertura. A comparação das duas observações revela bem o poder do Leviatã relativamente aos restantes telescópios reflectores da época[5] (Figura 9).

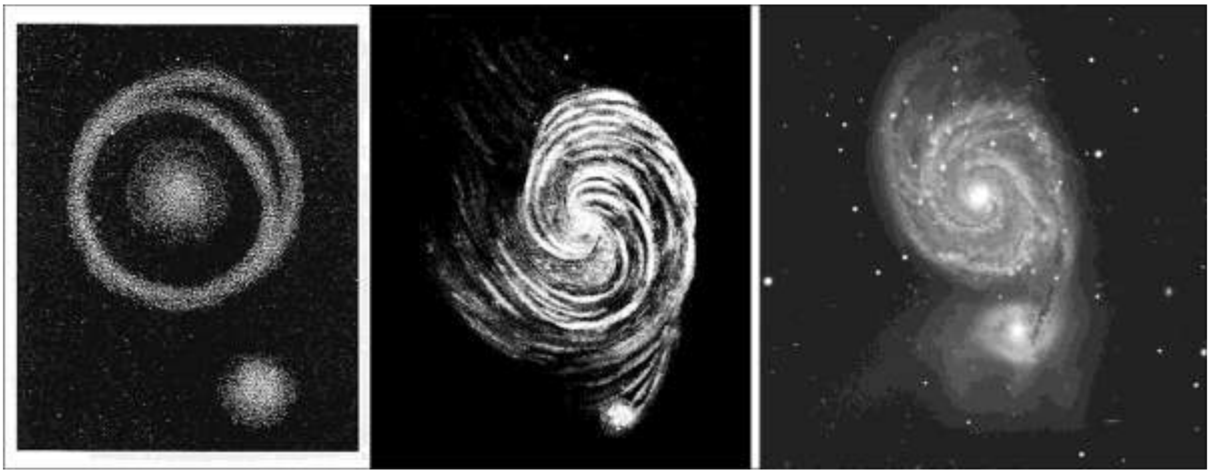
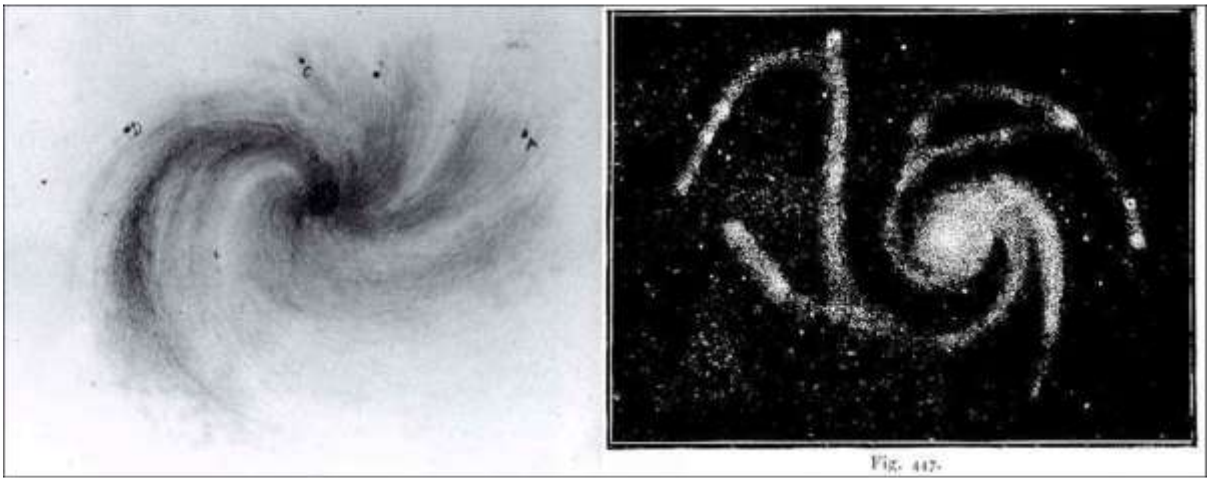


Figura 8- M 51: Desenho de John Herschel em 1828 (esquerda); Desenho de Lord Roose em 1845 (centro); Fotografia de Pedro Ré obtida em 2006 (direita).



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[4] Thompson, M. (2001). Revealing the Rosse Spirals. *Astronomy & Geophysics*, Volume 42, Issue 4, pp. 4.09-4.11.

[5] O telescópio de 6 pés de Lord Rosse foi o maior reflector do mundo até à construção do telescópio de 2,5 m do observatório do Mounte Wilson em 1917

Figura 9- Estruturas espirais detectadas por Lord Rosse nas nebulosas M 99 e M 101.

O Leviatã de Parsonstown foi sobretudo usado na observação de nebulosas. Com o auxílio deste instrumento, Lord Rosse e J.T.R. Robinson "resolveram" numerosas estrelas nestes objectos de tal modo que chegaram a afirmar que todas as nebulosas eram constituídas por estrelas. Em Março de 1846, Rosse refere a observação de numerosas estrelas na nebulosa de Orion (M 42), observação "confirmada" por W.C. Bond que utilizou o refractor de 38 cm de abertura do observatório de Harvard. Estas observações foram no entanto contestadas por inúmeros astrónomos.

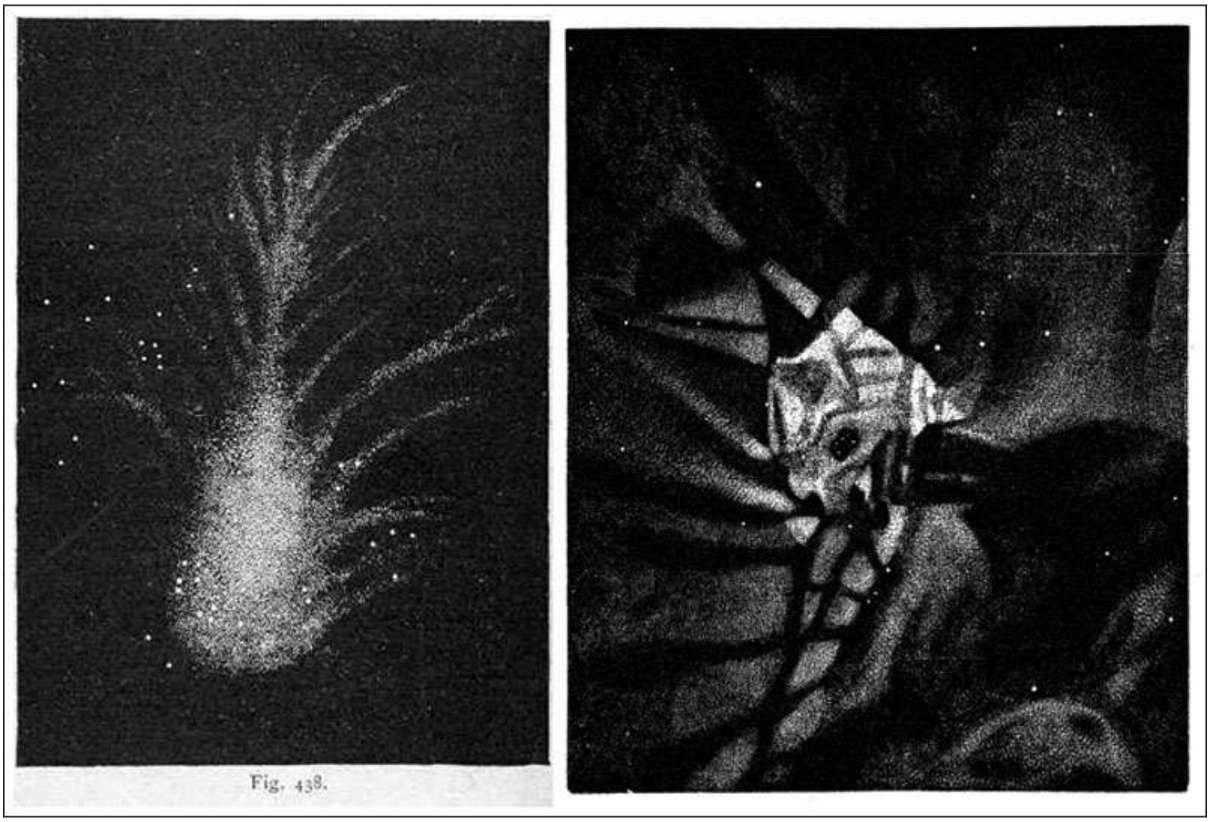

Figura 10- M 1 e M 42 desenhadas por Lord Rosse com o auxílio de diferentes instrumentos: M 1 telescópio de 3 pés (1844); M 42 telescópio de 6 pés (1865/1867).

A controvérsia manteve-se até 1864, ano em que William Huggins (1824-1910) descreve um espectro descontínuo em M 42, típico de uma nebulosa de emissão composta por gás. Após esta descoberta, Rosse desenha um sofisticado espectroscópio com cerca de 35 kg de peso que foi instalado no Leviatã. Efectou numerosas observações do espectro da nebulosa bem como um desenho minucioso da sua estrutura (Figura 10). Foi Lord Rosse que designou M 1 pela primeira vez como nebulosa do caranguejo. As observações que efectuou com o auxílio do telescópio de 3 pés mostraram uma estrutura semelhante a um caranguejo (Figura 10)[6].

Após a morte do 4^{O} Conde de Parsonstown em 1908, o Leviatã deixou de ser utilizado e foi finalmente desmantelado em 1914. Grande parte do metal do telescópio foi fundido e re-utilizado durante a 1ª Grande Guerra Mundial. Um dos seus espelhos metálicos foi depositado no Museu de Ciência de Londres (Figura 11). Recentemente (1996/1998) o telescópio foi

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[6] Mais tarde Rosse redesenhou M 1 com o auxílio do telescópio de 6 pés. A gravura que publicou foi completamente distinta do desenho original.

completamente restaurado tendo-se mantido tanto quanto possivel a sua configuração original (Figura 12).

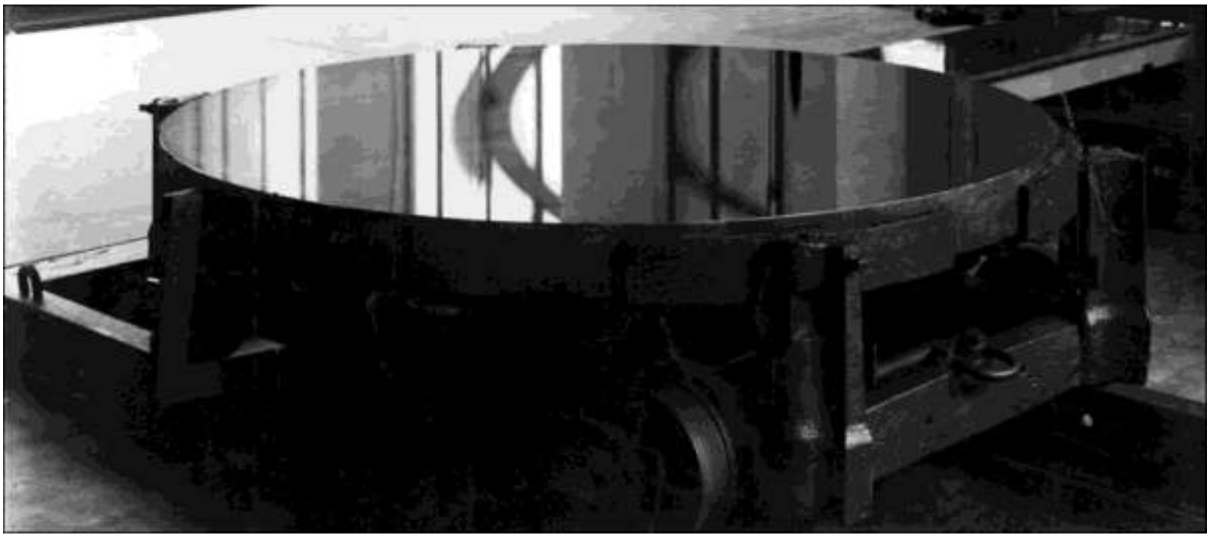

Figura 11- Espelho metálico do telescópio do 6 pés depositado em 1914 no Museu de Ciência de Londres.

Figura 12- Leviatã de Parsonstown restaurado.

Sources

- Dreyer, J.L.E. (1914). Lord Rosse's Six-foot Reflector. *Observatory,* Volume XXXVII, No. 480: 399-402.
- Hoskins, M. (ed.) (1997). *Cambridge Illustrated History of Astronomy*. Cambridge University Press.
- King, H.C. (1955). *The History of the Telescope*. Dover Publications, Inc. New York.
- Thompson, M. (2001). Revealing the Rosse Spirals. *Astronomy & Geophysics*, Volume 42, Issue 4, pp. 4.09-4.11.

THE 25-INCH NEWALL REFRACTOR

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Robert Stirling Newall (1812-1889) was a wealthy Scottish engineer and amateur astronomer. Newall commissioned Thomas Cooke (1807-1868) to build a telescope for his private observatory at Ferndene (Gateshead). The discs for a 25-inch (640 mm) refractor were ordered from the Chance Brothers Company in 1862. The lens had a focal length of 9.1 m and a combined weight of 66 kg. The Newall refractor took seven years to build (it was for a few years the largest in the world). It was erected in 1870 on Newall's estate, a very unfavorable site: during a period of fifteen years Newall had only one night in which he could use its full aperture (Figure 1 and Figure 2).

The Newall telescope was described in detail in an article that appeared in *Nature* (February 17, 1870). The full text of this article in transcribed below:

The 25-inch Equatorial Telescope, commenced several years ago by T. Cooke and Sons, of York, for R. S. Newall, Esq. of Gateshead, is now so far completed that it has been removed from the works at York into its observatory in Mr. Newall's grounds, at Ferndene.

The completion of a telescope with an object glass of 25 inches aperture, marks an epoch in astronomy, and its completion in England again places us in the front rank in the matter of the optical art, as we were in Dolland's time.

The history of the progress of the manufacture of telescopes since the time referred to shows very clearly the long-lasting effects of bad legislation; for it is not too much to say that the duty on glass stifled, if indeed it did not kill, the optical art in England. Hence we depended for many years upon France and Germany for our telescopes to such an extent indeed that the largest object-glasses at Greenwich, Oxford, and Cambridge are all of foreign make. The labors of the Germans culminated in the two magnificent instruments of 15 inches aperture in the observatories of Pulkowa and Cambridge, U.S. And then for a time America, thanks to the genius of Alvan Clarke, took the lead with the 18-inch glass now beginning to do good work in the observatory of Chicago. This instrument is at last eclipsed by the magnificent one now being erected at Gateshead.

In what we have said we have purposely omitted to touch upon reflecting telescopes, in the construction of which, since the time of Newton, England has always been pre-eminent, because we shall take occasion to refer to the reflector of four feet aperture, completed last year by Mr. Grubb, of Dublin, and now erected at Melbourne when it is fairly at work.

The general design and appearance of this monster among telescopes, which will be gathered from the accompanying woodcut (Figure 3), is the same as that of the well-known Cooke equatorials; but the extraordinary size of all the parts has necessitated the special arrangements of most of them.

The length of the tube, including dew-cap and eye-end, is 32 feet, and it is of cigar shape; the diameter at the object-end being 27 inches, and at the centre of the tube 34 inches. The cast-iron pillar supporting the whole is 29 feet in height from the ground to the centre of the declination axis, when horizontal; and the base of it is 5 feet 9 inches in diameter. The trough for the polar axis alone weighs 24 cwt., the weight of the whole instrument being nearly 9 tons.

The tube is constructed of steel plates riveted together, and is made in five lengths, screwed together with bolts and flanges. The plates of the central length are one-eighth of an inch thick, and those of each end one-sixteenth thick, so as to reduce the weight of the ends as much as possible, and avoid flexure.

Inside the outer tube are five other tubes of zinc, increasing in diameter from the eye to the object-end; the wide end of each zinc tube overlapping the narrow end of the following tube, and leaving an annular space of about an inch in width round the end of each for the purpose of ventilating the tube, and preventing, as much as possible, all interference by currents of warm air, with the cone of rays. The zinc tubes are also made to act as diaphragms.

The object-glass has an aperture of 25 inches (nearly), and in order as much as possible to avoid flexure from unequal pressure on the cell, it is made to rest upon three fixed points in its cell, and between each of these points are arranged three levers and counterpoises round a counter-cell, which act through the cell direct on to the glass, so that its weight in all positions is equally distributed among the 12 points of support, with a slight excess upon the three fixed ones. The focal length of the lens is 29 feet. A Barlow lens is arranged to slide on a brass framework within the tube. The hand is passed through an opening in the side of the tube, and by means of a handle attached to the cell the lens may be pushed into or out of the cone of rays.

Attached to the eye-end of the tube are two finders, each 4 inches aperture; they are fixed above and below the eye-end of the main tube, so that one may be readily accessible in all positions of the instrument. It is also supplied with a telescope having an O. G. of 6 ". This is fixed between the two finders, and is for the purpose of assisting in the observations of comets and other objects for which the large instrument is not suitable. This assistant telescope is provided with a rough position circle and micrometer eye-pieces, and is illuminated by new apparatus lately described in NATURE.

Two reading microscopes for the declination circle are brought down to the eye-end of the main tube; the circle-38 inches in diameter-is divided on its face, and read by means of the microscopes and prisms.

The slow motions in declination and R. A. are given by means of tangent screws, carrying grooved pulleys, over which pass endless cords brought to the eye-end. The declination clamping handle is also at the eye-end.

The clock for driving this monster telescope is in the upper part of the pillar, and is of comparatively small proportions, the instrument being so nicely counterpoised that a very slight power is required to be exerted by the clock, through the tangent screw, on the driving wheel (seven feet diameter), in order to give the necessary equatorial motion.

The declination axis is of peculiar construction, necessitated by the weight of the tubes and their fittings, and corresponding counterpoises on the other end, tending to cause flexure of the axis. This difficulty is entirely overcome by making the axis hollow, and passing a strong iron lever through it, having its fulcrum immediately over the bearing of the axis near the main tube, and acting upon a strong iron plate rigidly fixed as near the centre of the tube as possible, clear of the cone of rays. This lever, taking nearly the whole weight of the tubes, &c., off the axis, frees it from all liability to bend.

The weight of the polar axis on its upper bearing is relieved by friction rollers and weighted levers; the lower end of the axis is conical, and there is a corresponding conical surface on the lower end of the trough; between these two surfaces and three conical rollers carried by a loose or "live" ring, which adjust themselves to equalize the pressure.

The hour circle on the bottom of the polar axis is 26 inches in diameter, and is divided on the edge, and read roughly from the floor by means of a small diagonal telescope attached to the pillar; a rough motion in R. A. by hand is also arranged for by a system of cog-wheels moved by a grooved wheel and endless cord at the lower end of the polar axis, so as to enable the observer to set the instrument roughly in R. A. by the aid of the diagonal telescope.

The declination and hour circles will probably be illuminated by means of Geissler tubes, and the dark and bright field illuminations for the micrometers will be effected by the same means.

Mr. Newall, after the preliminary testing of this magnificent instrument at his own residence, purposes to erect it in some climate favorable for astronomical observation. It is very unfortunate that this means in other words that the telescope cannot remain in England. It is or should be among the things generally known that every increase in the size of an object-glass or mirror increases the perturbating effects of the atmosphere, so that the larger the telescope, the purer must be the air. In the absence of this latter condition, a "big" telescope is a "big evil," and skilled observers, mindful of this, reduce the apertures of their instruments when the air is not good.

We may regard this telescope as a clear gain to English science, for Mr. Newall with princely liberality has expressed his intention of allowing observes with a special research on hand to have the use of the instrument during certain regulated hours.

The observatory, of which we also give a sketch, is nearly 50 feet in diameter, and notwithstanding the enormous weight of the dome, like the telescope, it is easily moved into any required position.

When completed it will have attached to it a transit-room. And this reminds us that Mr. Marth, so well known for his great work done at Malta with the Lassell Reflector and elsewhere will have charge of this noble instrument of research.

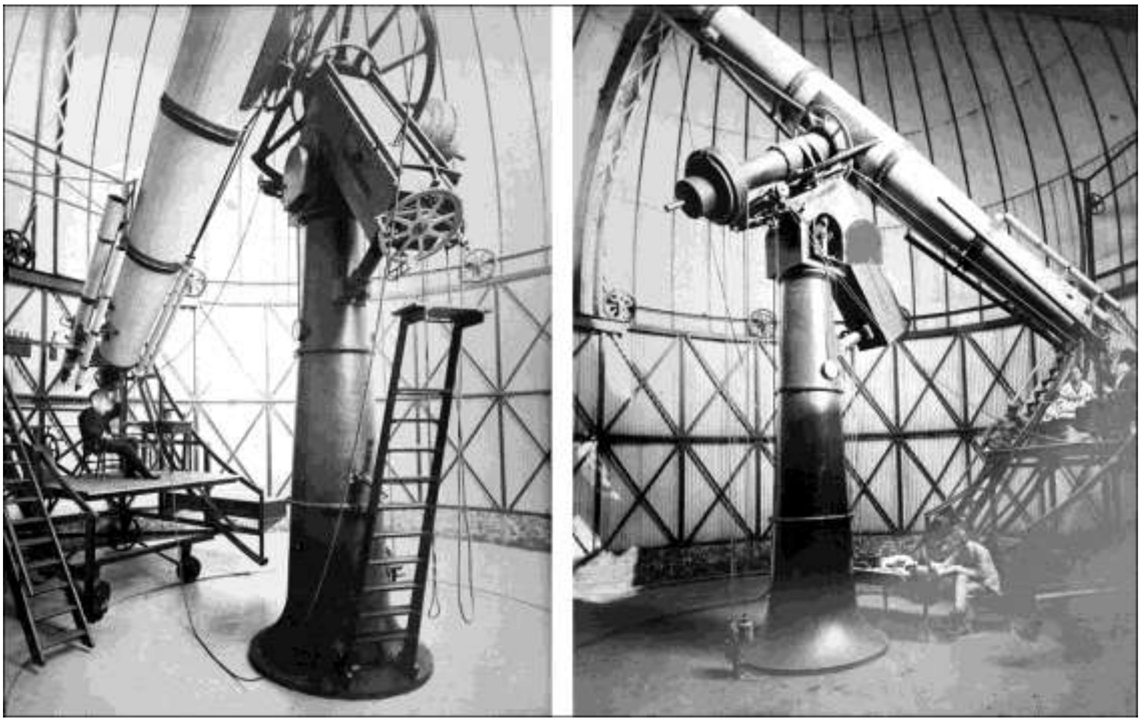

Figure 1- Photographs of the 25-inch Newall refractor and equatorial mount by Cooke of York (1872).

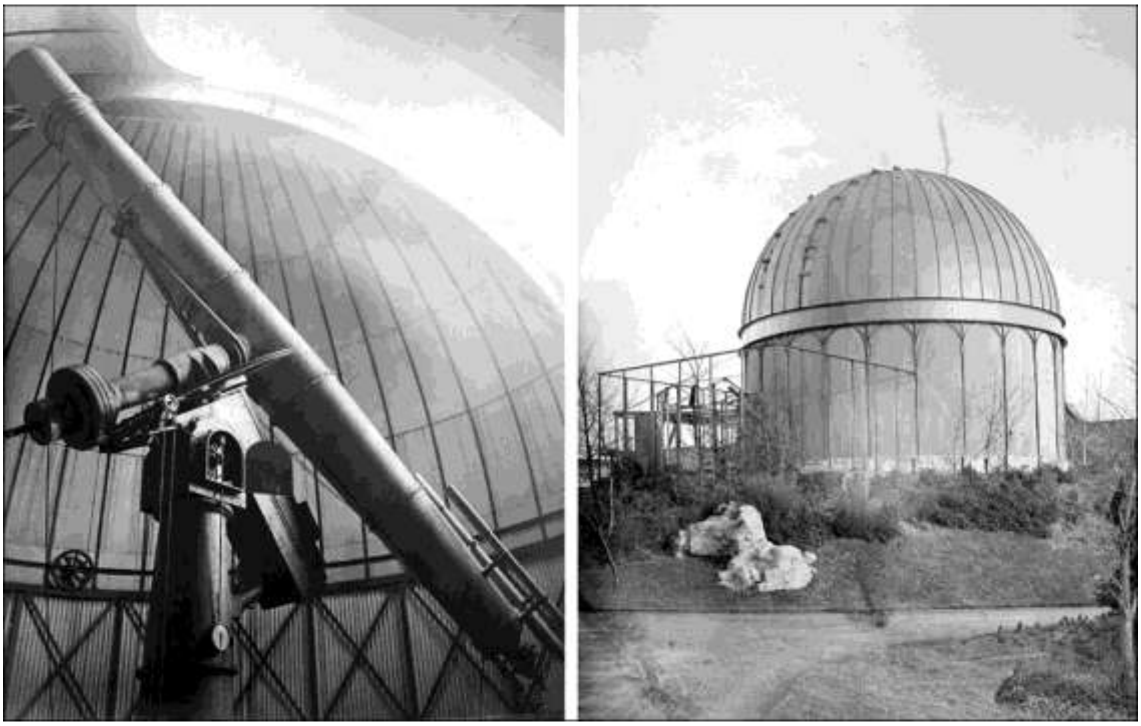

Figure 2- 25-inch Newall refractor and dome (1872).

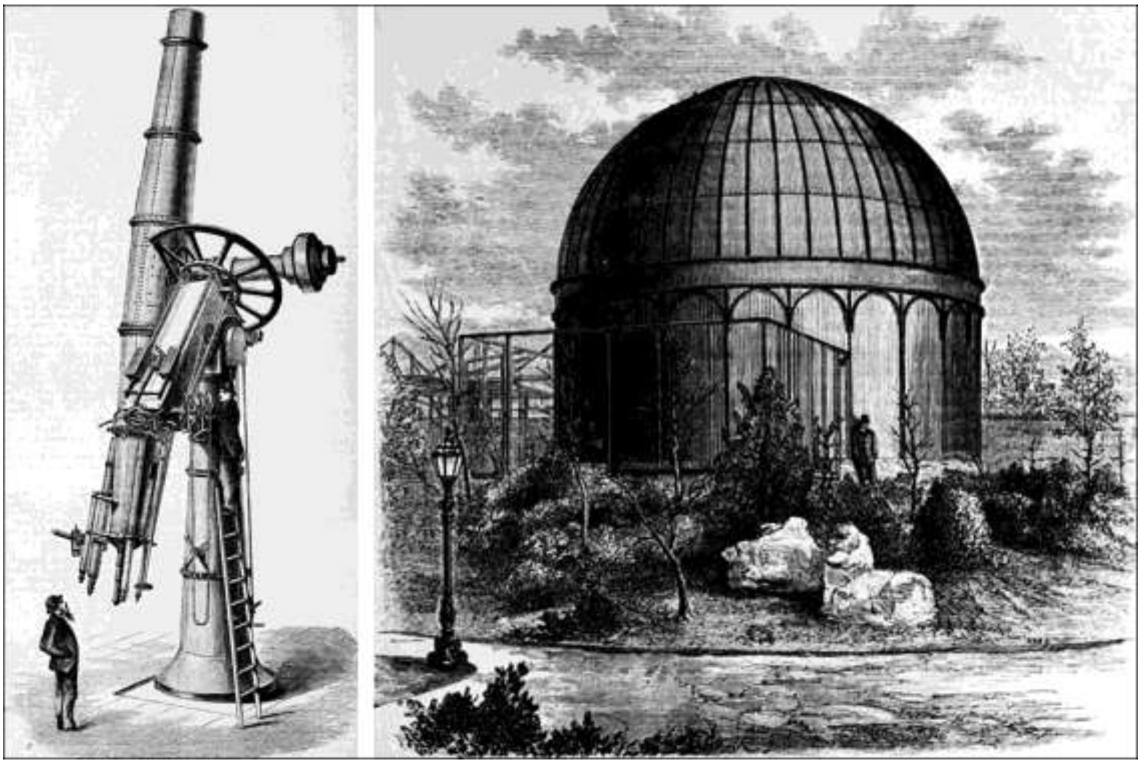

Figure 3- Figures from the *Nature* article. Captions: The great Newall telescope of 25 inches aperture, now being erected at Gaterhead (left); The observatory for the Newall Telescope (right).

After years of bad weather and sporadic use, Newall offered to loan the instrument to the Cape Observatory. David Gill (1834-1914), director of the observatory was eager to determine the parallax of alpha Centauri. The cost of dismounting and transporting the telescope to South Africa was considered prohibitive and the whole matter was put to rest.

Figure 4- Newall telescope at the University of Cambridge: spectroscope (left); telescope and dome (center); dome (*ca.* 1906).

In 1890 the 25-inch refractor was offered to the University of Cambridge (the telescope was moved in 1891). Newall's son, Hugh Frank Newall, worked for five years without any payment as the main observer responsible for the telescope. From 1891 to 1911, H.F. Newall conducted a huge series of spectroscopic observations with excellent results. The work continued until 1930 when the telescope became gradually outdated (Figure 4 and Figure 5).

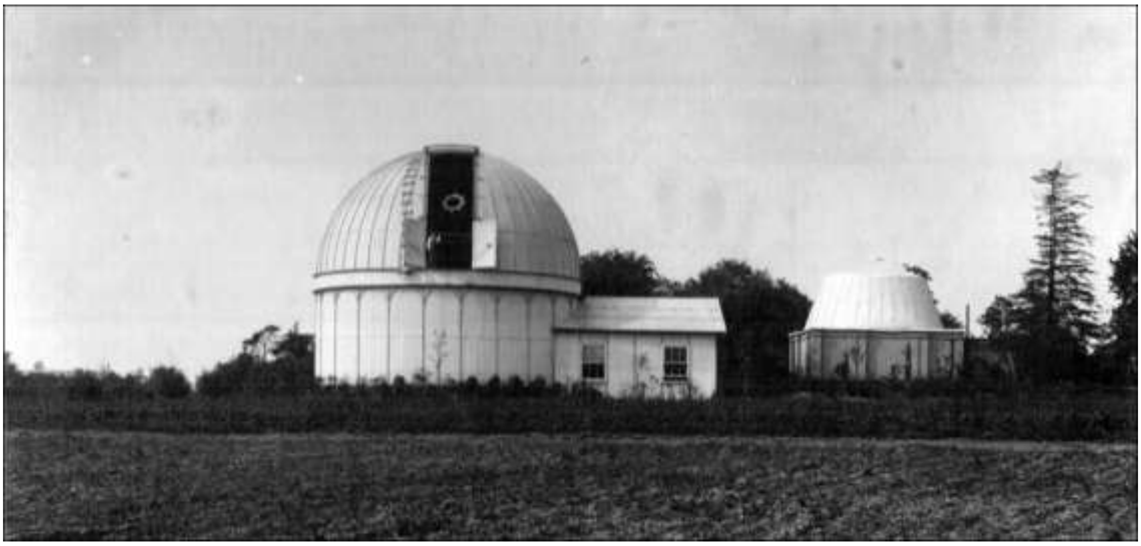

Figure 5- Newall telescope and dome at the University of Cambridge (*ca.* 1930).

In 1950 the telescope was rarely used and the dome needed repair. The University of Cambridge decided to donate the instrument. The National Observatory of Athens accepted the donation and the Newall refractor was transported to the Koufos hill near the Pendeli mountain (Greece). The construction of the new observatory started in 1957. The 25-inch refractor was installed at the top of a 5 m concrete pier (access to the eyepiece is facilitated by a moving floor). The new dome has a diameter of 14 m (Figure 6).

Figure 6- The Newall 25-inch refractor and new dome at the Penteli Astronomical Station (National Observatory of Athens - Greece).

Sources:

- King, H.C. (1955). *The history of the telescope*. Charles Griffin, High Wycombe, England.

O Telescópio de Craig (1852)

Pedro Ré
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O reverendo John Craig (1805-1877) construiu em 1852 um telescópio refractor com 24” (61 cm) de abertura em Wandsworth, próximo de Londres (Figura 1). Apesar de não pertencer a qualquer Associação astronómica, Craig tencionava realizar com este instrumento (o maior refractor existente até ao momento), observações do anél C de Saturno e verificar se o planeta Vénus possuia satélites.

Segundo Henry King (1955)[7] este telescópio refractor “*was a complete failure*”. Alguns trabalhos recentes descrevem de um modo pormenorizado este instrumento, dotado de uma montagem azimutal fora do comum[8] e que foi utilizado unicamente durante um período de 6 anos.

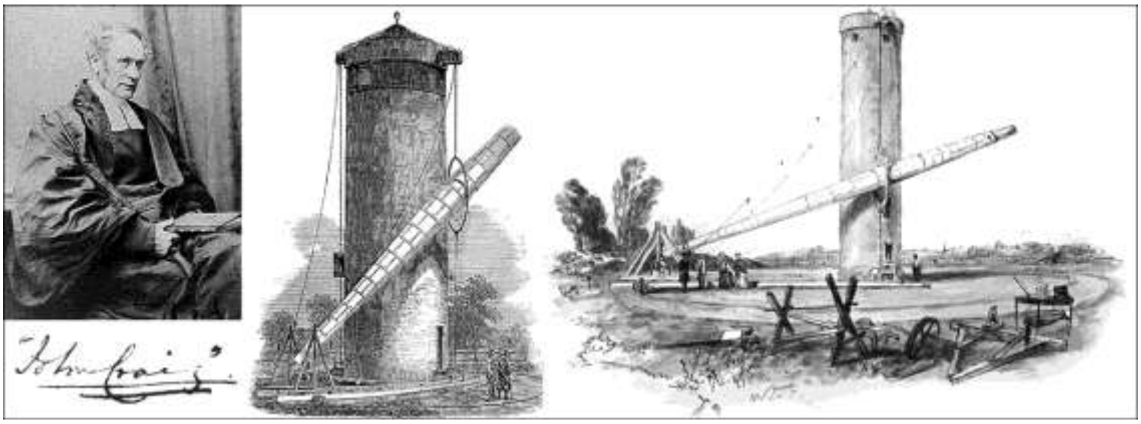

Figura 1- Telescópio de Craig (1852). John Craig (esquerda), gravuras e aguarela (centro e direita).

O telescópio de Craig é descrito na revista *Illustrated London News* em 18 de agosto de 1852:

During the past three months, the construction of a building on Wandsworth Common, for the reception of a monster achromatic telescope, has been rapidly progressing, and is, with telescope itself, now nearly completed. This great work is under the supervision of William Gravatt, Esq., F.R.S., or Rev. Mr. Craig, vicar of Leamington. The site, consisting of two acres, has been liberally presented by Earl Spencer, in perpetuity, or as long as the telescope shall be maintained.

As this gigantic instrument should have some distinctive name, the various friends of science who have been admitted to view it have denominated it 'The Craig Telescope' considering as the Duke of Northumberland's name has been handed down in connection with the Cambridge refractor - so, also, the originator, in fact, of this 85 feet focal length achromatic telescope, with an object-glass of two feet aperture and already capable of doing marvels, should have his name associated with a work completely novel in all its part, and we are happy to add, entirely of English workmanship. All other achromatic telescopes of any pretensions are foreign.

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[7] King, H.C. (1955). The history of the telescope. Diver Publications Inc.

[8] http://www.craig-telescope.co.uk/, http://homepage.ntlworld.com/greg.smyerumsby/craig/
Steel, D. (1982). The Craig Telescope of 1852. *Sky and Telescope*, 7: 12-13.

The Duke of Northumberland's telescope is foreign, the Oxford telescope is foreign, Sir James South's telescope is foreign, in fact, and these instruments were merely purchased by English money. Not so the present instrument, by far the largest achromatic telescope in the world.

In the retired study of a country clergyman, the idea of this instrument struck him, and having made in his own peculiar way his calculations the result was a fixed determination to carry them out, which he has more especially shown in the choice of his engineer, for many were those he had to reject, after looking into their plans of mounting his telescope. He has selected Wm. Gravatt, Esq., FRS, whose name, we believe, Mr. Craig, is more desirous to connect with his wonderful telescope than his own.

The powers of this Telescope, as a measuring instrument, are unapproachable by all others. It separates minute points of light so distinctly that its space penetrating qualifications will render it, as a discovering instrument, one of a most superior order. It resolves the Milky Way, not simply into beautiful and brilliant 'star dust', to use the language of astronomers, but actually subdivides it into regular constellations. We thus in what at best was heretofore separated into minute points of light, can now behold counterparts of our own Orion and Cassiopeia, our Greater and Lesser Bears and also evidently adorned with the most generous colors.

The Telescope is perfectly achromatic; Saturn exhibits itself with milky-light whiteness. Now that the instrument is adjusted, Mr Craig wishes the Planet Venus to be examined, for he hopes to settle the question as to whether she has a satellite or not, and we need not say what an advantage the solution of this fact would be to science. The moon is a magnificent object and perfectly colorless, so that the observer can behold her mountains and rocks with a vivid distinctness that makes us long for clear weather to bring the whole of the powers of this marvelous instrument to bear upon our planet. On a favorable evening, were such a building, for instance, as Westminster Abbey in the moon, this Telescope would reveal all its parts and proportions.

The central tower is of brick, and 61 feet in height, 15 feet in diameter, and weighs 220 tons. Every precaution has been taken in its construction to prevent the slightest vibration, which can still further be provided for by loading the several floors, and the most perfect steadiness will be thus ensured.

By the side of this sustaining tower hangs the telescope. The length of the main tube, which is somewhat shaped like a cigar, is 76 feet, having an eyepiece at the narrow end, and a dew cap, at the other: the total length in use will be 85 feet. The design of the dew cap is to prevent obscuration by the condensation of moisture, which takes place during the night, when the instrument is most in use.

Its exterior is of bright metal: the interior is painted black. The focal distance will vary from 76 to 85 feet. The tube at its greatest circumference measures 13 feet and this part is about 24 feet from the object-glass. The determination of this point was the result of repeated experiments, and minute and careful calculation. It was essential to the object in view that there should not be the slightest vibration in the instrument, and Mr. Gravatt has made the vibration at one end of the tube neutralize that at the other.

The ironwork of the tube, which is a splendid specimen of English workmanship, was manufactured by Messrs. Rennie, under the direction of Mr. Gravatt. The tube rests upon a light wooden framework with iron wheels attached, and is fitted to a circular iron railway at a distance of 52 feet from the centre of the tower. The chain by which it is lowered is capable of sustaining a weight of fifteen tons, though the weight of the tube is only three.

Notwithstanding the immense size of the instrument, it can move either in azimuth, or up to an altitude of 80 degrees, with as much ease and rapidity as an ordinary telescope, and from the nature of the mechanical arrangements, with far greater certainty as to results. The slightest force applied to the wheel on the iron rail causes the instrument to move round the central tower.

All the optical work has been executed by Mr. F. Slater, of Somer-place West, Euston-square. The two lenses, one of flint and the other of plate glass, are thus used: The plate-glass lens has a positive focal length of 30 feet 11/2 inch; its refractive index is 15103. The flint-glass lens has a negative focal length of

40 feet 101/2 inches; and the refractive index of this glass is 16308. These two lenses, placed in contact, are used in combination, and constitute the achromatic object-glass, the focal length of which is 76 feet to parallel rays – that is, to all celestial objects.

John Craig ocupou o cargo de reverendo em Leamington. Era um figura muito respeitada na sua paróquia e trabalhou intensamente para reconstruir a igreja de todos os santos em Leamington. Vistou diversas igrejas na Europa e em 1849, recorrendo a diversas doações, terminou a referida reconstrução. Em 1852 foi construído um novo transecto na referida igreja. A reconstrução da igreja coincidiu com a construção do telescópio. William Gravatt (1806-1866), membro da *Royal Society*, foi responsável pela parte mecânica do telescópio e Thomas Slater (1817-1889) foi encarregue da construção da objectiva.

A motagem do telescópio era constituída por uma torre construída com tijolos que suportava o tubo do telescópio (Figura 1, Figura 2).

Figura 2- Telescópio de Craig: fotografia da época (esquerda) e reconstituição do telescópio (direita), (http://www.craig-telescope.co.uk/).

A torre foi construída num período de apenas um mês. Tinha uma altura de 64 pés (19,5 m), um diâmetro de 15 pés (4,6 m) e um peso aproximado de 220 Toneladas. O tubo, em forma de charuto, foi construído a partir de peças metálicas rebitadas, segundo os métodos utilizados na indústria naval da época. Com um comprimento de 85 pés (25,9 m) e um peso aproximado de 3 Toneladas, o tubo não podia atingir altitudes superiores a 75/80 graus ou inferiores a 5 graus (Figura 3).

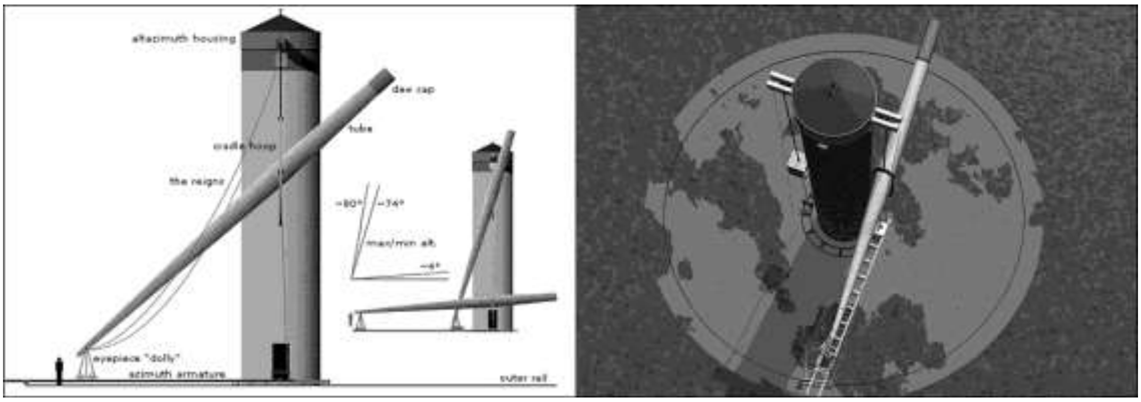

Figura 3- reconstiruição do telescópio de Craig ilustrando a altura máxima e mínima por este atingida (http://www.craig-telescope.co.uk/).

O tubo do telescópio podia rodar livremente à volta da torre. Estava suportado por uma corrente fixa a cerca de 24 pés (7,3 m) da extremidade do tubo e provida de um contrapeso. Na extremidade da ocular, o tubo era apoiado por um suporte em madeira provido de rodas (Figura 4).

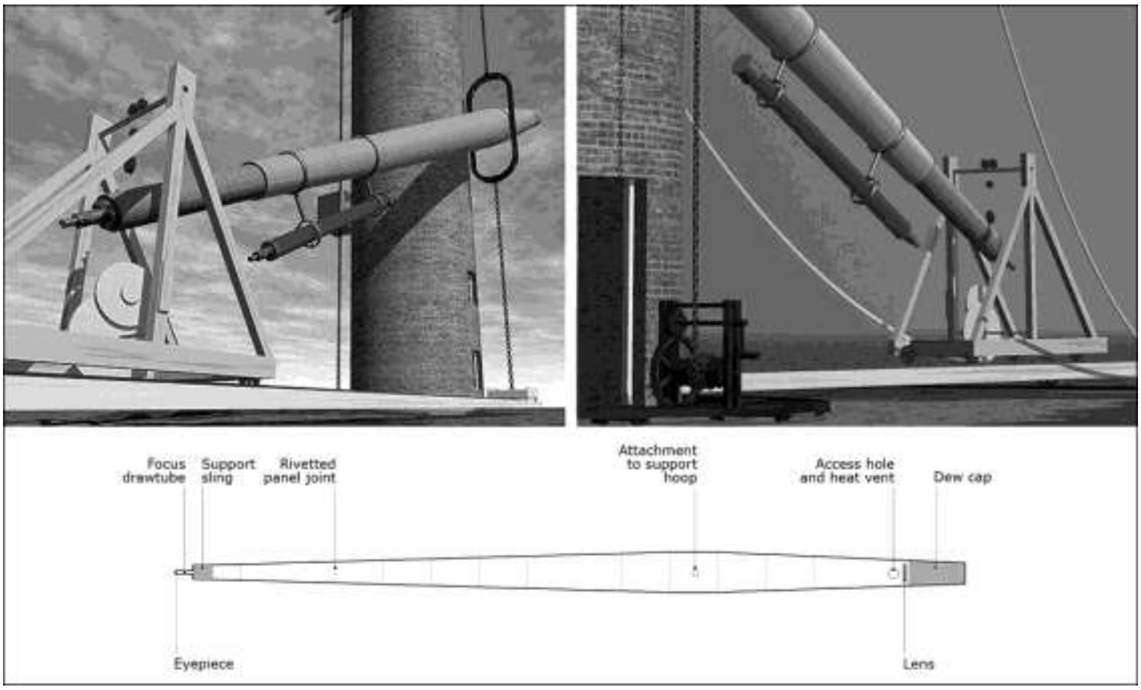

Figura 4- Reconstituição do tudo do telescópio de Craig, (http://www.craig-telescope.co.uk/).

O telescópio guia foi igualmente construído por Slater e devia ter uma abertura de 10 a 15 cm (Figura 4).

A objectiva do telescópio de Craig foi construída entre 1850 e 1852. Era constituída por um elemento *flint* fornecido pela firma *Chance Company* e por um elemento em vidro vulgar (*plate glass – Thames Plate Glass Company*). Aparentemente objectiva não era de grande qualidade e necessitava de ser diafragmada para ser utilizada em boas condições (Figura 5).

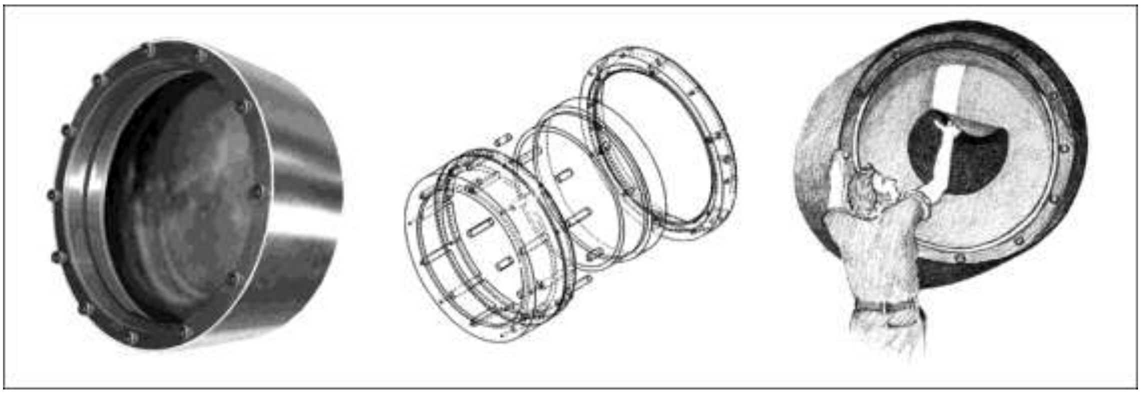

Figura 5- Reconstituição da objectiva de 24 pés do telescópio de Craig.

Um artigo da revista *Illustrated London News* refere-se à fraca qualidade da objectiva:

The Craig Telescope is, in a small portion of one of its lenses, too flat by about the five thousandth part of an inch. This has been stopped out when extreme accuracy of definition is required, as, for instance, in *observing such fine point of an object as Saturn's third ring. To many of our readers it will seem incredible that the five thousandth part of an inch is rendered, as to its results, in any degree evident, and is a quantity that can be positively measured. But so it is.*

Este erro representa uma correcção inferior a um comprimento de onda o que é totalmente inaceitável no que diz respeito à prestação de uma objectuva acromática.

O telescópio de Craig foi utilizado apenas entre 1852 e 1858. Durante este período de 6 anos foram realizadas sobretudo observações dos planetas Vénus e Saturno (Figura 6). A revista *Illustrated London News* em 16 de Outubro de 1852, refere a propósito da observação de Saturno:

When news of this reached England, the Northumberland achromatic, at our Cambridge University, was brought to bear, by Professor Challis, on the rings of Saturn, and he failed in discovering the third: so, also, with the giant reflector of the Earl of Rosse. Hence it became a matter of intense interest, as to whether there was in reality a third ring. We are happy now to exhibit an Engraving of the Ring, as seen in this country. In the Craig Telescope - engraved and described in the Illustrated London News for August 28 - this third ring is quite palpable; so that there can be no longer any doubt as to its existence. The colour of this ring is a brilliant slate. The great quantity of light which the telescope at Wandsworth brings to the eye of the observer from this planet gives, we presume. This bright appearance to what in instruments of less power is in fact completely invisible.

