From Dorpat to Yerkes: Evolution of Giant Telescopes in Nineteenth-Century America

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One underappreciated expression of the Industrial Revolution that swept 19th century America was the evolution of mechanical design for giant astronomical telescopes.

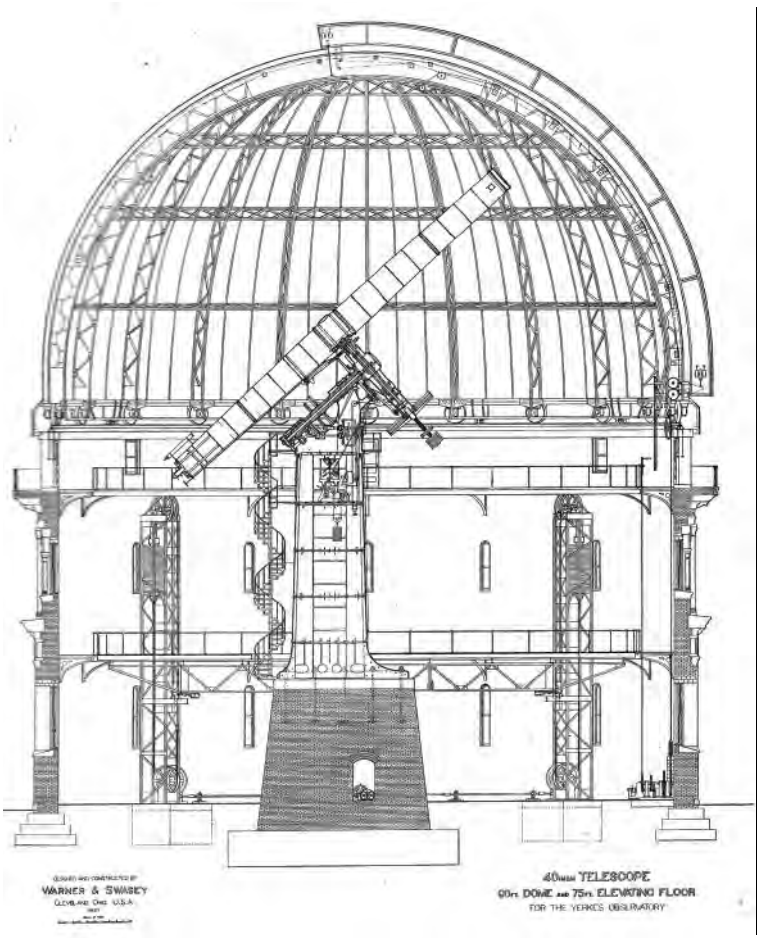


Figure 1 (left): The architectural drawing shows the giant 40-inch refractor mounted in 1897 at the Yerkes Observatory in Williams Bay, Wisconsin; its tube was 63 feet long and its objective lens in its cell weighed half a ton. Credit: Yerkes drawing, Plate 34 in *A Few Astronomical Instruments* (picture book published by Warner & Swasey, Cleveland, Ohio, 1900) (original in the collection of Trudy E. Bell).

Think of the U.S. Industrial Revolution from about 1820 to 1900, what comes to mind? The steam engine, railroads, textiles, and the McCormick reaper perhaps? Maybe steelmaking on a large scale, skyscrapers (and elevators), the Brooklyn Bridge (longest suspension bridge in the world at the time)? And of course, the telegraph, telephone, and manufacturing with interchangeable parts.

One underappreciated beneficiary of the U.S. Industrial Revolution, however, was the design and sheer size of refracting (lens) telescopes. Indeed, the 19th century was the golden age of giant refractors. It culminated in the highly publicized construction of a monumental precision marvel of glass and steel with 20 tons of moving mass, mounted in 1897 at the Yerkes (pronounced YER-keez) Observatory of the University of Chicago, in Williams Bay, Wisconsin.

This giant instrument had an exquisite objective lens fully 40 inches — three and a third feet (about the diameter of a round card table) — in diameter. The telescope's optics were ground, figured, and polished by premier U.S. telescope opticians Alvan Clark & Sons; the mechanics were by foremost engineers Warner & Swasey. It remains the world's largest refractor ever used for astronomical research.

How did artisans and engineers evolve such breathtaking technological prowess in less than one human lifetime?

THUMBNAIL BACKSTORY

Lenses have been around for centuries as magnifiers, burning glasses, eyeglasses, and even spyglasses for military application. The person usually credited with first directing a telescope toward celestial objects was Galileo (although other contemporaries did as well but Galileo published his observations first). But this nuts-and-bolts article is primarily about telescope mechanics (too often underappreciated), instead of the more usual history of optics (whose history has been better documented).

