

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).

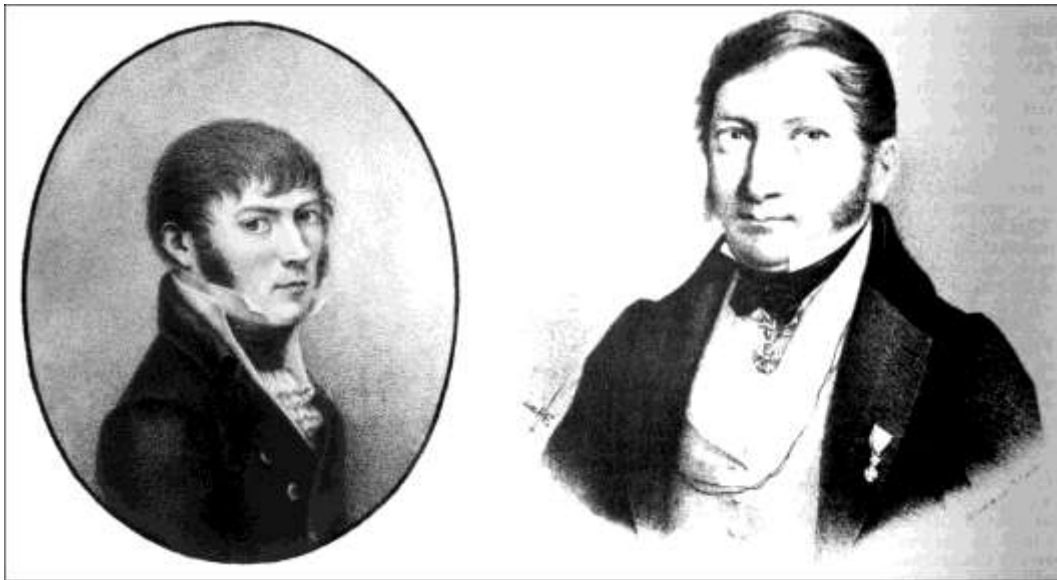


Figure 1- Joseph von Fraunhofer (1787-1826) (left) and Friedrich Georg Wilhelm Struve (1793-1864) (right).

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 Königsberg, 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 Line¹'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 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

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

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.

Sources:

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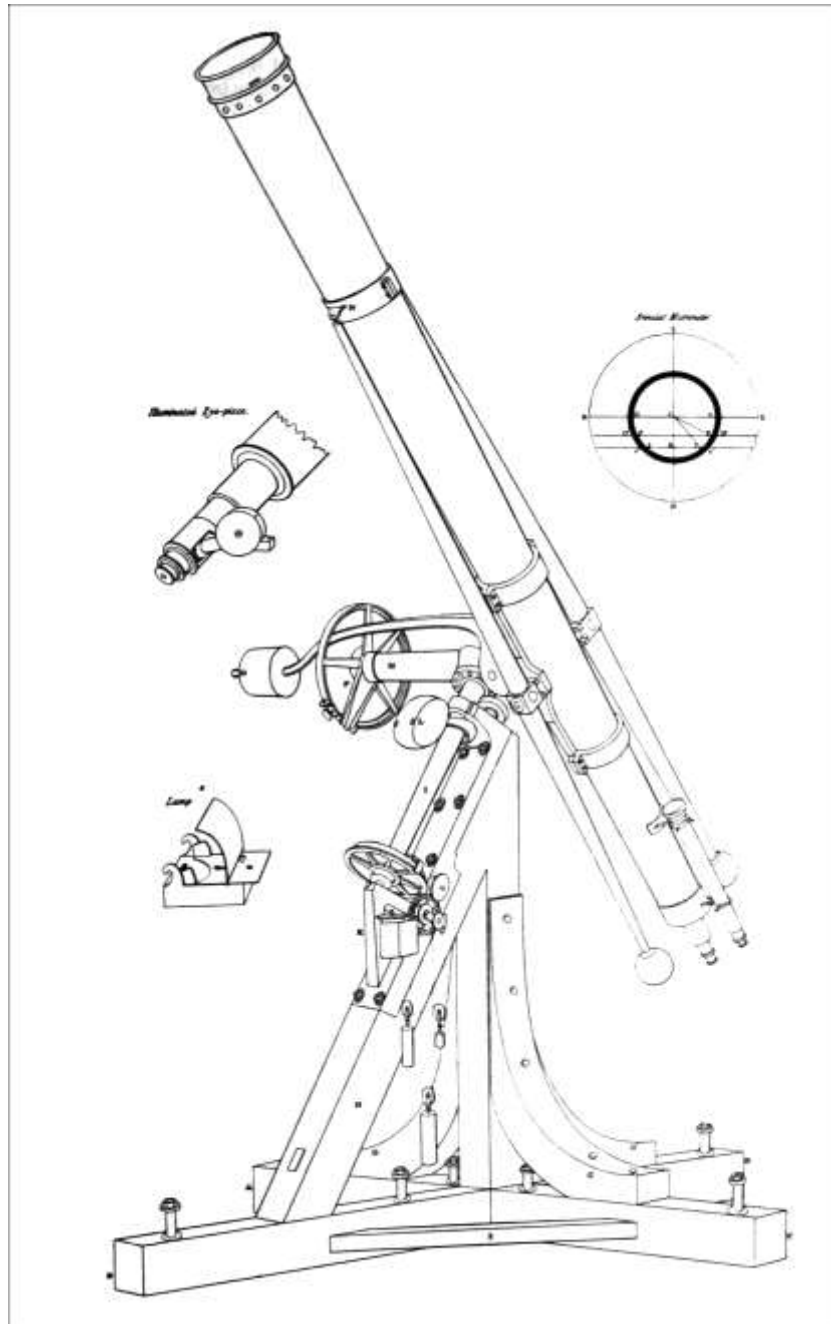


Figure 2- The great Dorpat refractor.



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.