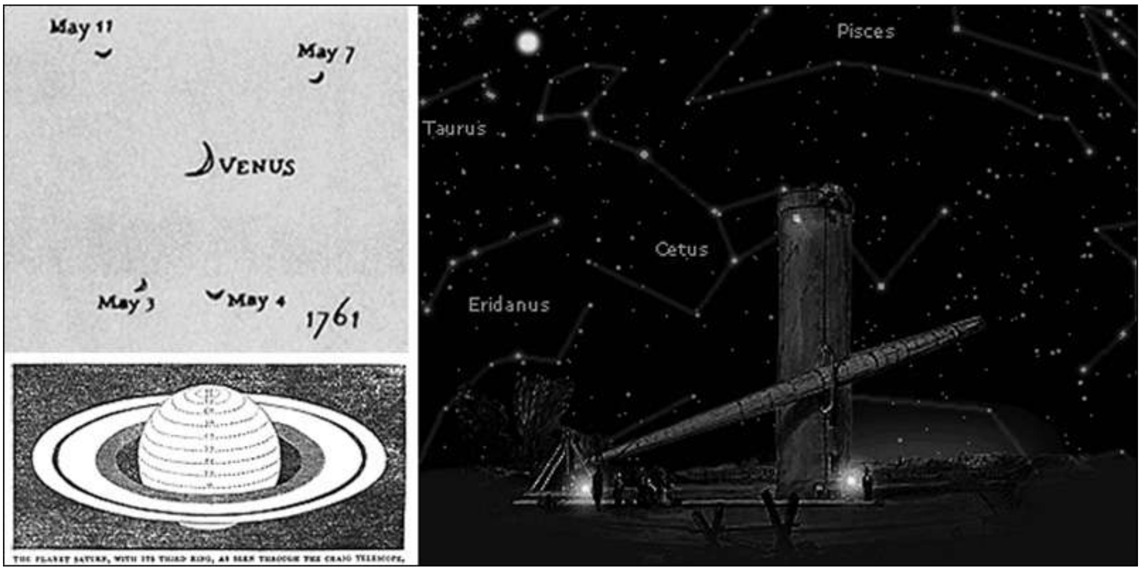

Figura 6- Observação ilusória dos satélites de Vénus efectuada em 1761 por Jacques Leibax Montaigne (1716 - 1785?) e observação do sistema de anéis de Saturno efectuada com o auxílio do telescópio de Craig (http://www.craig-telescope.co.uk/).

Apesar da montagem azimutal do telescópio não ser adequada para a realização de fotografias astronómicas, são feitas referências a imagens obtidas com o auxílio deste instrumento num trabalho apresentado à *British Association* em 1854:

Dr. Diamond, who printed the positive of the moon, found the sun picture, however, rather overdone for transferring. "It will be necessary, therefore, either to use collodion and nitrate of silver simply without any or but little sensitive solution or else pass the sun's rays through some colored glass, which will partially retard their energy. A series of pictures of the spots of the sun, as well as of the general surface, may then be successfully obtained; and hence it is not too much to anticipate some accession to our knowledge of the physical character of both our great luminaries by means of this gigantic telescope, which Dr. Diamond enables me to exhibit photographically to the [Astronomy] section.

O telescópio de Craig foi totalmente desmantelado no ano de 1870 (Figura 7). Existe uma referência à observação do cometa de Donati, efectuada em 1858 por Thomas Slater, com o auxílio de um telescópio refractor de 38 cm de abertura, em que é referida a seguinte passagem:

Slater's telescope is the largest refractor at present in use in this kingdom

Este facto parece indicar que o telescópio de Craig já não era utilizado regularmente em 1858.

Hery King (1955) refere ainda:

> ***The crude structure was dismantled after a few years' use, but not before it had formed a strange landmark for the residents of Wandsworth (…)***

A melhor descrição do desmantelamente do telescópio é efectuada por Slater na revista *The English Mechanic* em Maio de 1870:

> ***Having recently come to reside in this locality (Clapham Junction), and noticing Mr. Webb's late remarks respecting the great Wandsworth Telescope, I have been induced to try and seek it out. After two or three failures I met near the spot on which it used to stand a gentleman named Stilwell, an inhabitant of Wandsworth, who gave me the following particulars from his own personal knowledge. Pointing out the enclosure within which the instrument was erected, and indicating markings in the ground left by the tower from which it swung, he said that the whole affair was removed four or five years ago. The bricks were employed to aid in the erection of an [sic] hotel visible a few hundred yards off; the tube was bought by a Wandsworth broken [sic], who cut it into sections, and sold them to a gentleman at Wimbledon. These sections with bottoms inverted, formed tanks, from which the gentleman's cattle now drink. About the tramway there was some four tons of wrought iron, which M., Stilwell himself had converted into horse-shoes. As to the object glass, my informant could tell me nothing***

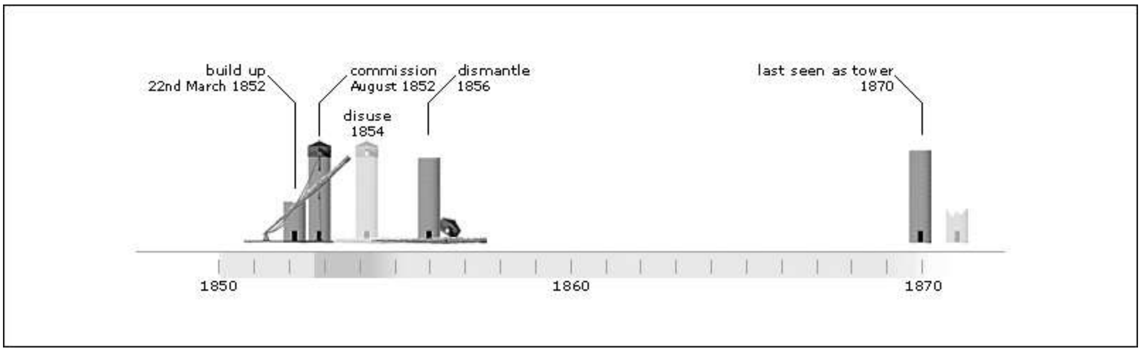

Figura 7- Construção e desmantelamento do telescópio de Craig (http://www.craig-telescope.co.uk/).

Bibliografia:

- King, H.C. (1955). The history of the telescope. Diver Publications Inc.
- The Craig Telescope websites http://www.craig-telescope.co.uk/
  http://homepage.ntlworld.com/greg.smyerumsby/craig/

\O GRANDE TELESCÓPIO DE MELBOURNE

Pedro Ré
http://astrosurf.com/re

O grande telescópio de Melbourne (GTM) foi construído em 1869 por Howard Grubb (1844-1931) (Figura 1). Foi o ultimo grande telescópio reflector a ser equipado com espelhos de metal (“specula”). O GTM foi utilizado entre 1869 e 1893, ano em que foi desactivado até ser adquirido pelo observatório de Mount Stromlo após a segunda grande guerra. O falhanço deste instrumento é normalmente atribuído ao facto dos seus elementos ópticos serem constituídos por uma liga metálica e não por vidro. Estudos recentes indicam que a equipa de observadores que o utilizou era demasiado inexperiente e com poucos contactos com outros centros astronómicos da época. O telescópio foi construído com uma única finalidade: realizar desenhos das nebulosas descobertas no céu austral por John Herschel (1792-1871) (Figura 1). Após o aparecimento das placas de gelatino-brometo de prata no final da década de 1870, o GTM rapidamente tornou-se num instrumento obsoleto uma vez que não tinha sido concebido para a realização de fotografias de longa pose.

Figura 1- Howard Grubb, GTM e John Herschel (da esquerda para a direita).

Os primeiros grandes telescópios reflectores

Após a invenção do telescópio reflector por Isaac Newton (1643-1727), os primeiros reflectores munidos de espelhos metálicos de grandes dimensões foram construidos e utilizados por William Herchel (1738-1822) e pelo seu filho John Herschel. Ao longo da sua vida W. Herschel construiu mais de 400 espelhos metálicos. Estes telescópios, apesar de serem relativamente simples (montagens azimutais de madeira), foram usados por Herschel para observar pela primeira vez um elevado número de nebulosas (Figura 2). John Herschel transportou um dos telescópios construídos pelo seu pai para o hemisfério Sul (Cidade do Cabo) onde realizou uma série de observações de enorme importância (Figura 3).

Na primeira metade do século XIX, James Nasmyth (1808-1890), William Lassel (1799-1880), William Parsons (3º Conde de Parsonstown, Lord Rosse) (1800-1867), Thomas Grubb (1800-1868) e Howard Grubb construiram telescópios reflectores com uma abertura considerável (Figura 4, 5 e 6).

O primeiro reflector a ser montado equatorialmente foi o telescópio construído por William Lassel em 1860. Este instrumento possuia uma montagem em garfo maciça que era demasiado pesada para ser movida pelos mecanismos de relojoaria usados na época (Figura 5).

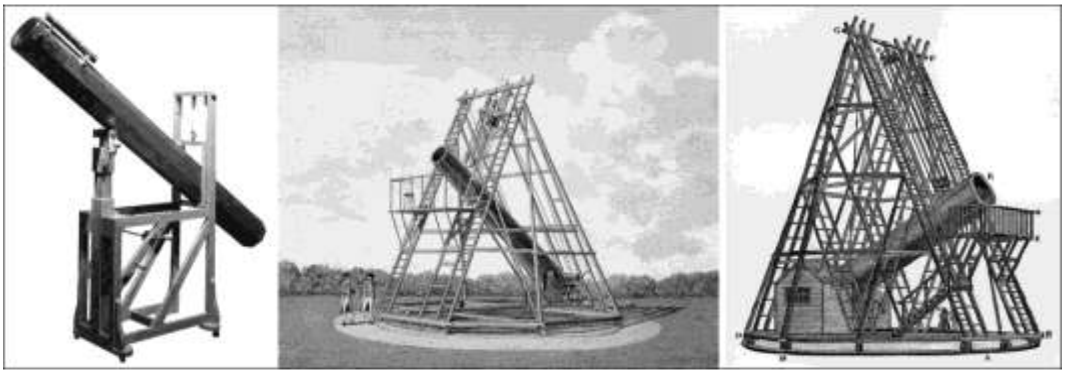

Figura 2- Telescópios construídos por William Herschel, da esquerda para a direita: 7 pés (15 cm de abertura); 20 pés (47,5 cm de abertura); 40 pés (126 cm de abertura).

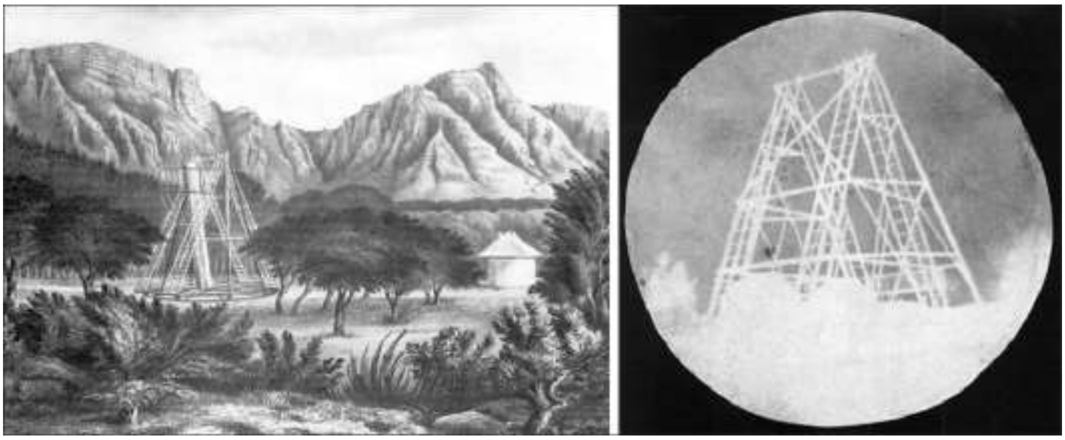

Figura 3- Telescópio de 20 pés (cidade do Cabo, *ca.* 1835) (esquerda), Fotografia do desmantelamento do telescópio de 40 pés obtida por J. Herschel em 1839 (Slough, Reino Unido) (direita).

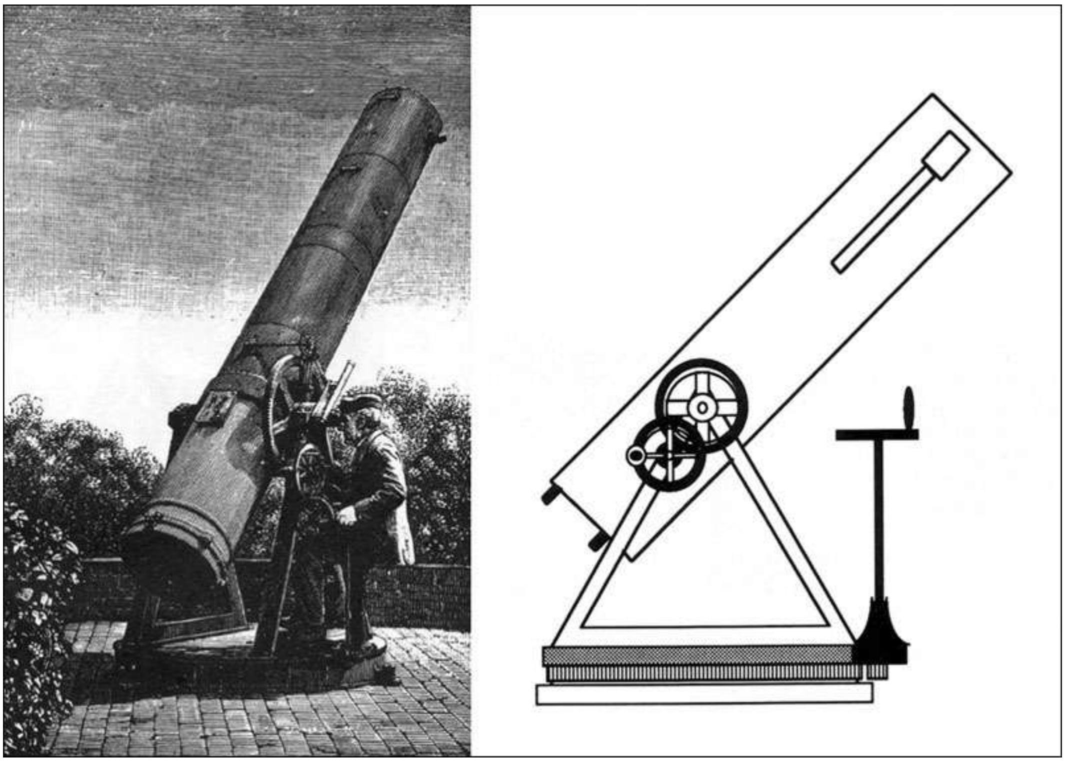

Figura 4- Telescópio Cassegrain-Newton de 50 cm de abertura construído por James Nasmyth (*ca.* 1845).

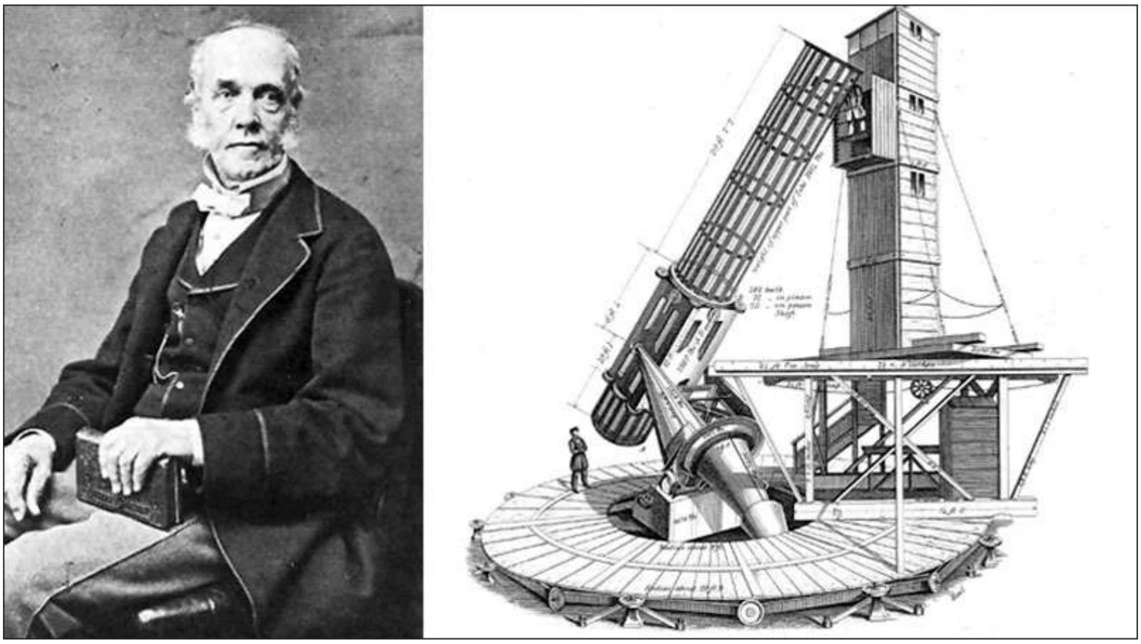

Figura 5- William Lassel (esquerda), telescópio equatorial de 48" (122 cm de abertura) (direita).

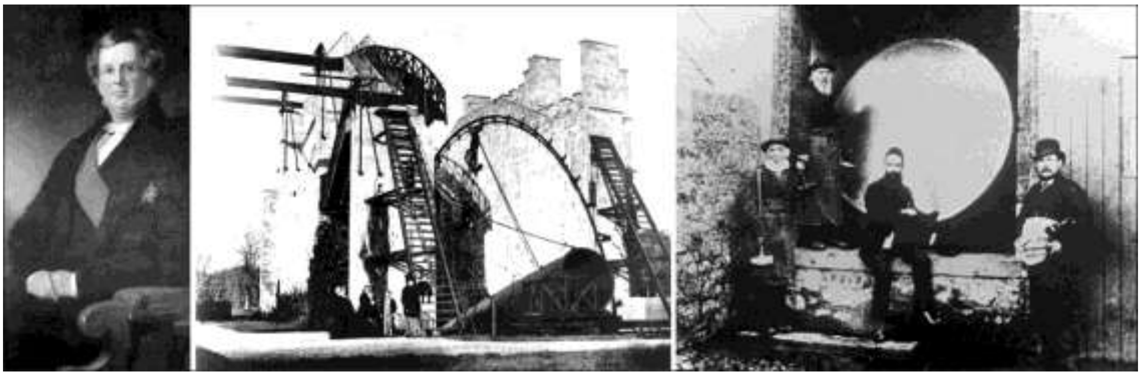

Figura 6- William Parsons (Lord Rosse) (esquerda) e o Leviatã de Parsonstwon (*ca.* 1845) (centro e direita).

Estes primeiros telescópios reflectores eram instrumentos muito difícies de usar com um peso elevado e sistema de guiagem muito deficiente. O movimento sideral do telescópio de Lassell era assegurado por um assistente, que accionava manualmente um dispositivo de arraste do garfo (uma rotação completa em cada minuto). O espelho primário (48") pesava mais de uma tonelada.

O telescópio construido por William Parsons só podia ser utilizado cerca de 30 min antes ou depois da culminação do objecto (passagem pelo meridiano do lugar) o que inviabilizava algumas observações de objectos celestes.

O Grande Telescópio de Melbourne

O GTM foi o último grande telescópio reflector o ser construído recorrendo ao uso de espelhos metálicos. Foi concebido por Thomas Grubb e pelo seu filho Howard Grubb. O telescópio de Melbourne foi o primeiro reflector de grandes dimensões a ser equipado com mecanismo de relojoaria que assegurava o movimento sideral. Possuia ainda um sistema de suporte adequado para o espelho primário (Figura 7). Alguns destes melhoramentos constituíram importantes inovações para a época, sendo ainda hoje usados em alguns instrumentos actuais. O GTM podia ser usado nas configurações Newton e Cassegrain com vantagens obvias para o observador (Figura 8). O sistema de movimentos era assegurado por chumaceiras percursoras dos rolamentos de esferas actuais.

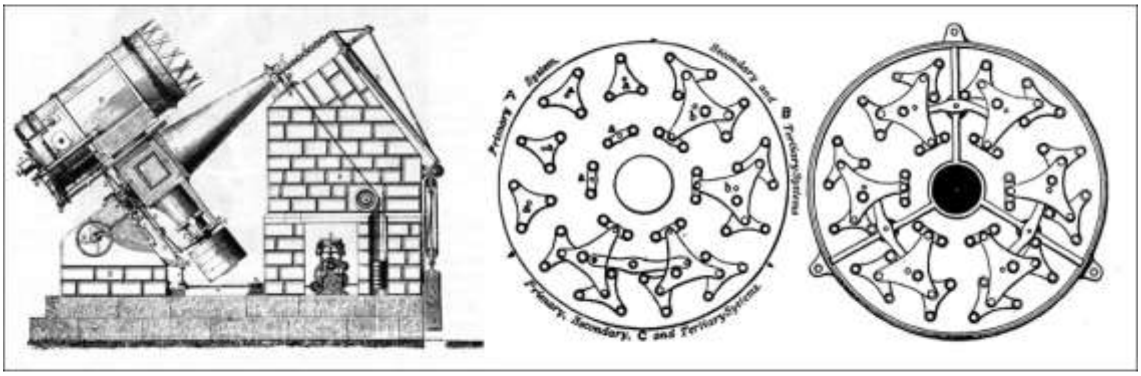

Figura 7- Grande telescópio de Melbourne: sistema de relojoaria (esquerda) e suporte do espelho promário (direita).

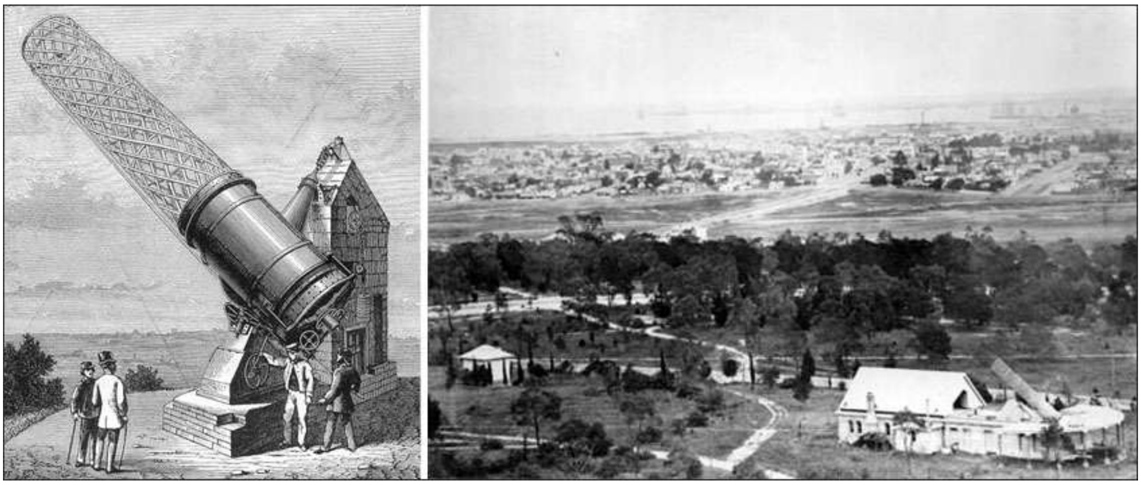

Figura 8- Telescópio de Melbourne (esquerda), observatório de tecto-de-correr (direita).

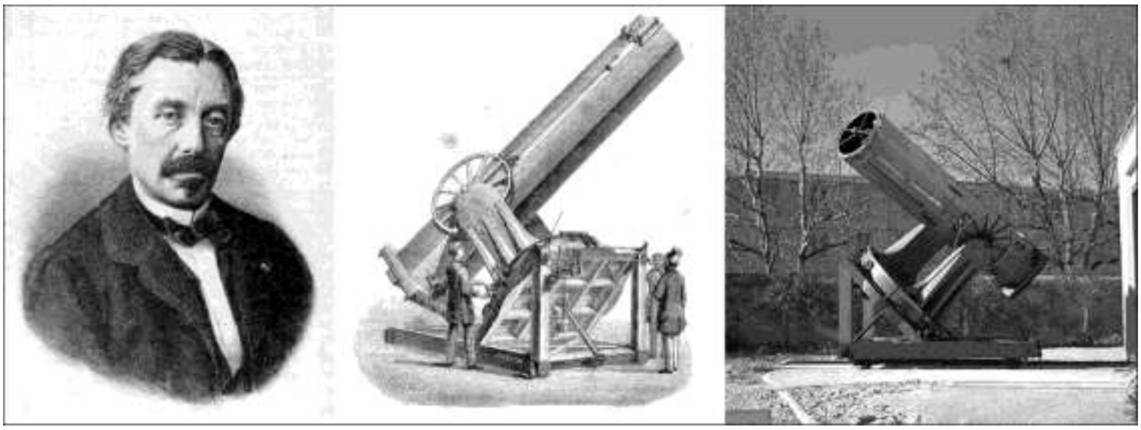

Figura 9- Telescópio reflector de 80 cm de abrtura construído por Leon Foucault.

Em 1862, Leon Foucault (1819-1868) constroi o primeiro telescópio reflector (80 cm de abertira) munido de um espelho de vidro espelhado a prata (Figura 9). As vantagens eram óbvias. Foucault desenvolve um sistema de teste das superfícies ópticas (teste de Foucault) que ainda é utilizado na actualidade. Ao contrário dos espelhos metálicos que necessitavam de um polimento frequente para manter o seu nível de eficiência, os espelhos de vidro, além de mais leves, eram mais fáceis de trabalhar. Uma vez construída a superfície óptica, bastava renovar a camada de prata com uma periodicidade de alguns meses ou anos. A montagem do telescópio de Foucault pesava apenas 1,5 T (montagem equatorial de garfo em madeira) enquanto que o GTM atingia 8,3 T.

Com o auxílio deste telescópio reflector L. Foucault, realiza numerosas observações de nebulosas, utiliza pela primeira vez um interferómetro de Fizeau e um étalon Fabry-Pérot. Realiza igualmente uma longa série de medições de estrelas duplas. Este telescópio foi usado até 1965 quase ininterruptamente.

Durante a segunda metade do século XIX a maioria dos astrónomos estavam sobretudo interessados em determinar paralaxes de estrelas e estudar estrelas duplas. Por este motivo usavam telescópios refractores que eram considerados como os instrumentos de precisão por excelência. Além destes estudos, os telescópios refractores eram também usados em instrumentos de passagem meridiana, essencias na determinação da hora e na catalogação de estrelas. Os telescópios reflectores eram considerados como instrumentos menores, e o falhanço do GTM não contribuiu em nada para alterar esta convicção que se manteve inalterada até ao início do século XX.

H.C. King refere no seu livro *History of the telescope* em 1955:

(...) by the middle of the late 19th century the refractor was more than ever before the basic instrument in both private and national observatories. A census of observatory instruments at this time shows that, out of the 40 British observatories, 32 possessed an equatorial refractor, 8 had alt-azimuth refractors, while only 7 possessed a reflector.

O trabalho desenvolvido por William Herschel (hemisfério Norte) e John Herschel (hemisfério Sul) era considerado como "definitivo" por muitos astrónomos neste período. Segundo alguns autores pouco mais havia a fazer no que dizia respeito à observação de objectos do céu profundo (nebulosas e enxames estelares).

O Leviatã de Parsonstown foi muito pouco usado e em apenas alguns meses "esgota" o seu potencial ao registar estruturas em espiral nalgumas nebulosas. O telescópio de Lassell foi usado durante cerca de 3 anos na ilha de Malta. O GTM ao ser instalado no hemisferio Sul tinha como principal objectivo observar em mais promenor e registar graficamente as nebulosas observadas por John Herschel alguns anos antes (1833-1838).

O observatório de Melbourne dirigido por Robert Lewis John Ellery (1827-1908)[9] (Figura 10) foi o primeiro a ser equipado com um reflector de grandes dimensões no hemisfério Sul. Ellery não tinha grande experiência prévia na utilização deste tipo de instrumentos:

(...) It is a somewhat difficult matter to speak critically of the merits of this telescope, as there are only three in the world that reach the dimensions of this, namely, Herschel's, Lord Rosse, and Mr. Lassell's, and these are again of a different form, which renders even a comparison difficult. I have no experience with the reflectors in question.

A proposta para o GTM ser instalado no hemisfério Sul partiu do reverendo John Thomas Romney Robinson (1792-1882), director do observatório de Armagh (Figura 10). Robinson refere em 1850, numa alocução que fez à "British Association for the Advancement of Science" de que era presidente:

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[9] Ellery ocupou o cargo de director do observatório durante um período de 42 anos.

That work implies a minute re-examination of at least all the brighter nebulae of Sir John Herschel catalogues; embodied in drawings, based on micrometer measures, and so correct that each of them may be referred to as an authentic record of the original appearance at a given epoch.

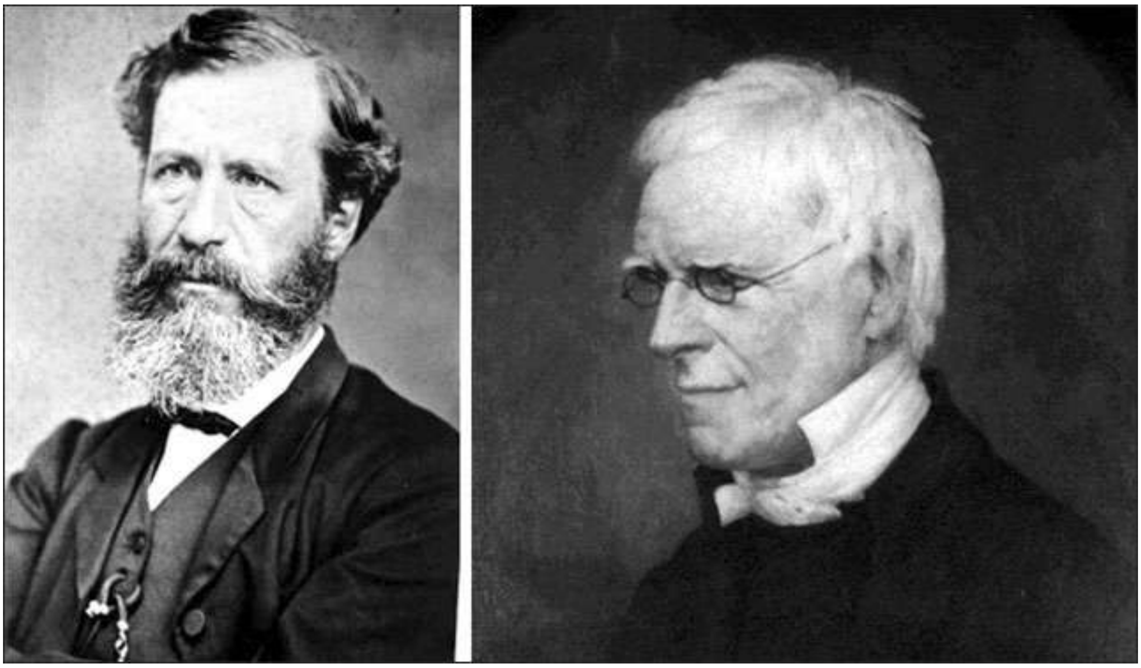

Figura 10- Robert Lewis John Ellery (esquerda) e Rev. John Thomas Romney Robinson (direita).

Como resultado destas observações a “Royal Society” nomeou uma comissão que incluía Robinson, Lord Rosse, Warren de la Rue e John Herschel. Esta comissão estudou as propostas apresentadas por Thomas Grubb para a construção do grande telescópio reflector.

Em 1857, Leon Foucault apresenta uma comunicação intitulada “A telescope speculum of silvered glass” na reunião da “British Association” que decorreu em Dublin. Na mesma sessão, Grubb descreve os seus planos para a construção do telescópio de Melbourne. Foucault visita o telescópio de Lord Rosse e descreve o que observou após o seu regresso ao observatório de Paris:

(...) Le télescope de Lord Rosse est une blague. Pour les anglais le mien n’existe pas, il a été, il est, il sera encore quelque temps come non avenue; il ne m’en ont pas moins fait docteur in utroque”.

A comissão decide que o telescópio devia ser equipado com espelhos metálicos apesar de não desconhecer os trabalhos de Foucault. Robinson refere a este propósito num relatório:

It seemed imprudent to risk the success of the undertaking by venturing on an experiment whose success was not assured; it was not known whether the silver could be uniformly deposited on so large scale; some facts appear to show that glass is more liable to irregular action than speculum metal; and the intensity of light in these telescopes is not as great as had been expected.

Os espelhos em vidro espelhados a prata foram pela primeira vez utilizados com sucesso em 1856. As suas vantagens são bem conhecidas. A prata (recentemente aplicada) reflecte cerca de 92% da luz incidente, é mais duradoura do que os espelhos metálicos, pode ser reaplicada inúmeras vezes e uma vez construída a superficie óptica não necessita de ser refeita.

John Herschel, um dos membros da comissão, não desconhecia estes factos. Em 1860 num artigo que escreve para a Enciclopédia Britânica refere:

The advantages offered by its construction (a glass as opposed to a metal mirror) are immense. In the first place, glass, weight for weight, is incomparably stiffer than metal; so that a glass speculum, to be equally strong to resist change of figure by flexure, need weigh only one-fourth of a metallic one. Secondly, a glass disc of 6 or 8 feet (1,8 to 2,4m) in diameter may be cast, annealed, and wrought with infinitely less labour, hazard, and cost than one of speculum metal. Thirdly, supposing a slight tarnish to arise from sulphuration, the reproduction of the polish is the work of a few minutes, and is performed without any chance of injuring the figure. Even if irretrievably spoilt, the silver coating may be instantly removed, and a fresh one laid on at a comparatively trifling cost, the parabolic figure once given being indestructible. Fourthly and lastly, the reflective power of pure silver is, to that of the best speculum alloy, as 91 to 67, or as 1.36 to 1.

A Comissão decide igualmente que o telescópio devia poder ser utilizado no foco Cassegrain, algo que não era muito comum nos telescópios da época. O espelho primário de 48" tinha na sua concepção original uma distancia focal de 9,3 m (*f*/ 7,6) no foco Newton e de 51 m (*f*/41) no foco Cassegrain. As observações visuais no foco Cassegrain eram por este motivo dificultadas devido à enorme distância focal e a realização de fotografias praticamente impossível.

Após a sua construção pela firma de Grubb, o telescópio chegou a Melbourne em 1868 (6 de Novembro). Foi instalado de um modo definitivo em Junho de 1869, num observatório de tecto-de-correr, ficando assim exposto ao vento, durante os períodos de observação. Grubb construiu dois espelhos metálicos (A e B) que produziram resultados distintos. O espelho B foi montado de um modo deficiente e de início não produziu boas imagens. O espelho A teve que voltar a ser polido uma vez que antes do transporte para Melbourne Grubb aplicou uma camada protectora de verniz que detriorou a sua superfície óptica.

Tal como já foi anteriormente referido o telescópio foi sobretudo utilizado para efectuar desenhos de nebulosas no foco Cassegrain. Existem no entanto registos de algumas experiências fotográficas realizadas no foco principal do GTM. Estas imagens foram consideradas como as melhores fotografias lunares da época. Para o efeito foi usado um porta-chapas e obturador concebido por Warren de la Rue. Um dos cadernos de observação do GTM refere a técnica usada:

The photographs of the Moon have been taken at or near a fixed focus, viz. 9.0-11.5 of scale. (…) Many of these suggest that they are not in proper focus, and point to the desirability of a correct focus being obtained each evening that photographs are attempted, the focus for each night being obtained upon the Moon herself. The difficulty of obtaining such focus has occupied much of my (Joseph Turner) attention, and tonight I tested a plan that I had for some time being considering. A light ladder lashed inside the telescope tube and of such a length as to extend the entire length of the lattice work and project about four feet beyond the mouth of the tube. When about to take photographs the end of the tube is lowered toward the travelling steps on the outside stage, the ladder being already securely lashed inside the tube, and the tube being lowered in such a manner that it can be raised and pointed to the Moon by the declination movement alone. When thus lowered I got inside the tube going as far down the tube as the length of the ladder will permit (…). I then carefully ascend the ladder, passing out *beyond the mouth of the tube and a little beyond the extremity of the camera. Then (…) I focus by means of a ground glass screen and magnifier as accurately as possible upon some prominent crater etc. Having obtained the best possible focus I descend the ladder, the tube is lowered, I come out upon the travelling steps, the ladder is removed from inside the tube, and the photographing proceed as usual (…) This method of obtaining correct focus, though very excellent, is attended with so much danger to the observer that some safer plan will require to be devised as missing one's hold at such elevation in the dark might prove fatal.*

O espelho A, após ter sido polido foi instalado no telescópio em 1871. Este espelho foi usado durante um período de 2 anos sem sofrer um novo polimento. O mesmo espelho foi usado nos 17 anos seguintes tendo sido limpo e polido por diversas vezes. Em 1883, após a morte de um dos observadores mais activos (Joseph Turner) é referido nos cadernos de observação que:

The mirror now dismounted did tolerably good work, yet I (Pietro Baracchi) have never been able to get a large star in proper focus, and Jupiter and Saturn never appeared well defined even on the best night and lowest power".

Estas observações atestam bem os problemas que os diversos observadores tiveram que superar (deficiente colimação, problemas de reflectividade dos espelhos metálicos, má qualidade do polimento...). Robert Ellery tentou observar os dois satélites de Marte pouco tempo após a sua descoberta por Asaph Hall em 17 de Agosto de 1877. A observação de Marte era bem mais favorável no hemisfério Sul, mas apesar disso Ellery não conseguiu detectar os dois satélites (efectou observações durante 16 noites sem sucesso). É provavel que este insucesso esteja relacionado com uma má colimação bem como com a difusão de luz provocada pelo deficiente polimento dos espelhos. Após este episódio o GTM foi considerado como um telescópio obsoleto e passou a ser utilizado intermitentemente.

Joseph Turner obteve em 1883 com o auxílio de placas de gelatino-brometo de prata, algumas imagens da nebulosa de Orion (M 42) com o auxílio do GTM. Estas fotografias foram as primeiras obtidas no hemisfério Sul. Turner enviou algumas cópias para a "Royal Astronomical Society". Apesar destes primeiros resultados e de outras tentativas subsequntes, o GTM não se revelou adequado para a realização de fotografias de longa pose, devido sobretudo ao deficiente sistema de guiagem.

Em 1885, Ellery publica finalmente os desenhos e descrições de 49 nebulosas observadas com o auxílio do GMT. No ano anterior (1884), Andrew Ainslie Common (1841-1903), realizou com o auxílio do seu telescópio de 36" (92 cm) algumas fotografias da nebulosa de Orion[10]. As fotografias de Common tornam os desenhos de nebulosas obtidos pelo telescópio de Melbourne totalmente obsoletos. Em 1886 o espelho primário estava de tal modo detriorado que o GTM deixou de ser usado regularmente. Apesar disso o espelho foi removido e polido, tendo sido usado pela primeira vez o teste de Foucault nas oficinas de óptica do observatório.

O telescópio de Common foi mais tarde utilizado por James Edward Keeler (1857-1900) director do observatório de Lick. Keeler inicia um extenso programa com o principal objectivo de registar fotograficamente os objectos mais brilhantes (nebulosas) do catálogo de Herschel. Mais de metade destes objectos foram registados satisfatoriamente. Foi deste modo possível verificar pela primeira vez que a maioria das nebulosas apresentava uma estrutura espiral e não irregular como se pensava na época.

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[10] Como resultado destes trabalhos, é atribuída a Common a Medalha de mérito da "Royal Astronomical Society".

George Willis Ritchey, pioneiro da astrofotografia e da construção dos primeiros telescópios reflectores de grande abertura, escreveu em 1904 o seguinte comentário sobre o GTM:

I consider the failure of the Melbourne Instrument to have been one of the greatest calamities in the history of instrumental astronomy; for by destroying confidence in the usefulness of great reflecting telescopes, it has hindered the development of this type of instrument, so wonderfully efficient in photographic and spectroscopic work, for nearly a third of a century.

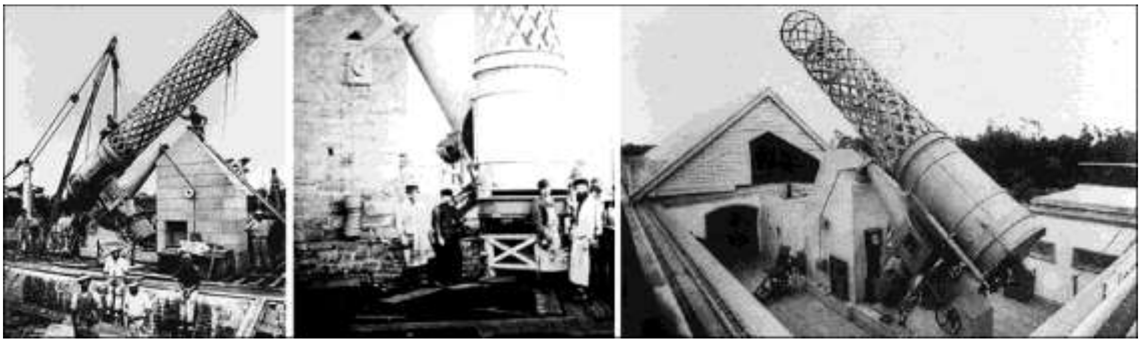

Figura 11- GMT, esquerda e centro (Dublin – Fábrica de Grubb) e direita (Melbourne).

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O GRANDE REFRACTOR DA EXPOSIÇÃO DE PARIS (1900)

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O grande telescópio da Exposição Universal de Paris (1900), com uma objectiva acromática de 1,25 m de diâmetro, foi o maior refractor construído até aos nossos dias. Este telescópio constituiu a maior atracção da referida exposição. O mentor deste ambicioso projecto, foi François Deloncle (1856-1922), membro da câmara de deputados de Paris. O grande refractor foi utilizado somente durante a exposição e não produziu quaisquer resultados significativos por duas razões principais: (i) a montagem não era adequada para a realização de observações astronómicas e (ii) o local em que foi instalado ("Palais de l'Optique" em Paris) estava sujeito a diversos tipos de perturbações (turbulência, poluição luminosa, poeira...).

Os grandes refractores do século XIX

O primeiro refractor moderno foi construído em 1824 por Joseph von Fraunhofer (1787-1930). Este telescópio foi instalado no observatório de Dorpat. Fraunhofer construiu a objectiva acromática de 23 cm e a montagem equatorial. A maioria dos refractores da primeira metade do século XIX são no essencial idênticos a este instrumento (Figura 1).

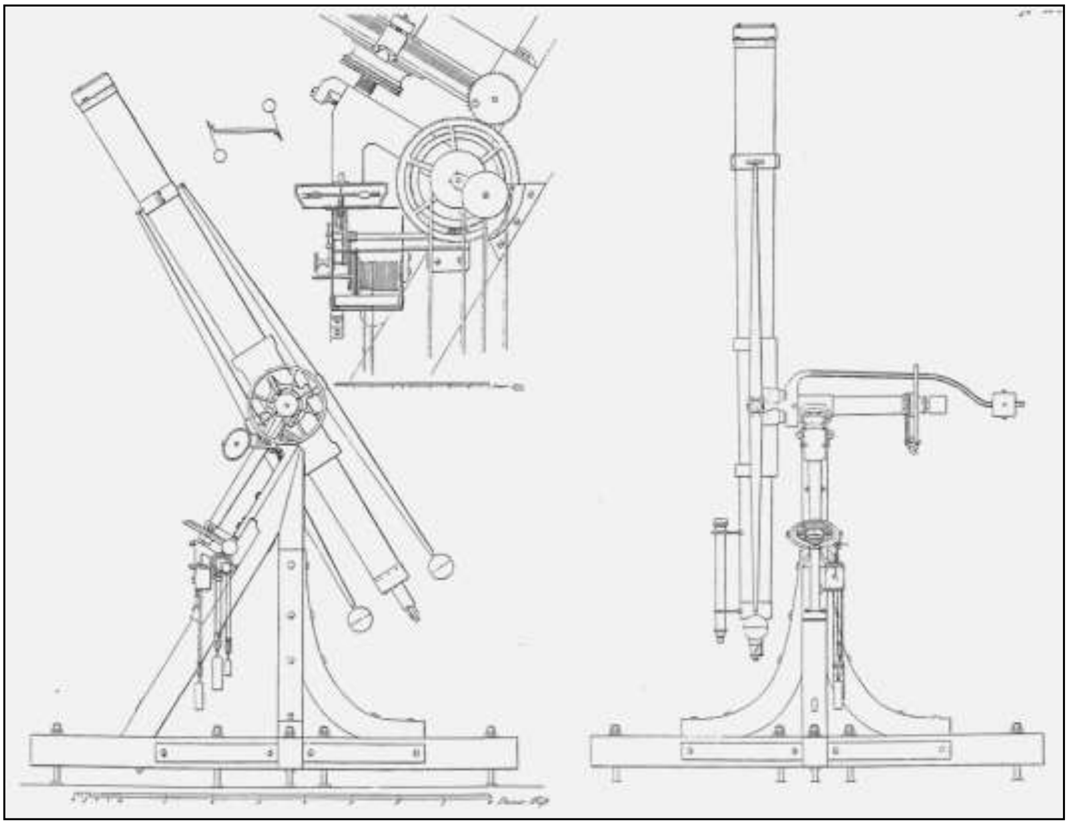

Figura 1 – Refractor de Fraunhofer: 230 mm *f*/18.

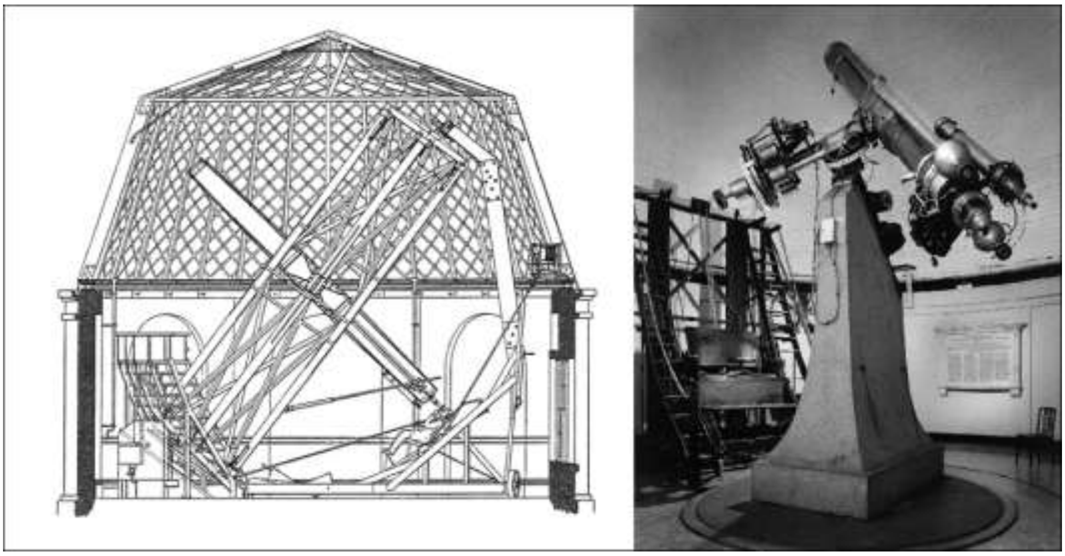

Figura 2- Refractor Northumberland (Cambridge) de 30 cm de abertura (esquerda) e refractor de 38 cm (Harvard) (direita).

Figura 3- Telescópio de Craig (1852). Fotografia da época (esquerda) e reconstituição do telescópio (centro e direita).

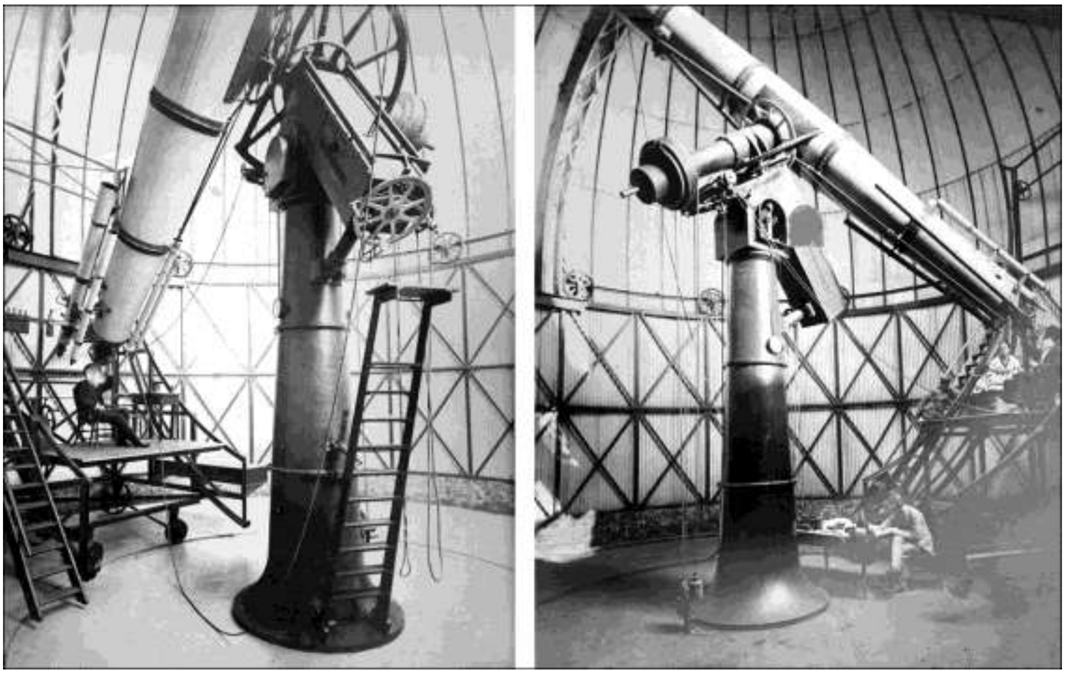

Figura 4- Refractor de Newall: 64 cm $f/14$.