To be practical for astronomical use, a telescope must have a sturdy mount that allows the telescope to point in all directions around the heavens, anchored to a steady stand or pier to minimize shaking of the image in the eyepiece when the instrument is touched by a person or a breeze. In most telescopes, the mount should also have a driving clock to track a celestial object across the night sky as the Earth turns, so the image remains centered in the eyepiece instead of drifting across the field of view as the Earth turns.

For a couple of centuries, people experimented with many mount designs, ranging from ultralong aerial structures to a ball-and-socket universal joint (Isaac Newton's concept). But most varied in their degree of awkwardness for practical use, and essentially none had a driving clock.

Many early observers defaulted to some form of an altazimuth mount, one with vertical and horizontal axes that moved in local altitude (up and down) and azimuth (left and right parallel to the local horizon). An altazimuth mount could be made sturdy; however, as the Earth turns, an observer needed to keep adjusting the telescope's pointing direction in a stair-step pattern to keep a star or planet in the eyepiece's field of view.

ENTER THE EQUATORIAL MOUNT

What was needed was a sturdy *equatorial mount* — a design in which one axis (the "polar axis") is not vertical but is tilted to be parallel to the rotational axis of the Earth, that is, inclined at the angle of the observer's latitude. With an equatorial mount, the telescope swings around the polar axis in a plane parallel to the plane of the equator, smoothly tracking a star across the sky to compensate for Earth's rotation.

The first truly workable design for an equatorial mount was the so-called "English" mount, usually credited to Jesse Ramsden around 1791.[1] In an English mount, the polar axis is supported at each end by a pillar, one being short and the other tall, to hold the polar axis at an angle equal to the observer's latitude. While working well for a telescope fixed in an observatory, an English mount was bulky and not adjustable or readily transportable for expeditionary astronomy (such as traveling to a different latitude to observe a total solar eclipse).[2]

In 1824, all that changed with the installation of a refracting telescope in the Observatory at the Imperial University at Dorpat (now called the Tartu Observatory in Estonia).[3] The telescope was placed atop a revolutionary new type of equatorial mount, the handiwork of brilliant optical designer and physicist Joseph von Fraunhofer in Munich — yes, the same guy who directed sunlight through a prism and identified dark absorption lines in the solar spectrum still called Fraunhofer lines, which set a foundation for spectroscopy.

In addition to grinding and figuring the largest and finest objective lens of the time (9.6-inches aperture),[4] Fraunhofer gave the refractor one center of motion atop a single pier. Moreover, he gave it a gravity-powered clock drive that automatically compensated for the Earth's rotation to keep the telescope focused on one celestial object.[5]

The clock drive used a centrifugal regulator rotating one way in a conical housing, akin to the type of regulator developed for steam engines. Moreover, the regulator's speed was adjustable, allowing the clock to be slightly sped up or slowed so it could track the motion of the moon, asteroids, a comet, or other relatively nearby solar system objects moving against the background of distant stars.

In 1824, clockwork for a telescope was virtually a novelty, (although the basic idea dates back to Newton's contemporary and rival Robert Hooke).[6] Variable drive rate became especially important later in the century after the advent of long-exposure photography and spectroscopy.

In sum, with the Dorpat refractor, Fraunhofer incorporated the fundamentals of what is now called the German equatorial mount (GEM for short). Indeed, in the early-middle 19th century, German-mounted refractors came to be called simply "equatorials" (although reflecting telescopes later in the century also used German equatorial mounts).

Fraunhofer died prematurely at age 39 in 1826, but his design innovations were carried on by his former partners in the Merz dynasty of telescope makers in Munich.

As a result, by the 1840s, German-mounted refractors closely modeled on the Dorpat instrument were installed in several European observatories. Indeed, one mounted in 1828 at the Berlin Observatory achieved worldwide fame in 1846 when two young astronomers there optically discovered the solar system's outermost major planet Neptune, whose existence had been hypothesized by mathematical predictions.[7]