Em 1835, Robert-Aglaé Cauchoix (1776-1845) fabrica uma objectiva com 30 cm de diâmetro de excelente qualidade e George Bidell Airy (1801-1892) desenha uma montagem equatorial em berço inglês que é instalada em Cambridge (Reino Unido). Em 1839 a firma alemã Merz & Mahler (sucessores de Fraunhofer) constrói um refactor com uma objectiva de 30 cm para o novo observatório de Pulkovo (S. Petesburgo, Russia) (Figura 2). Um instrumento idêntico é encomendado pelo observatorio de Harvard em 1847 (Figura 2).

Em 1852 o reverendo John Craig constroi um refractor com uma objectiva de 61 cm de fraca qualidade. Este refractor foi instalado próximo do centro de Londres numa montagem azimutal (Figura 3). O telescópio de Craig foi utilizado apenas durante de 3 anos.

Em 1862, Robert Stirling Newall (1812-1889) encomenda a Thomas Cooke (1807-1868) um refractor de 64 cm *f*/14. O telescópio foi instalado em 1869/1870 num local muito pouco apropriado para a realização de observações astronómicas (Newall durante um período de 15 anos teve apenas uma noite em que pode utilizar o refractor em boas condições) (Figura 4).

A maioria dos telescópios refractores desta época eram instalados sob cúpulas hemiféricas idênticas à que foi construída no observatório de Paris em 1847 (Figura 5).

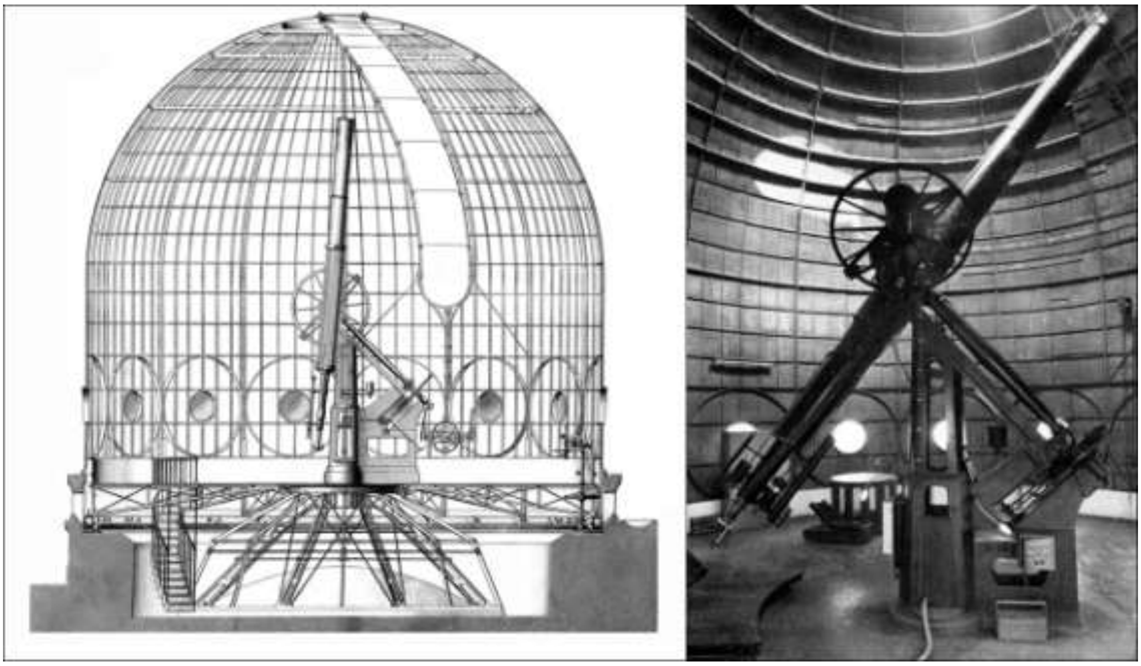

Figura 5- Cúpula hemisférica do observatório de Paris (1847): Refractor de 38 cm.

O refractor de Lick (91 cm *f*/19) foi construído em 1888 pela firma Clark & Sons (Figura 8). A montagem Warner & Swasey foi a montagem standard deste tipo de instrumentos no final do século XIX. Em 1893 é instalado no observatório de Greenwich um refractor de 71 cm *f*/12 na mesma montagem desenhada por Airy em 1835. Este refractor podia ser usado em modo visual ou fotográfico, alterando a posição dos dois elementos da objectiva acromática. Este interessante sistema não produziu resultados satisfatórios e o telescópio foi sobretudo utilizado na observação visual de estrelas duplas (Figura 6). Em 1896 é instalado em Greenwich um refractor fotográfico de 66 cm *f*/10 de abertura construído por Thomas Grubb (1800-1878).

Figura 6- Refractor de Greenwich: 71 cm *f*/12.

O refractor duplo do observatório de Meudon foi construído por Gauthier e pelos irmãos Henry em 1896. Este telescópio possui duas objectivas, uma fotográfica com 83 cm *f*/20 e outra visual com 62 cm *f*/26, montadas lado a lado num tubo de secção rectangular (Figura 7)

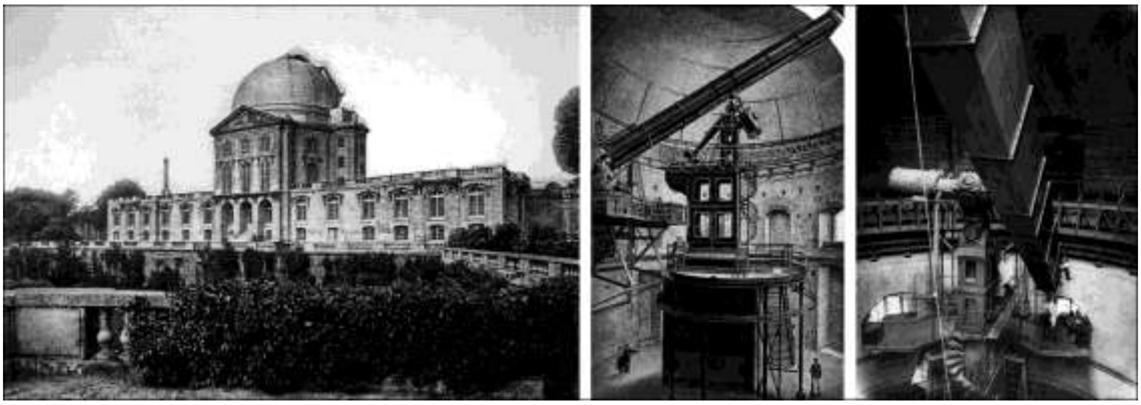

Figura 7- Observatório e grande luneta de Meudon (1896).

O refractor de Yerkes, o maior refractor existente (102 cm *f*/19), foi construído em 1897 por Clark & Sons (óptica) e Warner & Swasey (montagem) (Figura 8).

A qualidade óptica de diversos refractores do século XIX foi avaliada por E. Baillaud em 1913 (teste de Hartmann), revelando algumas diferenças importantes (Figura 9)[11]. A evolução das dimensões dos refractores construídos neste período é ilustrada na Figura 9. James Lequeux (2009) ilustra nesta figura a cronologia da construção dos diversos telescópios refractores com um diâmetro superior a 40 cm.

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[11] A qualidade óptica do refractor de Yerkes é excelente

O refractor de 76 cm do observatório de Allegheny foi um dos últimos refractores a ser construído no século XX (1912) (Figura 10). A firma Zeiss construiu diversas lunetas após esta data e os dois útimos telescópios refractores foram instalados na Venezuela em 1955 e no Japão em 1972 (65 cm *f*/16).

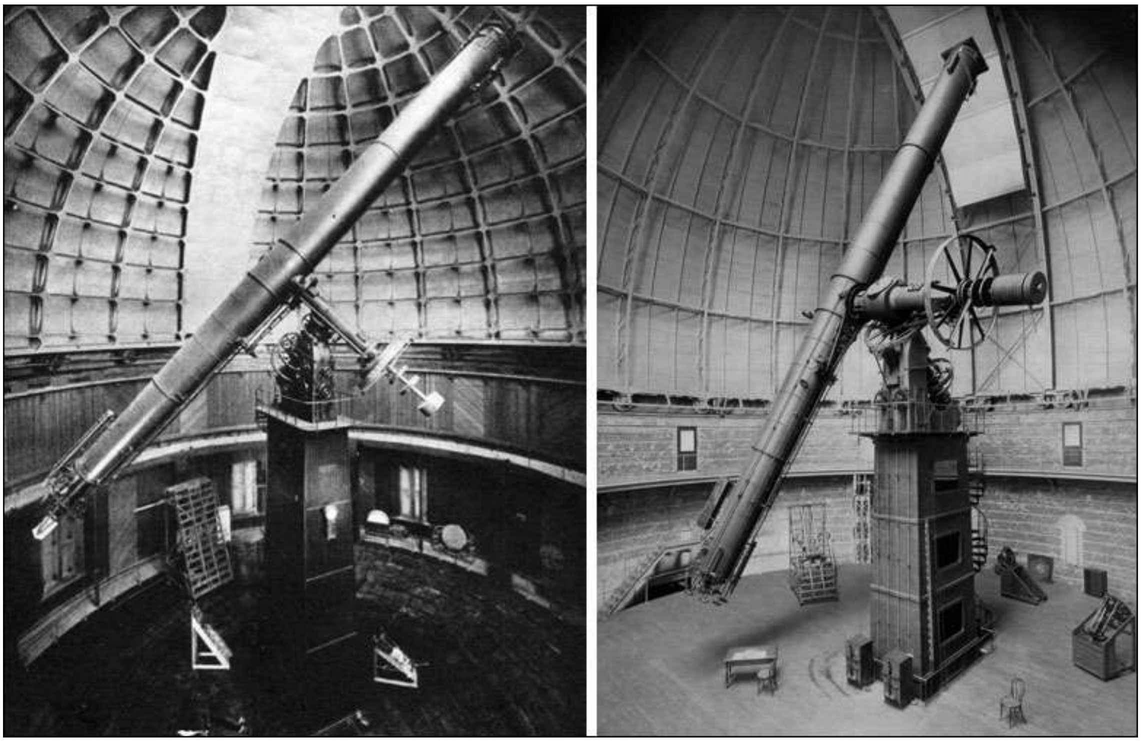

Figura 8- Refactor de Lick (esquerda) e de Yerkes (direita).

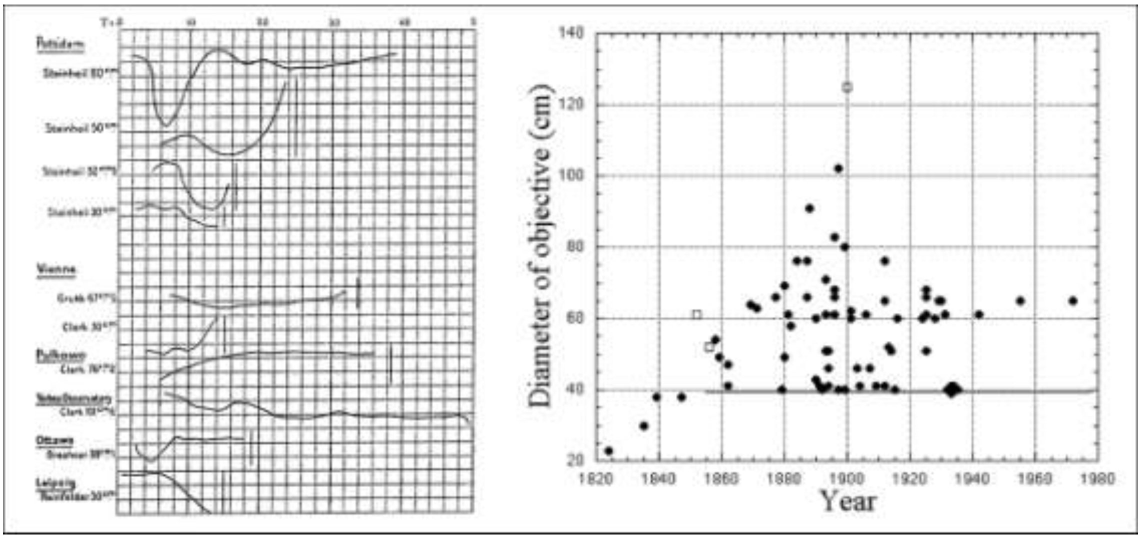

Figura 9- Resultados do teste de Hartmann relativos a diversas objectivas de refractores do século XIX (esquerda). Cronologia da dimensão dos refractores (diâmetro da objectiva): os quadrados indicam os refractores que não produziram resultados relevantes. Adaptado de Lequeux (2009).

Figura 10. Observatório de Allegheny e refractor de 76 cm (*ca.* 1914).

O grande refractor de Paris

A concepção do grande telescópio refractor de Paris data de 1892. A exposição universal de Paris surge na sequência das exposições de 1878 e 1889. A ideia subjacente à construção deste telescópio foi a de apresentar na exposição uma estrutura que rivalizasse com a Torre Eiffel. François Deloncle contacta a Paul Gauthier (1842-1909) encarregando-o da construção deste instrumento (óptica e mecânica). O grande refractor tinha uma abertura de 1,25 m e uma distância focal de 60 m. O tubo foi instalado em posição horizontal e a luz dos objectos celestes era dirigida para a objectiva por um gigantesco celóstato com um espelho plano de 2 m de diâmetro (Figura 11). A construção deste telescópio constituiu um enorme desafio para os vidreiros, ópticos e engenheiros da época. Alguns desenhos publicados antes da construção do instrumento ilustram os planos iniciais (Figura 11).

Paul Gauthier começou por construir o espelho do celóstato. Após 9 meses de trabalho intenso, utilizando diversas máquinas construidas expressamente para o efeito, o espelho plano de 2 m foi terminado (Figura 12). Foi o maior espelho plano realizado até à época. depois do espelho de 90 cm do observatório de Paris. O vidro foi fornecido pela firma Jeumont em 1895.

Édouard Mantois (1848-1900) sucessor de Henry Guinand e Charles Feil forneceu as bolachas de vidro para a construção das duas objectivas (visual e fotográfica). Gauthier foi encarregado de construir as superfícies ópticas apesar de não ter grande experiência prévia neste tipo de trabalhos. A objectiva visual não foi completada a tempo da exposição universal (Figura 12).

A grande luneta foi instalada no "Palais de l'Optique" próximo da Torre Eiffel. A galeria Foucault onde o tubo com 60 m foi erigido, encontrava-se orientada no sentido Norte/Sul. O tubo era constituido por 24 secções cilíndricas com 1,5 m de diâmetro, suportadas por pilares de cimento e aço (Figura 12). O tubo encontrava-se a cerca de 7 m do solo e o celóstato, protegido por uma estrutura móvel, foi instalado no mesmo pavilhão. A ocular do telescópio situava-se na sala Galileo próximo de uma sala com uma capacidade de 300 lugares sentados. Nesta sala eram projectadas imagens da Lua fornecidas por Maurice Loewy (director do observatório de Paris), do Sol e nebulosas providenciadas por Jules Janssen (director do observatório de Paris/Meudon). Após a falência da companhia que construiu o telescópio, o refractor foi colocado à venda em 1909. O que resta do telescópio encontra-se actualmente no observatório de Meudon (mecânica) e no observatório de Paris (óptica).

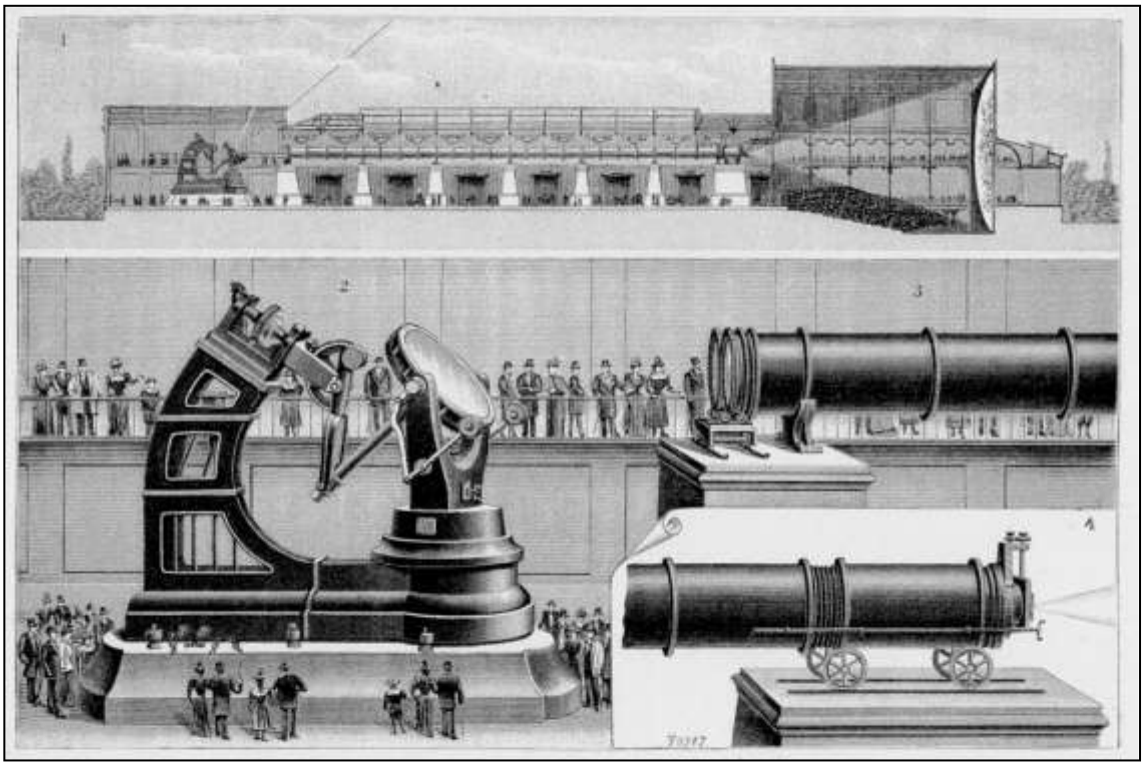

Figura 11- Gravura do grande refractor de Paris publicada em 11 de Fevereiro de 1899 na revista *La Nature*.

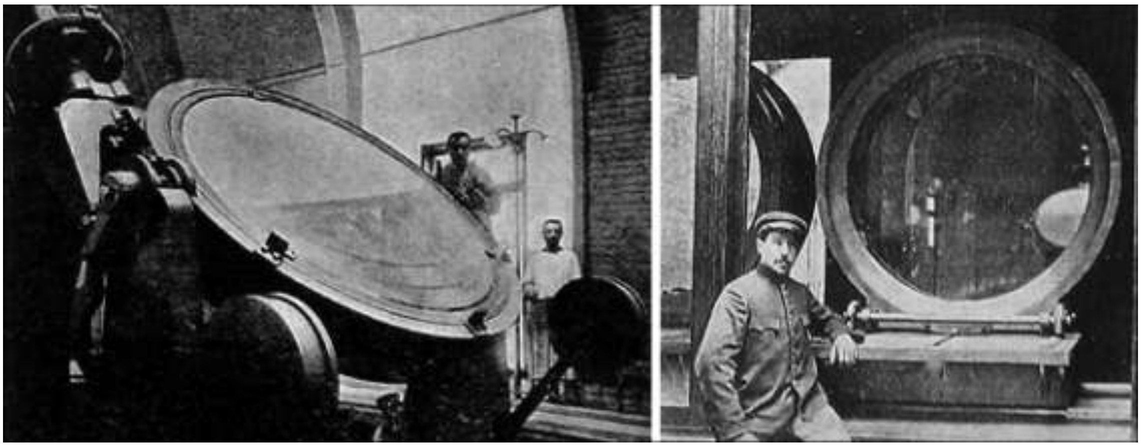

Figura 12- Espelho plano do celóstato (2 m) e objectiva fotográfica do grande telescópio de Paris. Adaptado de Launay (2007) e revista *Knowledge*.

Figura 13- Grande refractor de Paris. *Le Panorama, Strand Magazine, L'encyclopédie du siècle (1900).*

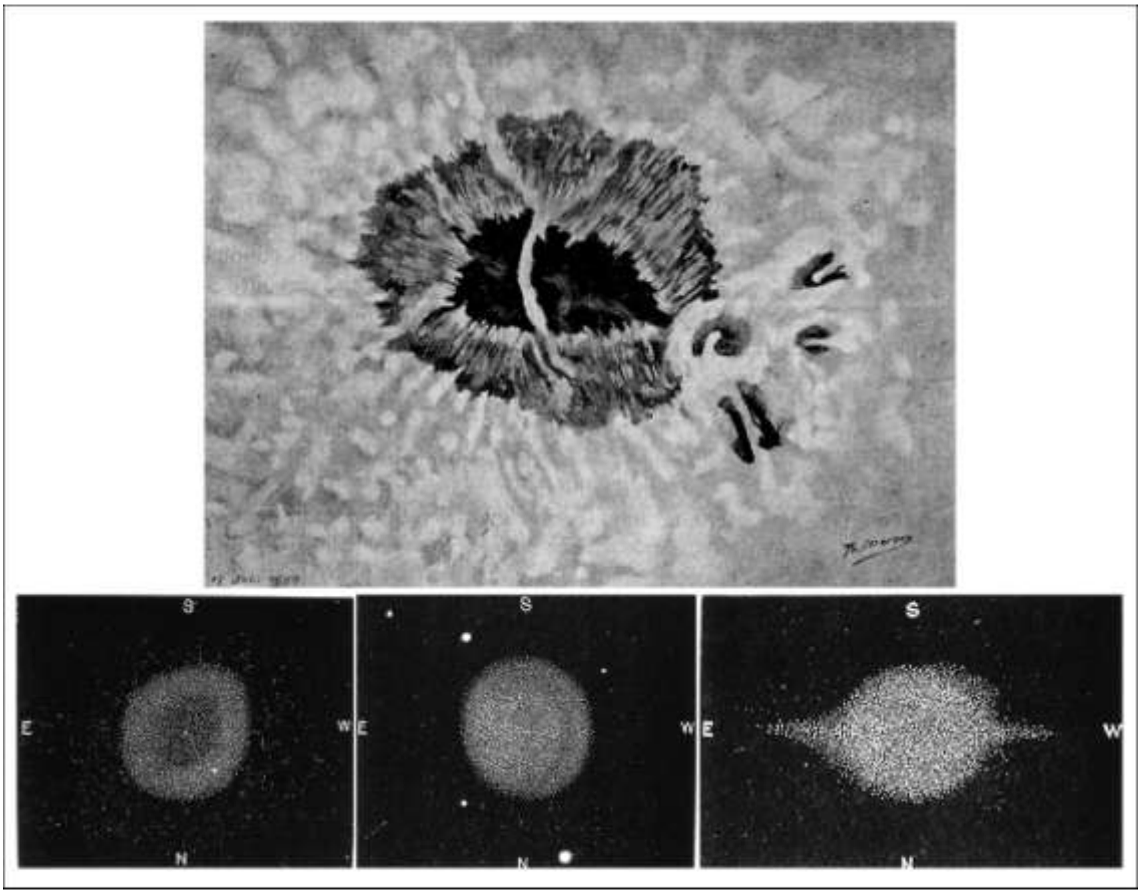

Figura 14- Desenhos de uma mancha solar (17 de Junho de 1900) e de nebulosas, obtidos com a grande luneta de Paris (da esquerda para a direita – NGC 6894, NGC 6905 e NGC 7009).

O grande refractor foi unicamente utilizado durante a exposição universal. Poucos observadores realizaram diversas observações apesar das condições adversas que se fazim sentir no local (*e.g* poluição luminosa, poeira, turbulência, número elevado de visitantes). A objectiva usada foi a objectiva fotográfica (corrigida para a região violeta do espectro electromagnético).

O padre Théophile Moreux (1864-1954), director de um observatório privado em Bourges e conhecido astrónomo amador, observou uma mancha solar que desenhou pormenorizadamente (Figura 14). Eugène-Michel Antoniadi (1870-1944), astrónomo de origem grega na altura assistente de Camille Flamarion no observatório de Juvisy, realizou alguns desenhos de nebulosas (Figura 14) bem como observações do planeta Vénus. Antoniadi refere que o celóstato era relativamente fácil de operar e que o movimento horário era extremamente preciso. Finalmente são conhecidas três fotografias da Lua obtidas por Charles Le Morvan (1865-1933), astrónomo do observatório de Paris, em três noites sucessivas (Agosto de 1900) (Figura 15). Estas imagens, publicadas na revista londrina *Strand Magazine* em Novembro de 1900, tinham cerca de 60 cm de diâmetro nas chapas originais.

Figura 15- Fotografias da Lua obtidas com a grande luneta de Paris (15, 16 e 17 de Agosto de 1900).

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THE 26-INCH CROSSLEY REFLECTOR

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http://astrosurf.com/re

The 36-inch Crossley Reflector was used by James Edward Keeler (1857-1900) during the last two years of his short productive scientific life for a systematic and epoch making astrophotographic study of diffuse, planetary and "spiral" nebulae. Keeler became one of the first astronomers to successfully use large reflecting telescopes in the United States.

This telescope was built by Andrew Ainslie Common (1841-1903), a wealthy engineer and amateur astronomer of Ealing, London. Common commissioned a 36-inch silver-on-glass mirror from George Calver (1834 - 1927) and mounted it in 1879 as a newtonian with a fork mount. Common used this instrument mainly as a photographic telescope. Several photographs of the Orion nebulae were obtained with considerable success. In 1883, Common produced images that showed for the first time, stars that were not seen by visual observers (Figure 1).

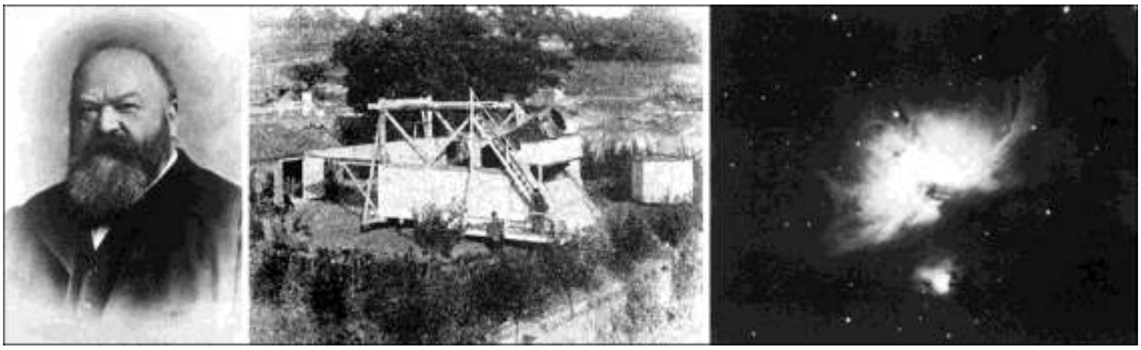

Figure 1- Andrew Ainslie Common (left), 36-inch reflector (center), M 42 photograph obtained in 1883 (right).

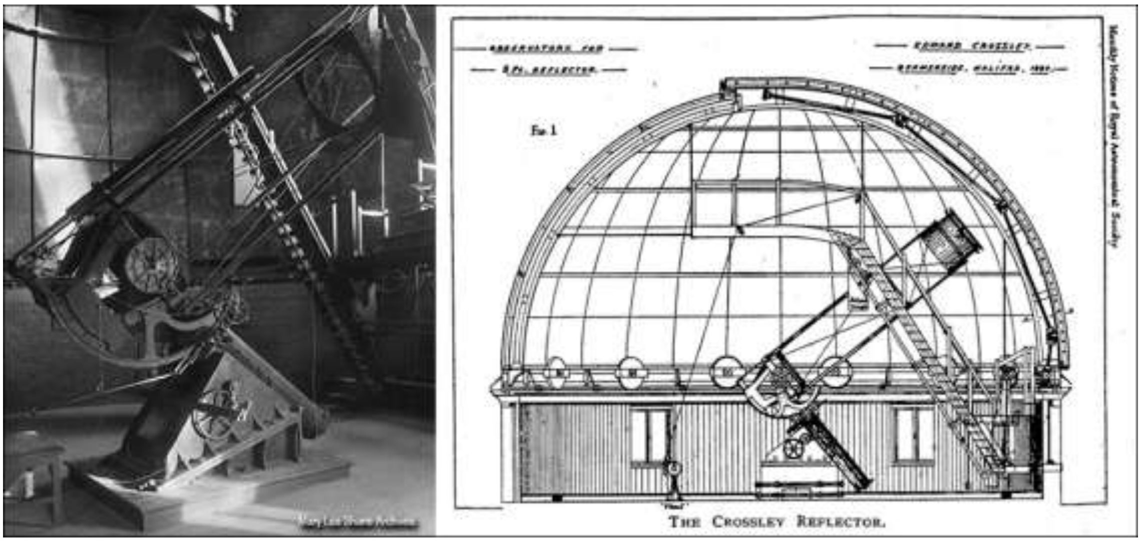

Figure 2- 36-inch Crossley reflector (left) and iron dome (right).

The telescope was sold to Edward Crossley (1841-1901) in 1885. Crossley, also a British amateur astronomer, installed it in Halifax (Yorkshire, England). Crossley designed and constructed a dome to house the telescope. This iron covered dome was almost 40 feet in diameter and weighted 15 tons. It was moved by a water engine (one full turn lasting 5 min). Heat exchange was minimized by a clever system of water pipes running on the ground of the observatory. There was also an elevated platform for the observer (Figure 2).

The Halifax climate was very unfavourable and in 1883 Crossley decided to sell the observatory and telescope. Edward Singleton Holden (1846-1914), director of the Lick Observatory in Mount Hamilton California, was very interested in acquiring this instrument. After an exchange of several letters, Crossley decided to donate his telescope and dome to the Lick Observatory. In 1895 the whole package was finally shipped to California. By June 1986 it was installed on Mount Hamilton (Figure 3). The dome was provided with a rope and pulley system instead of the native water engine. Calver built two mirrors for the Crossley telescope (A and B). When it was installed at Lick the B mirror was used (36-inch *f*/5.8) which proved to be of excellent quality. The equatorial mount was however not suitable for long exposure direct photographs.

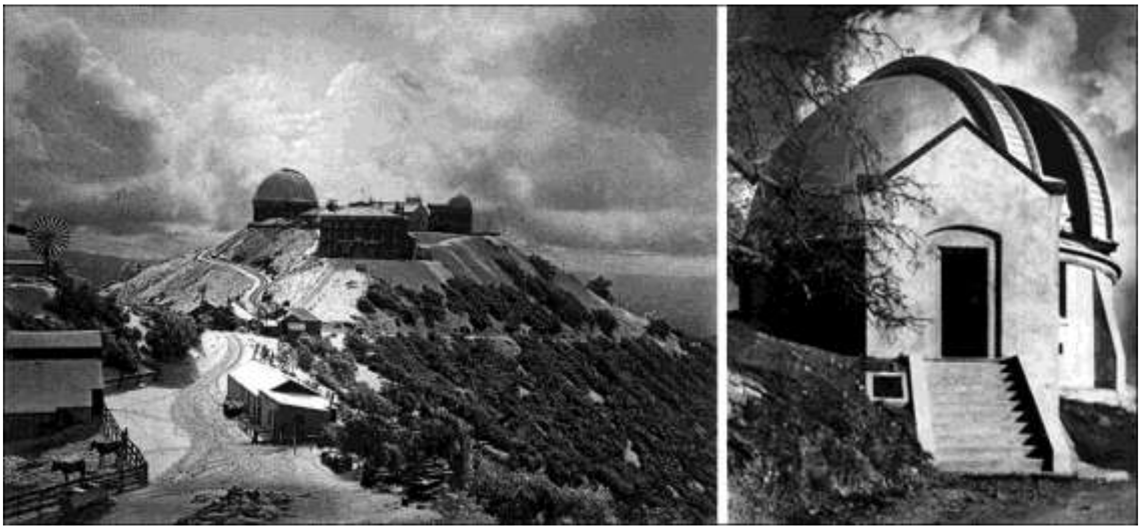

Figure 3- Lick observatory (left) and dome of the 36-inch Crossley reflector (right).

When the Crossley reflector was installed at Mount Hamilton in 1896 it was the largest reflector telescope in the United States. The telescope was first mounted by William Joseph Hussey (1862-1926). Progress was very slow and for Hussey it was a never-ending bad dream. When the telescope arrived at Lick it was a real mechanical nightmare. The open tube was not well designed and proper collimation of the optical components was very difficult. The drive clock was inefficient meaning that direct photography was very difficult.

James Edward Keeler assumed the directorship of Lick observatory on January 1, 1898. Keeler first job was to align the mount to the pole[12]. Keeler introduced many modifications in order to improve the operation of the Crossley reflector. The pier was cut down by two feet providing more clearance between it and the dome. Other modifications included the addition of a windscreen, a new drive clock and improvements to the double-sided plate holder. Keeler also adjusted the mirror so that its optical axis was accurately aligned with the center of the tube and added a new low-power finder telescope. Keeler was able to obtain long exposures of up to four hours by 1899 but the instrument still proved difficult to handle and inadequate for

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[12] Hussey's previous alignment was incorrect by more than 2 degrees.

longer direct photographs. The major problem was the mount, which was inadequate in holding the telescope steady during high winds conditions and flexed excessively near the zenith. Adding to these problems was the occasional slippage of the mirror in its cell.

Keeler described in detail the adjustments he made to make the Crossley reflector operation in a 1900 publication of the Astrophysical Journal[13]:

(…) On taking charge of the Lick Observatory in 1898, I decided to devote my own observing time to the Crossley reflector, although the whole of my previous experience had been with refracting telescopes. I was particularly desirous of testing the reflector with my own hands, because such preliminary trials of it as had been made had given rise to somewhat conflicting opinions as to its merits (…).

Keeler also designed a spectrograph for the Crossley reflector (Figure 4). It consisted originally[14]:

(…) of a 50^o quartz prism with a circular aperture of 27 mm, placed directly in the converging beam of light of the main mirror, at a distance of 15 cm inside the focus; of a plate-holder suitably placed; and of a guiding eyepiece working in the same principle as that employed in ordinary nebular photograph (…) The instrument was completed on the day Professor Keeler left Mount Hamilton for the last time, about a fortnight before his death.

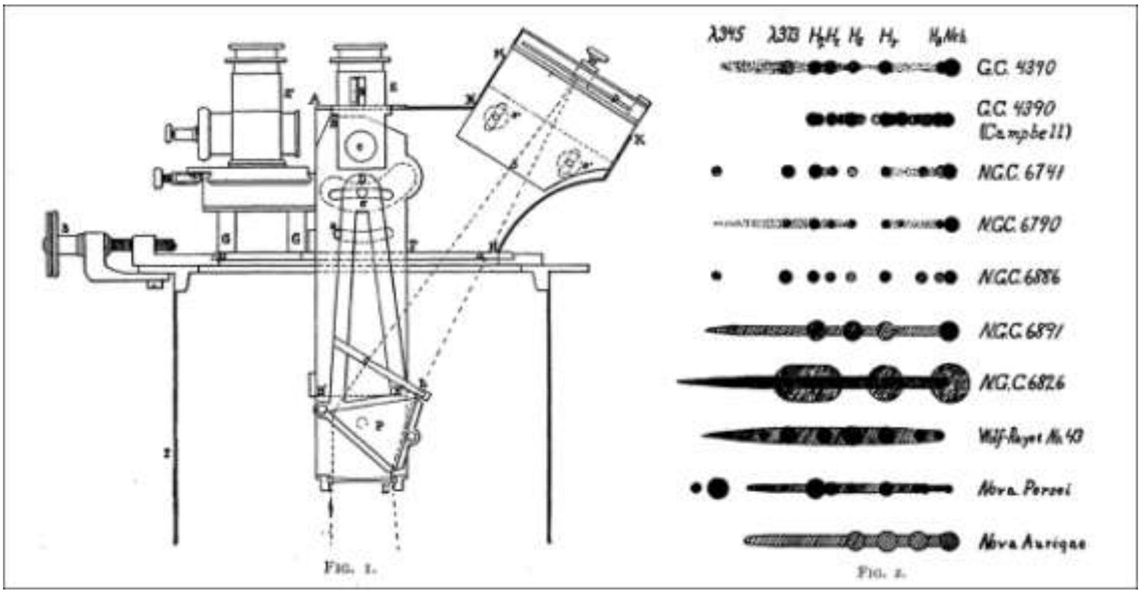

FIG. 1.

FIG. 2.

Figure 4- Spectrograph designed by E. Keeler for the Crossley reflector (left) and several spectra obtained with this instrument (right).

Keeler initiated an extended program of nebular photography showing for the first time that a great majority of these objects exhibited a spiral structure. After Keeler's death, Charles Dillon Perrine (1867-1951) completed the project and renewed the telescope completely between 1902 and 1904. Common original open tube and mount were replaced with a much more rigid closed tube on an English equatorial mount (Figure 5).

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[13] Keeler, J. (1900). The Crossley refector of the Lick observatory. *Astrophysical Journal*, XI (5): 325-353.

[14] Palmer, H.K. (1903). An application of the Crossley reflector of the Lick observatory to the study of very faint spectra. *Lick Observatory Bulletin No. 35:218-235.*

Perrine improved the mount, mechanical drive and gears. He also removed the secondary mirror and mounted the plate-holder directly at the prime focus of the telescope. A clever system of prisms and lenses were also installed so that the observer could guide during the long exposures directly from an eyepiece outside the telescope tube. In this way the Crossley reflector became a much faster and efficient instrument for direct nebular photography.

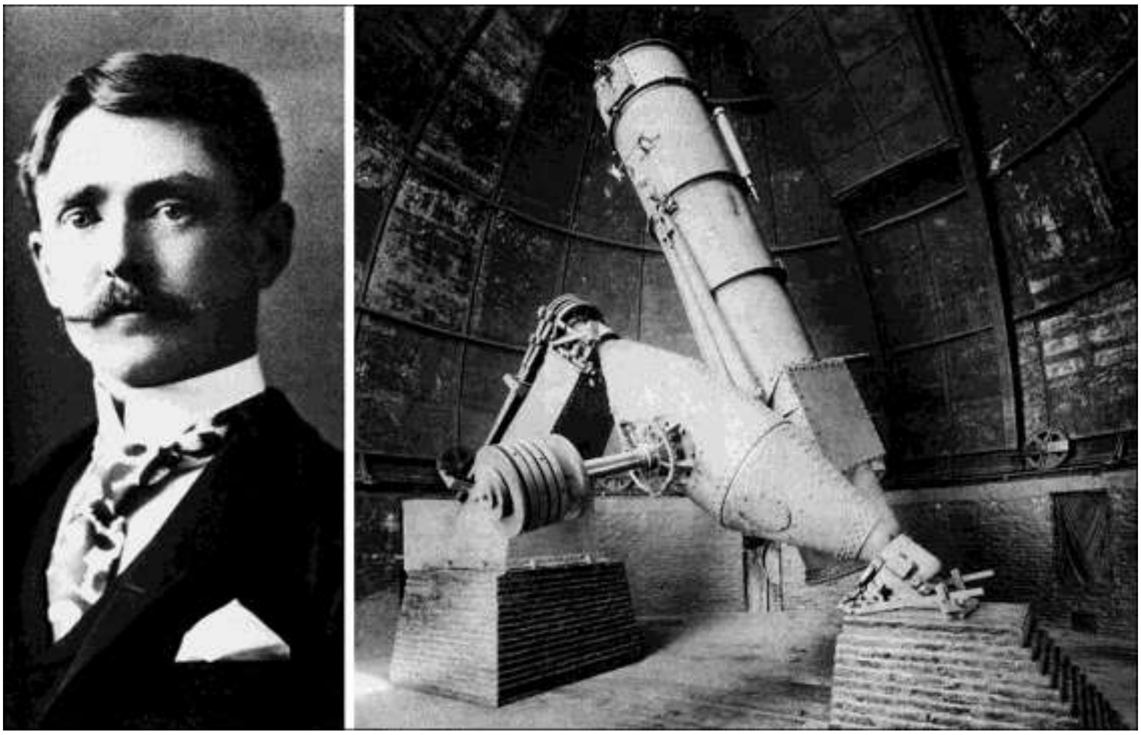

Figure 5- Charles Dillon Perrine (left) and the rebuilt Crossley reflector (right) (*ca.*1905).

These first successful photographic results obtained with this telescope helped to establish the reflector as the preferred observatory instrument.

After Keeler's death, his colleagues at Lick Observatory arranged for the publication of his and Perrine's photographs of nebulae and clusters in a special volume of the Lick Observatory publications[15] (Figure 6).

George Ellery Hale (1868-1938) wrote the following about the publication of the Crossley direct photographs:

The resulting photographs of nebulae surpass any similar photographs ever before obtained, and reveal new and unexpected features of the first importance (…). The remarkable success of his experiments with the Crossley reflector has impressed everyone who has seen the wonderful photographs of nebulae and star clusters made with this instrument.

The Crossley reflector was also used for many important studies of stellar evolution, planetary nebulae and spectral analyses of variable stars.

In 1908 Edward A. Fath (1880–1959) used the Crossley to obtain continuous spectra of spiral nebulae showing that these consisted of individual stars[16].

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[15] Keeler, J. E. (1908). "Photographs of Nebulae and Clusters made with the Crossley reflector. *Publications of the Lick Observatory, Vol. 8*.

Between 1912 and 1923 Herber Doust Curtis (1872-1942) publishes a long list and descriptions of nebulae and clusters based on direct photographs obtained with the Crossley reflector. Curtis also observed many "new stars" (supernovae) in spiral nebulae leading to the conclusion that these systems were outside our own galaxy. Curtis was one of the first astronomers mentioning that spirals were island universes. His views were very different from those expressed by Harlow Shapley (1885-1972). The two astronomers held in 1920 a great debate, also known as Shapley/Curtis debate, concerned with the nature of spiral nebulae and the size of the universe, at the National Academy of Sciences (Washington, DC).

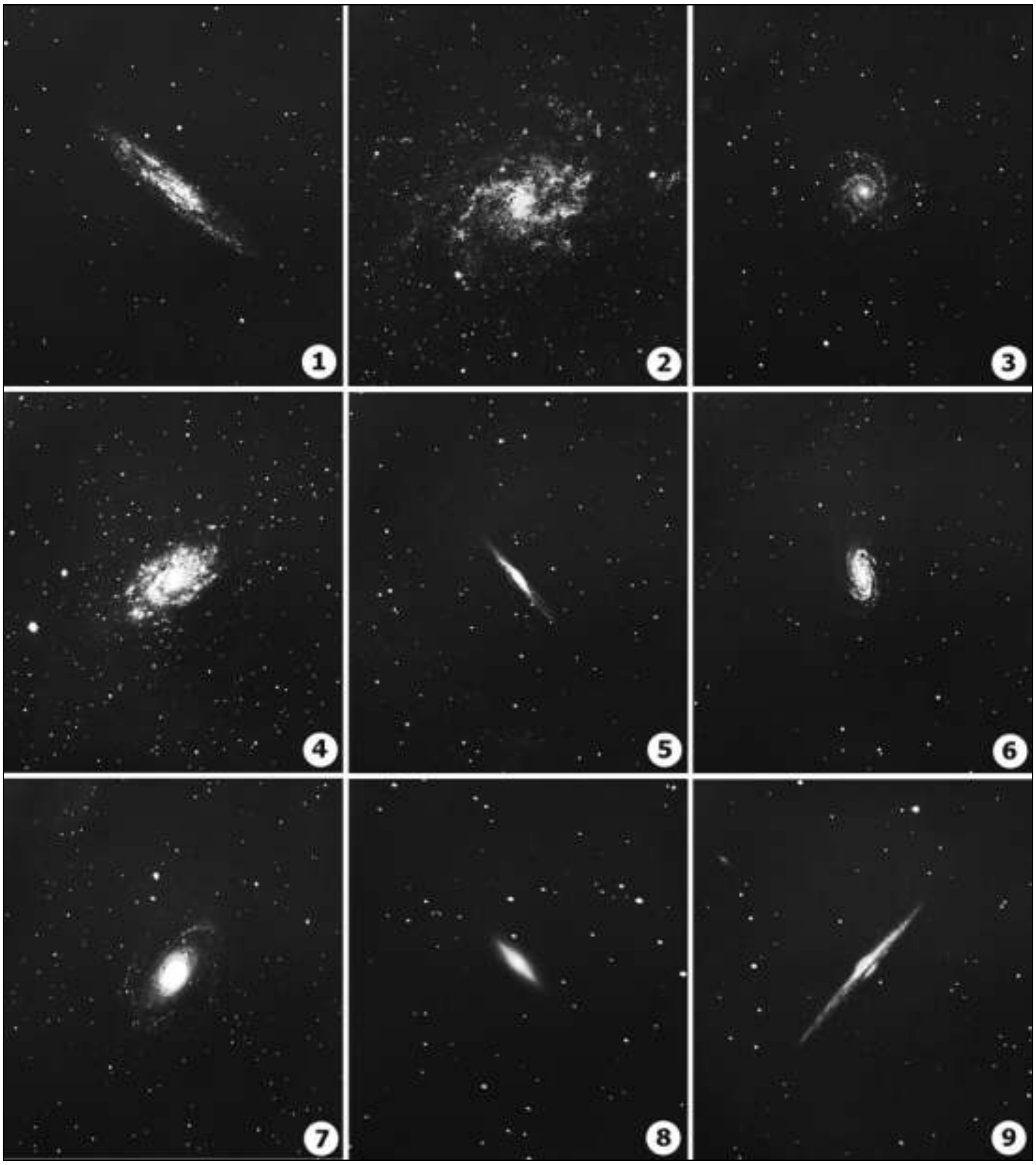

Figure 6- Selection of photographs obtained by Keeler and collaborators with the Crossley reflector: 1- NGC 253, 3h, November 18-20, 1902; 2- M 33, 3h30min, September, 12 1899; 3- M 74, 4h, October 31, 1899; 4- NGC 2403, 3h, February 27, 1900; 5- NGC 2683, 3h30min, February 23, 1900; 6- NGC 2903, 3h30min, February 24, 1900; 7- M 81, 3h55min, March 21, 1900; 8- NGC 3115, 2h30min, April 9, 1901; 9- NGC 4565, 3h, April 21, 1901.

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[16] The physical nature of spirals was an unsolved puzzle at the time.

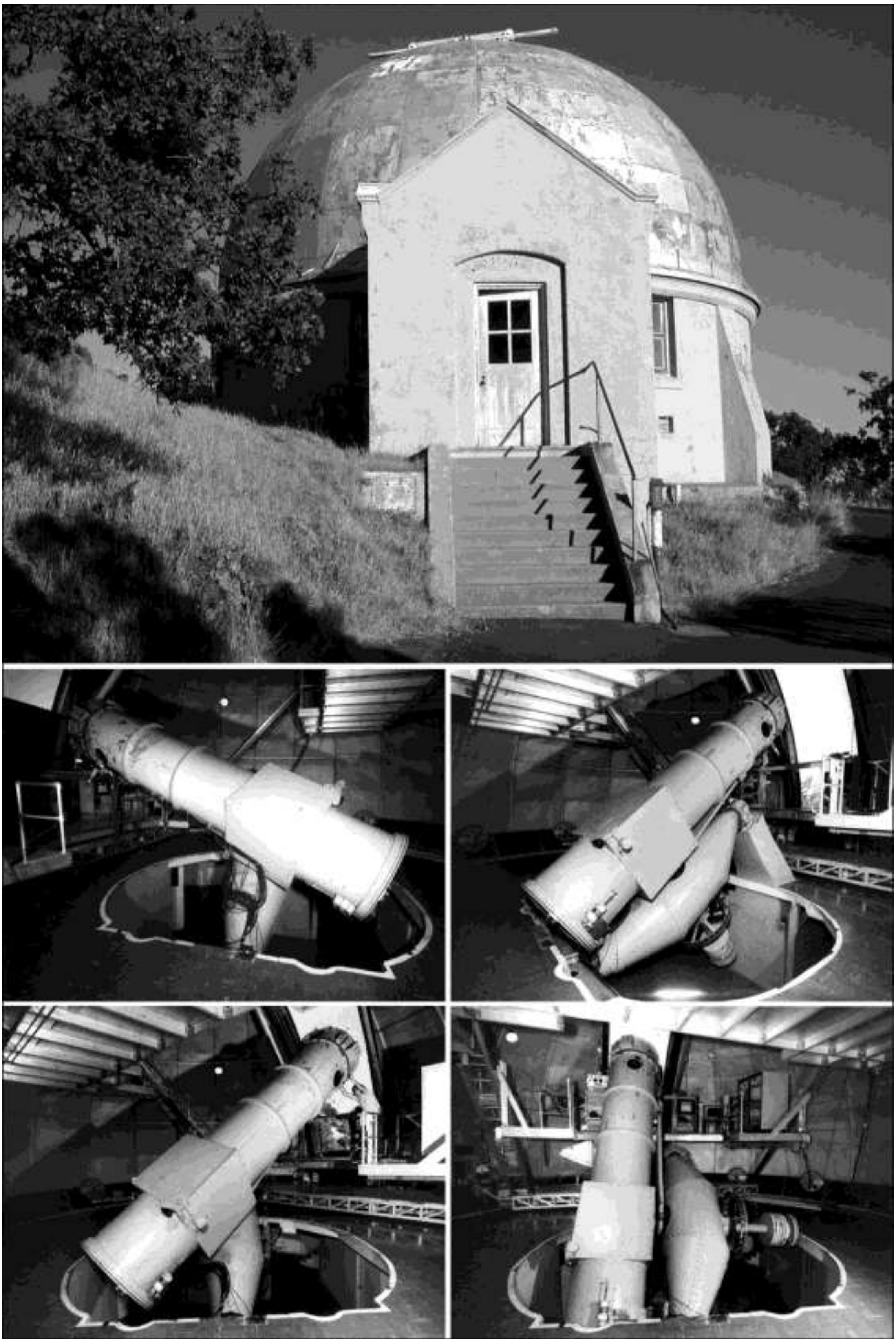

Figure 7- The Crossley reflector today.

Sources:

- Keeler, J. (1900). The Crossley refector of the Lick observatory. *Astrophysical Journal*, XI (5): 325-353.
- Keeler, J.E. (1908). Photographs of nebulae and clusters made with the Crossley reflector. Publications of Lick Observatory, Vol. 8.
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- Osterbrock, D.E. (1988). *Eye on the Sky: Lick Observatory's First Century*. Berkeley, California: University of California Press.
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BUILDING LARGE TELESCOPES: I- REFRACTORS

PEDRO RÉ
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The second half of the nineteenth century was the age of the refractor. During this period we saw the growth of the refracting telescope to the greatest size attained to date (Figure 1). In the twentieth century the reflector surpassed the refractor.

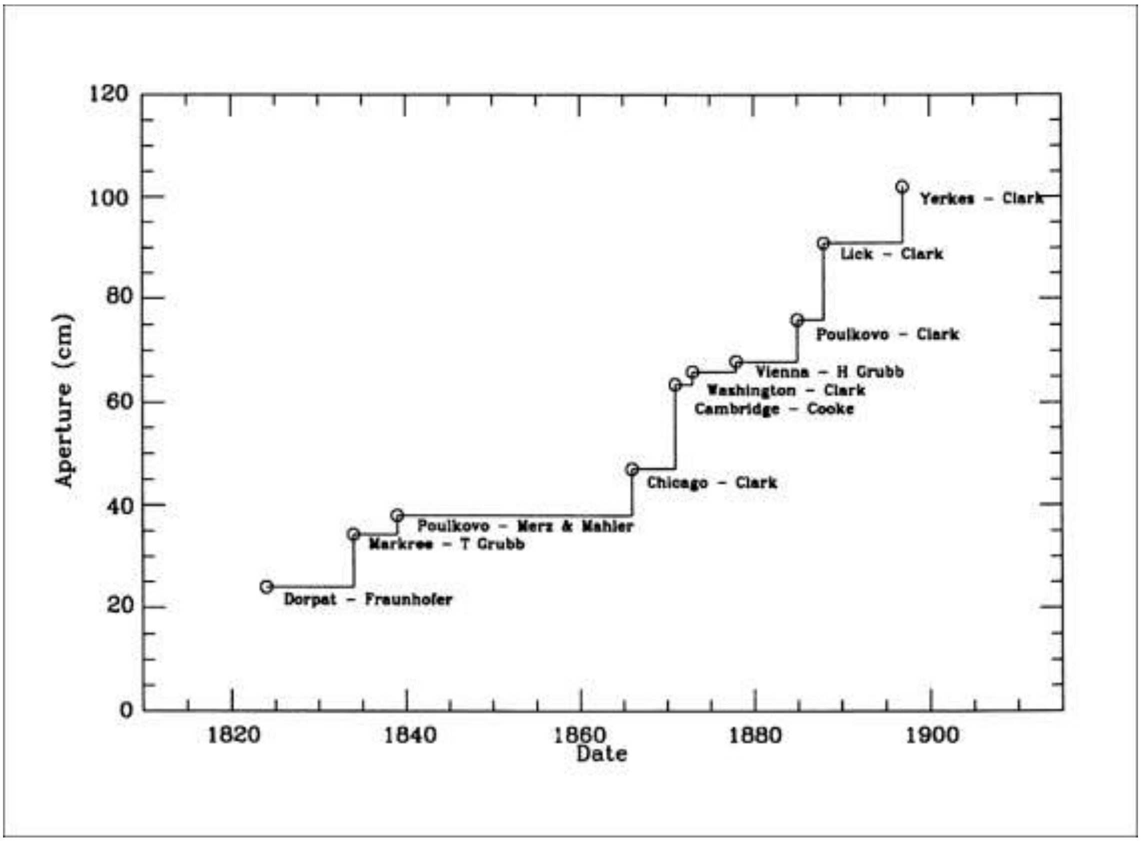

Figure 1- Growth in size of refracting telescopes during the second half of the nineteenth century. Adapted from Danjon & Couder (1935).

The first modern refractor was was built in 1824 by Joseph von Fraunhofer (1787-1826). The great Dorpat refractor with a 9.5-inch lens (14 foot focal length) was noted for his high quality optics but also for its mounting, the first example of what became known as the "German equatorial mount" (Figure 2).

The 13.3-inch Markee Observatory refractor was built by Thomas Grubb (1800-1878). This was T. Grubb first big contract as a telescope maker. The lens was built in 1831 by the French optician R.A. Cauchoix (1776-1845). The equatorial mount built by Grubb in 1832 was very solid compared to the equatorial of the great Dorpat refractor. The refractor was erected in 1834 on a triangular pier made of black marble (Figure 3). This telescope was not housed under a dome. The instrument was exposed to the weather with only the lens covered when not in use. Circular walls build around the mount protected the observer from the wind.

Figure 2- The great Dorpat refactor (left) was installed at Dorpat Observatory (center) under the rotatory cupola (right).

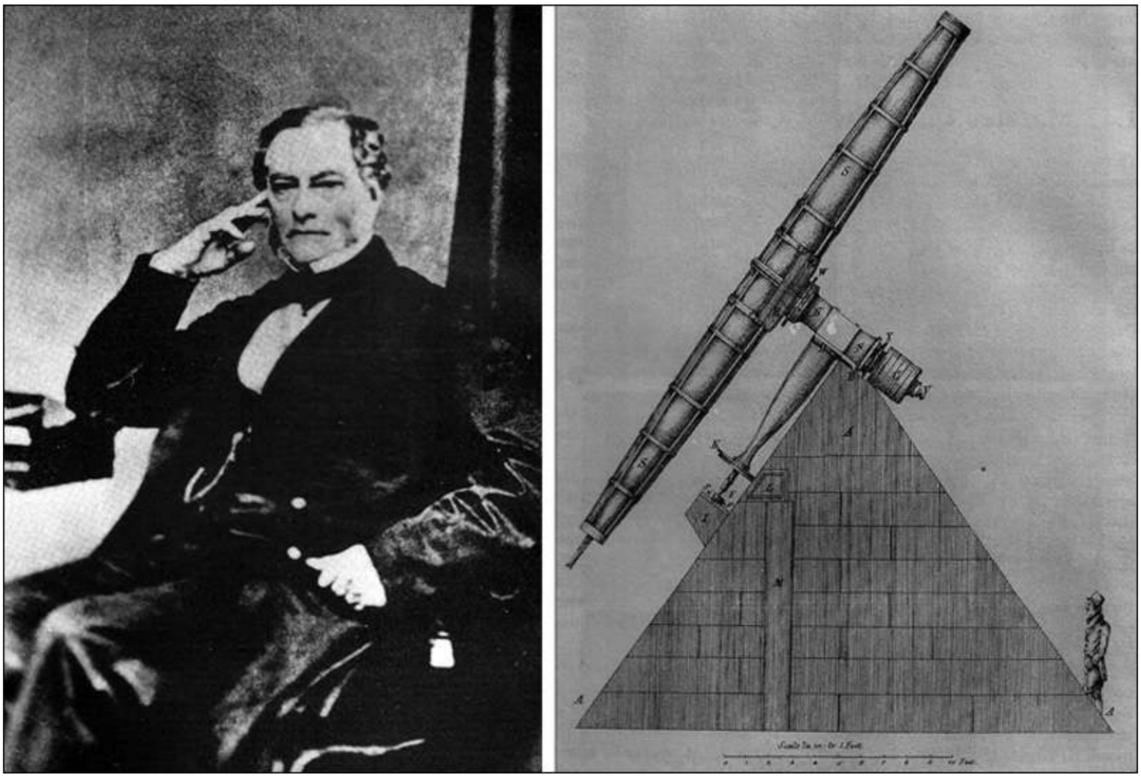

Figure 3- Thomas Grubb (1800-1878) and the 13.3-inch Markee Observatory refractor (1834).

In 1850 the largest refractors were the 15-inch (38 cm) instruments at Pulkovo and Harvard (Figure 4). These two telescopes were built by Merz & Mahler (Munich). In the middle of the nineteenth century the largest reflector was the Leviathan of Parsonstown built in 1845 by William Parsons, third Earl of Rosse (Birr Castle, Ireland). During this period refractors were largely preferred by astronomers for precision work at the observatory. Apart from periodical cleaning, the optical system of refractors needed no further attention. These instruments had several drawbacks: residual chromatic aberration, high cost and size limitations (lens plus mount). Reflectors do not exhibit chromatic aberration. The first mirrors were made of a copper-tin alloy that tarnished and had to be frequently re-polished. Only after the introduction silver-glass mirrors the reflector was able to compete with the refractor as far as precision work at the observatory is concerned.

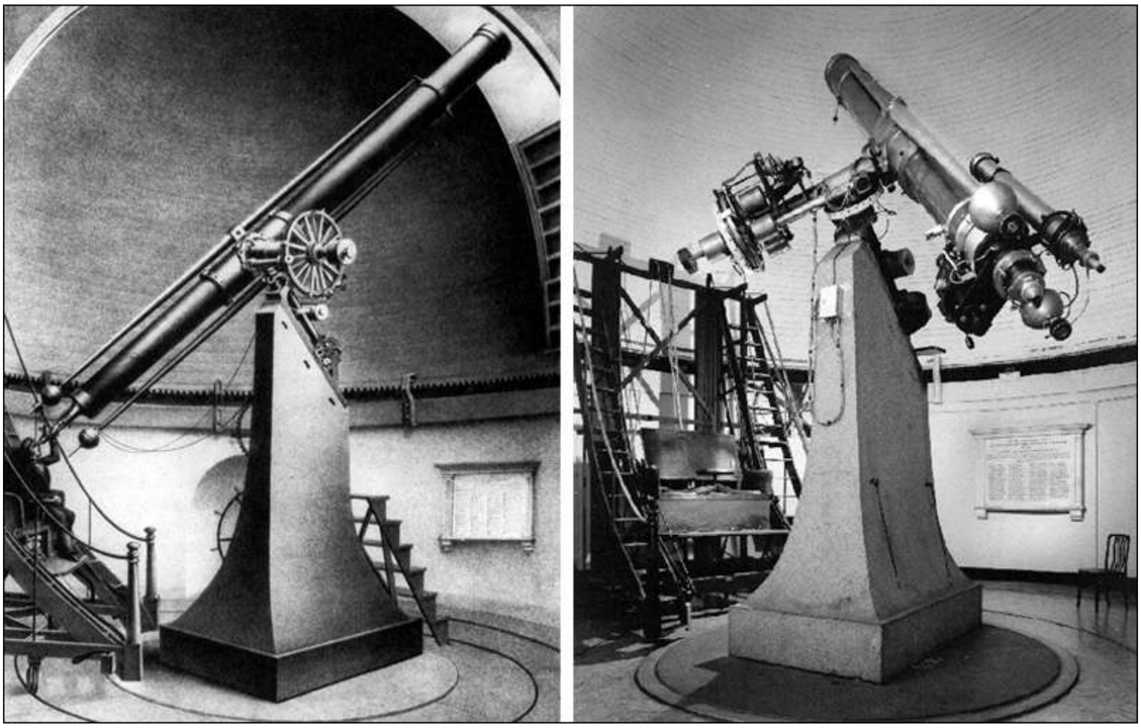

Figure 4- “The Great Refractor" of the Harvard observatory installed in 1847, was for twenty years the greatest refractor in the United States.

The next big refractor was built by Alvan Clark (1804-1887). Alvan Clark and his sons, George Bassett Clark and Alvan Graham Clark were the main makers of large refracting telescopes in the late nineteenth century. For five times the Clarks made the objectives for the largest refracting telescopes in the world. The first of these object glass was the 18.5-inch (470 mm), 8.2 m focal length Dearborn telescope, commissioned in 1856 by the University of Mississippi (Figure 5). When Alvan Graham Clark tested this objective for the first time in 31 January 1862, he discovered the companion of Sirius. The telescope was only erected after the end of the American Civil War in 1866, by the University of Chicago.

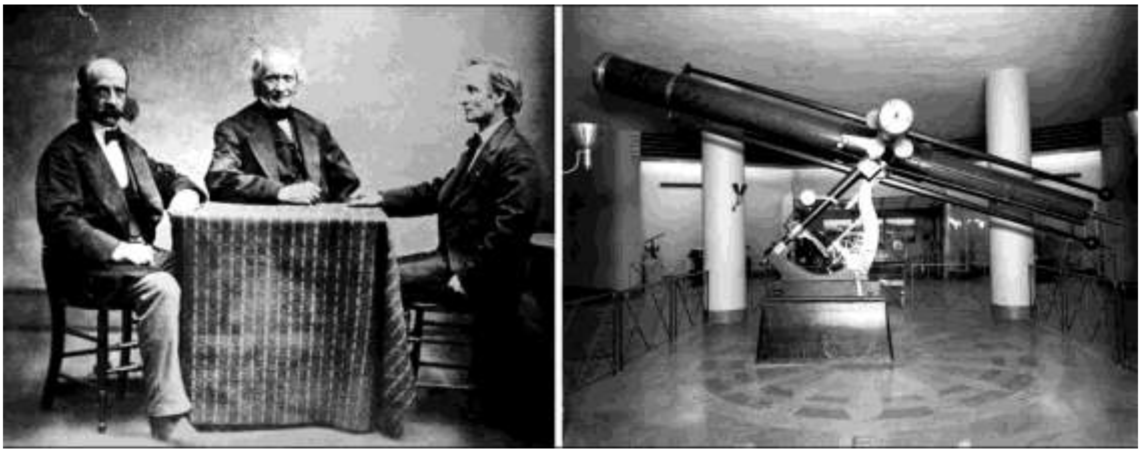

Figure 5- Alvan Clark & Sons (left) and the Dearborn refractor (right) erected in 1864.

The 18.5-inch refractor did not remain the largest refractor in the world for a long time. Robert Stirling Newall (1812-1889) a wealthy Scottish engineer and amateur astronomer, commissioned Thomas Cooke (1807-1868) to build a telescope for his private observatory at Ferndene. The discs for a 25-inch (64 cm) refractor were ordered from the Chance Brothers Company in 1863. The lens had a focal length of 9.1 m and a combined weight of 66 kg. The Newall refractor took seven years to build. It was for a few years the largest in the world. Newall erected this telescope in 1871 on his estate, a very unfavorable site: during a period of fifteen years he had only one night in which he could use its full aperture (Figure 6).

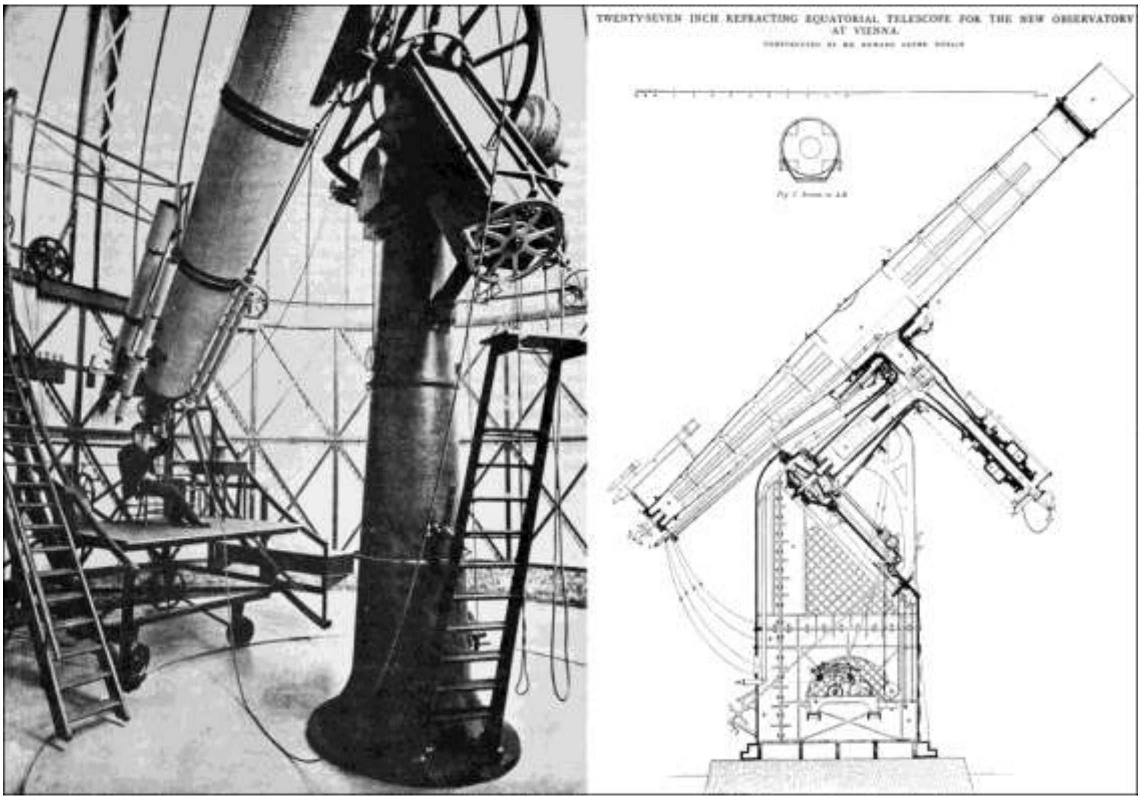

Figure 6- The 26-inch Newall refractor (left) and the 27-inch Grubb refractor of the Vienna Observatory (right). The 27-inch surpassed the 26-inch Clark of the U.S. Naval Observatory becoming the model of all mountings for subsequent large refractors.

The Clark firm also built in 1873 the 26-inch (660 mm) objective lens for the United States Naval Observatory. In 1883, they finished the 30-inch (760 mm) telescope for the Pulkovo Observatory in Russia (Figure 7). Asaph Hall (1829- 1907) discovered the two satellites of Mars (Phobos and Deimos) using the 26-inch lens in 1877. The mount of the United States Naval Observatory was modeled after the Newall refractor.

The contract for building the 27-inch refractor of the Vienna Observatory was given to Thomas Grubb in 1872. Grubb introduced many innovations in the equatorial mount. The mount was very sturdy as compared to the Clark mounts. This equatorial mount became the model for all future mounts of large refractors (Figure 6).

Georg Wilhelm Struve (1793-1864), director of the Pulkovo observatory contracted the Repsold firm in Hanover for building the mount of a large 30-inch (76 cm) refractor (14.1 m focal length). The lens was made by Clark & Sons in 1884. The world largest refractor went into operation at the Pulkovo observatory in 1885 (Figure 7).

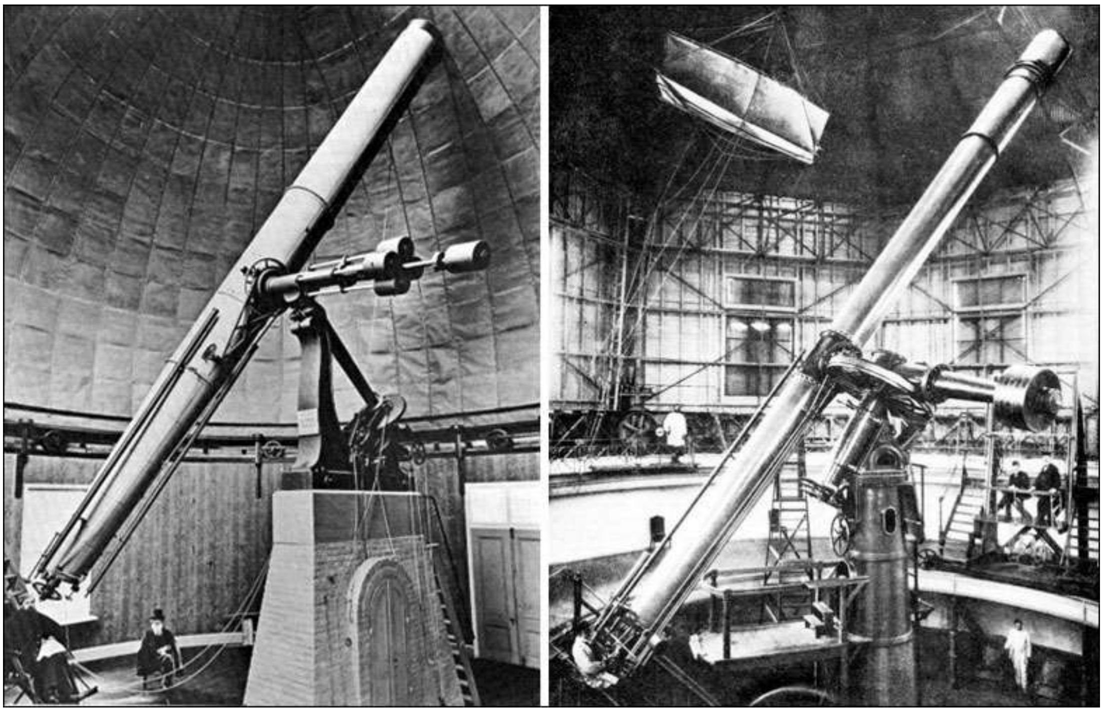

Figure 7- The 26-inch U.S. Naval Observatory refractor (left) and the 30-inch Pulkovo Observatory refractor (right) built by the Clark & Sons firm.

The next two big refractors were also built by the Clarks. In 1880 the Clark firm was given a contract to build a 36-inch (91 cm) objective and photographic corrector. The lens with a focal length of 17.6 m was finished in 1885 but the photographic corrector (33-inch, 84 cm) was only completed in 1887. The mount for this refractor was built by the Warner & Swasey firm and erected on Mount Hamilton (Lick Observatory) in 1887. The Lick refractor was one of the most productive instruments in the history of astronomy (Figure 8).

The Clarks agreed to make a 40-inch (102 cm) objective for the Yerkes observatory (Figure 8). Alvan Graham Clark, the last surviving member of the Clark family began figuring the lenses and Warner & Swasey were asked to supply the equatorial mount. The mount was finished in 1893 being displayed at the Columbia Exhibition in Chicago that same year. The 40-inch refractor (19.3 m focal length) went into operation only in 1897 after the foundation of the Yerkes Observatory in 1895. This refractor is still the largest in the world today. The combined weight of the two components of the 40-inch objective was 225 kg (Figure 9).

Before his death in 1897, Alvan Graham Clark declared his intention to make a 60-inch (152 cm) lens. In the twentieth century several attempts were made to build larger refractors without any success. By this time reflectors were the main instruments used for spectroscopy and astrophotography.

The limit of refractors was reached with the 40-inch. According to James Edward Keeler (1857-1900) that examined the lens in 1896:

"From these tests it appears that the character of the image varies with the position of the lenses relative to each other, and, to a less extent, with the position of the objective as a whole

relatively to its cell. It is probable that flexure of the lenses is the principal cause of the observed changes, and it is interesting to note that there is here evidence, for the first time, that we are approaching the limit of size in the construction of great objectives".

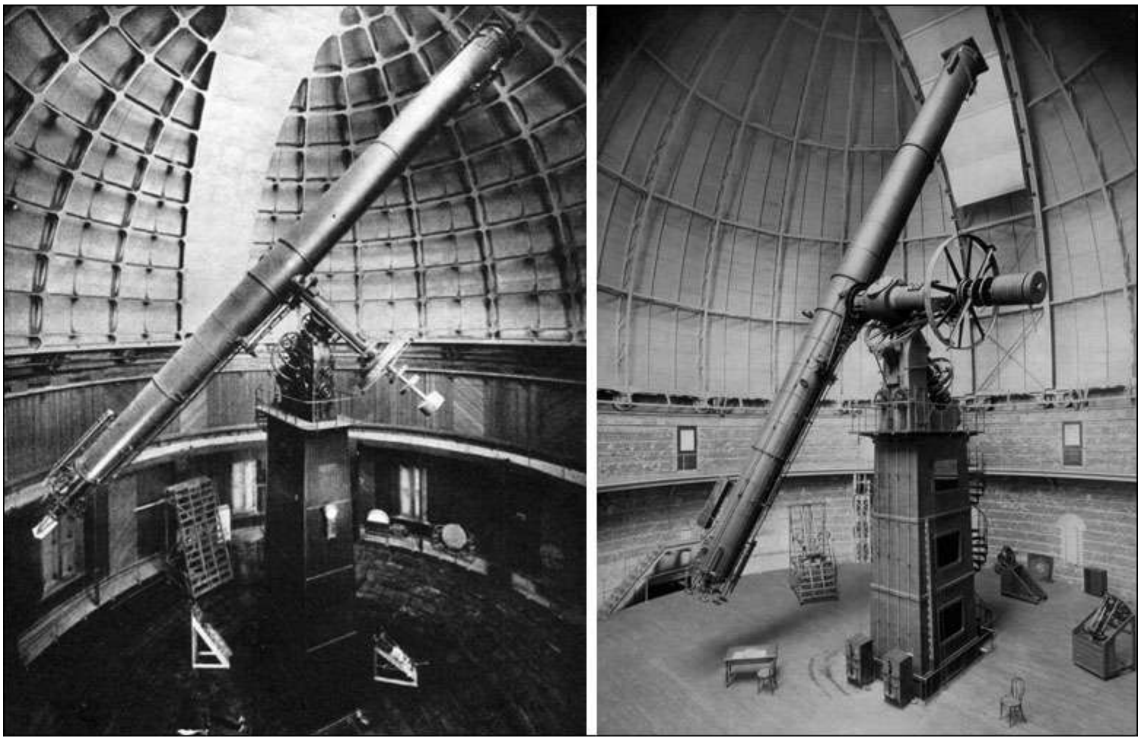

Figure 8- The 36-inch Lick Observatory refractor (left) and the 40-inch Yerkes Observatory refractor (right).

Figure 9- Alvan Graham Clark and Carl Lundin with the 40-inch object glass.

Sources:

- Danjon, A. & A. Couder (1935). *Lunettes et Télescopes.* Livrarie Scientifique et Technique, Paris.
- Glass, I.S. (1997). *Victorian Telescope Makers: The Lives & Letters of Thomas & Howard Grubb*. Institute of Physics Publishing, London
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BUILDING LARGE TELESCOPES: II- REFLECTORS

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On the turn of the twentieth century the refractor was rapidly approaching its limits in terms of aperture. The main reason for this was the difficulty in manufacturing discs of crown and flint glass with diameters greater than 100 cm. Manufactures of plate-glass could however cast large disks of ordinary crown glass, of lower optical quality, that were suitable for mirrors. It was also known that the light losses in lenses of more than 100 cm would be much greater that those in mirrors of equal aperture, especially in the blue region of the electromagnetic spectrum where the highest sensitivity of the first photographic plates lay. Lenses with diameters of more than 1 m were also very difficult to mount and flexure was a major drawback. Mirrors were easy to mount, the focal ratios were smaller and there were no residual chromatic aberrations. Astrophysicists aimed at the largest possible aperture and perfect color correction. The reflector was the way to go. The lower focal ratio of the reflector meant shorter tubes, smaller domes and lower overall costs. Reflectors were, in spite of all, considered by the majority of astronomers around the turn of the century, as imprecise and difficult to use instruments. The mounts of the first big reflectors were imperfect and the mirrors sagged under their own weight. For this reason the reflector was being mainly used by amateur astronomers.

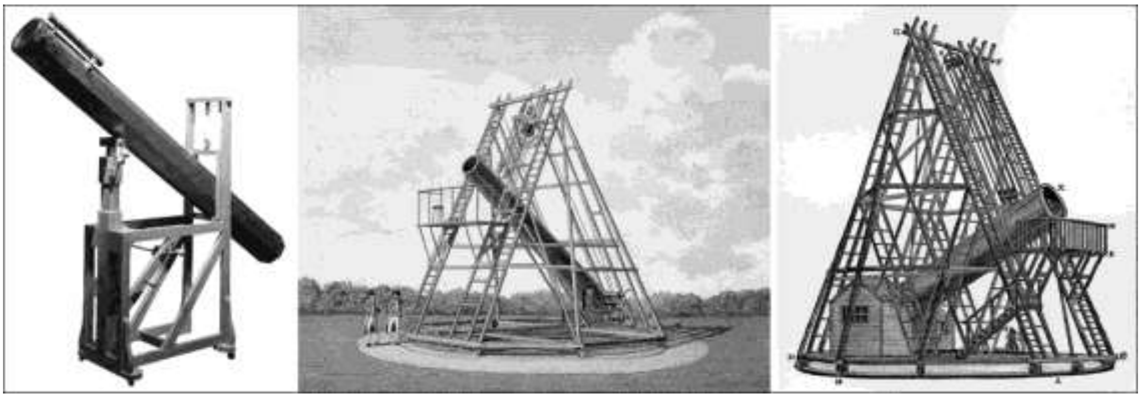

Figure 1- William Herschel's telescopes. From left to right: seven-foot reflector, twenty-foot reflector and forty-foot reflector.

First big reflecting telescopes

The first big reflectors were built by William Herschel (1738-1822). During the course of his career, Herschel constructed more than four hundred telescopes. The largest of these reflectors was the 40 ft (12 m focal length) telescope. This telescope with a primary mirror with a diameter of 126 cm was very difficult to use and most of W. Herschel's observations were conducted with smaller instruments (15 and 48 cm apertures) (Figure 1).

Herschel cast his first solid speculum mirror in late October 1773. These consisted of a compound of copper, tin and antimony. Its surface was shaped and finally polished to a high gloss. Most of Herschel's telescopes were mounted in wooden tubes and alt-azimuth mounts (Figure 1). Herschel became the greatest telescope maker of the eighteenth century (between 1773 and 1795 he casted and polished 430 telescope mirrors). Herschel used no scientific approach to test his mirrors. The mirrors were tested on a distant object and then tried on the sky. In 1774, Herschel began his systematic survey of the heavens, observing and keeping a log book of all his observations (planets, double stars, cluster of stars and nebulae). On March 13, 1781, observed a "star" that he "perceived as larger than the rest". It had a perceptible disk with a sharp border. This object was no comet but a new planet (Uranus). According to Herschel logbook:

"It was a lucky accident that brought this star to my view (…) in the regular manner I examine every star of the heavens, not only of that magnitude but far inferior, it was that night its turn to be discovered (…) had business prevented me that evening, I must have found it the next".

In 1783, Herschel completed a twenty-foot reflector (48 cm aperture) that he used to sweep the heavens for the next three decades. This telescope was suspended within a rotating wooden frame operated by assistants that raised or lowered the tube by hand. Herschel used no secondary mirror; instead he observed near the periphery of the tube opening, on a platform, fifteen-feet above the ground (Figure 2).

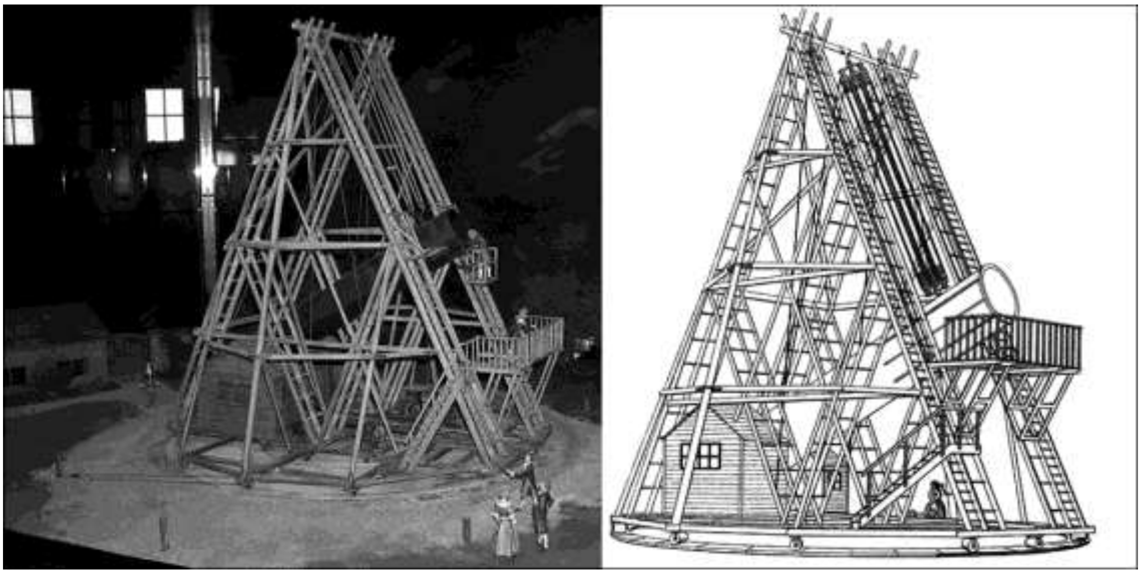

Figure 2- Herschel forty-foot reflector.

According to William Herschel sister (Caroline) astronomy was a dangerous business:

"I could give a pretty long list of accidents of which my brother as well as myself narrowly escaped of proving fatal; for observing with such large machineries, when all round in darkness, it is not unattended with danger".

Caroline impaled her leg when she tripped over a metal hook hidden under a blanket of snow. On another night the entire mounting of the twenty-foot reflector collapsed moments after Herschel had climbed down from the observing platform.

In 1876, the Herschel moved to Slough in pursue of a drier climate and more space to mount their telescopes. The forty-foot telescope was completed in 1789. This big reflector never lived up to Herschel's expectations. The mirror required frequent repolishing and sagged under his own weight, giving imperfect images at the eyepiece. The preparation for an observing night took many hours. Taking this into account, Herschel used mainly the twenty-foot for most of his observing sessions. Herschel's telescopes were capable of looking deeper into space than any other telescope to date. With these instruments, Herschel collected an amazing number of discoveries that according to his son John Herschel (1792-1871) include: the discovery of Uranus and two of its satellites; the measurement of the rotation period of Saturn's rings; measurement of the height of lunar mountains; confirmation of the gaseous nature of the Sun; discovery of almost 1000 double stars and more than 2000 nebulae and star clusters; discovery of infrared light and the determination of the solar system movement thought space.

Herschel also used the twenty-foot for "star gauging". With this project he hoped to determine the shape of the local universe. Herschel counted (gauged) the number of stars in 3400 different star fields. He assumed that the fainter stars were farther from the Earth and was able to produced a three dimensional model of our Galaxy[17] (Figure 3).

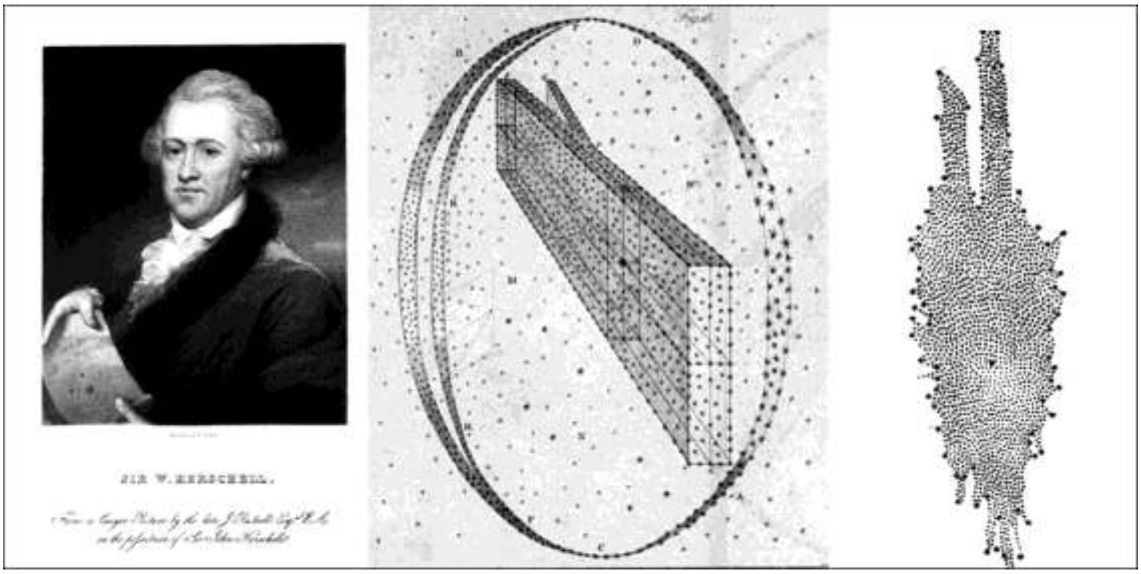

Figure 3- William Herschel depiction of the shape of our Galaxy.

During the first half of the twentieth century several large reflectors were built by William Parsons (Third Earl of Parsonstown, Lord Rosse) (1800-1867), William Lassel (1799-1880), Thomas Grubb (1800-1868) e Howard Grubb (1844-1931) (Figure 4, 5, 6 and 7). These first big reflectors were also very difficult to use, its weight was enormous and tracking was deficient (see below).

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[17] Star gauging was performed under the wrong assumption that all stars are identical in their light output.

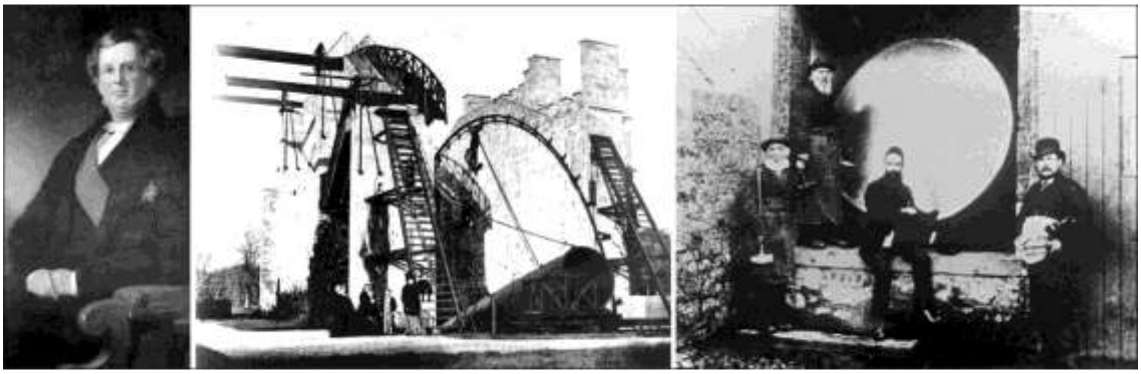

Figure 4- Lord Rosse and the Leviathan of Parsonstwon (*ca.* 1845).

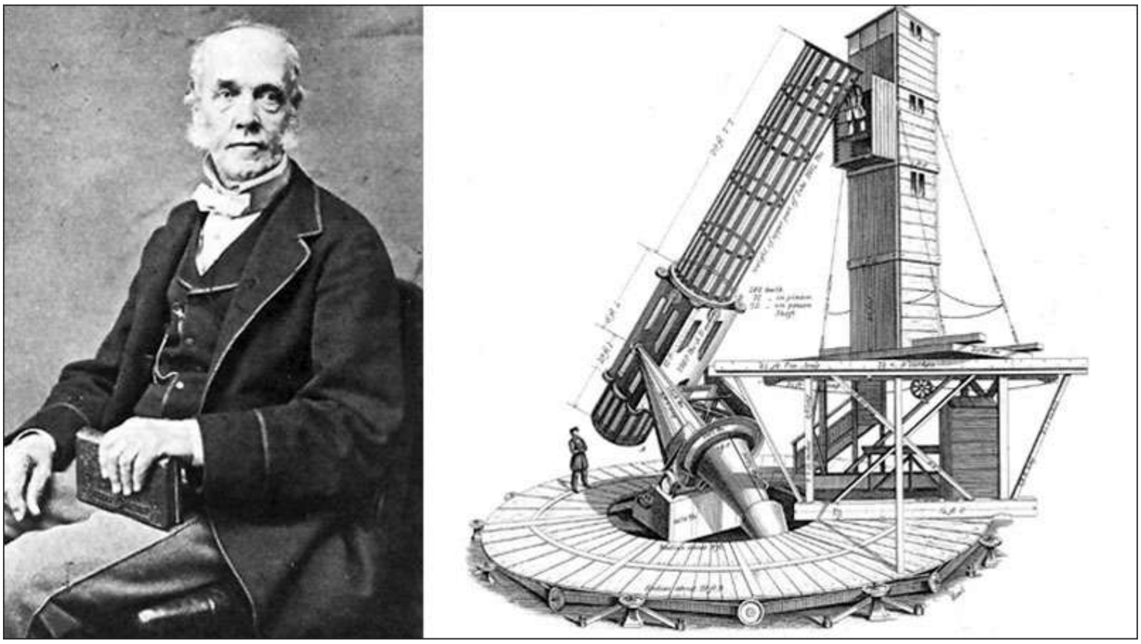

Figure 5- William Lassel and the 48-inch (122 cm) equatorial telescope (*ca*. 1852).

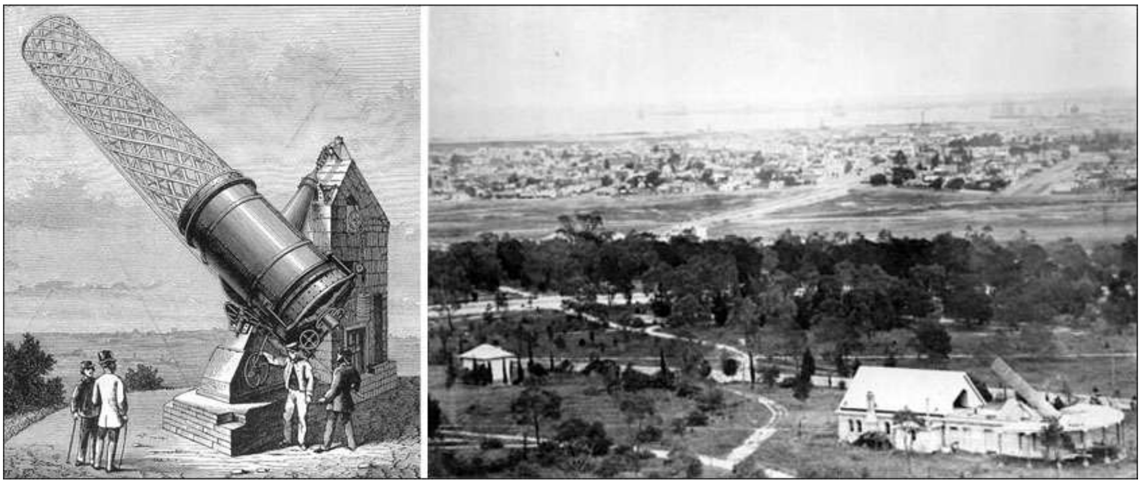

Figure 6- The Great Melbourne Telescope and its roll-of-roof observatory (*ca*. 1869).

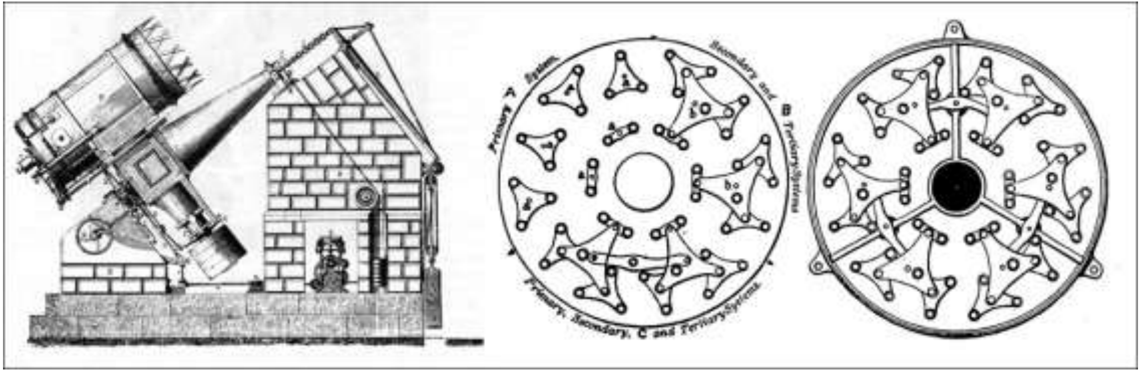

Figure 7- Equatorial Mount and mirror support of the Great Melbourne Telescope.

William Parsons, third Earl of Rosse was the first to surpass Herschel telescopes. Rosse experimented with compound specula and eventually was able to cast several mirrors with increasing diameters. In 1840, a three-foot mirror was mounted in a similar way to Herschel's telescopes. This telescope was used with a Newton configuration (plane secondary mirror). Rosse was able to produce highly reflective surfaces. He considered that the three-foot reflector was "the best ever produced". Shortly after, Rosse drew planes for a reflector of double the size. The six-foot reflector mount was erected from 1842 to 1844 (Figure 4). It featured parallel piers of solid masonry that carried several observing platforms. This telescope had very limited movements (limited to an observing window of about 15^o). To raise or lower the tube the assistance of two workmen was required. Slow motions were assured by turning two small hand wheels on the observing platform. The mirror weighted four Tons. Observations started in 1845. In April of the same year, Lord Rosse described for the first time spiral structures in M 51. Together with his assistants, Rosse described these structures in a considerable number of nebulae.

William Lassel was the first to apply Franhofer's equatorial mount to large reflectors. In 1844 Lassel visited Parsonstown were he inspected the erection of the Leviathan. Lassel added a small quantity of arsenic to his specula, but the reflective power was mainly due to the purity and correct proportions of copper and tin. In 1861, Lassel erected a 48-inch equatorial in the isle of Malta (Figure 5). This telescope had two alternative mirrors weighting over a Ton. The telescope had a fork mount and an open tube. Slow motions were assured by an assistant that turned a winch handle once every second.

The Great Melbourne Telescope (GMT) was the last great reflector that was fitted with a speculum-metal mirror. It went into operation in 1869 and was not only the biggest equatorial telescope in the world but also the largest and most expensive scientific equipment ever built in the Australia (Figures 6 and 7). The telescope was built by Howard Grubb and was mainly used to produce sketches of nebulae first discovered by John Herschel in the southern hemisphere. George Willis Ritchey (1864-1945) published the following statement in 1904:

"I consider the failure of the Melbourne Instrument to have been one of the greatest calamities in the history of instrumental astronomy; for by destroying confidence in the usefulness of great reflecting telescopes, it has hindered the development of this type of instrument, so wonderfully efficient in photographic and spectroscopic work, for nearly a third of a century".

Recent evidence has shown that the failure of the Great Melbourne Telescope should be associated with the fact that it was built to produce drawings of nebulae: direct photography and spectroscopy were precluded.

In 1862, Leon Focault (1819-1868) completed an 80 cm reflector with a silvered-on-glass mirror (Figure 8). It was also the first large mirror that was figured using a novel approach: Foucault's knife edge test. It had a fork mount and tube made of wood. The total weight of the telescope was 1.5 Tons (much less than the GMT that weighted 8.3 Tons). This telescope was very successful in a number of different fields: observation of faint nebulae, first application of the Fizeau interferometer and the Fabry-Perot etalon and double star measurements.