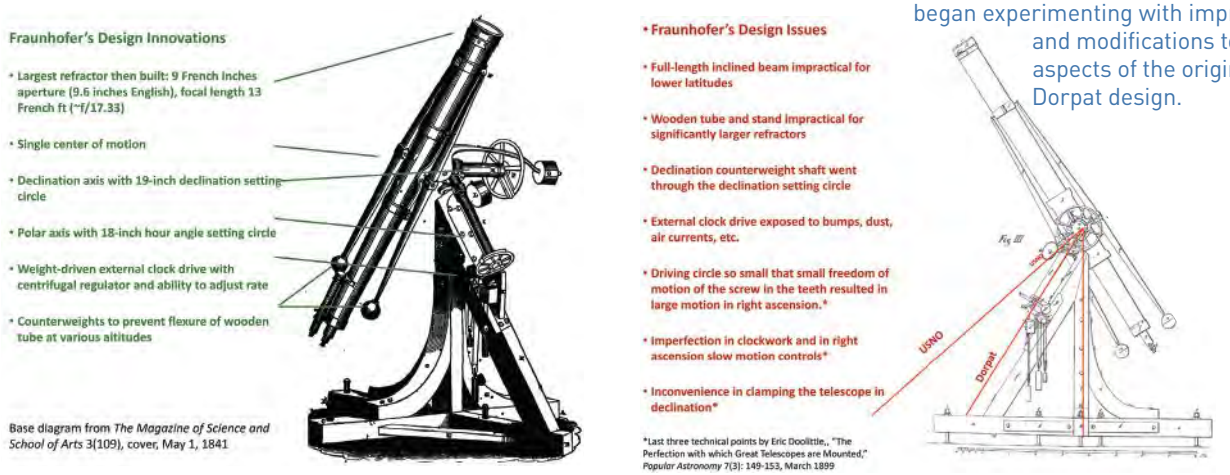
MODIFYING THE DESIGN

Historian James Lequeux, in France, has called the Dorpat telescope "the first modern refractor."[8] Although he did not specify what he meant by "modern," the Dorpat instrument's overall design was hugely influential on the general morphology of both portable and observatory telescopes worldwide in the 19th century.

No place was this truer than in the young United States. In the 1840s, published descriptions of U.S. observatories reveal that more than a dozen fixed main equatorial refractors were explicitly described as having been modeled after the "Dorpat," "Fraunhofer," or "German" style. By 1860, the number was closer to three dozen. Even later in the 19th century, images and descriptions show that most refractors had German mounts, even though that fact was no longer called out as a special point — likely because by then the style had become so universally accepted.

Figure 2 (bottom, left): Several of Fraunhofer's innovations for the Dorpat refractor heavily influenced 19th century telescope design.

Figure 3 (bottom, right): By 1840, U.S. (and European) instrument makers began experimenting with improvements and modifications to many aspects of the original Dorpat design.



But as brilliant as it was, Fraunhofer's prototype design was not perfect. Illustrations and text in periodicals, books, instrument catalogues, and observatory publications document that U.S. (and European) astronomers and instrument makers immediately began modifying or improving the pier, mount, clock drive, and tube to reduce cost or weight, or to increase the ease or comfort of visual observing. Further modifications were made later in the 19th century to accommodate the new technologies of spectroscopy and long-exposure photography.

NO BROKEN LEGS

One of the first and most obvious alterations for the American market was elimination of Fraunhofer's inclined beam supporting the polar axis and clock drive. Indeed, no U.S.-mounted Fraunhofer-style refractor ordered from any nationality of maker, including Merz, included a full-length inclined beam. Instead, the beam was truncated close to the lower end of the mount's polar axis.

That major design change is evident right from the first Merz refractor mounted in 1840 at the Philadelphia High School Observatory — a telescope credited as introducing the work of German instrument makers (plus rigorous German observational and mathematical techniques) to U.S. astronomers.[9]

Although no 19th century document explains the change, the reason for eliminating the inclined beam seems self-evident. The Dorpat Observatory was at latitude 58.4 N, so the angle of the inclined beam was very steep, remaining relatively close to the vertical support. But most of the United States falls at a substantially lower north latitude, from the mid-40s to the mid-30s. Thus, a telescope's polar axis in the U.S. must point at a lower angle than one in northern Europe.

That means that any perpendicular inclined beam would have extended a foot or two farther horizontally — posing an access challenge and even a tripping hazard. As it was, in the Dorpat Observatory itself, European astronomers Wilhelm Struve [pronounced STROO-vay] and Heinrich Schumacher each broke a leg while using the telescope.[10]

ROCK SOLID

The U.S. Navy, for its "Depot of Charts and Instruments" (the U.S. Naval Observatory at its first site in the Foggy Bottom neighborhood of Washington, D.C.) ordered a telescope from Merz identical in size (9.6 in) and detail to the Dorpat refractor with one major exception — instead of a wooden stand, the telescope was ordered to be ready to mount to a pier of stone laid in hydraulic cement and capped with a block of Maryland granite.[11] It was mounted in 1844–45.

Similarly, the Cincinnati Observatory for its 11-inch Merz refractor (installed in April 1845) and the Harvard College Observatory for its 15-inch Merz (installed in June 1847) also ordered their instruments to be adapted for mounting on a stone or masonry pier. All three instruments were fitted with Fraunhofer-style polished wooden tubes with two long brass counterweights running the full-length of the tube to prevent flexure.