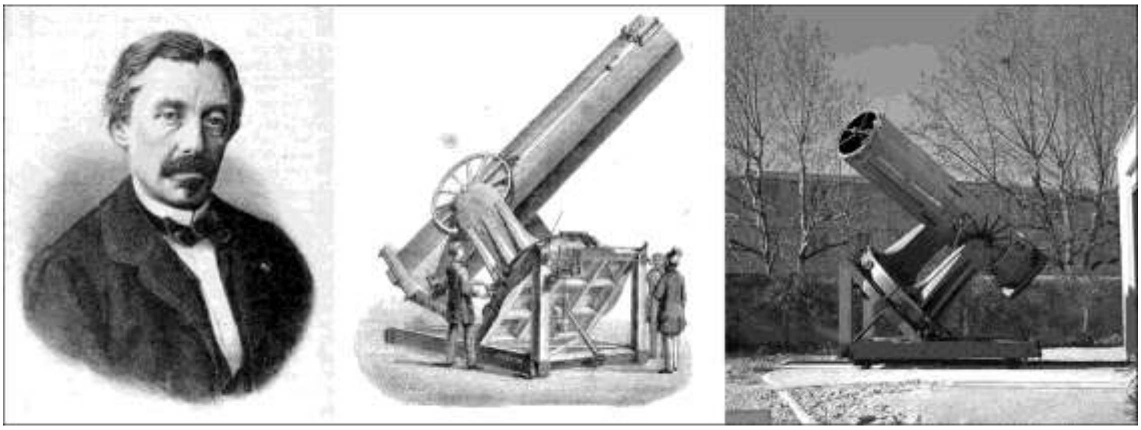

Figure 8- Leon Focault and the 80 cm reflector.

Silver-on-glass mirrors were suggested as early as 1827 by George Biddel Airy (1801-1892). It was only in 1856 that C.A. Steinheil and L. Focault produced independently small parabolic glass mirrors with a thin coat of silver deposited by precipitation. Producing a good parabolic surface in glass mirrors proved to be more difficult that in speculum-metal mirrors. These first difficulties were overcome and the silver-on-glass mirrors became standard equipment from 1870 onwards. The advantages were obvious. Once the optical surface was produced, the silver coating had to be renewed from time to time without the need to repolish the surface.

The reflectors were free from chromatic aberrations and its shorter focal ratios proved to be invaluable for astrophysical work. These advantages were very instrumental for the development of astrophotography and spectroscopy.

Henry Draper (1837-1882) started by grinding metal mirrors but soon changed to silver-coated glass mirrors. Draper obtained the first photograph of a nebula in September 30, 1880 using an 11-inch Clark refractor. In 1864, Draper wrote an extensive monograph entitled "*On the construction of a silvered glass telescope, fifteen and a half inches in aperture, and its use in celestial photography*".

Andrew Ainslie Common (1841-1903), a wealthy engineer and amateur astronomer, was mainly interested in producing astronomical photographs. Common started with refractors around 1870, but soon changed to silver-on-glass reflectors that were built by G. Calver (1834-1927). Common used two Newton reflectors with apertures of 46 and 91 cm provided with fork mounts. These mounts had several important innovations. One of these was a mercury floating device for the polar axis to reduce friction.

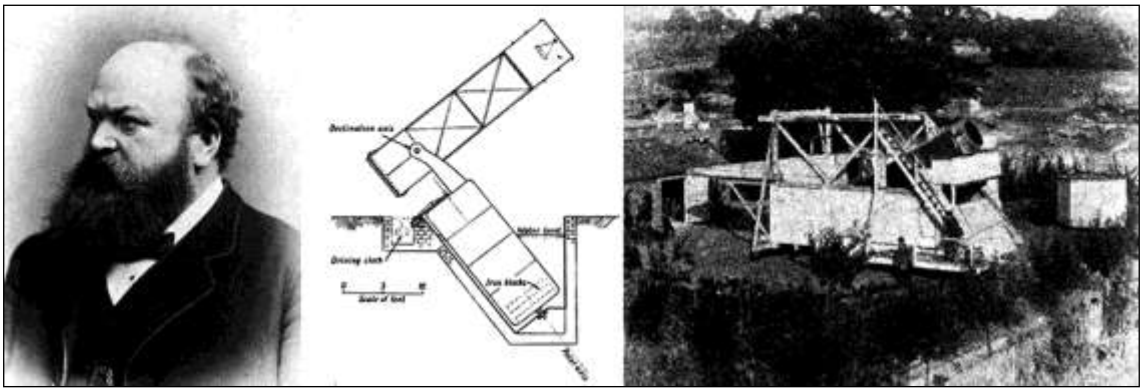

Figure 9- Andrew Ainslie Common and the five-foot reflector.

Common used his instruments mainly as photographic telescopes. Several photographs of the Orion nebulae were obtained with considerable success. In 1883, Common produced images that showed for the first time, stars that were not seen by visual observation. In 1885, the 91 cm reflector was sold to Edward Crossley (1841-1905) and Common started to work on a 5-foot disk (155 cm) (Figure 9). The instrument was finished in 1889. The polar axis (hollow cylinder) floated in a tank of water. This telescope in spite of its good optical quality produced few results.

Crossley, after retiring from astronomy in 1893, offered the 91 cm Common reflector to the Lick observatory. This instrument was extensively used by James E. Keeler (1857-1900) for nebular photography between 1898 and 1900. After Keeler's death, Charles Dillon Perrine (1867-1951) completed the project and renewed the telescope in 1902 and 1905 (Figure 10). These first successful photographic results helped to establish the reflector as the preferred observatory instrument.

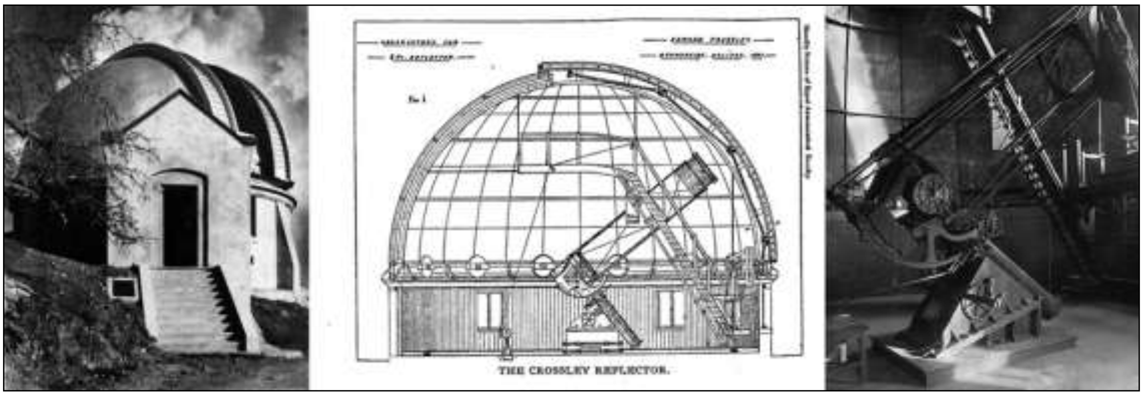

Figure 10- Crossley reflector at Lick observatory (*ca.* 1900).

Modern reflectors

The next big reflecting telescopes were built by George Willis Ritchey (1864-1945). Ritchey was the prophet and builder of the first large successful American reflecting telescopes. He was also a master of astronomical photography. Ritchey worked at Yerkes observatory at the turn of the nineteenth century, a well established leading center for astrophysical research, and was in charge of the optical and instrument shops. There he designed and produced auxiliary equipment for the 40-inch Yerkes refractor and also grinded and finished a 60-inch disk. His first big mirror was a 24-inch of 8-foot focal length that was also used at Yerkes (Figure 11).

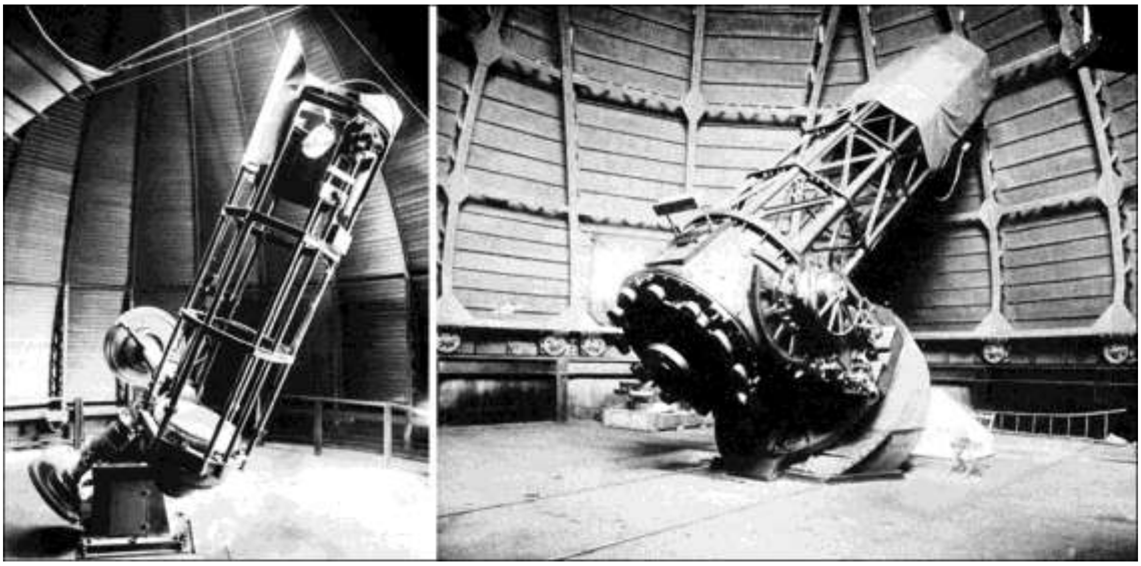

Figure 11- Yerkes 24-inch (left) (*ca.* 1900) and Mount Wilson 60-inch (right) (*ca.* 1908) reflectors built by G.W. Ritchey.

In 1904, Ritchey publishes an extensive work entitled "*On the Modern Reflecting Telescope and the Making and Testing of Optical Mirrors*" that quickly became an essential reference. In the introduction Ritchey refers:

"The present paper describes the methods employed by the writer in the optical laboratory of the Yerkes Observatory in making and testing spherical, plane, paraboloidal, and (convex) hyperboloidal mirrors. On account of the very great importance of supporting mirrors properly in their cells when in use in the telescope, a chapter is devoted to the description of an efficient support system for large mirrors. Intimately related to this, and equally important, is the subject of the mounting, the mechanical parts, of a modem reflecting telescope (…)".

Ritchey was one the first telescope makers to use standard methods at the optical shop. Every precaution was used to exclude dust. The walls and ceiling were varnished, and the floor was kept wet during polishing operations. Double sealed widows were also used and the incoming air was filtered. A canvas was suspended over the mirror to protect the surface from falling particles. Room temperature was kept constant and the optician was properly dressed with cap and gown. The mirror was tested using the Foucault method that required the use of a plane mirror of great precision.

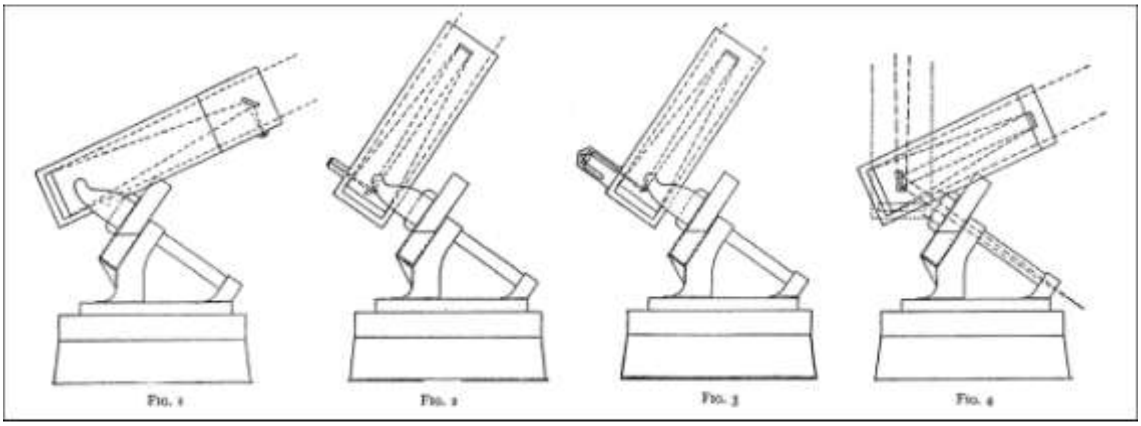

Figure 12- The four possible optical configurations of the 60-inch Mount Wilson reflector.

\The Mount Wilson 60-inch reflector had an innovative design with an open tube and a fork mount. Four optical arrangements were possible: Newton; two modified Cassegrain and a polar or Coudé Cassegrain (Figure 12).

The first visual and photographic observations with this instrument were made in 1908. George Ellery Hale (1868-1938) wrote in a 1909 report:

“Visually the images of stars, planets and nebulae obtained with it on a good night are excellent. The star images are very small and sharp and can be observed with great precision. Such an object as the Great Nebula in Orion shows bewildering variety of detail. Globular clusters are especially remarkable because of the large number of stars visible by the great light-gathering power”.

The first photographic tests with this instrument were conducted by Ritchey in 1908. Several nebulae and star clusters were imaged at the Newton and Cassegrain focus. These first results were described in 1909:

“The new plate-carrier (...) takes plates 3 ½ inches (89 mm) square. This small size is chosen because it allows the guiding eyepiece to be near the center of the field. It includes a clear field about 36 minutes of arc square, and fully covers the entire central region which is free from objectionable distortion. A second guiding eyepiece is also used, the two being on opposite sides of the center. Each gives a magnification of about 750 diameters. This allows any slight rotation of the field to be detected immediately; such rotation is corrected by rotating the bronze plate which carries the guiding eyepieces and plate-holder; two fine screws with graduated heads are provided for effecting this rotation. The small metal plate-holder, is so designed that it can be quickly removed and replaced as frequently as desired during long exposures, thus allowing access to the focal plane for the purpose of refocusing by means of the knife-edge. The position of the plate-holder is defined by small hardened steel surfaces so that when replaced it returns accurately to its original position with reference to the guiding eyepieces. With the small apparent change of focus which takes place since the canopy has been in use, it is found that refocusing every 25 or 30 minutes in the early part of the night, and every 40 or 45 minutes after 11:00 P.M., is usually sufficient. With the new plate-carrier, all of the uncertainties which usually occur in making long exposures with very large telescopes are eliminated. A plate can be exposed night after night, if desired, with the assurance that no error in focus greater than one or two thousandths of an inch can occur, and that no rotation of field can take place without immediately being detected and corrected. Both of these conditions are absolutely necessary for the finest results with an instrument as powerful and sensitive as the 60-inch. With these conditions no injury or elongation of the star-images or nebular details can occur and the full effect of the prolonged exposure is secured. All of the negatives which have been secured with the new plate-carrier show perfectly round star-images. On the best negatives, with exposures of eleven hours, the smallest star-images are 1.03” in diameter”.

Even before the 60-inch first light, George Ellery Hale was already planning the constructing of a 100-inch reflector. The mirror was casted after several failures by the same firm that supplied the 60-inch (St. Gobain Glass Company). The disc arrived at Mount Wilson in December 1908 but was discarded by Ritchey since it was filled with gas bubbles. In spite of this drawback Ritchey was able to start grinding in 1911. The English yoke mount was also designed by Ritchey and further refined by Hale and Francis Gladheim Pease (1881-1938) (Figure 13).

By the end of 1914 a near perfect spherical curvature was obtained, the mount was finished in 1917 and the telescope was in regular use in 1919.

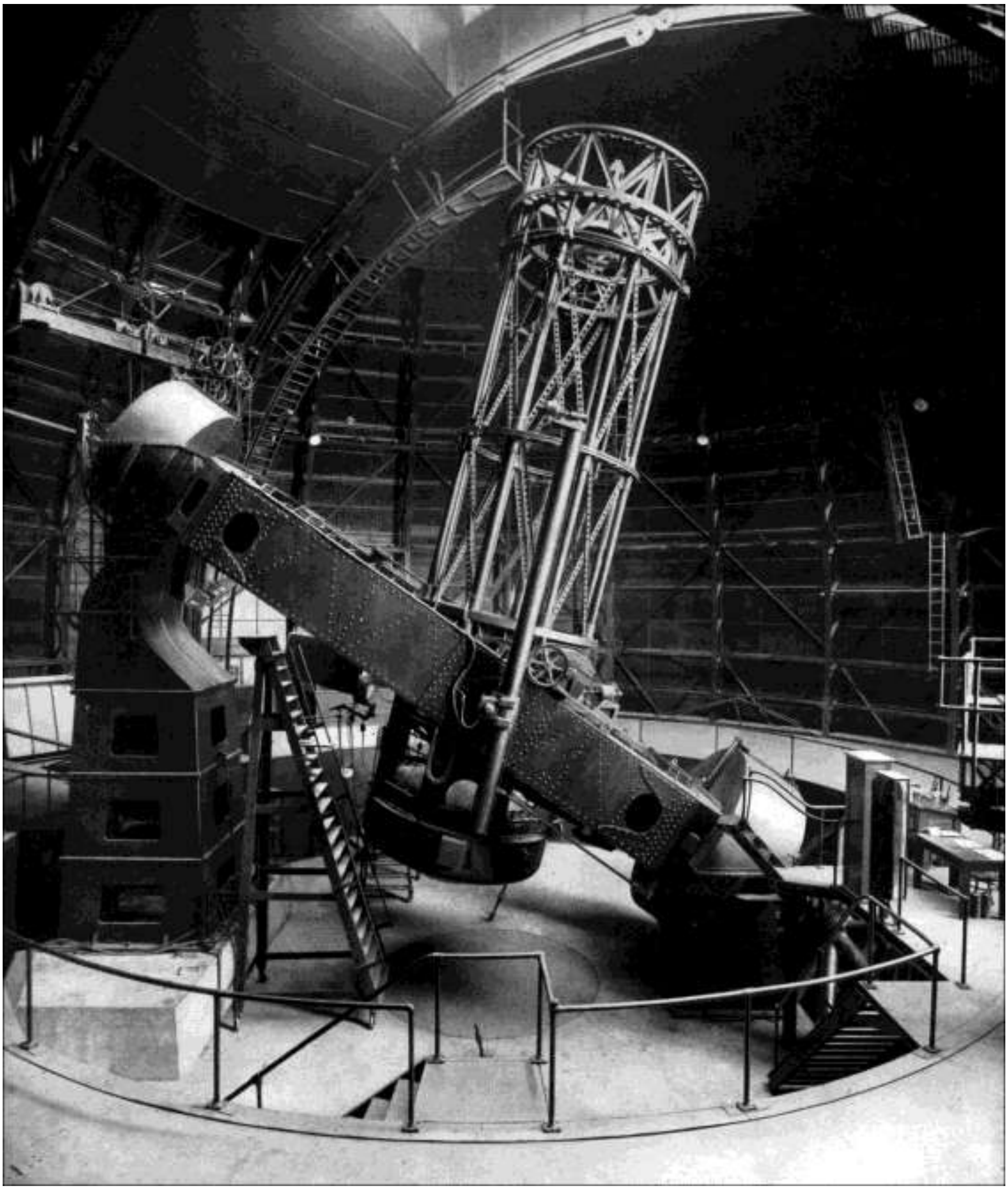

Figure 13- 100-inch Hooke telescope (Mount Wilson observatory) (*ca.* 1919).

The Hooker telescope is similar in optical design to the 60-inch. It can be used as an *f*/5 Newton, as an *f*/16 modified Cassegrain and as an *f*/30 Coudé. The 100 Ton English yoke is supported by means of mercury flotation bearings. The dome is also similar to that of the 60-inch.

Edwin Hubble (1889-1953) used the Hooke telescope to determine for the first time the distances and red shifts of neighboring galaxies. In 1929 Hubble's proved that the universe was expanding in all directions at a constant speed (Hubble's constant).

In 1928, Hale started a campaign to gather funds for a larger telescope. His article “The possibilities of large telescopes” published in the Harper’s Magazine was very instrumental.

Hale started the article with a prophetic phrase:

“Like buried treasures, the outposts of the universe have beckoned to the adventurous from immemorial times. Princes and potentates, political or industrial, equally with men of science, have felt the lure of the unchartered seas of space, and through their provision of instrumental means the sphere of exploration has rapidly widened (…)”.

In a letter to the International Education Board Hale stated:

“No method of advancing science is as productive as the development of new and more powerful instruments and methods of research. A larger telescope would not only furnish the necessary gain in light space-penetration and photographic resolving power, but permit the application of ideas and devices derived chiefly from the recent fundamental advances in physics and chemistry (…)”.

Hale and its staff began to consider a telescope with an aperture of 200 or 300 inches. After some initial difficulties, the Rockefeller foundation awarded (autumn of 1928) a sum of $6 million dollars to the California Institute of Technology to build the giant telescope.

The design and construction of the 200-inch telescope was not an easy task. The first major problem was the cast of the primary mirror. After a series of trials with fused quartz, the mirror was made of Pyrex with a ribbed structure by Corning Glass Works. The mount was also another challenge. The first options were between an open-fork (preferred because it allowed access to the North Pole) and a yolk type equatorial. In 1932 a new yolk design (horseshoe) was adopted with considerable success. After approval, the Westinghouse Company (Philadelphia) started work on the mount in 1936. The primary mirror has a short focal ratio (*f*/3.3). This low focal ratio meant that a Field-Flattener had to be built. Frank Elmore Ross (1874-1960) of Yerkes observatory was selected to design and built the corrector. Ross corrector lenses made for the 60-inch and 100-inch were very successful. Ross correctors became standard equipment for large reflectors.

The 200-inch (Figures 14 and 15) was the first telescope large enough to allow an observer to ride in a cage at the primary focus of the telescope. The observing cage is 72-inch in diameter and carries the secondary mirrors and the Ross correctors (Figure 16). The only other large telescope featuring an observer’s cage is the 120-inch Shane reflector (Lick observatory), completed in 1959 (Figure 18). The 120-inch primary mirror of the Shane reflector was originally a glass test blank cast in Corning Labs for the Palomar Observatory 200-inch reflector.

In 1934, Palomar Mountain in Southern California was chosen to install the 200-inch reflector. When G.E. Hale died in 1938, the 200-inch mirror was still in the figuring process. The 42 m dome designed by Russell Porter (1871-1949) was already erected at Palomar. The mirror was only finished in 1947 and "first light" photographs were taken by Edwin Hubble on January 26, 1949 (Figure 17).

The 200-inch telescope optically is similar to the 100-inch and 60-inch reflectors. At the prime focus with the two most frequently used Ross correctors focal ratios vary (*f*/3.6 and *f*/4.7). In the Cassegrain configuration it has a focal ratio of *f*/16. The 200-inch reflector was named after G.E. Hale. It was dedicated on June 3, 1948. Most of the large reflectors that followed (third quarter of the nineteenth century) incorporated many features of the 200-inch design.

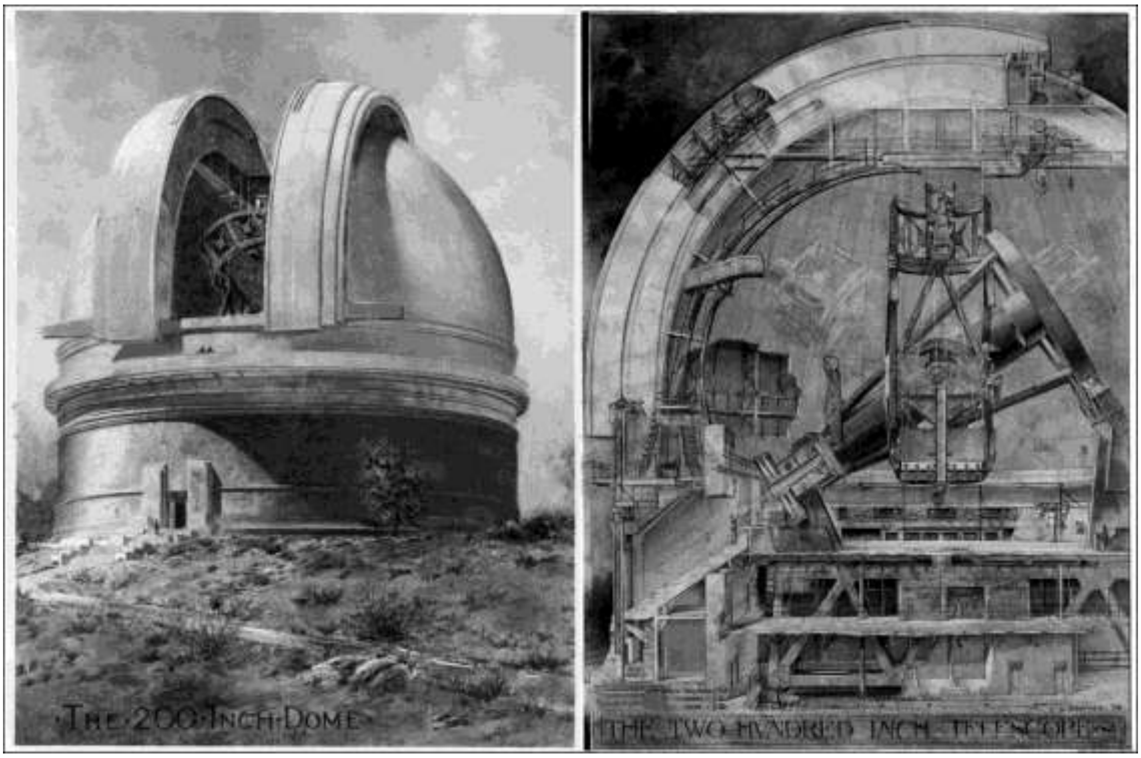

Figure 14- 200 inch (5.08 m) Hale telescope. Cutaway drawings by Russell W. Porter.

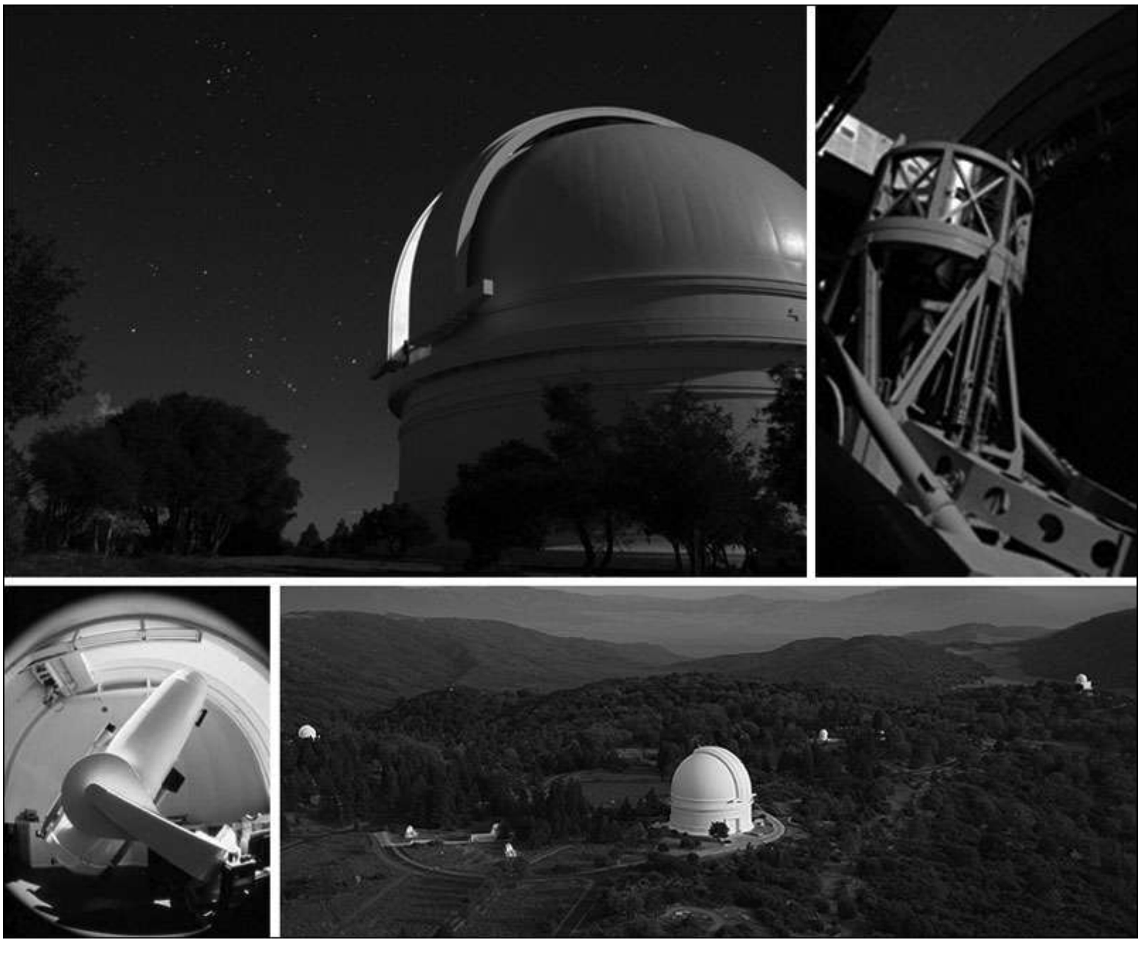

Figure 15- Palomar observatory.

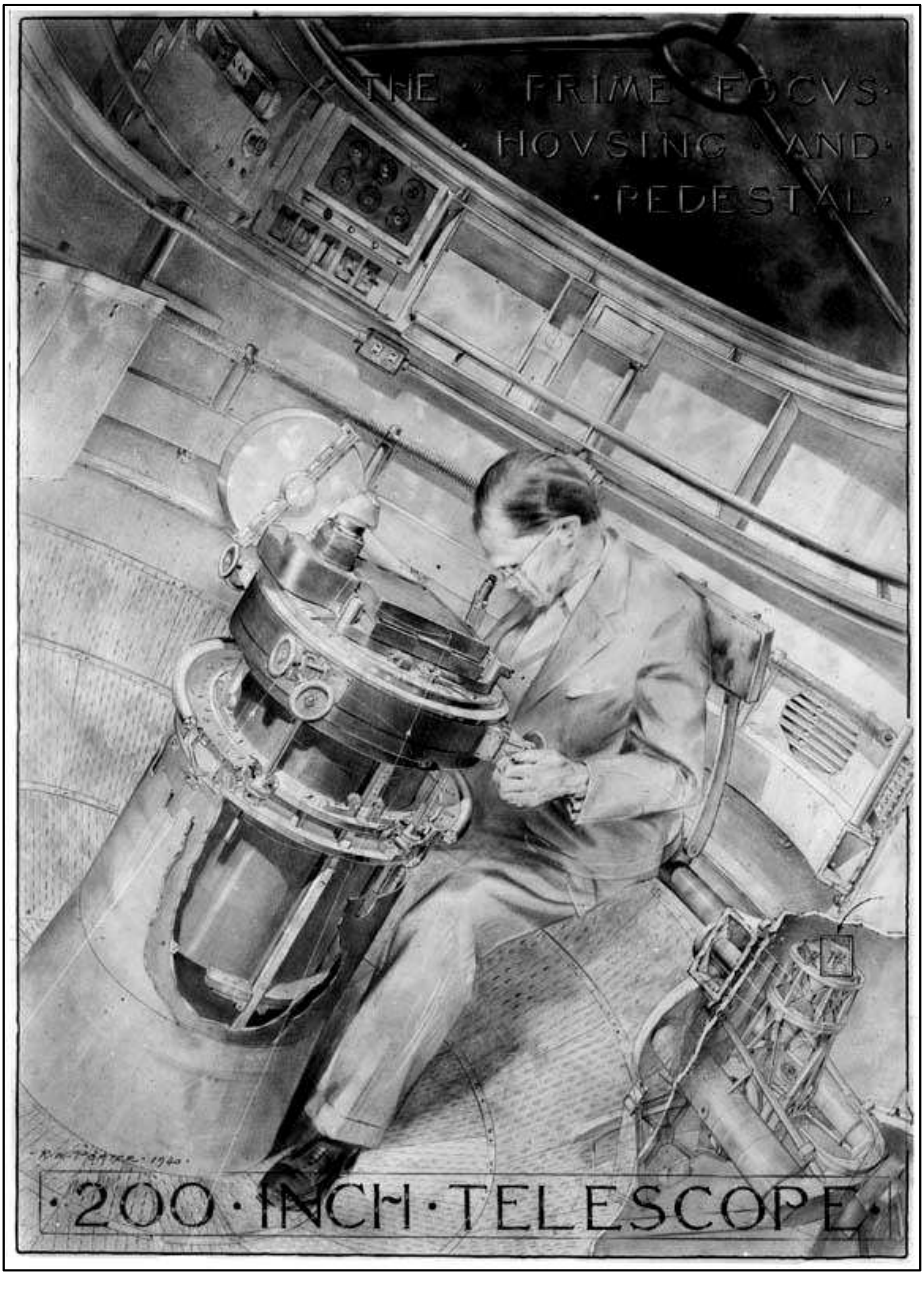

Figure 16- Observing in the prime-focus capsule. As astronomer is shown seated in the adjustable chair with the photographic plate-holder locked to the pedestal, and his eye at the guiding eyepiece. Exposures range from a few minutes to several hours. The astronomer's seat can travel completely around the capsule and tilt through a large angle to compensate for any position to which the telescope may be tipped. Dials on the wall above the astronomer's head tell him exactly where the telescope is aimed, and switches below allow him to activate essential equipment. The plate-holder can be changed for a spectrograph or a photoelectric photometer. Cutaway drawing by Russell W. Porter.

Figure 17- First-light image (200-inch reflector), taken by Edwin Hubble on January 26, 1949 (NGC 2261).

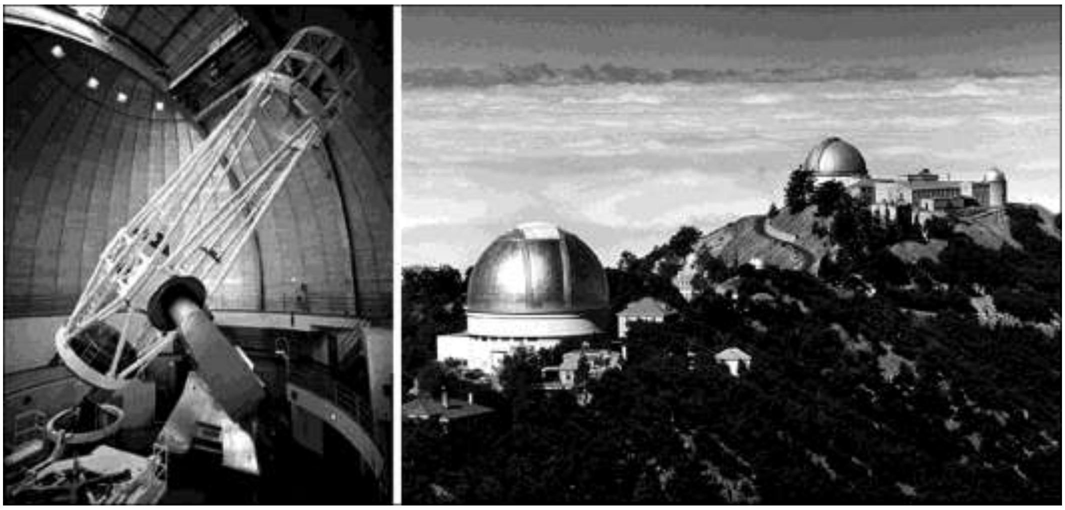

Figure 18- 120-inch Shane reflector (*ca.* 1959).

Sources:

- Danjon, A. & A. Couder (1935). *Lunettes et Télescopes.* Livrarie Scientifique et Technique, Paris.
- Glass, I.S. (1997). *Victorian Telescope Makers: The Lives & Letters of Thomas & Howard Grubb*. Institute of Physics Publishing, London
- King, H.C. (1955). *The History of the Telescope*. Dover Publications, Inc. New York.

THE SPECTROHELIOGRAPH AND THE SPECTROHELISCOPE

PEDRO RÉ
http://www.astrosurf.com/re

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.

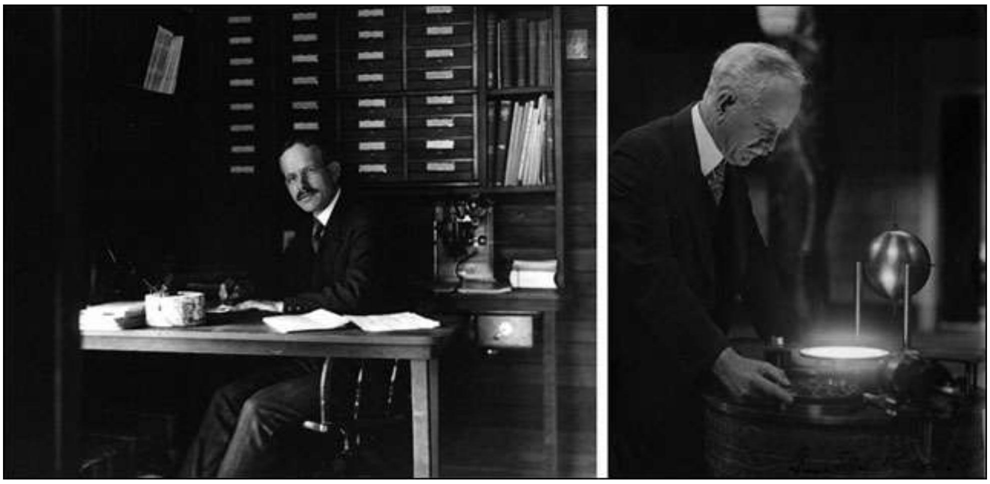

Figure 1- George Ellery Hale (1868-1938).

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[18].

"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[19]:

"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".

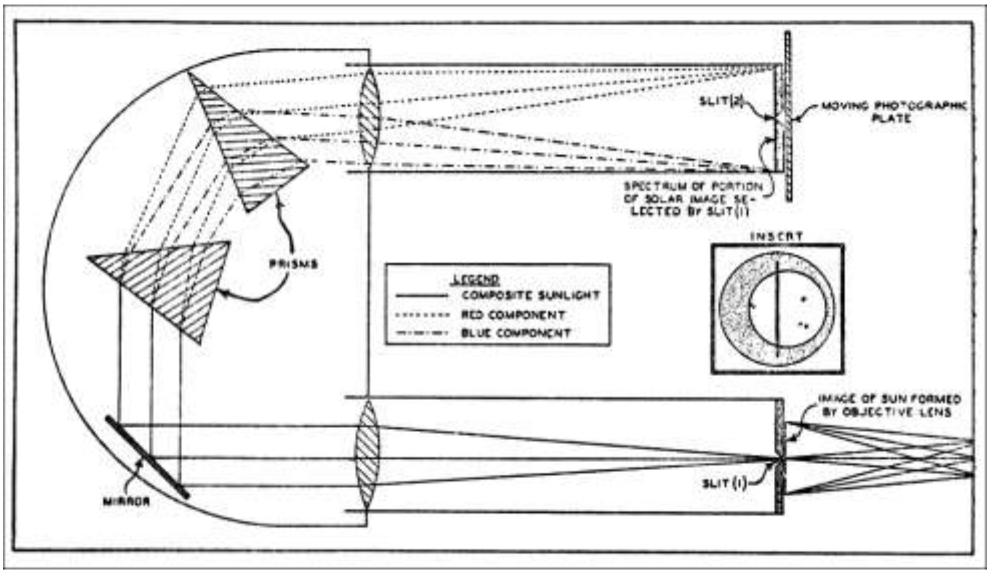

Figure 3- Principle of the spectroheliograph: Slit (1) selects a particular segment of the solar image; Slit (2) isolates a particular wevelenth in the spectrum of that segment and allows it to impress its image on the photographic plate. As the sun's image is made to move across the slit (1), the photographic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

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[18] 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.

[19] 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[20]:

"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".

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

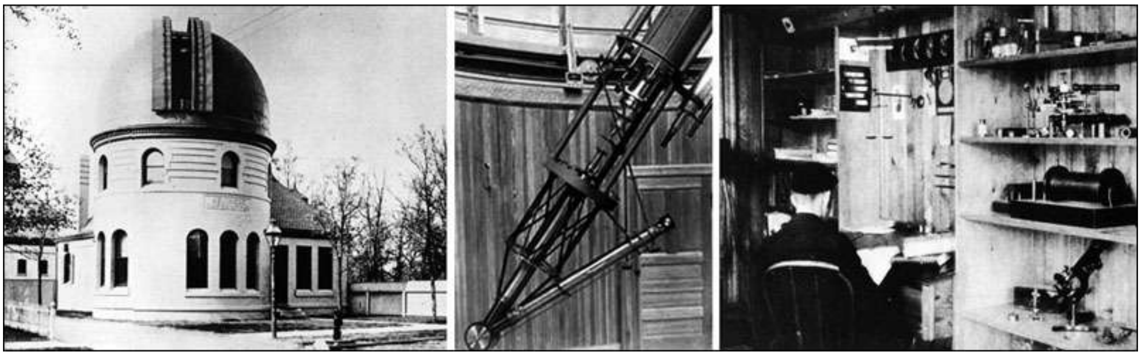

Figure 4- Kenwood observatory (left), spectroheliograph attached to the 12-in refractor (center), G.E. Hale in the Kenwood laboratory (left).

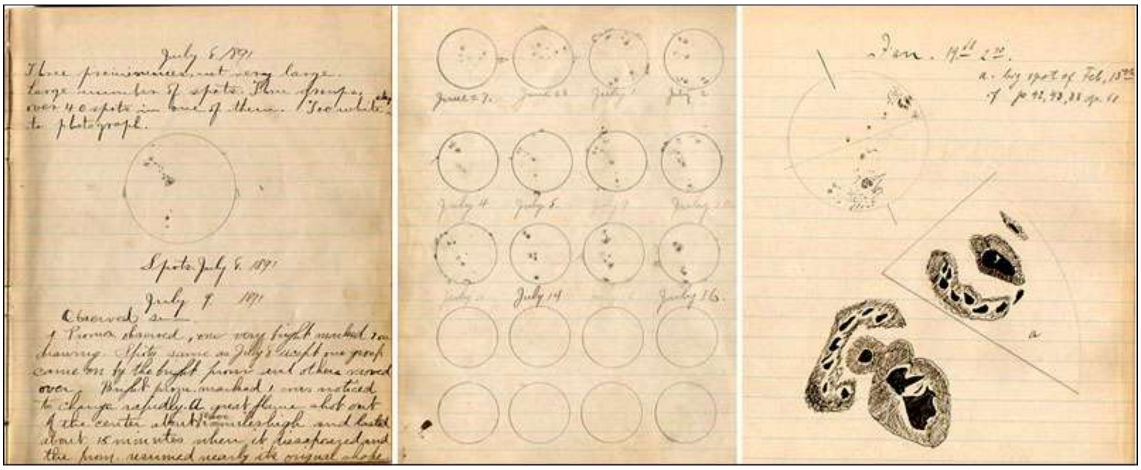

Figure 5- Sunspot drawings by G.H. Hale "Kenwood Astro-Physical Observatory" notebook, June 22, 1891 to January 2, 1893.

Hale used extensively the spectroheliograph at the Kenwood observatory[21]. 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).

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[21] 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.

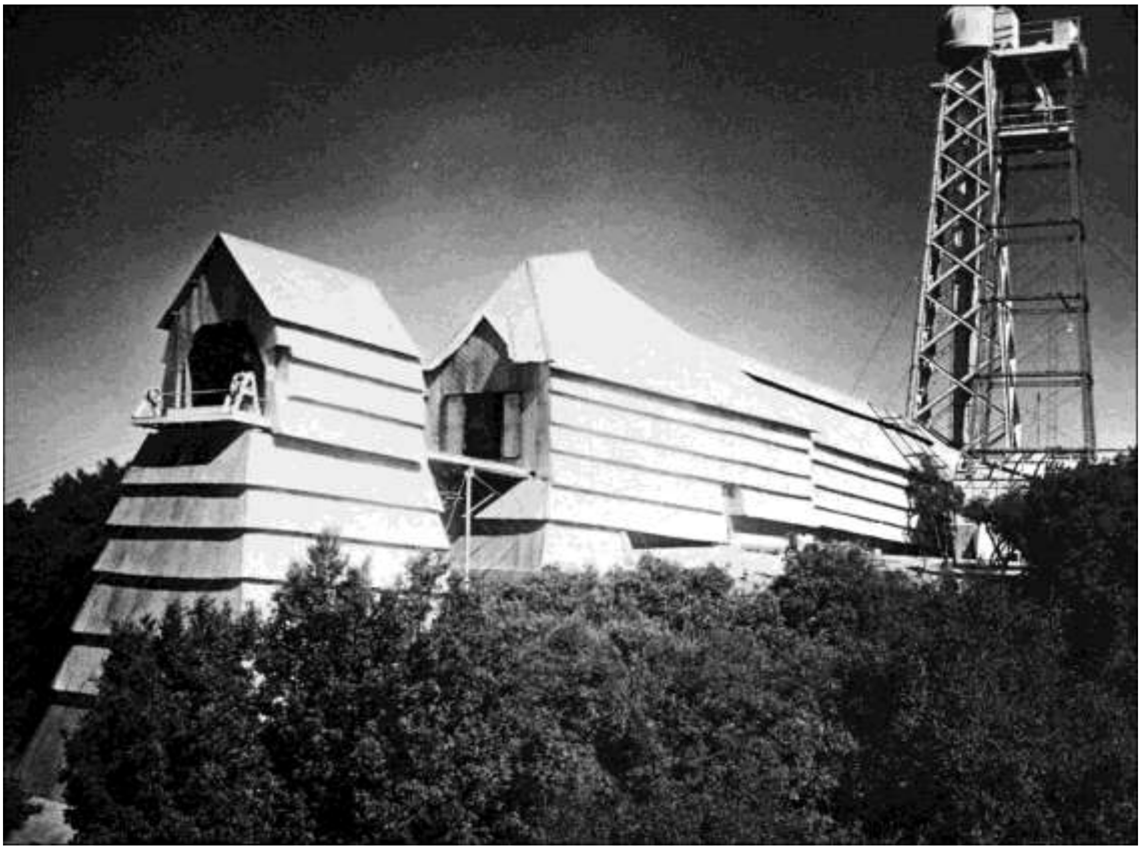

Figure 6- Snow telescope at Mount Wilson observatory (*ca.* 1905). The 60-foot tower telescope is seen in the background.

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[22], 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".

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[22] 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.

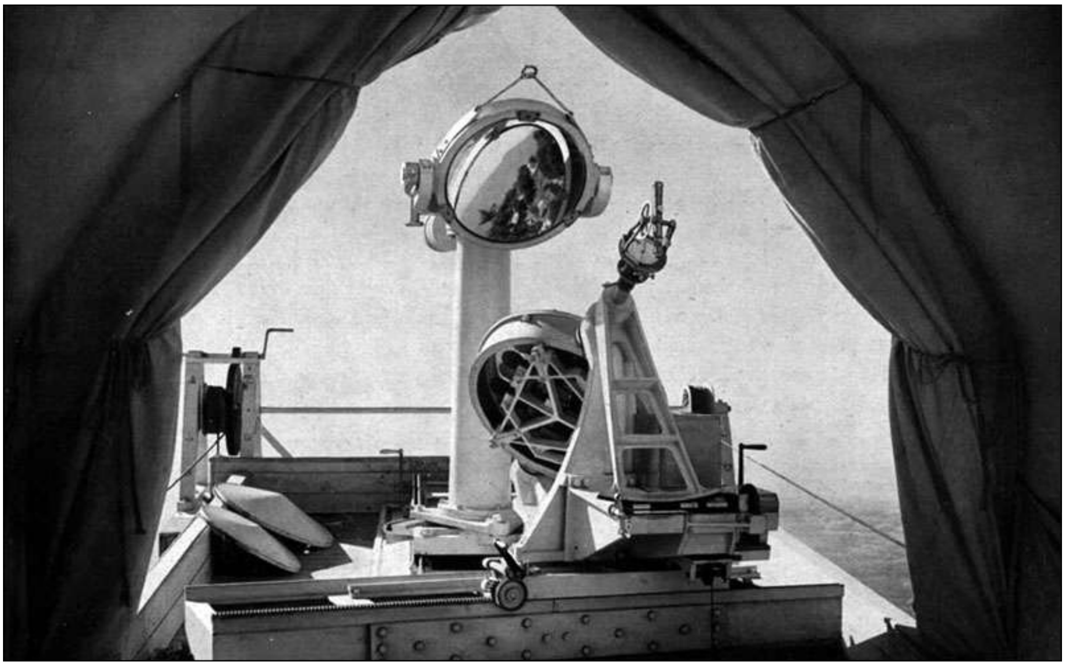

Figure 7- Coelostat of the Snow horizontal telescope.

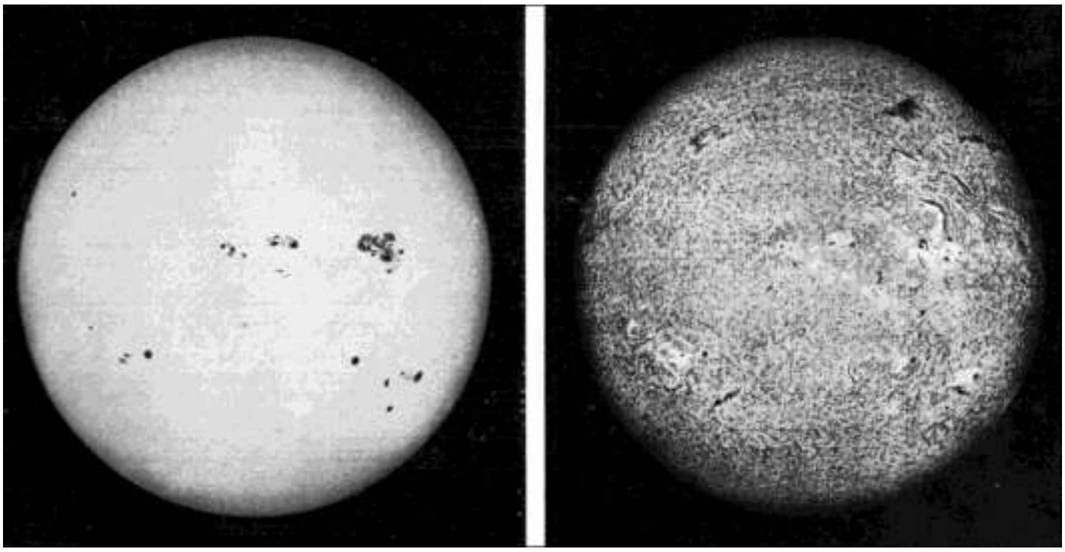

Figure 8- The sun in visible light (left) and in H-alpha (right). Mount Wilson observatory, August 12, 1917.

This instrument, described by Hale in 1929[23], 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.

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

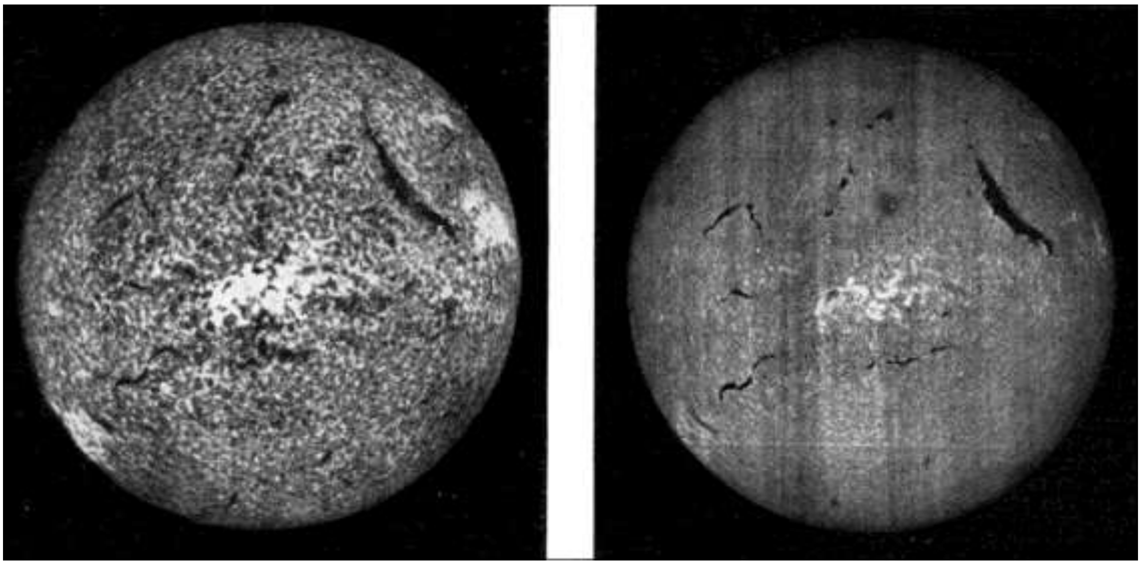

Figure 9- Spectroheliographs obtained at Meudon observatory: Calcium (left) and H-alpha (right). March, 21, 1910.

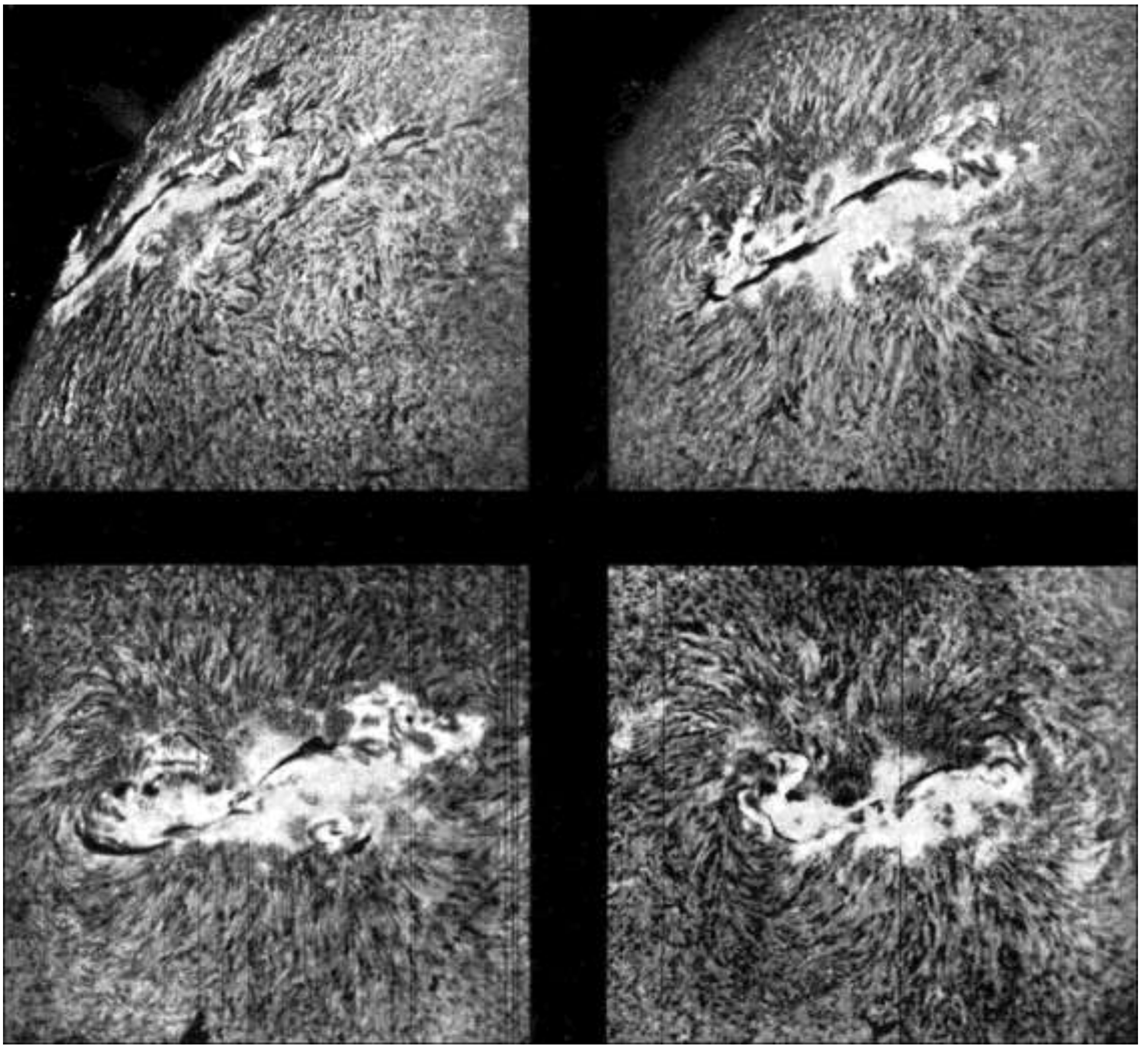

Figure 10- Spectroheliograph images (H-alpha). Mount Wilson observatory, August, 3, 5, 7 and 9, 1915.

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.

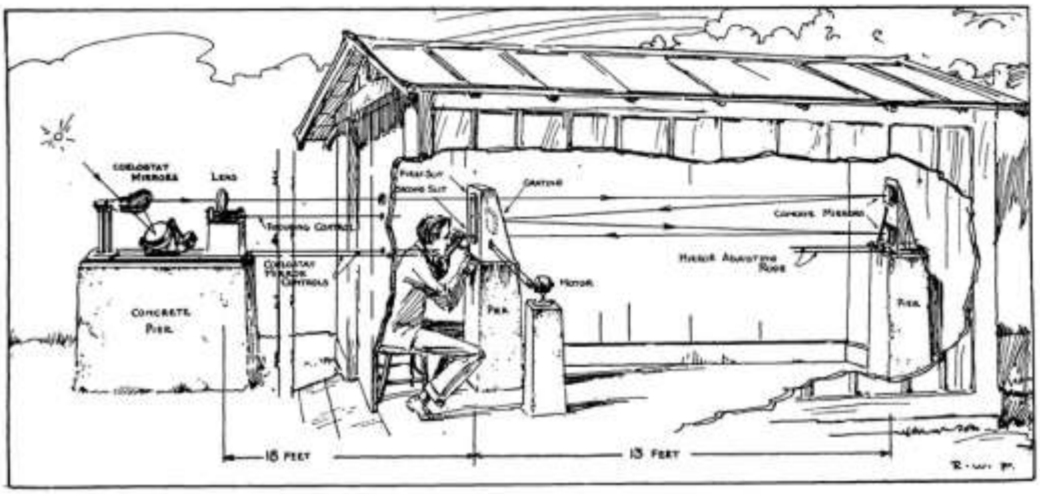

Figure 11 – Coelostat telescope and spectrohelioscope. Drawing by Russel W. Porter (1929).

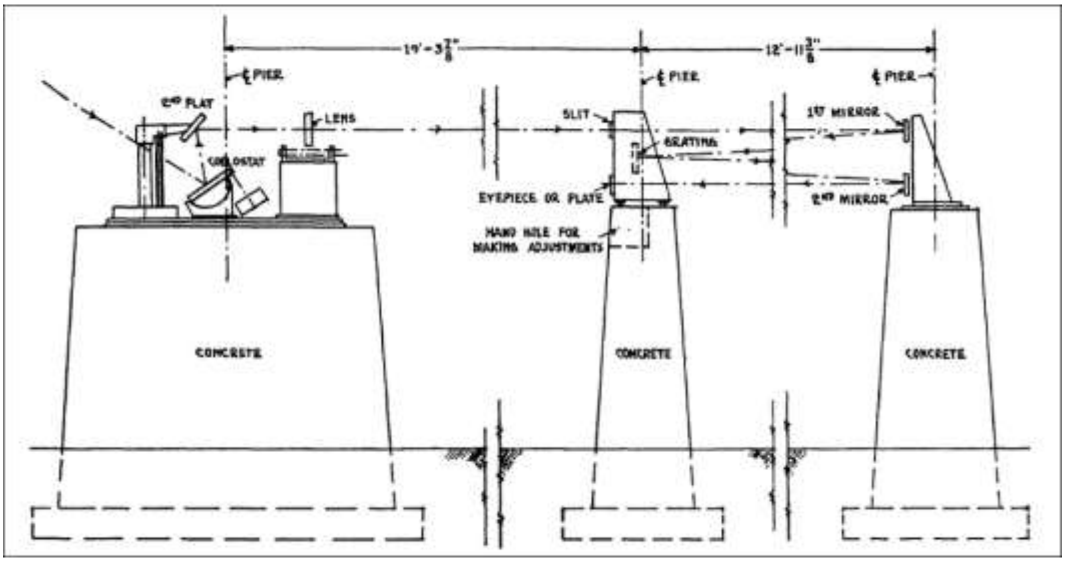

Figure 12- Concrete piers for the coelostat and spectrohelioscope.

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).

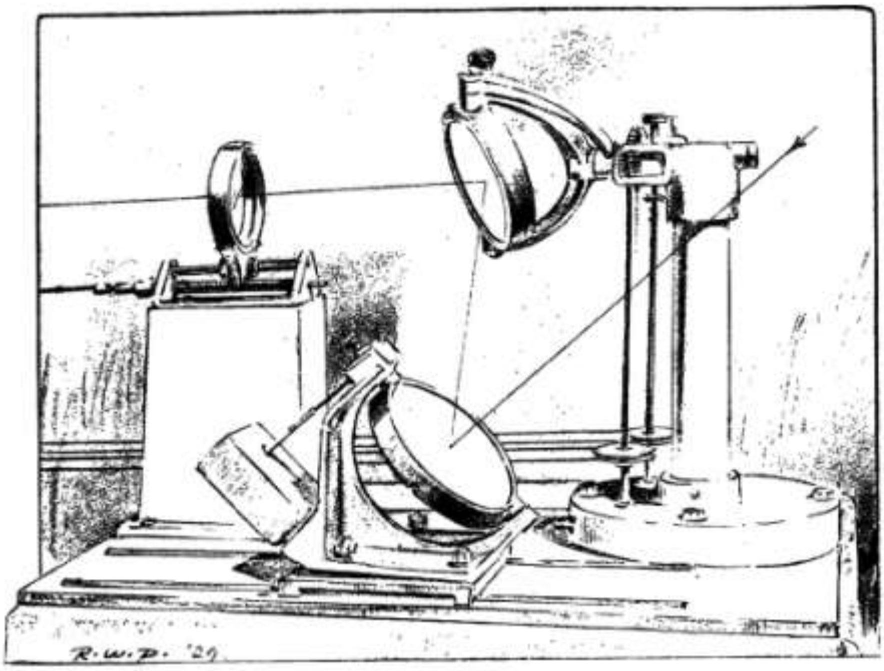

Figure 13- Coelostat, second mirror and telescope lens. Drawing by Russel W. Porter (1929).

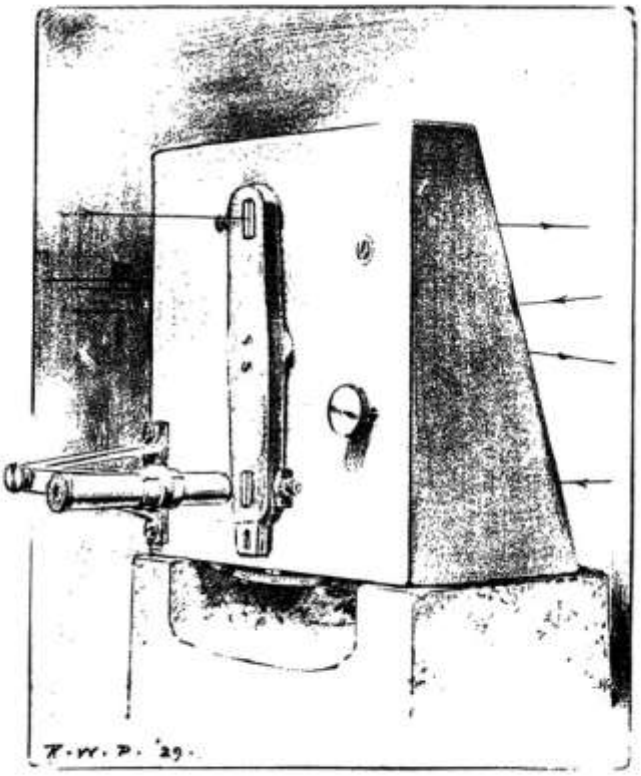

Figure 14- Oscillating slits and eyepiece of the spectrohelioscope. Drawing by Russel W. Porter (1929).

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.

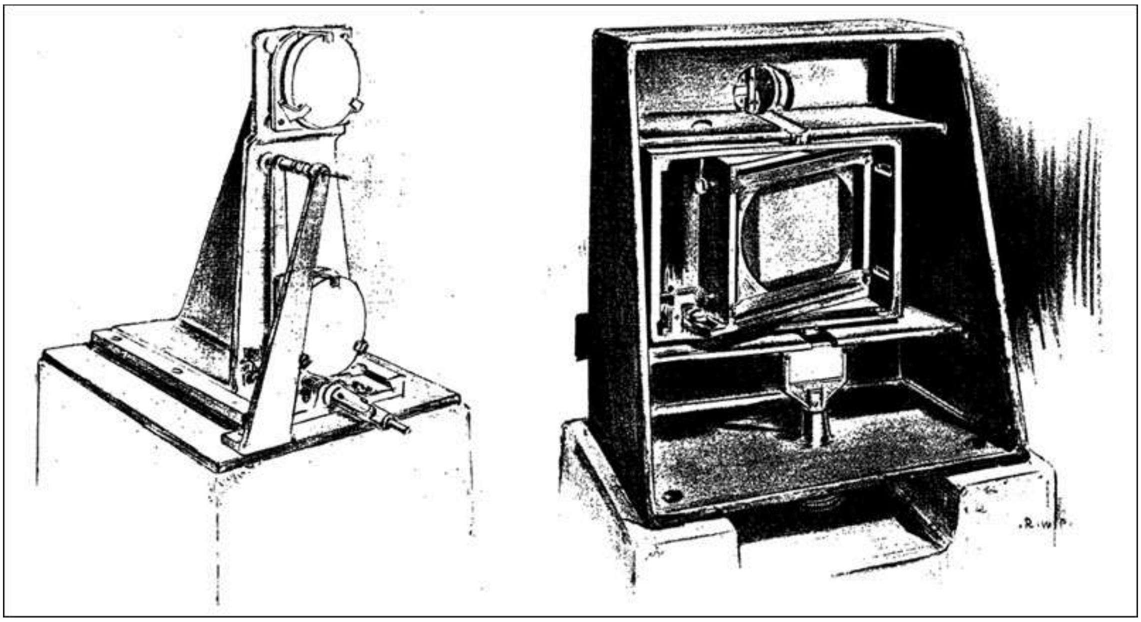

Figure 15- Concave mirrors of the spectrohelioscope (left) and grating support and line-shifter.
Drawing by Russel W. Porter (1929).

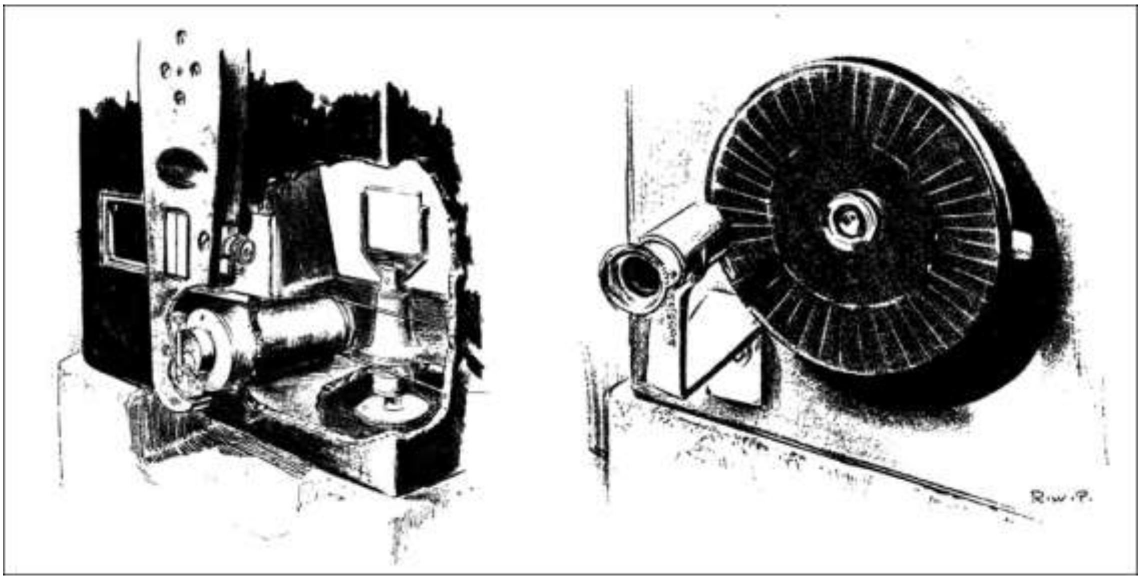

Figure 16- Second slit, driving mechanism, line-shifter (left) and spinning disk with radial slits (right).
Drawing by Russel W. Porter (1929).

Sources:

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

RUSSELL PORTER (1871-1949) AND THE GLASS GIANT OF PALOMAR

PEDRO RÉ
http://www.astrosurf.com/re

Russell W. Porter (1871-1949) was one of the first leaders of the amateur telescope making movement and as an illustrator of the Hale 200-inch telescope project. After designing amateur telescopes, Porter was hired to help with the design of a 200-inch Hale telescope for the Mount Palomar Observatory. His cutaway drawings for this project are nothing less than exceptional. He also made conceptual designs for the Griffith Observatory and served as a consultant to the architects (Figure 1).

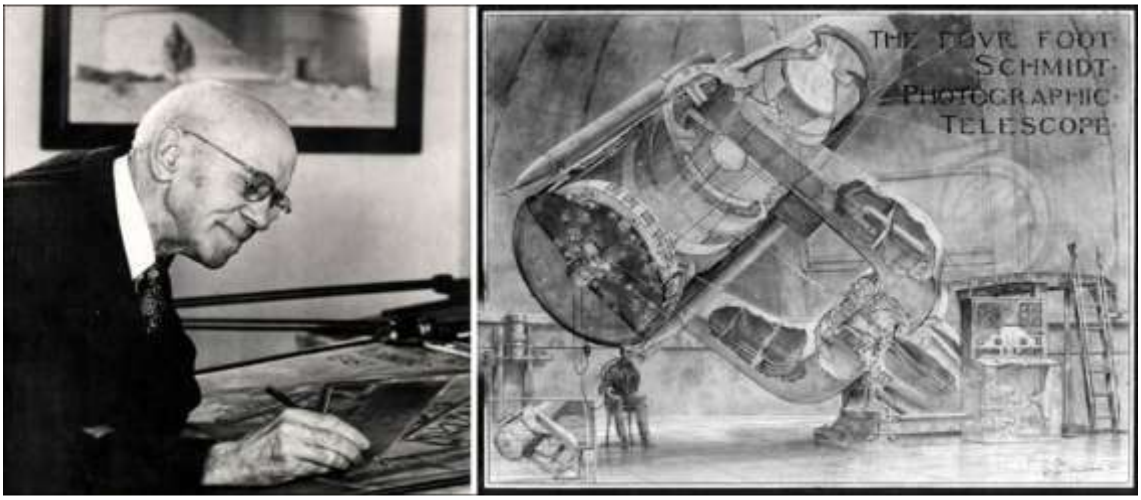

Figure 1- Russell Porter (left) and one of his cutaway drawings (48-inch Schmidt telescope).

Russell Porter was born in 1871 as the youngest of five children in the village of Springfield, Vermont. Russell showed an early talent for drawing as well as a restless nature. He studied engineering for a year at Norwich University and latter at the University of Vermont. In 1891, he moved to Boston to study architecture and art at the Massachusetts Institute of Technology.

Porter was a man of many vocations. He was an architect, arctic adventurer, builder, inventor, mapmaker, photographer, scientist, surveyor, telescope designer, and writer.

Porter caught the Arctic fever when, in 1892, he attended a lecture by Robert Peary. The next year, the scientist Frederick Cook came to Boston to advertise a summer cruise up the coast of Greenland. Porter negotiated passage on Cook's voyage by offering to serve as surveyor and artist. This would be the first of Porter's eight northern adventures over the next 15 years. The first ended above the Arctic Circle, when the small steamship was damaged on a reef and then collided with an iceberg. The crew was rescued by Eskimos and returned to Boston by fishing boat (Figure 2).

In 1928 Russell Porter was employed by Caltech (California Institute of Technology) in Pasadena after being recruited by George E. Hale to work on the design of the 200-inch

Palomar telescope. He designed three campus buildings (the astrophysics lab, machine shop, and optical shop) that were used for work on the 200-inch telescope.

While working on the design of the Palomar telescope, Porter perfected his "cutaway" drawing technique. During the Second World War he assisted in the war effort by designing and drawing military hardware. He was dubbed the "Cutaway Man" by Pentagon officials for his ability to draw the internal workings of complex machinery by cutting through the outer "skin".

Figure 2- Arctic Sketches of Russell W. Porter.

Throughout his later years he was closely involved with the Stellafane Amateur Telescope-Makers movement in his hometown of Springfield, Vermont. The Stellafane Observatory stands at an elevation of about 1270 feet on an exposed shoulder of a hill about one-quarter mile southeast of the Breezy Hill Road in Springfield, Vermont. The observatory complex consists of two buildings designed by Russell W. Porter: the clubhouse of the Springfield Telescope Makers, Inc., and the observatory containing a 16-inch, reflecting, turret telescope also designed by Porter (Figure 3).

In 1949, while working on his last telescope project, Porter dies of a heart attack at the age of 77.

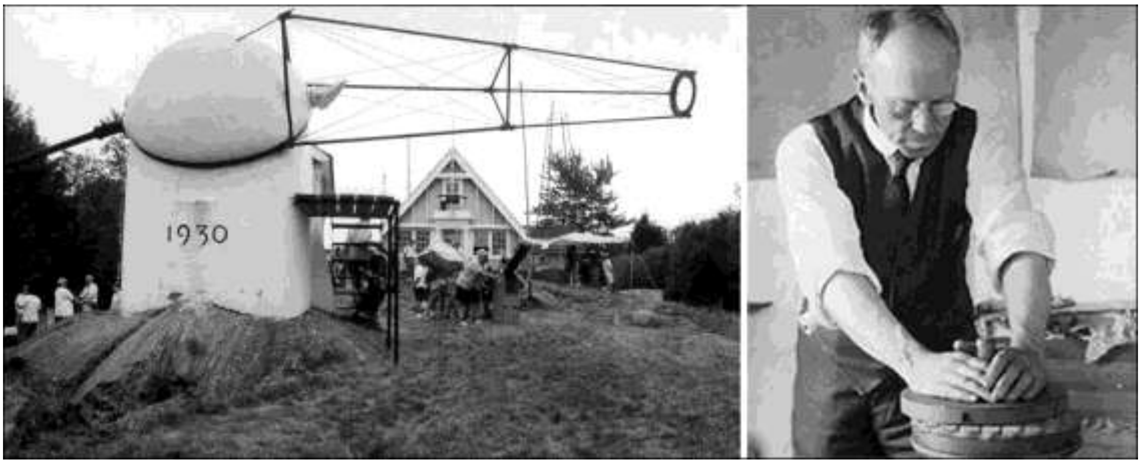

Figure 3- Stellafane turret telescope built by Russell W. Porter.

Russell W. Porter's colleague at Caltech, James S. Fassero, wrote the following introduction in his 1947 book of Porter's cutaway drawings which is entitled "Photographic Giants of Palomar":

"*Dr. Russell W. Porter made this unique collection of drawings over a period of 12 years using his ability to faithfully portray mechanical objects in perspective. With pencil and paper he was able to "cut away" sections of the telescope to show the inside details; something which cannot be done with a camera. His artistic and mechanical abilities have combined to produce a set of drawings which have proved of indispensable value not only to the laymen but to all those who already are familiar with the instrument.*"

Maxfield Parrish, another fellow artist, wrote about Porter drawings:

“ If these drawings had been made from the telescope and its machinery after it had been erected they would have been of exceptional excellence, giving an uncanny sense or reality, with shadows accurately cast and well nigh perfect perspective; but to think that any artist had his pictorial imagination in such working order as to construct these pictures with no other material data than blue prints of plans and elevation of the various intricate forms – is simply beyond believe. These drawings should be in a government museum as standards, in a glass case, along with the platinum pound weight, yard stick, etc. to show the world and that comes after just what a mechanical drawing should be. Not only that, but the rendering is a work of art, exact and lifelike, and done with a delightful freedom of technique. I doubt if there are drawings anywhere which can in any way compare with these for perfection in showing what a stupendous piece of machinery is going to look like when finished… Their creation should be world news.

This 200-inch (5.08 m) Palomar telescope is named after astronomer George Ellery Hale. It was built by Caltech with a 6 million dollar grant from the Rockefeller Institute, using a Pyrex blank manufactured by Corning Glass Works. The telescope (the largest in the world at that time) saw "first light" in 1948 (Figure 4, Figure 5).

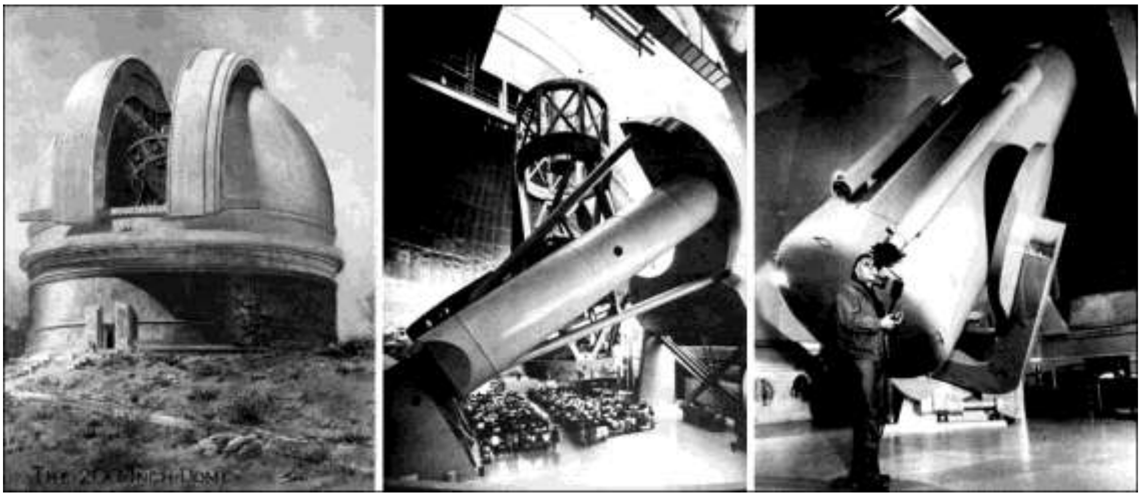

Figure 4- Palomar observatory: dome (R. Porter drawing), 200-inch dedication (1948), 48-inch Schmidt telescope.

Figure 5- Palomar observatory.

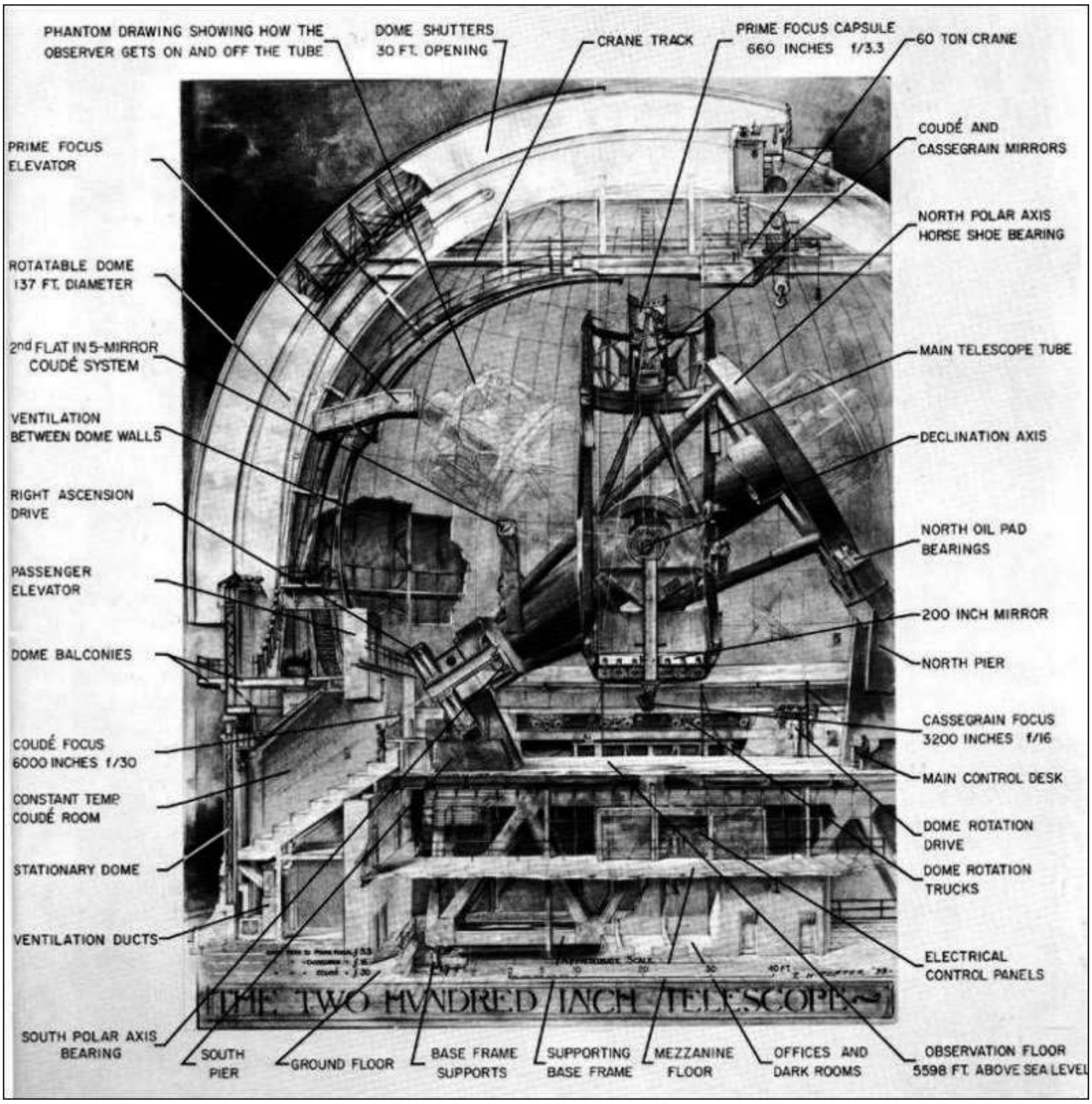

Figure 6- Meridian cross-sectional drawing of the 200-inch Hale Telescope and dome with marginal identification of major features. The vertical structure near the center of the drawing is the main telescope tube that carries the 200-inch mirror. Astronomers can work at the primary focal cage suspended in the center of the tube at the top end, actually riding with the telescope. The main tube weights 150 tons, is supported on ball-bearings anchored in the large yoke which consists of two 10-foot diameter inclined tubular girders tied together at the south end (left) by a cross member supported on a pivot bearing and at the north end by a giant horseshoe bearing. The whole telescope weights 530 tons.

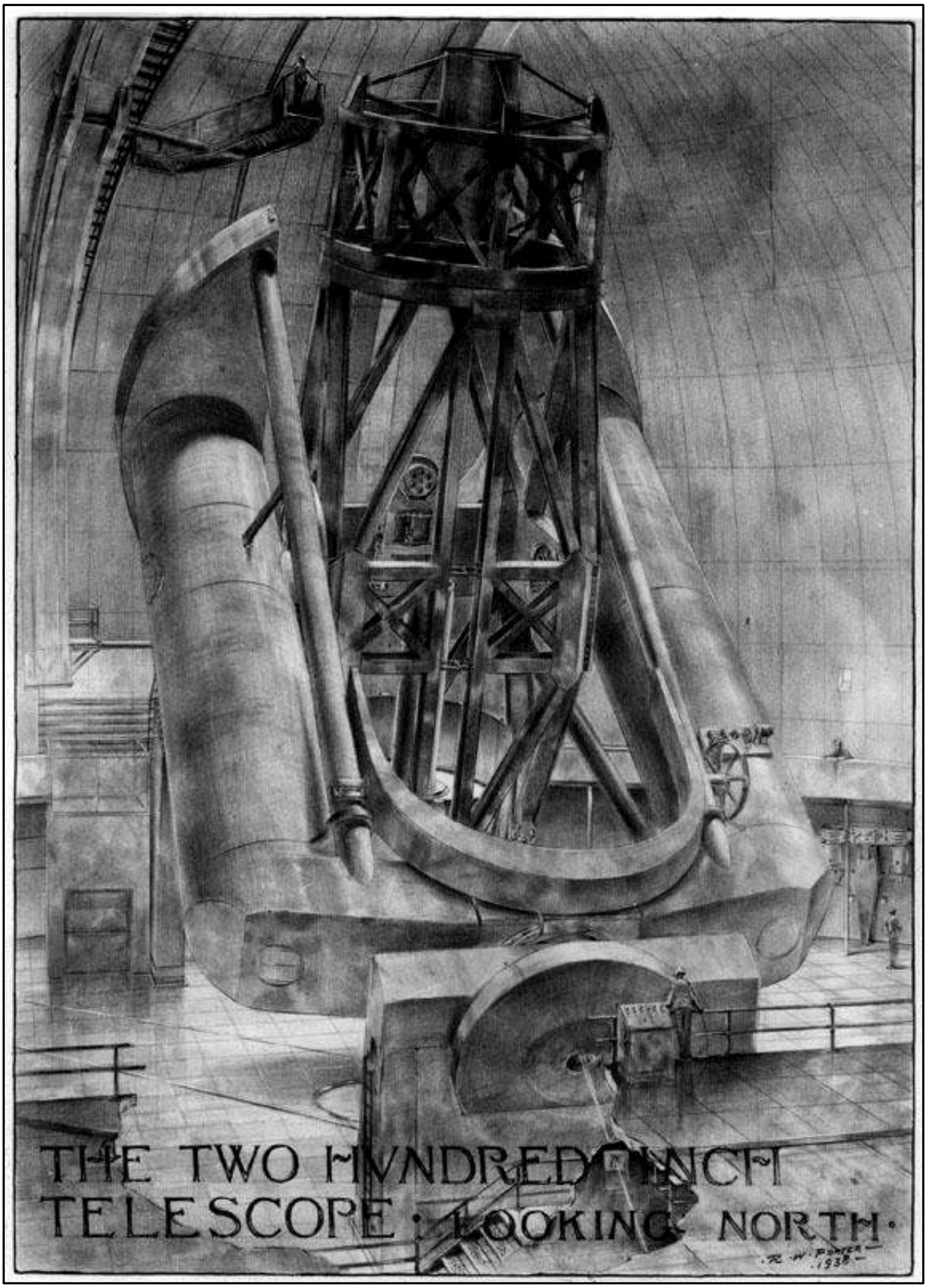

Figure 7- 200-inch telescope looking north. Below the telescope at the foot of the North pier is the main control desk where an assistant controls the mechanical operation of the instrument. At the lower right is a console containing controls for adjusting the balance of the telescope and for inserting the secondary mirrors that change the focal length of the instrument. The cube in the foreground is the top of the passenger elevator shaft that carries astronomers to the observing floor.

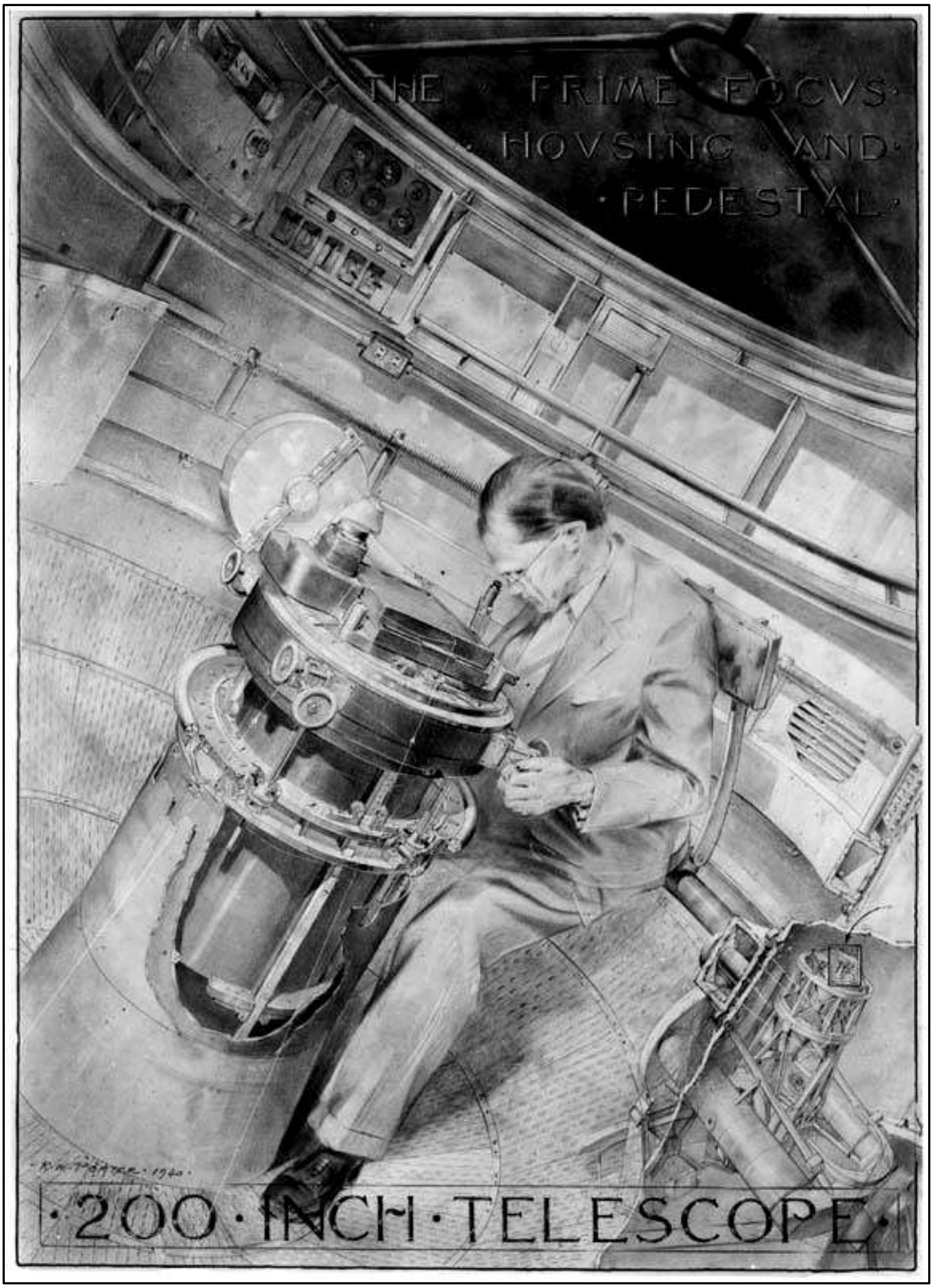

Figure 8- Observing in the prime-focus capsule. As astronomer is shown seated in the adjustable chair with the photographic plate-holder locked to the pedestal, and his eye at the guiding eyepiece. Exposures range from a few minutes to several hours. The astronomer's seat can travel completely around the capsule and tilt through a large angle to compensate for any position to which the telescope may be tipped. Dials on the wall above the astronomer's head tell him exactly where the telescope is aimed, and switches below allow him to activate essential equipment. The plate-holder can be changed for a spectrograph or a photoelectric photometer.

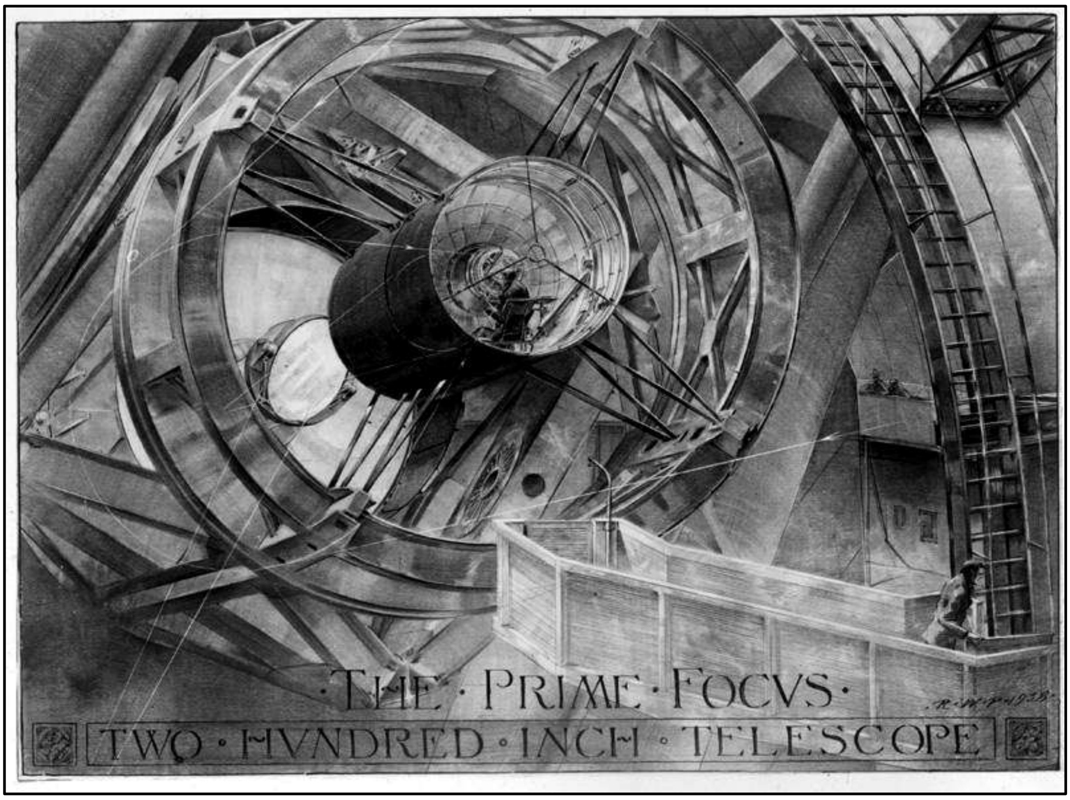

Figure 9- The prime-focus observing capsule. The astronomer rides in the capsule at the top of the telescope when taking photographs or using other equipment at the prime focus of the telescope.

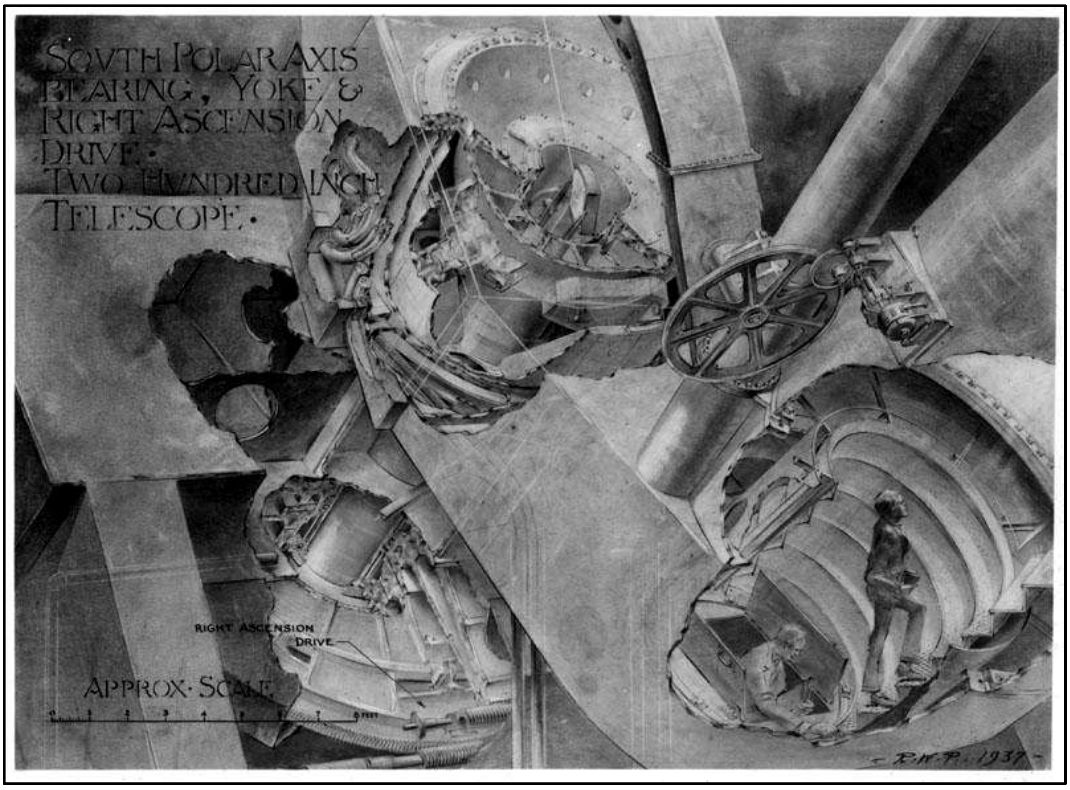

Figure 10- South polar-axis bearing, yoke, and right ascension drive gears. General view of the south end.

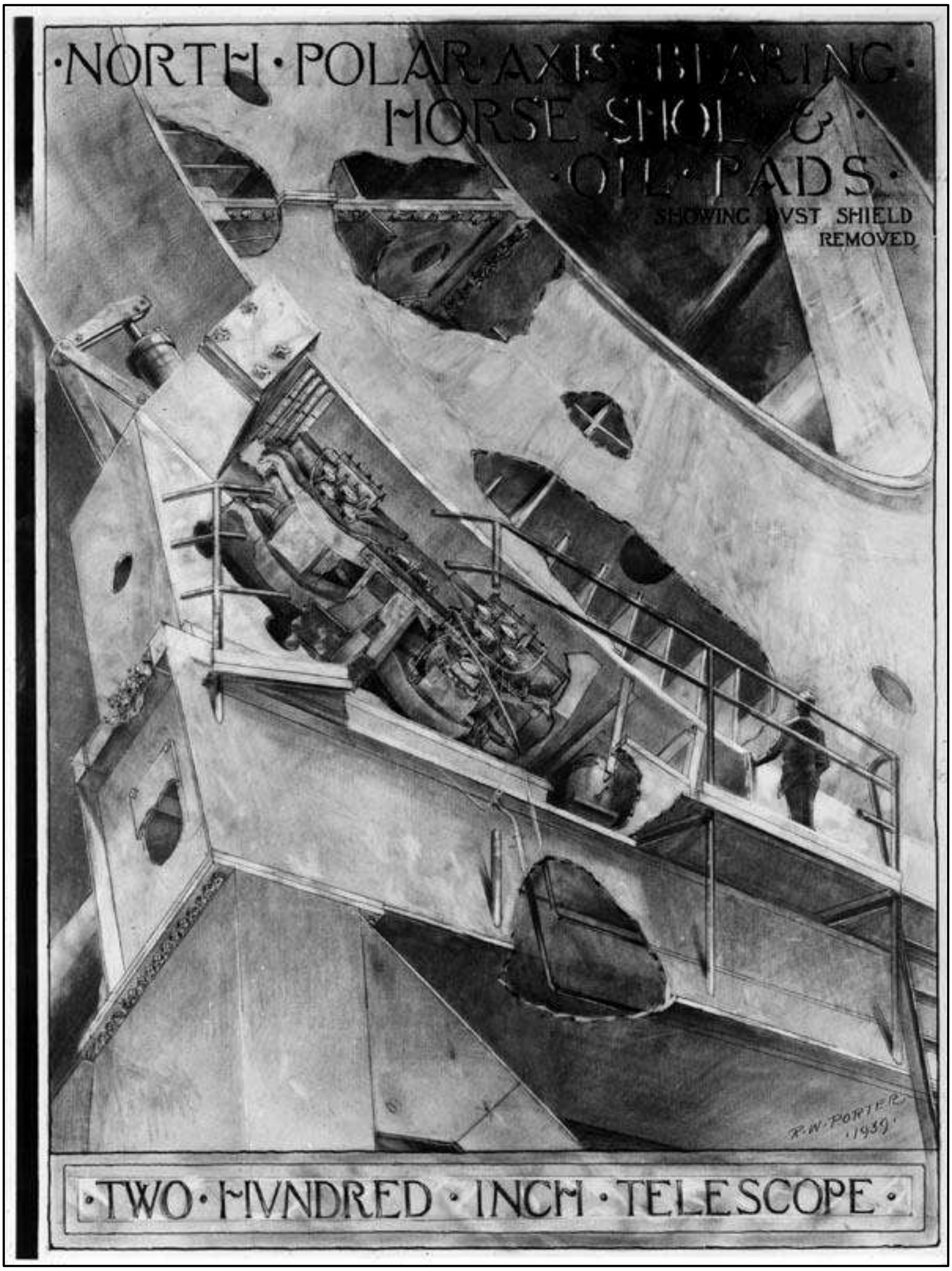

Figure 11- North polar-axis bearing. This horseshoe-shaped bearing at the north end of the yoke glides on a film of oil giving almost complete freedom from friction despite of tremendous load.

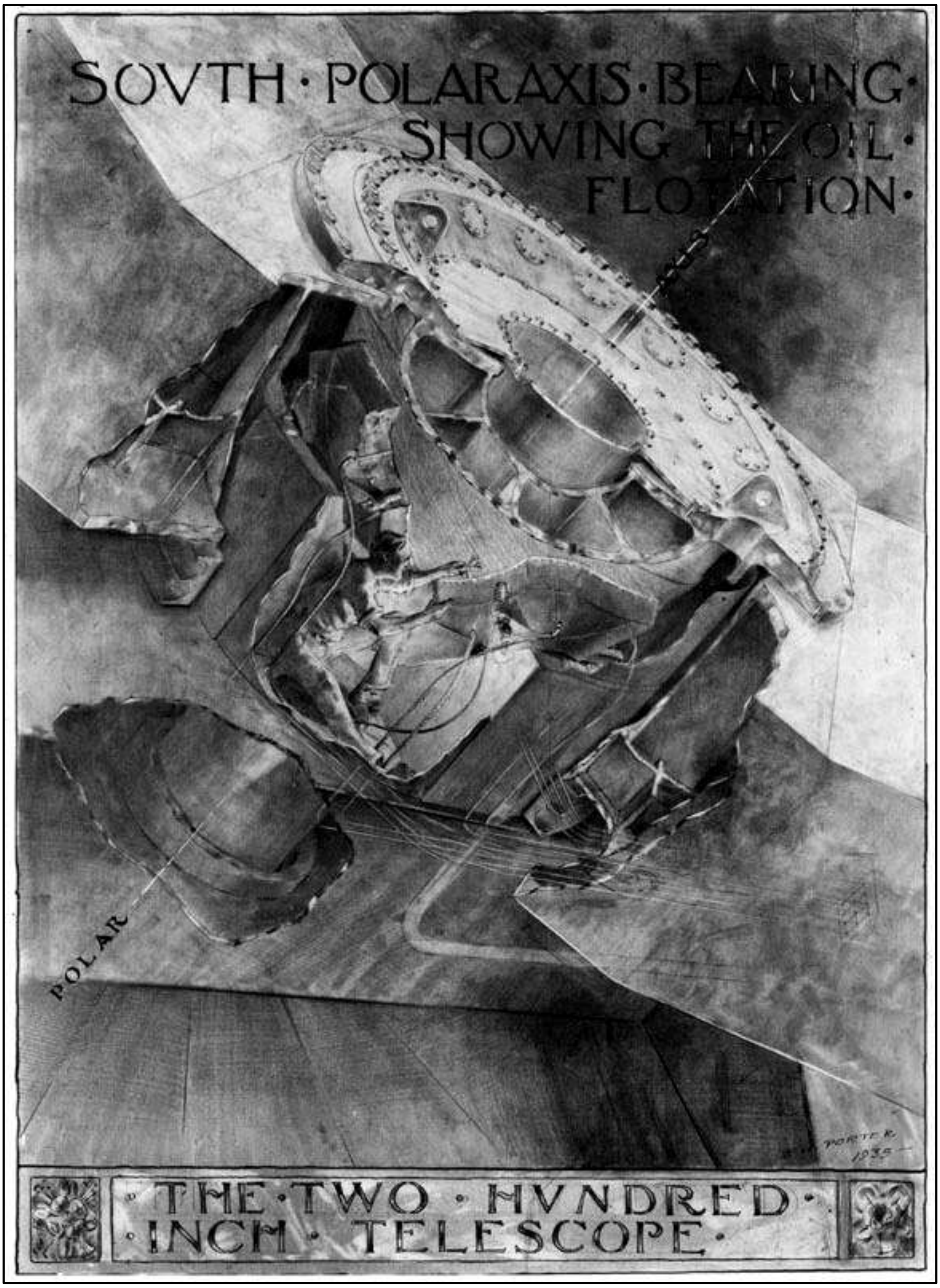

Figure 12- South polar-axis bearing. A steel hemisphere, three metal supporting pads, and a film of oil comprise the essential parts of the bearing at the south end of the telescope yolk.

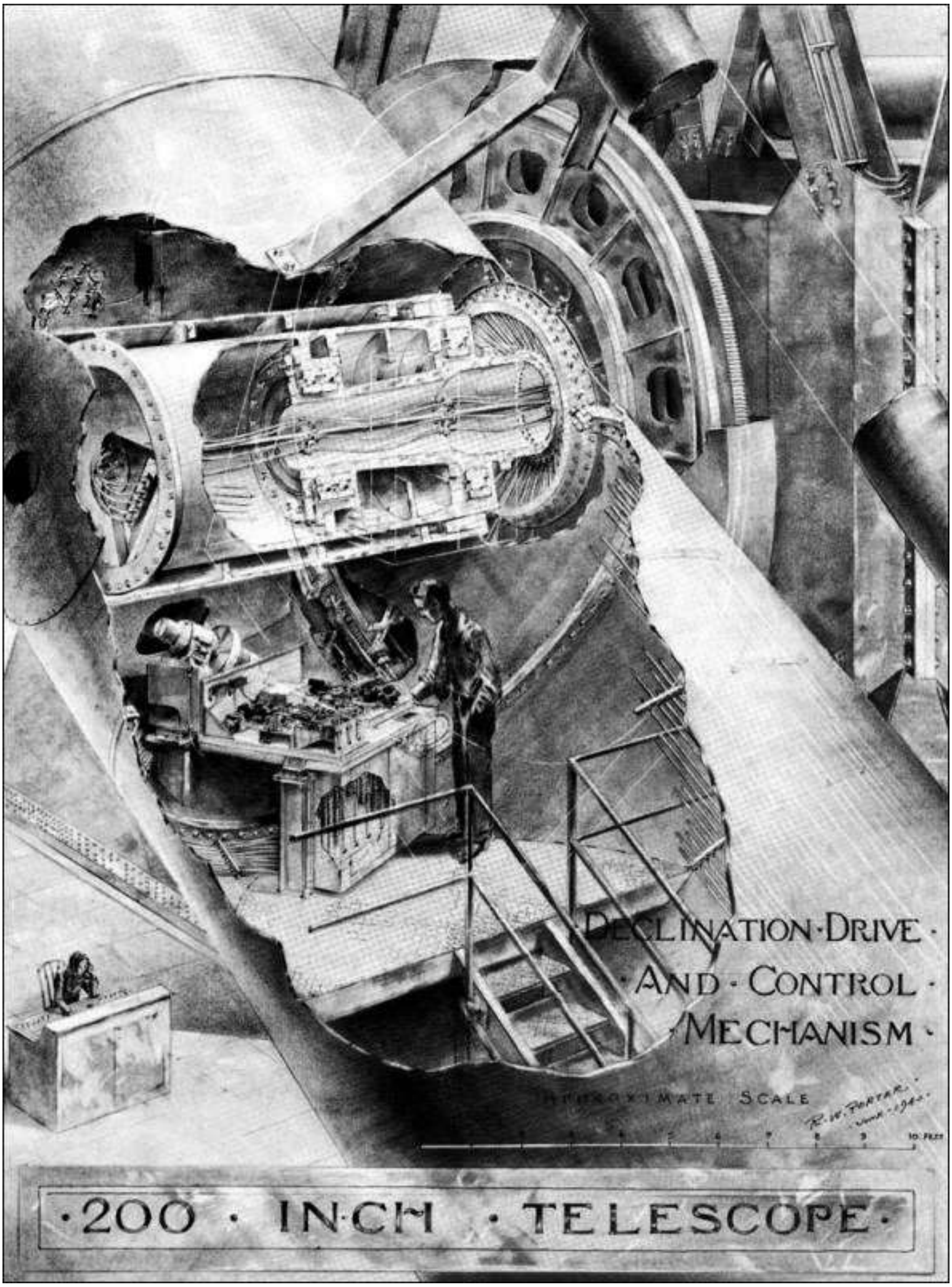

Figure 13- West declination Trunnion. One of the two bearings that support the telescope tube.

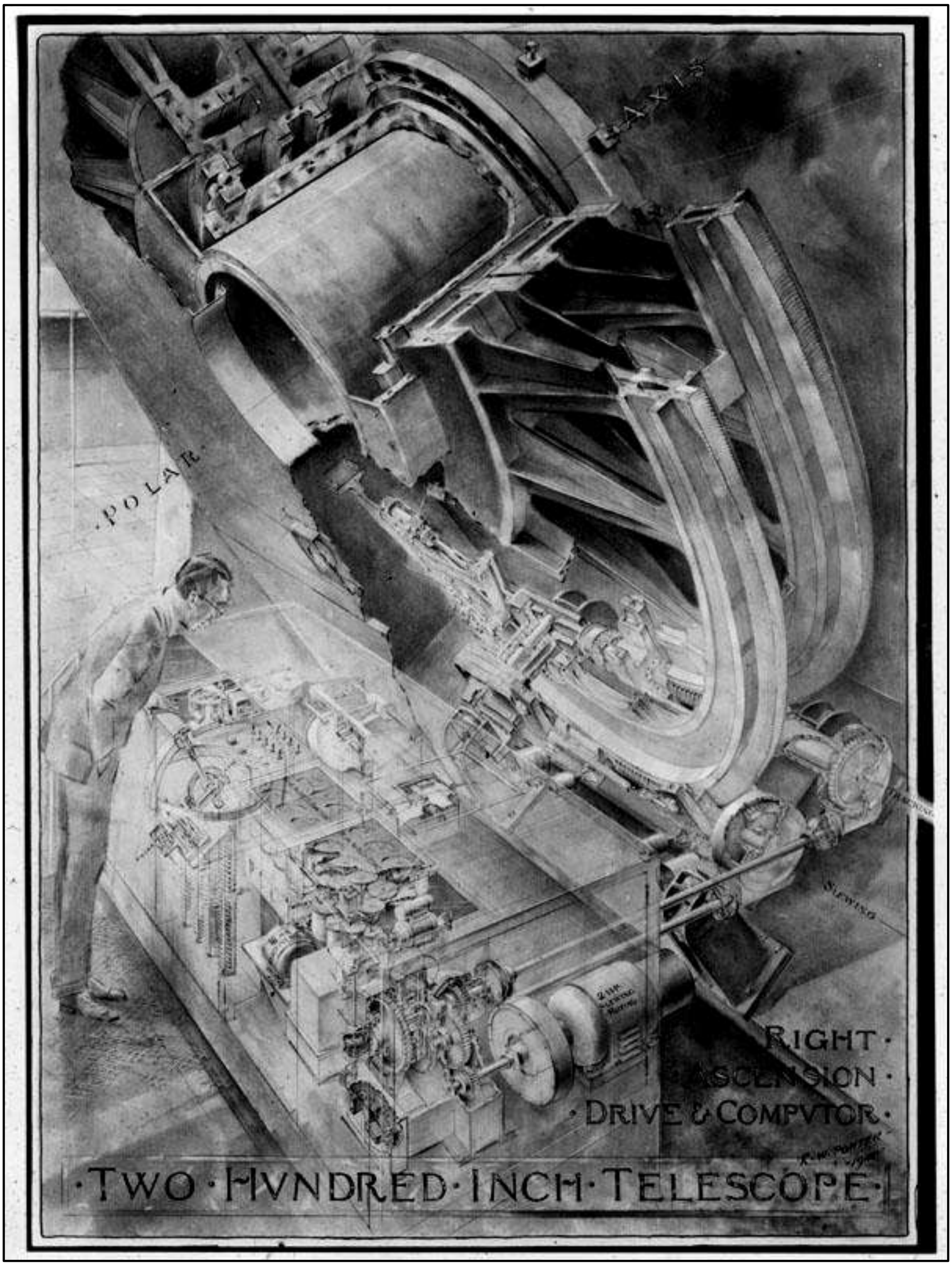

Figure 14- Right ascension drive and computer. Two large gears are used to move the telescope; one slews it east or west to the required position, the other makes it follow the stars. A mechanical computer system simplifies the task of aiming the telescope.

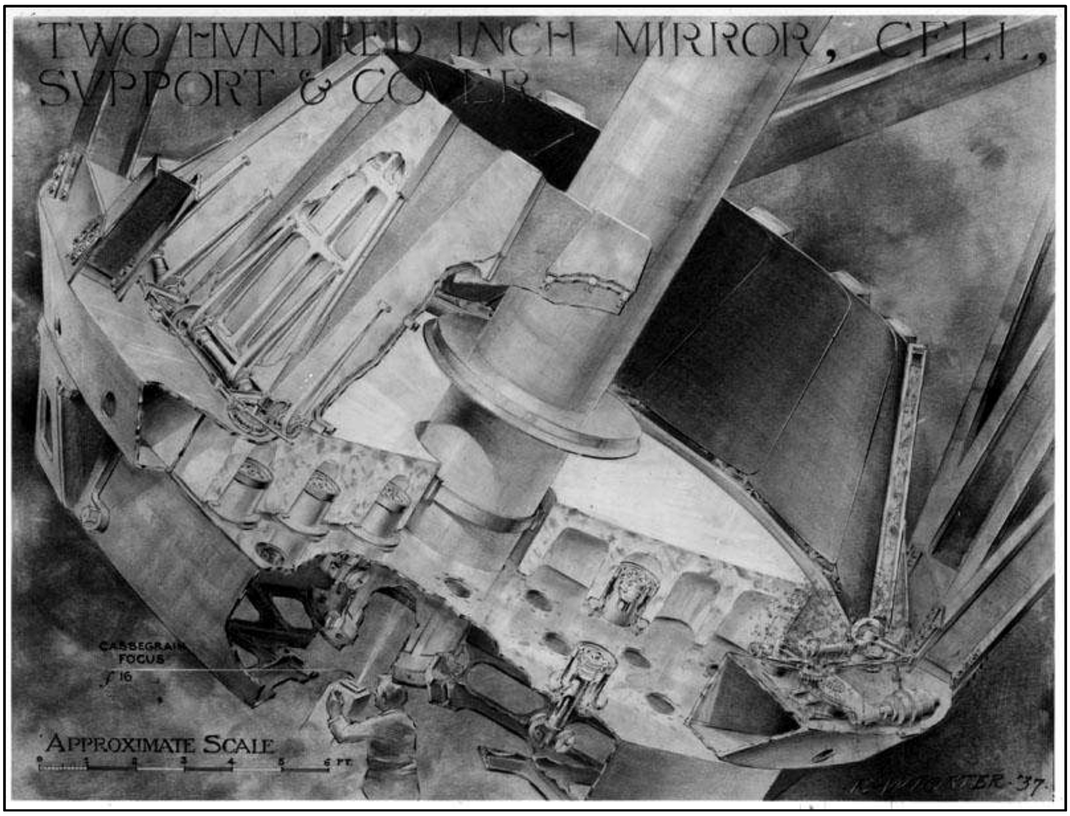

Figure 15- The 200-inch mirror. Cutaway view of the bottom of the main tube, showing the covers, counterbalance supports and the steel cell.

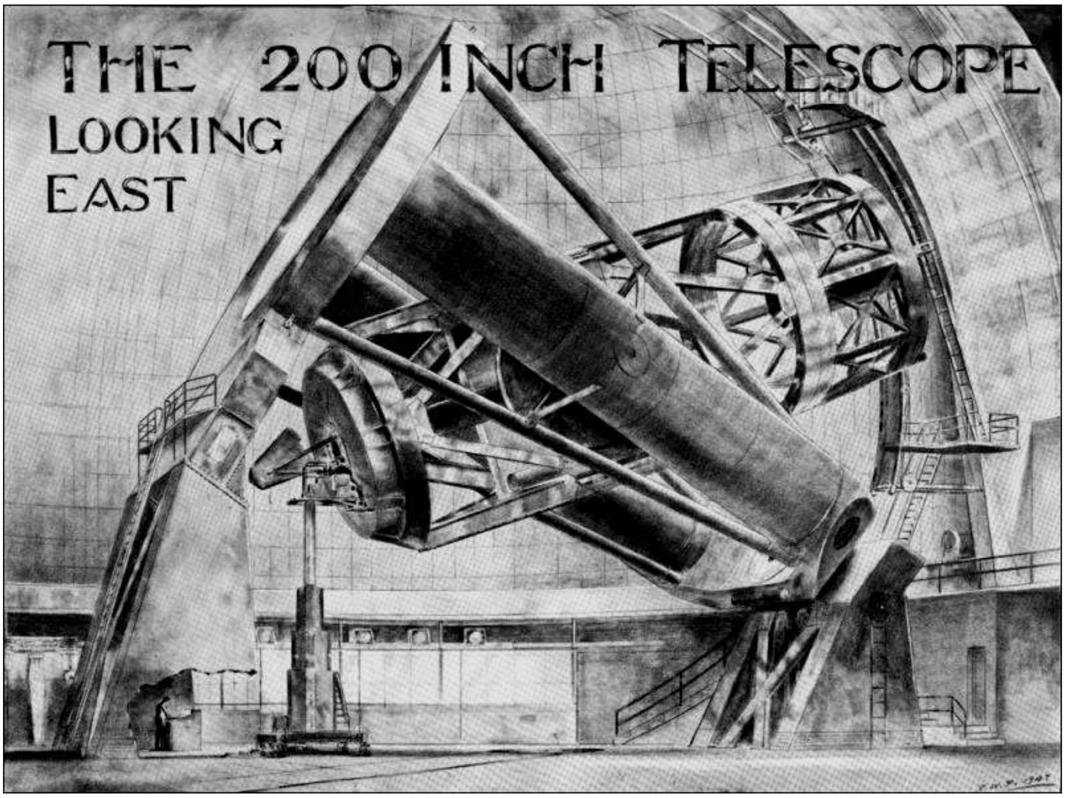

Figure 16- 200-icn telescope being used at the Cassegrain focus by an astronomer on an elevating chair.

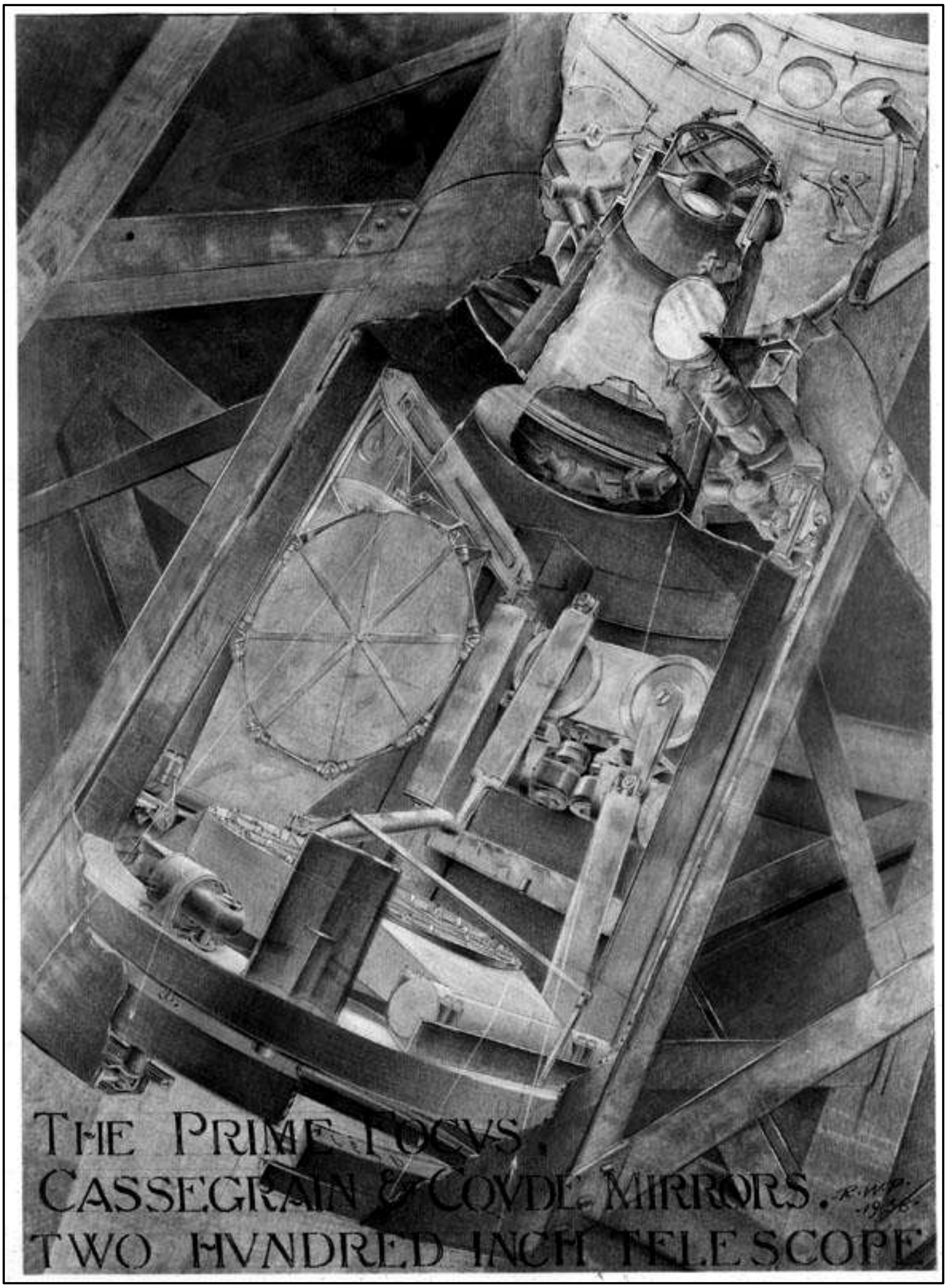

Figure 17- Cassegrain and Coudé secondary mirrors. Cutaway drawing showing the lower section of the prime-focus capsule that contains the interchangeable convex secondary mirrors used to increase the focal length of the telescope.

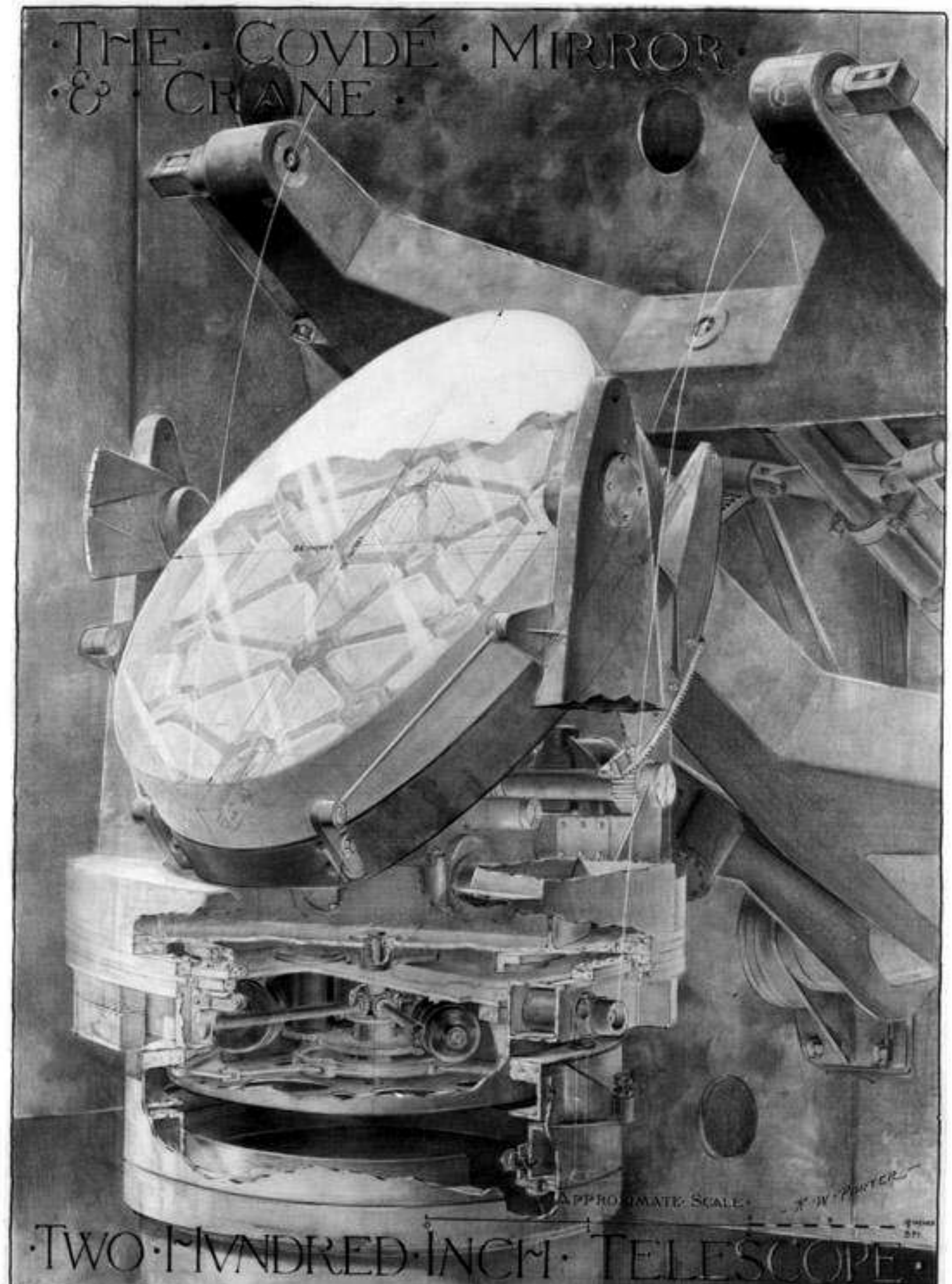

Figure 18- Cassegrain-Coudé diagonal mirror. Mounted in line with the declination trunnions, this diagonal flat mirror reflects the image formed by the main mirror either into the yoke girder or down the south polar-axis to the coudé spectrograph room.

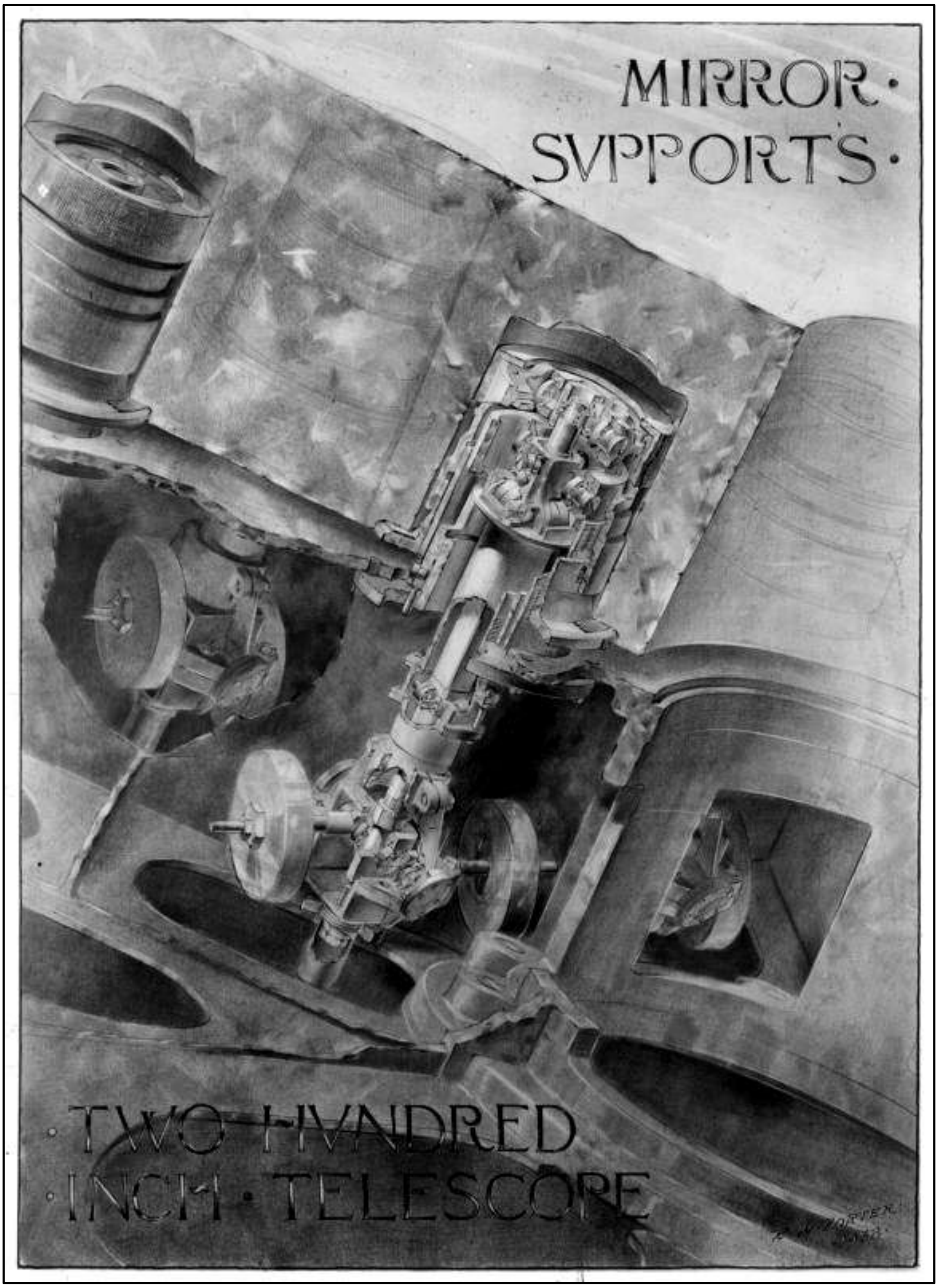

Figure 19- Mirror counterbalance supports. Thirty-six of these intricate double-acting counterbalance devices support the 200-inch mirror at its center of gravity to prevent distortions of the huge disk when it is tilted in different directions.

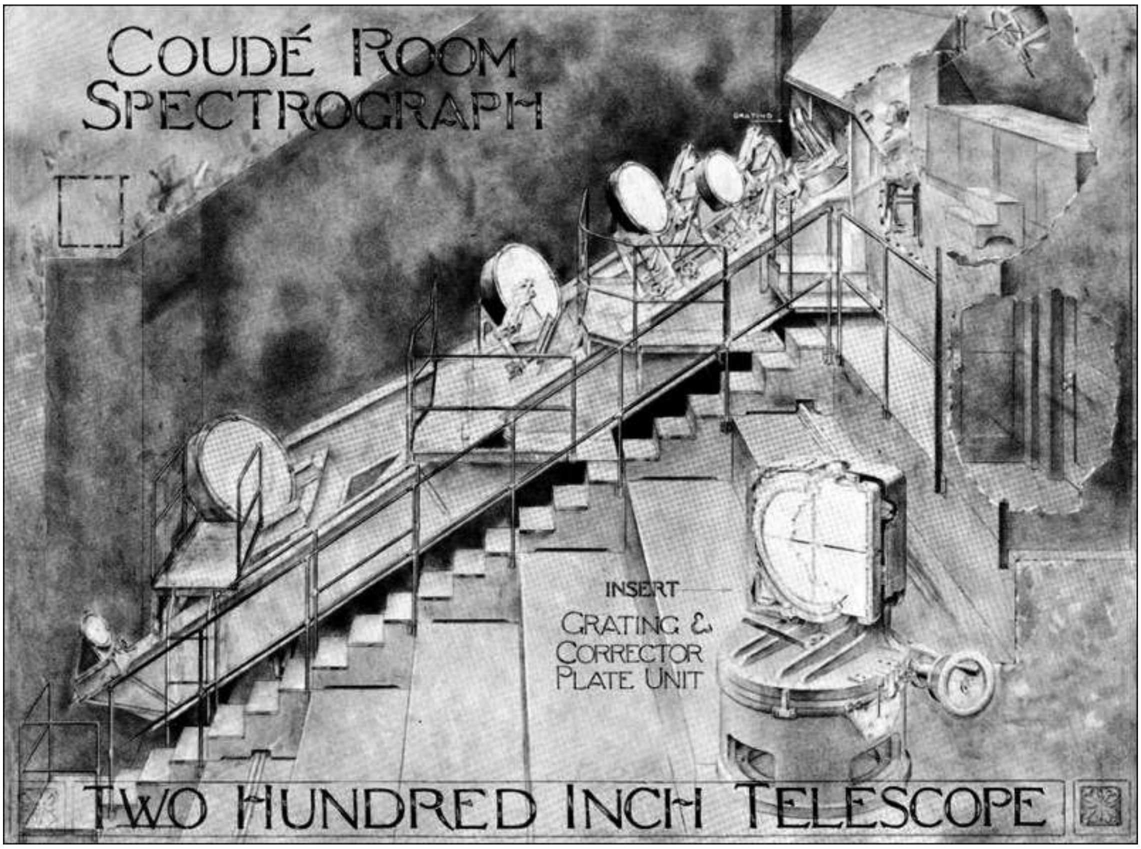

Figure 20- The coudé spectrograph room containing four spectrograph mirrors of different focal lengths.

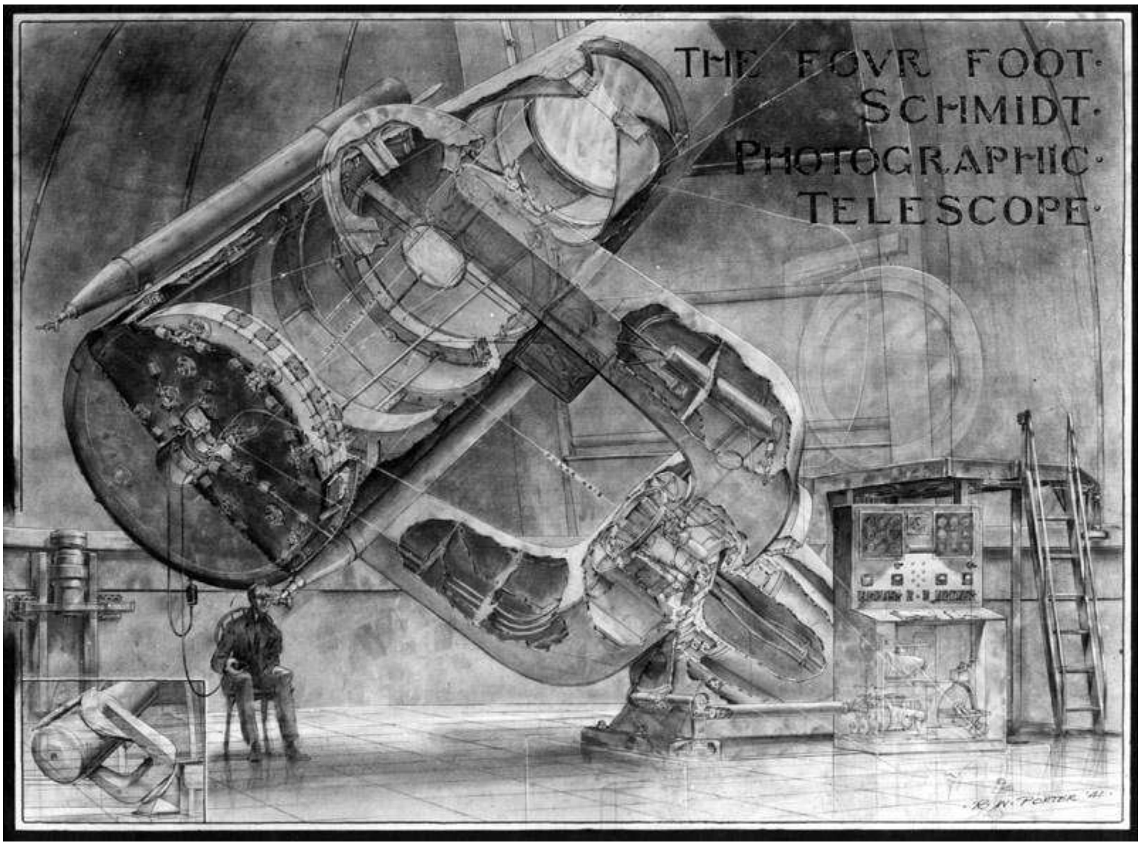

Figure 21- 48-inch Schmidt telescope (corrector plate 48-inch, main mirror 72-inch).

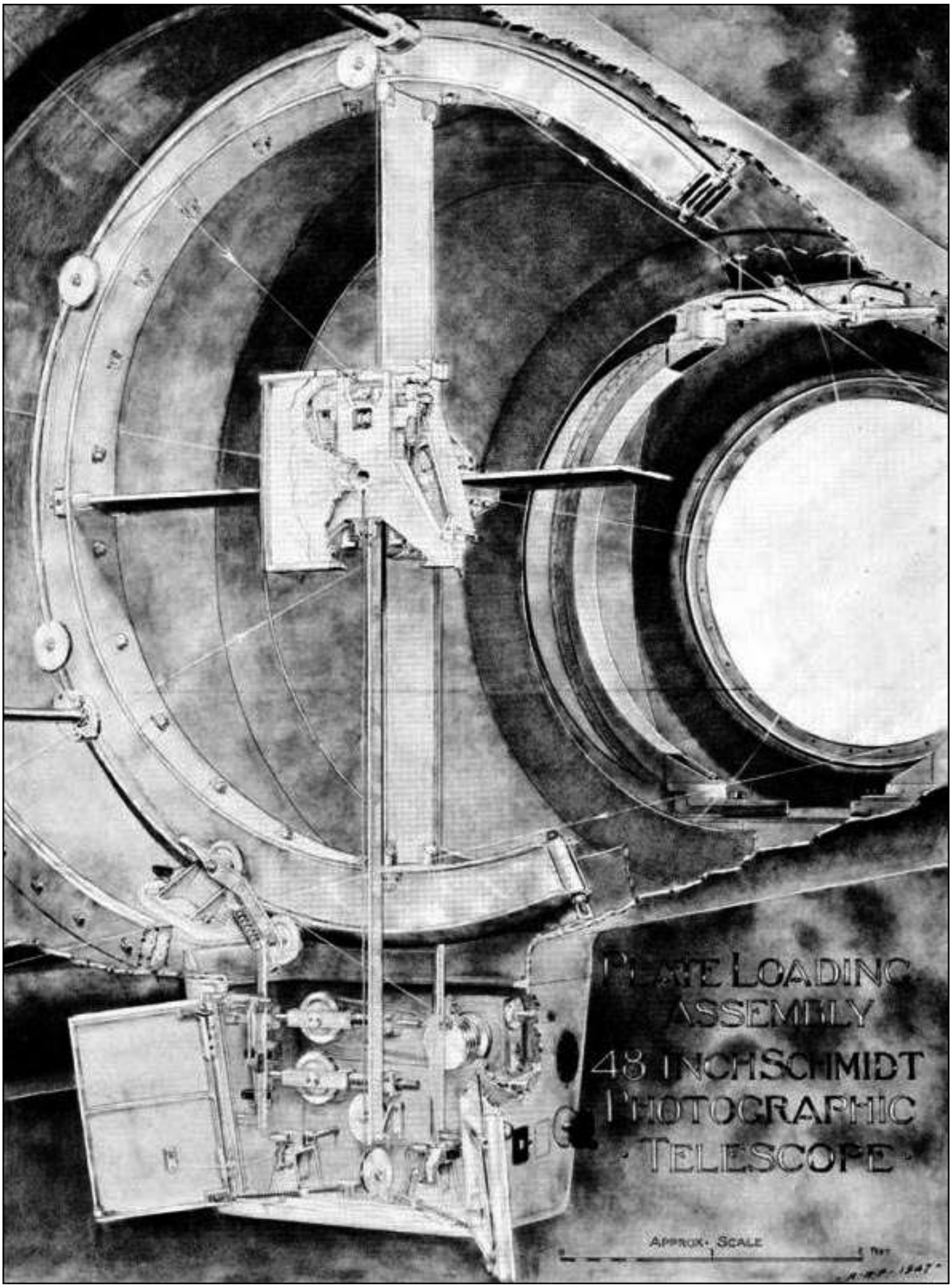

Figure 22- 48-inch telescope’s plate-loading mechanism. Plateholders capable of holding 14-inch plates are heavy and would be difficult to place in position in the center of the telescope tube. A mechanical device performs this task.

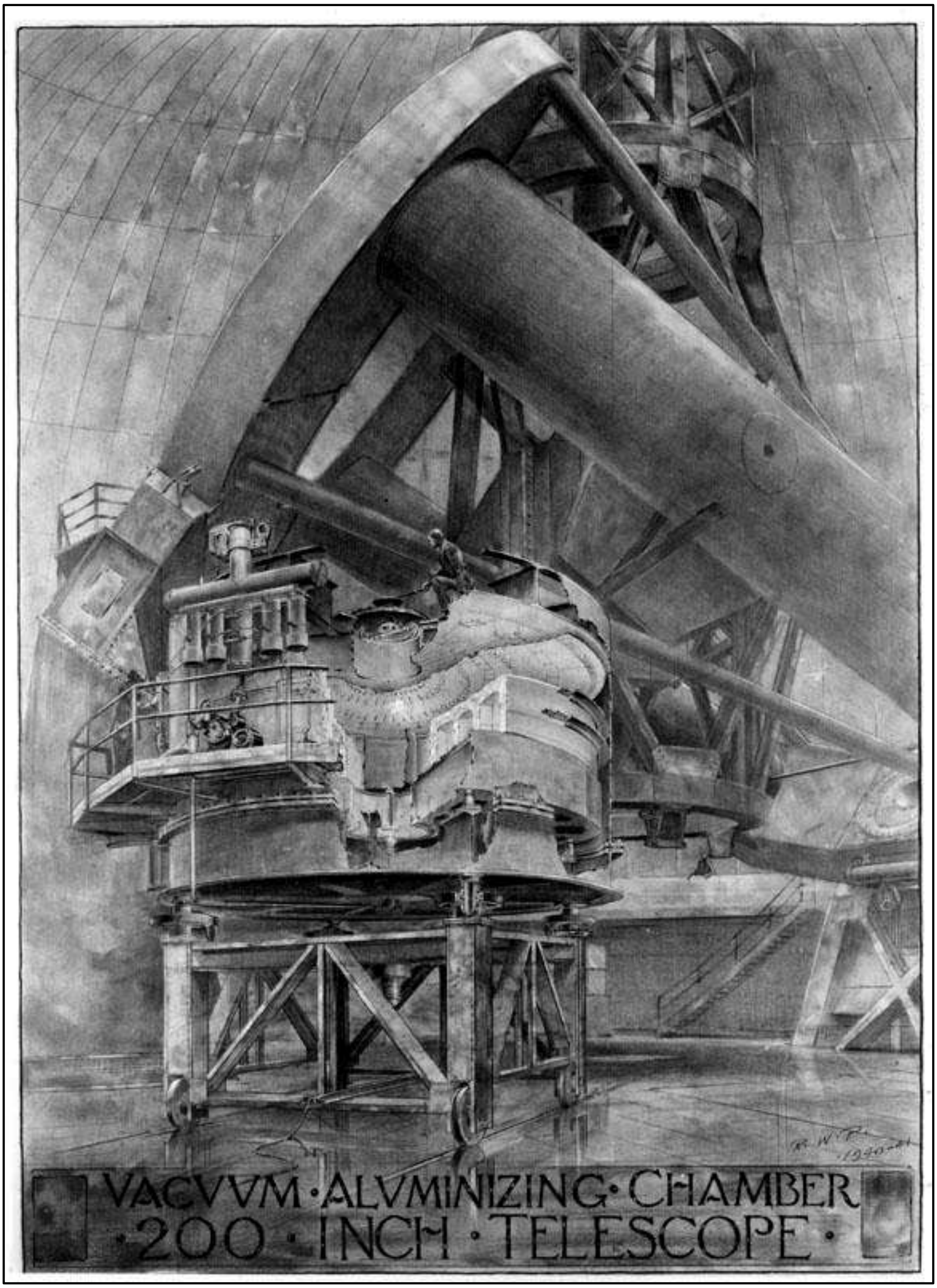

Figure 23- Vacuum aluminizing chamber of the 200-inch mirror.

UNUSUAL TELESCOPES – I
RUSSELL PORTER’S UNUSUAL TELESCOPES

PEDRO RÉ
http://www.astrosurf.com/re

Russell Williams Porter (1871-1949) studied architecture at the Massachusetts Institute of Technology. For many years Porter devoted his life to arctic exploration, making eight extended trips north of the Arctic Circle with the Admiral Robert Peary, acting in these expeditions in the capacity of artist, astronomer, surveyor, topographer and museum collector. Later in his life Porter became interested in telescope making. When the United States entered World War II he turned his skills to the advantage of the government, doing optical work throughout the war period at the National Bureau of Standards in Washington. Later he returned to Springfield, Vermont, his birthplace, as Optical Associate with the Jones and Lamson Machine Co. As a side line he built about fifty “Garden Telescopes”, each with a 6” mirror (see below). In 1921, Porter organized the “Telescope Makers of Springfield”. Porter was also involved in the design and construction of the 200-inch Palomar Telescope (1928 onwards). Many amateur astronomers worldwide regard Russell Porter as the father of amateur astronomy and amateur telescope making.

Porter designed and built several unusual telescopes. Among these we can mention the “Garden Telescope”, the “Springfield equatorial Mount” and the “Turret Telescope”.

Garden Telescope

Porter designed and patented the Garden Telescope in the 1920s. These telescopes were meant to stay outdoors as garden ornaments. The owner had to detach the primary mirror and eyepiece-diagonal assembly and take these indoors, out of the weather. Fewer than 60 garden telescopes were built (Figure 1).

These instruments were fitted with a mirror cover and sometimes were left outside facing the weather also acting as a Sundial. The castings depicted a lotus bowl holding the primary mirror with one long leaf holding the eyepiece and prism/diagonal assembly. The mount is a three-axis type with azimuth, right ascension and declination axis. If the azimuth axis is unclamped, the telescope can be used to observe terrestrial objects as an alt-az instrument. During night operation the azimuth axis is rotated until the polar axis points to the North Pole and the telescope can be used as a classical equatorial mounted instrument (Figure 2).

Springfield Equatorial Mount

The Springfield Equatorial Mount is basically a fixed eyepiece mount. The observer is kept stationary at the eyepiece end while the telescope swings around the sky. The optical path is brought out through the declination axis. The first Springfield Mount was designed by Russell Porter and build by Oscar Marshall in 1920 (assembled and tried at Stellafane[24] Amateur Telescope-Makers in Vermont). This mount employs two reflections by small prisms bringing both right ascension and declination circles very close to the observer’s eye. Although there is some light loss due to the extra mirror or prisms, the viewing position is fixed and comfortable

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[24] The term "Stellafane" refers to the site on the summit of Breezy Hill in Springfield, Vermont where a convention is traditionally held wevery year, and where the Springfield Telescope Makers hold most of their meetings.

and compatible with sketching and note taking. The orientation of the sky rotates with respect to the eyepiece as the telescope turns around the sky. The main counterweight of the Springfield mount is not in line with the telescope tube. This might be considered a serious drawback in the dark. Most Springfield mounts are known to carry Newton reflectors (Figures 3 and 4). Some were made around the tri-schiefspiegler reflector rather than the Newtonian.

Figure 1- Original Porter Garden Telescope sold in 2007 in auction for $18,000 US (serial number 53). The primary mirror and diagonal prism are not original.

Figure 2- Replica of the Porter Garden Telescope offered by the Telescopes of Vermount for $59,000 US.

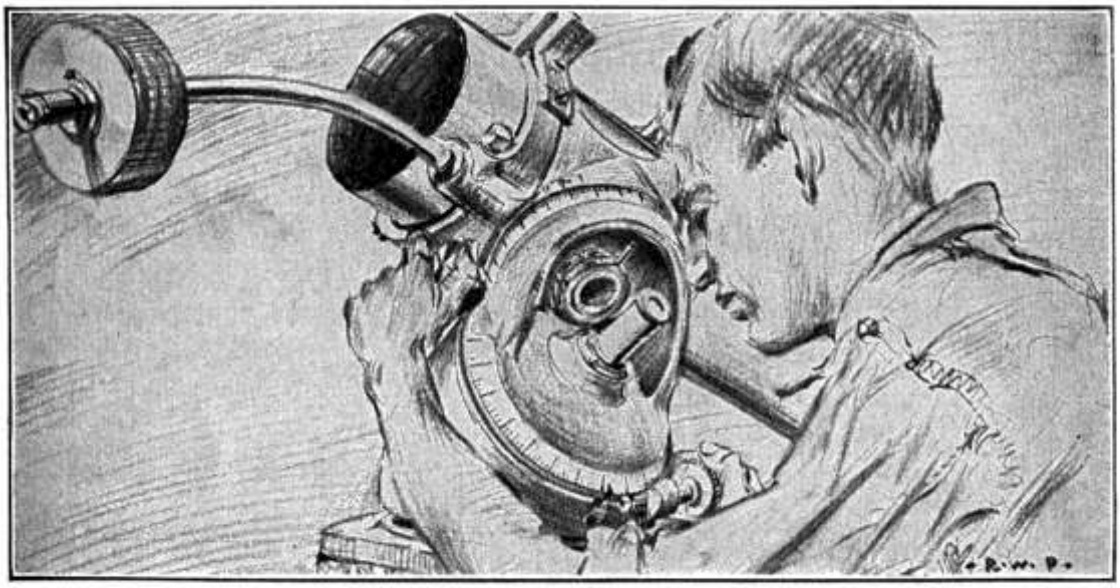

Figure 3- The Springfield Equatorial Mount, with detail of Setting Circles. Note the slow motions screws for following the stars within reach of the observer. Drawing by Russell Porter.

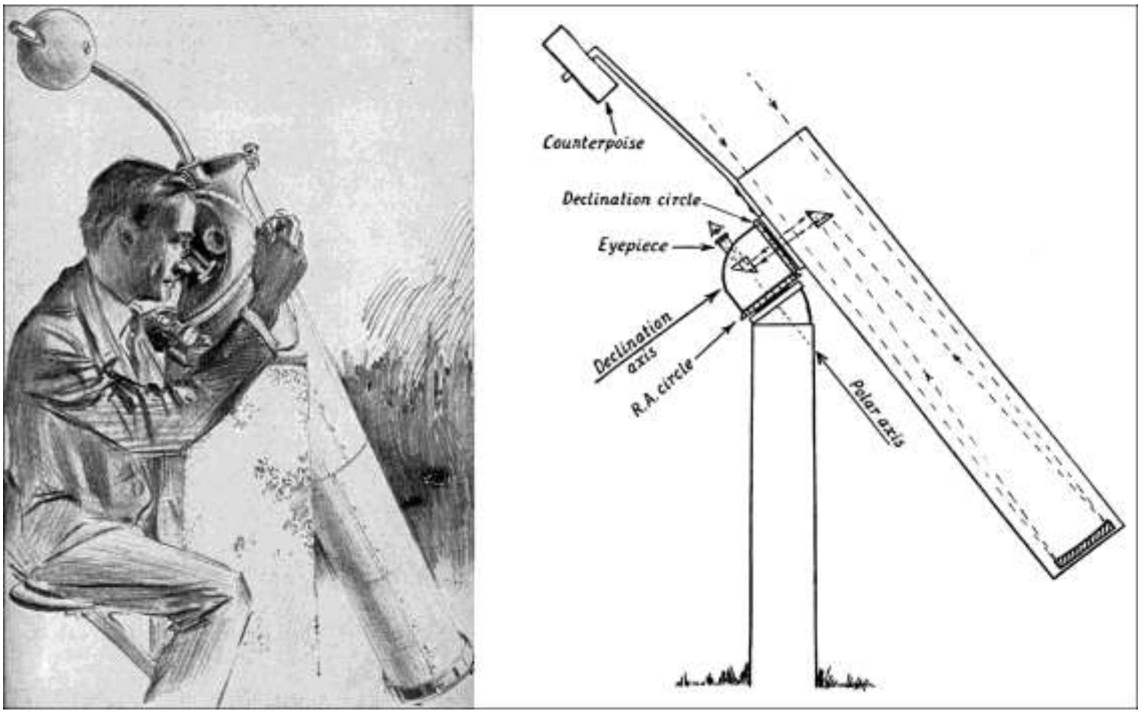

Figure 4- The Springfield Equatorial Mount. The observer's position is fixed and comfortable. Drawing by Russell Porter (left).

Turret Telescope

The Hartness Turret Telescope (24.5 cm refractor) was described for the first time in 1911[25] (Figure 5).

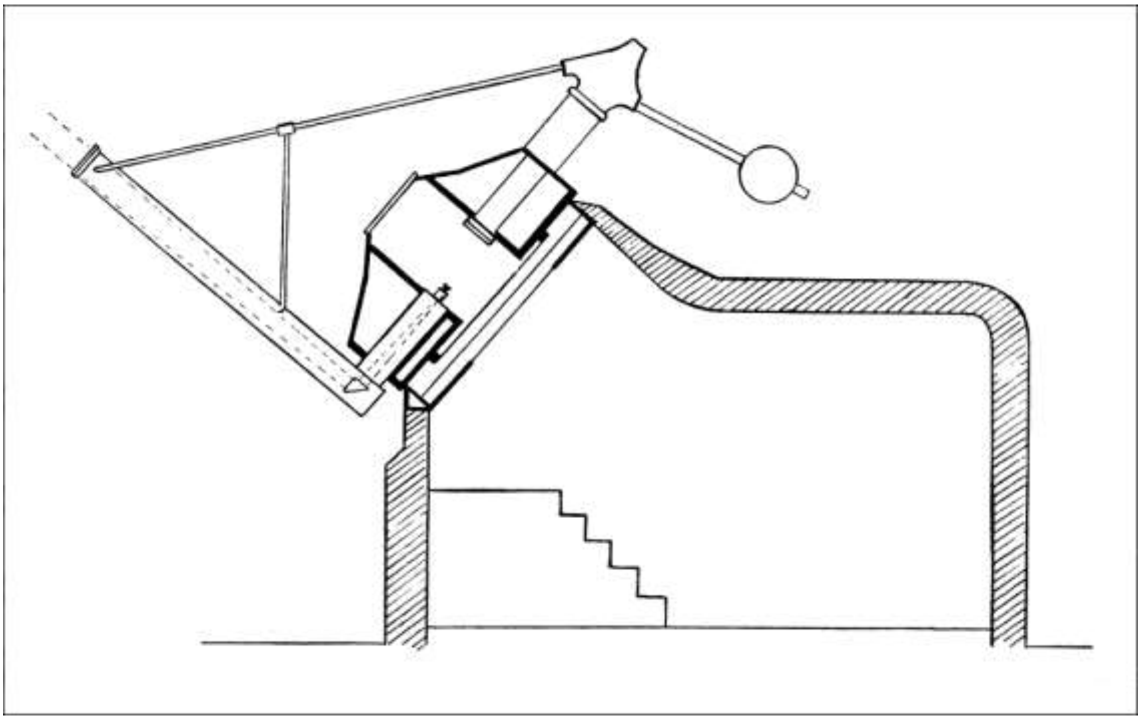

Figure 5- Diagram of the Hartness turret Telescope.

In the Hartness telescope the whole turret is rotated in order to move the telescope in right ascension. Declination motion is provided by swinging the tube of the refractor. Several windows build on the turret allow the observer to see the sky and aim the telescope. This can also be done using large setting circles.

A similar turret telescope was built in 1930 by Porter at Stellafane (Amateur Telescope Makers of Sprinfield) (Figure 6). This turret telescope is a reflector instead of a refractor. Starlight strikes a flat mirror located near the dome being reflected towards a main parabolic primary mirror located at the end of the struts. The light is then directed back through the hole in the flat to the eyepiece inside the dome. The flat rotates around an axis connecting the eyepiece with the primary in order to change declination. The flat can be controlled from inside the dome and the whole assembly move together in right ascension.

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[25] *Journal of the American Society of Mechanical Engineers*, December, 1911: pages 1511-1537.

Figure 6- Recent photograph of Porter's turret telescope at Stellafane. The Springfield Telescope Makers' pink clubhouse is seen at the background. A Springfield mount can also be seen in front of the clubhouse.

Several observers can use the telescope at the same time. The Porter's turret telescope after being recently renovated is still in operation and is often used by club members.

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UNUSUAL TELESCOPES – II
FIXED-EYEPIECE TELESCOPES

PEDRO RÉ
http://www.astrosurf.com/re

Fixed-eyepiece or stationary-eyepiece telescopes were built since the early 1800s. James Hall Nasmyth (1808-1890) was one of the first astronomers to tackle the problem. Nasmyth (inventor of the steam hammer) was a master engineer with his own workshop for casting specula in Patricroft (near Manchester, U.K.). He casted several metal mirrors (8-inch to 20-inch). This large mirror was used as a Cassegrain-Newton telescope mounted in a sheet-iron tube that was moved on trunnions, just like a cannon. Nasmyth modified and alt-az mounted Cassegrain-Newton by adding a third mirror in front of the primary in such a way that the light path was deflected to the side of the tube horizontally through the elevation bearing. The tube and trunnions were mounted on a large platform. By turning two hand wheels the observer could maneuver the telescope around the sky. In some Nasmyth reflectors the observer was seated at the eyepiece end, literally riding the telescope (Figure 1).

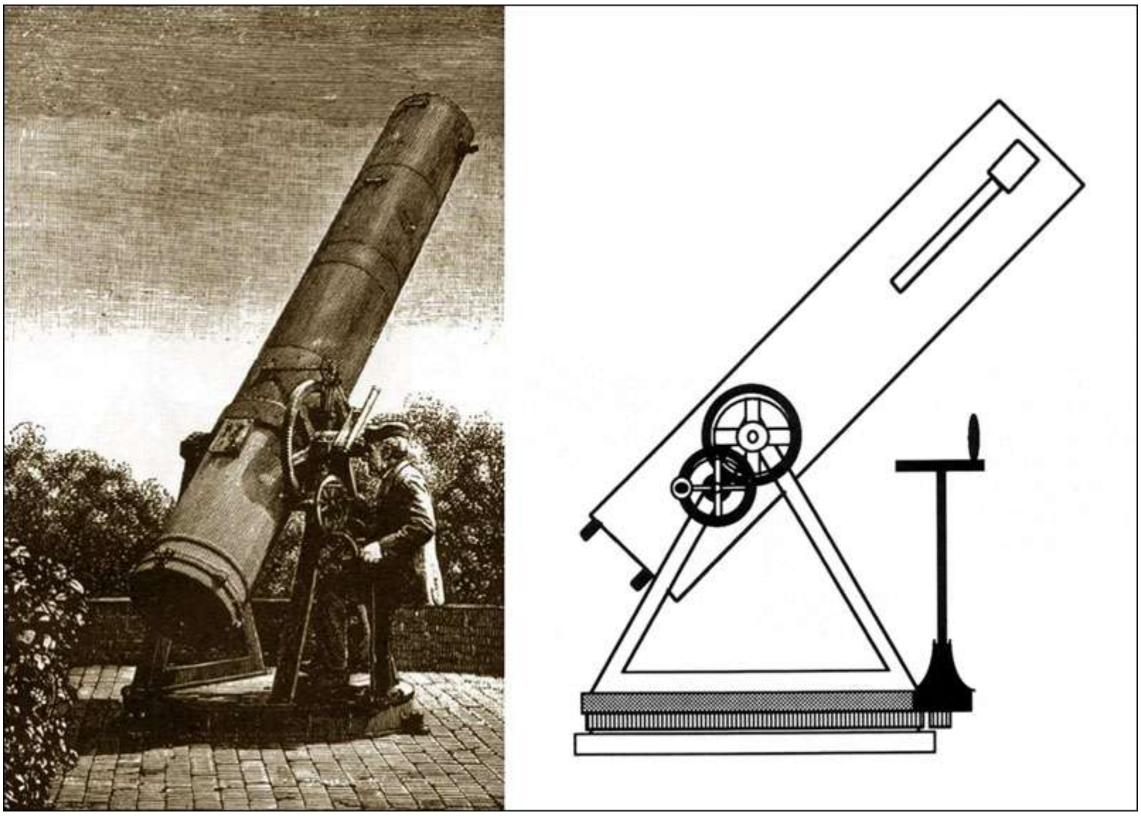

Figure 1- Nasmyth's 20-inch Cassegrain-Newton (around 1845) (left).
Diagram of a Nasmyth stationary-eyepiece telescope (right).

Another unusual telescope with more or less stationary eyepiece is the Treptow refractor of the Berlin observatory. This equatorial mounted instrument weighting 120 tons was built in 1896. The 68 cm *f*/21 lens is still the world longest telescope with a focal length of 21 m. The telescope was designed is such a way that the eyepiece is located at the center of rotation of both axes (right ascension and declination). The observer stands in this position and the telescope turns around him. The Treptow refractor was damaged during the Second World War. Renovation took place in 1959. The telescope is still in operation at the Archenhold Observatory (Berlin) (Figure 2).

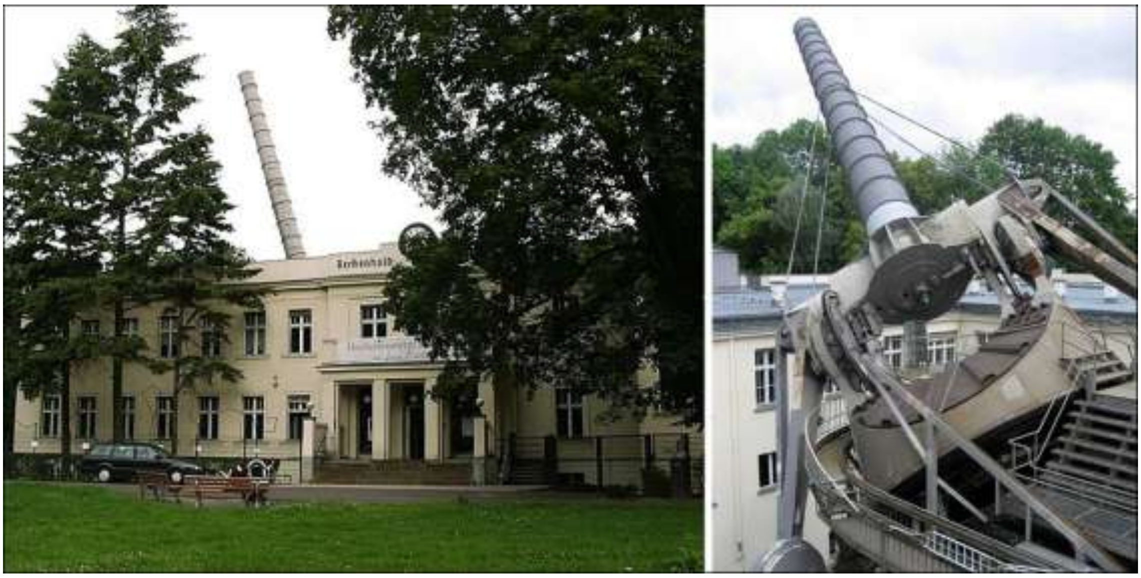

Figure 2- Archenhold Observatory and Treptow great refractor (Berlin, Treptow).

Other types of fixed eyepiece telescopes include the Turret Telescopes that were built around refractors as well as reflectors. The observer stays inside a closed room entirely independent from outside temperature. Figure 3 shows some examples of fixed eyepiece and turret refractors. The eyepiece can be fixed or it can describe a small arc of 180° (Hartness turret).

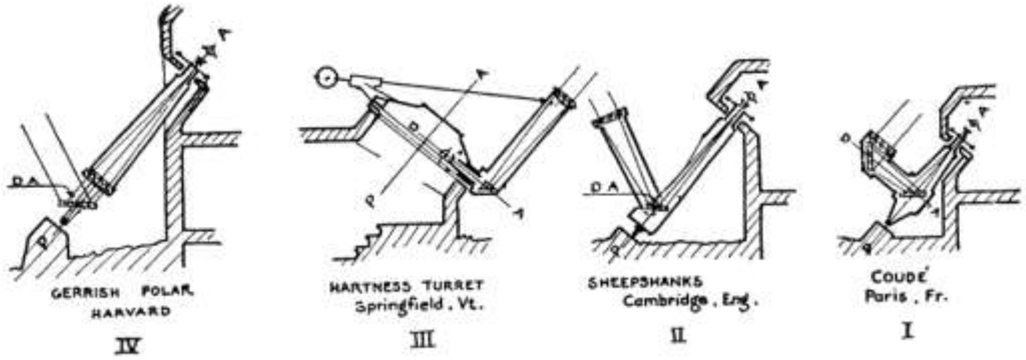

Figure 3- Fixed eyepiece refractor telescopes. Drawings by Russell Porter
(Adapted from Amateur Telescope Making, Book One).

As far as reflectors are concerned the solutions are similar. Turrets can carry several telescopes as shown in Figure 4 (Porter Turret Telescope). Polar telescopes are also a possibility (Newton or Cassegrain) (Figure 4).

Perhaps the best known fixed eyepiece telescope is the Paris Observatory Coudé refractor (Figure 3 and Figure 5). This telescope was designed by Moritz Loewy in 1891 at the Paris Observatory. The image plane is kept at a fixed position while the telescope swings around the sky. The observer stays in a warm room while observing or taking astrophotographs. The Henry brothers of the Paris observatory[26] built two Coudé refractors (10-inch and 23.5-inch). Two different objectives were built for visual and photographic work. With the aid of this unusual telescope the first Moon photographic atlas was published between 1896 and 1910 by Moritz Loewy (1833-1907) and Pierre-Henri Puiseux (1855-1928)[27].

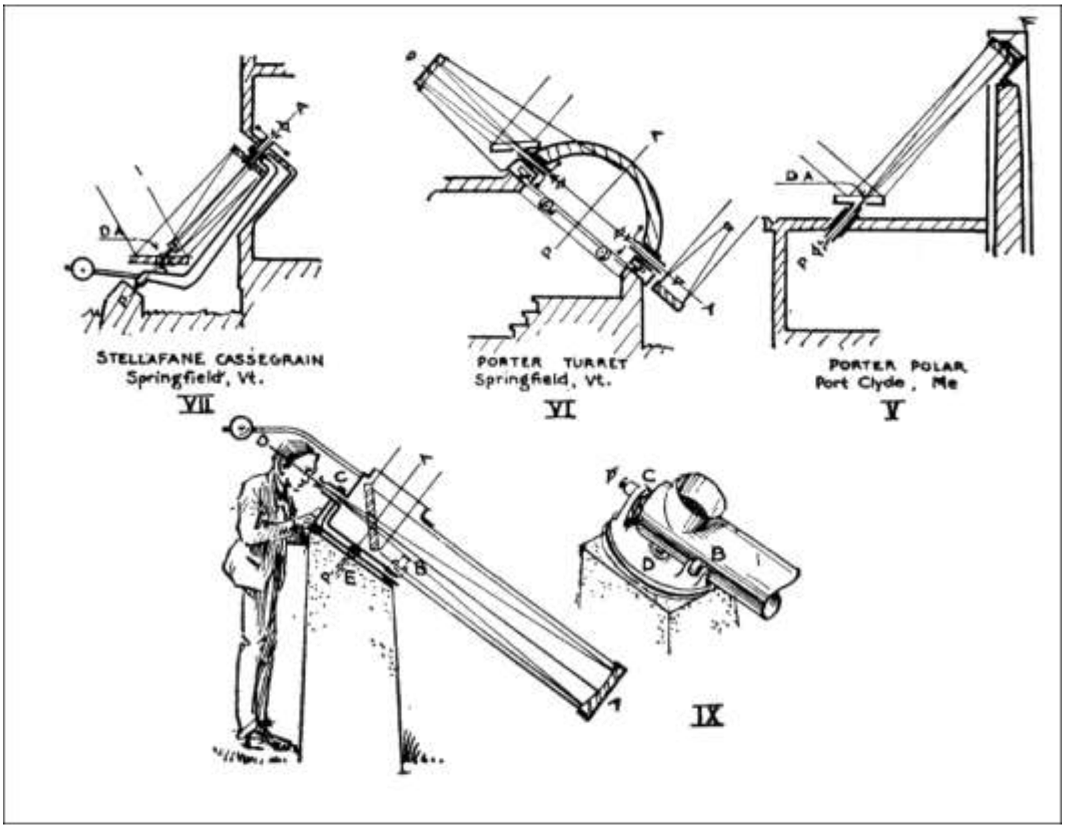

Figure 4- Fixed eyepiece reflector telescopes. Drawings by Russell Porter (Adapted from Amateur Telescope Making, Book One).

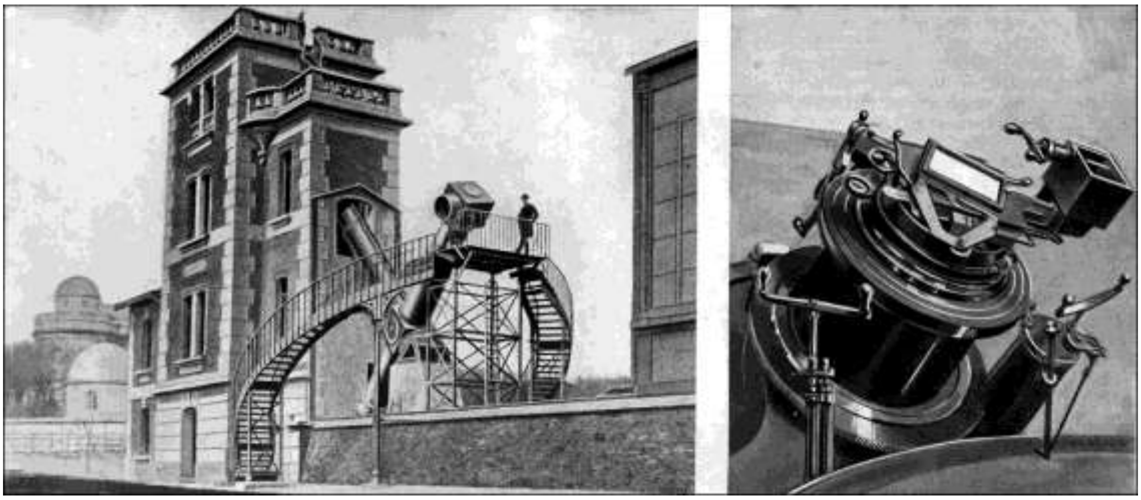

Figure 5- Paris Observatory Coudé refractor. Whole telescope (left), fixed eyepiece end (photographic plate) (right).

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[26] Paul Henry (1848-1905) e Prosper Henry (1849-1903).

[27] *Atlas photographique de la lune, héliogravures*, Paris, 1896-1910, Collections de l'Observatoire de Paris.

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RITCHEY'S FIXED UNIVERSAL TELESCOPE

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George Willis Ritchey (1864-1945) was the prophet and builder of the first large American reflecting telescopes and a master of celestial photography. Ritchey worked closely with George Ellery Hale[28] and the Mount Wilson Observatory stands today as a monument to their collaboration. Ritchey is usually associated with the Ritchey-Chretien system, used in almost all large reflecting telescopes today. The largest telescopes in activity clearly demonstrate the validity of many of Ritchey's predictions, which seemed fantastic if not impossible to most of the astronomers of his day.

After the completion of the 100-inch, Ritchey devoted eight years to the study of a fixed, vertical, universal reflecting telescope, with a coelostat and cellular mirrors. This unusual telescope was designed mainly (in Ritchey's own words) "*to overcome the technical difficulties and the inconveniences of all kinds which are encountered with very large equatorial reflectors*". He also mentioned that "*this type (of telescope) is incomparably well adapted for the highest requirements of astronomical photography, and of astrophysical work with very large and elaborate accessory instruments*".

Ritchey's first designs of the fixed universal telescope were completed in March 1924. These included three concave 5 m mirrors and a coelostat with two 6 m plane mirrors. The six secondary mirrors (Newtonian – plane, Schwarzschild – concave, Cassegrain and Ritchey-Chrétien – convex) also of cellular construction, varied from 1.52 m to 1.83 m in diameter. A general view of this first fixed telescope is given in Figure 1. A later design which only Schwarzschild and Ritchey-Chrétien combinations are used is illustrated in Figure 2.

In these telescopes, the coelostat is far above the ground in order obtain the "*best atmospheric definition*". The coelostat and the mounting of the second large plane mirror rest upon the massive, horizontal summit of the inner building, which is of reinforced concrete. An outer building of strong steel that supports the dome, entirely separated from the inner one, acts as a protection from the wind, weather and sudden temperature changes. This outer building and dome are protected by exterior sheet-steel sun-shield and the two sheet-steels walls are separated by ample ventilation, and all are painted white.

Figure 1 shows two floors below ground level (marked Sol). In the first designs the vertical distance between floors 1 and 3 was 18 m, the vertical distance between floors 3 and 4, 26 m and the total height from floor 3 to the summit of the dome 53 m. The dome had a diameter of 32 m (fixed universal telescope of 5 m mirrors).

The second large plane mirror in the dome receives the stationary beam of light from the coelostat, and reflects it vertically downward, in the fixed vertical tube of the telescope. On the first floor three or more concave mirrors lie horizontally, face-up each with its mechanical flotation system and carriage (rolling on straight horizontal rails). These mirrors could me quickly moved into position with automatic adjustment and alignment with reference to the fixed vertical optical axis of the telescope.

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[28] Ritchey's career is clearly intertwined with that of G.E. Hale in such a way that it is impossible to treat one without mentioning the other.

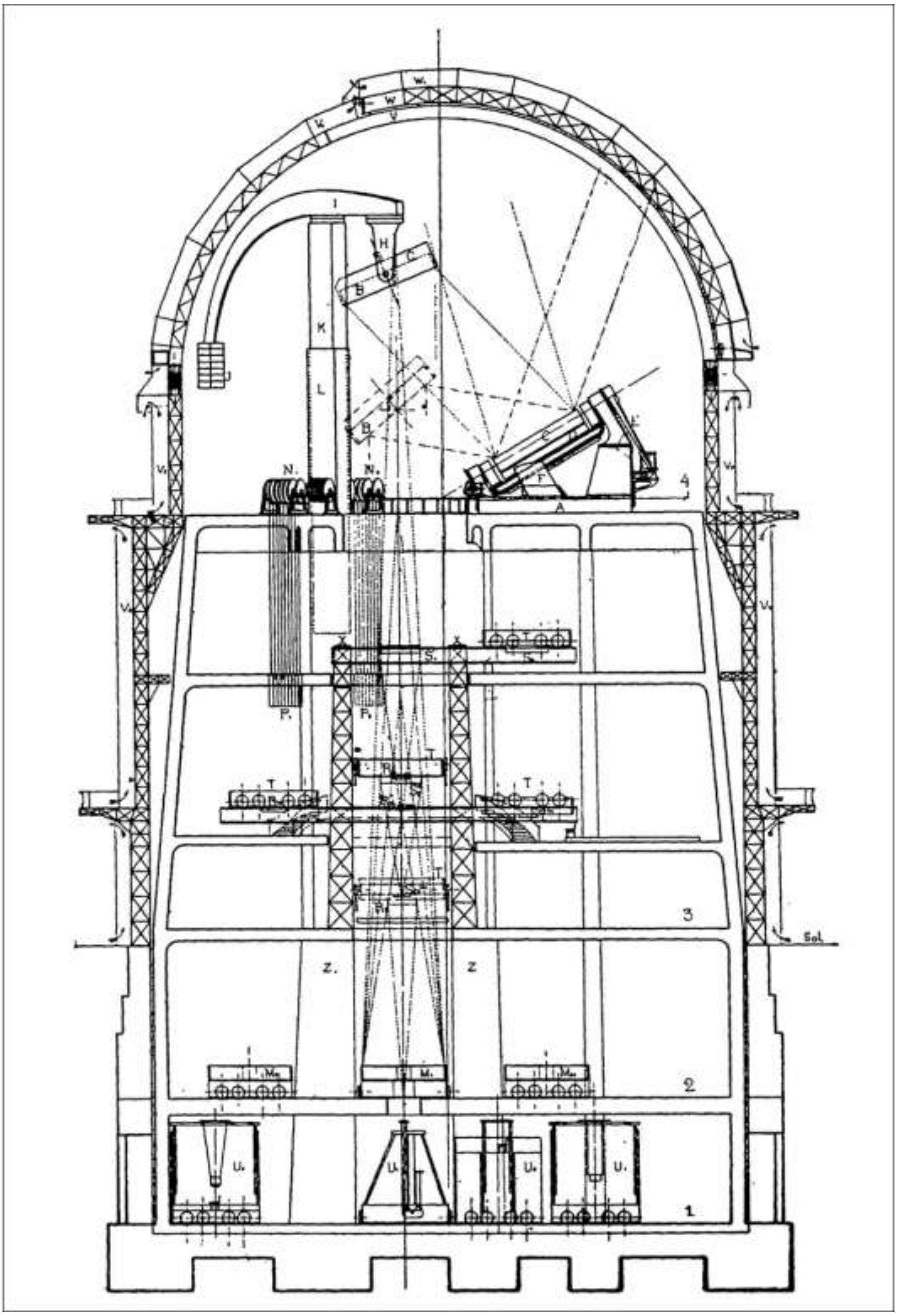

Figure 1- Ritchey's design for a fixed vertical telescope. The coelostat consisting of two large plane mirrors is at the top. The ground level is marked "Sol". A 5 m diameter primary mirror, Marked M, is in use, two others are on wheeled carriages on both sides of it. Several secondary mirrors, marked R and S may be used. Adapted from Ritchey, G.W. (1928) The modern photographic telescope and the new astronomical photography. Part I- The fixed universal telescope. *Journal of the Royal Astronomical Society of Canada*, 12 (5): 159-177.

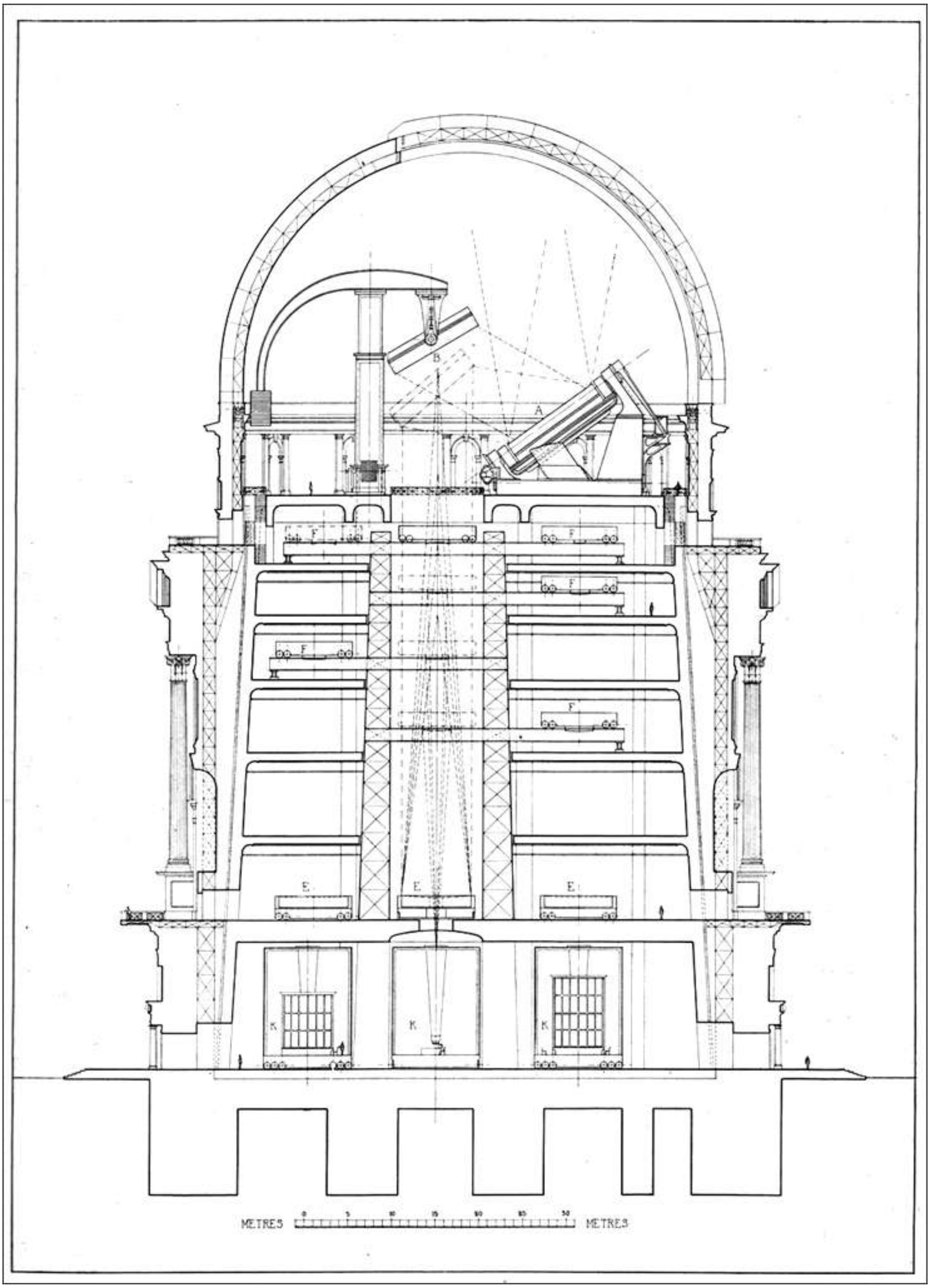

Figure 2- Ritchey's design for a 8 m fixed vertical Universal Telescope. Note the human figures that show the gigantic scale of this instrument. Adapted from Ritchey, G.W. (1929) *L'Évolution de l'Astrophotographie et les Grands Télescopes de L'Avenir*. Société astronomique de France.

In the first design the three large concave mirrors were: Newtonian (paraboloidal) and Cassegrain combinations (Schwarzschild and Ritchey-Chrétien). The secondary mirrors were also supported by a flotation system and roll into position with automatic adjustment and alignment. The accessory instruments (spectrographs, bolometers, radiometers, interferometers, photographic apparatus…) could be rolled smoothly, on straight horizontal rails, into position. Whatever the size of the telescope, the interchange from any combination to another could be accomplished in a few minutes.

The square tube of the fixed telescope consisted of four strong steel vertical square columns. The combinations and focal ratios planned for the mirrors included: (i) one Schwarzschild type with one large concave mirror and a small concave mirror, giving a very large field and a small focal ratio (*f/*3); (b) one Newtonian with a paraboloidal mirror (*f/*6); one Ritchey-Chrétien with one large concave and small convex mirrors (*f/*6.8); one low power Cassegrain combination (*f/*12) and one high power Cassegrain combination (*f/*30).

All these plans were made by Ritchey while working at the Mount Wilson observatory (1910-1924). During the period of 1924-1828 Ritchey develops new designs for the fixed telescope in the optical shop of the Paris observatory in co-operation with Henri Chrétien.

Ritchey did not publish his plan for a fixed universal telescope until 1927. He claimed that he had been working on these designs since 1919, the year G.E. Hale fired him from the Mount Wilson Observatory.

In these new plans, without changing the general design or the mechanical arrangements of the universal type, the Newtonian and Cassegrain combinations were omitted in favor of the Schwarzschild and Ritchey-Chrétien designs. These included five combinations and focal ratios instead of the six described above. Four large concave primary mirrors and five small secondary mirrors were described:

(i) Schwarzschild (*f*/2.75);
(ii) Schwarzschild (*f*/4);
(iii) Ritchey-Chrétien (*f*/6.8);
(iv) Ritchey-Chrétien (*f*/12);
(v) Ritchey-Chrétien (*f*/20).

Ritchey mentioned the advantages of the fixed universal telescope as follows:

A- Convenience, comfort and safety for the observers;
B- Ease of use of accessories (photographic, spectrographic…);
C- Every known configuration of reflecting telescopes can be used;
D- In long-exposure photography (direct and spectrographic) all mirrors in use (with the exception of the coelostat plane mirror) are stationary throughout the exposure;
E- The coelostat rotates only one-half as fast as that of an equatorial telescope;

A few drawbacks/limitations were also identified:

A- Large plane mirrors are subject to deviations from optical flatness as a result of temperature change (the use of cellular mirrors can be a solution to this problem);
B- All fixed type of telescopes are subject to additional loss of light by reflection from one to two large mirrors;

C- The fixed telescope is not adapted for the observation of the whole sky. If a declination of 30º is considered, the telescope can be used without serious loss of light through a range of about 40º (from 12ºN to 52ºN)[29].

D- Difficulties in interchanging mirrors and accessory equipment.

Ritchey planed to install three fixed universal telescopes at different latitudes in order to cover the whole sky (33ºN, 0º and 33ºS) each working at no farther than seventeen degrees from the zenith and covering about 78% of the whole sky (from 50ºN to 50ºS).

The advantage of using these combinations of telescopes is stressed by Ritchey based on his own experience while working at the Mount Wilson observatory.

"*Let us assume that immediately after dark, atmospheric definition is at 5 on a scale of 10 (on a scale o 1 to 10: 1 to 2 being very bad; between 2 and 3 being usable only with the smallest focal ratio of 2.75 to 1; 5 being moderately good and 10 being the most perfect ever seen), the observer therefore changes to the combination best adapted for moderate seeing, that is a medium focal length of 6.8 to 1, a medium magnifying power for a very fine climate. He begins a long-exposure photograph of a spiral nebula with this combination, and continues it for two hours, when he notices that the wind is gradually increasing and the definition gradually falling. When, in another half-hour, definition has gone down to 4, which is his low limit for this focal ratio, his assistant change the mirrors to a different combination (focal ratio of 4. He puts away in a dark drawer the plate-holder and its guiding eyepieces used for the photograph begun earlier, and he continues with a this combination a long exposure photograph of a very faint, extended nebula which he had begun on the preceding night. Definition continues between 3 and 4 until midnight; if it had fallen as low as 3 he would have changed to the lowest-power combination. At midnight he has secured the full time of exposure desired for this photograph. Since definition continues the same he starts another long-exposure photograph of another faint extended nebula. At one o'clock he notices a decrease in the wind, and a very marked improvement in definition, so marked that he goes out on the balcony of the dome, expecting to see a low fog forming in the valleys around and below the observatory. He finds that this is so, and he returns to the telescope and to work, to see whether definition continues to improve rapidly, or goes downward again. Within half an hour definition goes gradually up tp 7, as the wind dies down to a dead calm. He knows that with this calm, and with this low fog he may expect extraordinary definition (seeing), perhaps as high as 8 or 9. He cannot afford to waste such precious conditions on low power work, and he does not need to do so, because he has a quickly interchangeable telescope. He takes a chance, and changes to the highest-power combination, with a focal ratio of 20, and to the photographic accessory instrument for planetary photography with very high powers. He is not taking a serious chance, because he can change back to another combination, if necessary, in four minutes. Definition improves to 9 and to 9.5. It is his great, long awaited opportunity, the one supreme hour of a thousand! He and his assistants work quickly, skillfully, smoothly, in photographing very bright planetary nebulae and planets with magnifying powers of many thousand diameters. Every known invention for their convenience, comfort, facility and speed in their strenuous work of guiding, occulting, re-focusing, with extremely high magnifying powers, is provided and at hand, in the stationary, constant-temperature laboratory containing this high-power photographic apparatus. All of the extreme speed and skill, like those of the virtuoso, which they have acquired by long training with the double-slide practice-machine, stand them in good stead now, and enable them to photograph smaller details and more delicate contrasts of shading and color that any eye can detect visually with the same aperture. But without the quickly*

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[29] Ritchey mentions that most of the long exposure astrophotography with large apertures should be only attempted at a maximum distance of fifteen to twenty degrees from the zenith.

interchangeable telescope the nearly perfect atmospheric conditions, which occur so rarely, and which continue for so short a time, could not have been taken full advantage of, unless, indeed, a complete, separate telescope, fitted for photographic work with the highest powers, had been kept always ready and waiting for such conditions".

In 1928, Ritchey revealed his plan to build a large fixed telescope at the edge of the Grand Canyon in Arizona (Figure 3) and the following year he finally published his book "*The Development of Astro-photography and the Great Telescopes of the Future*". This relatively short book includes many illustrations in large format was written in English and French. The book summarizes Ritchey's work and his own ideas related to the building of large reflectors. It includes the best astrophotographs taken by Ritchey with the 24-inch refractor and 24-inch reflector of the Yerkes Observatory and with the 60-inche reflector of the Mount Wilson Observatory. He also conveys the evidence that spiral nebulae are galaxies, a concept he advanced in 1917 based on the observation of several novae. In this book Ritchey proposed plans for 8 m fixed telescope (Figure 2) and a 6 m equatorial fork mounted reflector (Figure 4). He also proposed building a chain of five fixed vertical observatories at several latitudes (0º, 16ºN and 16ºS, 36ºN and 36ºS).

Figure 3- Ritchey's drawing of a fixed vertical telescope at the edge of the Grand Canyon.

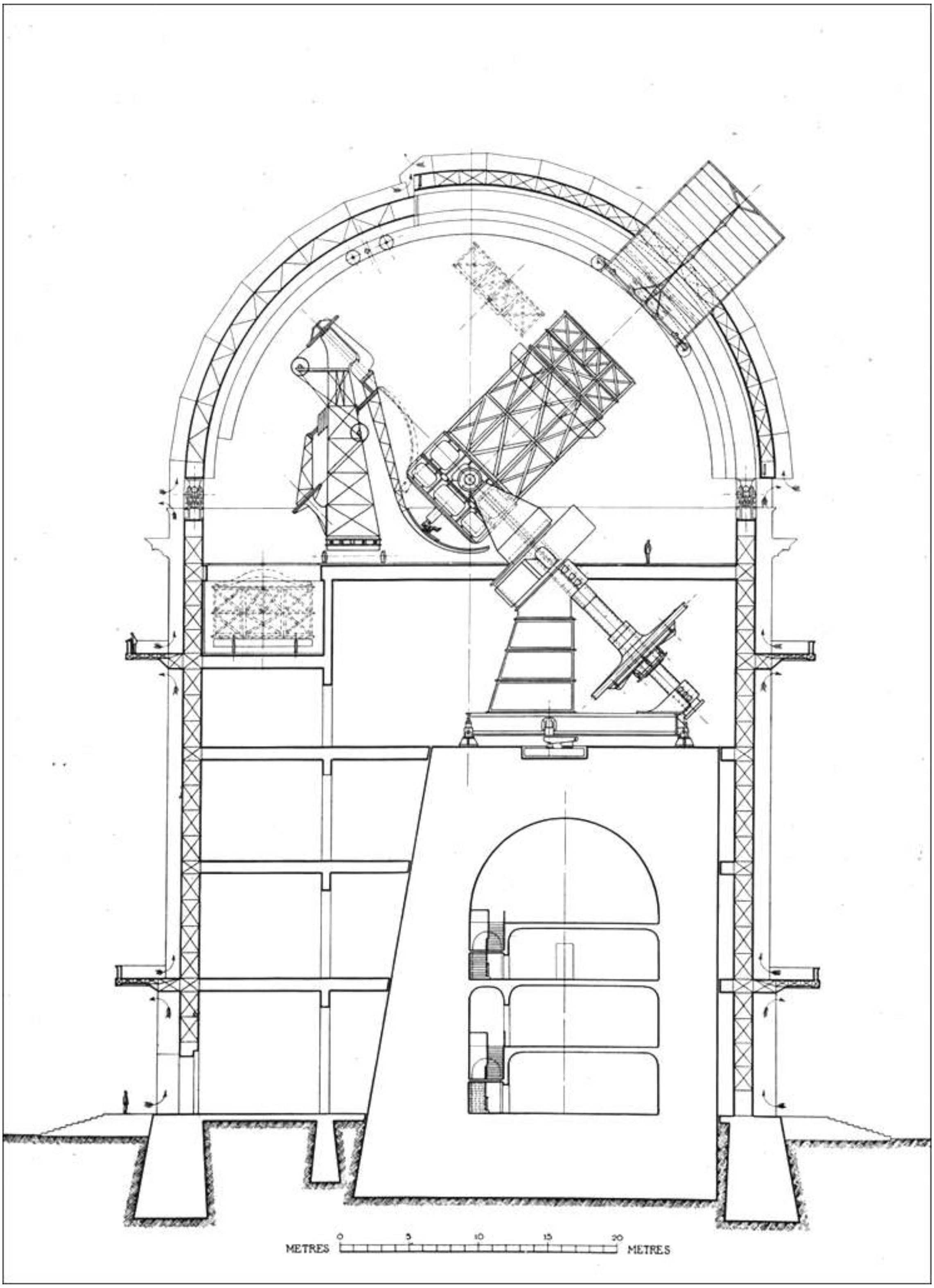

Figure 4- Ritchey's design of a 6 m equatorially mounted Ritchey-Chrétien telescope. An observer was drawn at the curved movable arm behind the primary mirror. Note the size of the human figures on the floor and ground.

Ritchey's ideas were far ahead of his time. The fixed vertical telescopes were never built. Ritchey was an outstanding craftsman; he developed and perfected the methods for making large reflector telescope mirrors that were the best at the beginning of the twentieth century.

His outstanding astronomical photographs received lots of attention. The Ritchey-Chrétien design, cellular mirrors, thermal control of telescope mirrors, mountings and domes, rapid changes of telescope configurations to take advantage of the best seeing conditions never achieved success during his life time. The fixed vertical telescope is another example of Ritchey's prophetic views that never achieved any recognition from his peers, at least to date.

Figure 5- M51. 60-inch telescope, 10h 45m exposure (April 7 and 8, 1910). G.W. Ritchey.

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