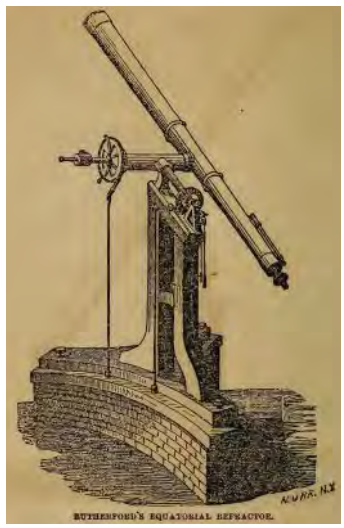
COMPACT DESIGNS

Meantime, at least by the winter of 1847–48, the early U.S. commercial telescope maker Henry Fitz in New York City was experimenting with making more compact and economical versions of Fraunhofer's wooden stand for mounting an equatorial in smaller observatories.

For a new 6-inch refractor for Lewis M. Rutherfurd's private observatory in New York City (a few blocks from Fitz's workshop in what is now Manhattan's lower east side), Fitz had his mountmakers Gregg and Rupp build a compact, streamlined three-legged variation of Fraunhofer's four-legged stand. The next year (1849), Fitz completed another three-legged wooden stand for a 5.6-inch refractor for the observatory at Erskine College in Due West, South Carolina.

Fitz also experimented with light-weighting the equatorial mount atop the wooden stand. In 1851, he completed a clock-driven 8-inch refractor for the housetop observatory of John Campbell in New York City, installed in 1852. The mount "after the Frauenhofer plan" was not made of brass, but of cast iron; both axes were cast hollow, "which gives great firmness [i.e., stiffness] with little weight."[12]





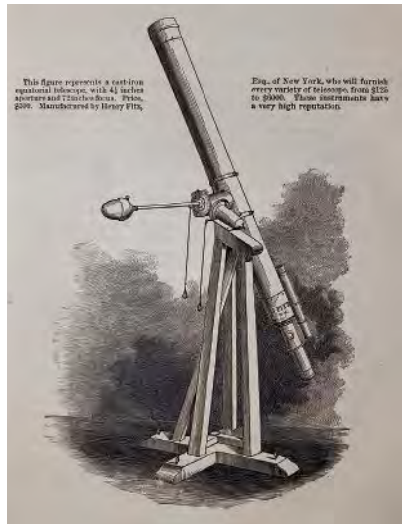


Figure 4 (bottom left): The 6½-inch Merz and Mahler refractor of the Philadelphia High School Obs., installed in 1840, is credited with introducing German telescopes and methods to the U.S. It was mounted like the famous Fraunhofer refractor at the Dorpat Obs., with two notable exceptions: there was no full-length inclined beam, and the declination counterweight no longer passed through the declination setting circle. Source: *Elias Loomis, Recent Progress of Astronomy; Especially in the United States*, (New York: Harper & Brothers, 3rd edition, 1856): p. 216. (collection of Trudy E. Bell).

Figure 5 caption is located on page 11.

By 1852, Fitz was advertising the superiority of "using a single piece of cast-iron in the place of several pieces of brass-work," which he claimed lowered the prices of his telescopes by up to $900, depending on aperture.[13]

MOVING A BIG TELESCOPE

Mid-century, before the advent of electric motors, slewing a telescope from one celestial object to another elsewhere in the sky was a manual task: the observer pushed or pulled the refractor's tube to the correct celestial coordinates (trying not to overshoot). Then he or she (or an assistant) then grabbed a handle to muscle the dome's slit in the right direction. But as telescopes grew to record size and moving mass, some other more effective, safer method was clearly needed for manhandling both telescope and dome.

One of the first changes, employed by Alvan Clark & Sons for their second world's largest refractor — the 26-inch, mounted in 1873 at the U.S. Naval Observatory (USNO)— was a system of pulleys and ropes for pointing the telescope. But ropes could absorb moisture, fray, slip, tangle, jam, snag on projections, or just be confusing in the dark.

So, astronomers and instrument makers in both Europe and the U.S. experimented with rigid control rods that could be turned and clamped by the observer from the eyepiece end. Individual functions could be distinguished in the dark by different shapes, textures, positions, or distances of the rods' wooden handles. Control rods also eliminated whatever safety hazard was posed by festoons of dangling ropes.

Figure 6 (far right, p. 8): Fitz reduced the cost and the price of a small telescope by dispensing with all elegance and ornamentation in a plain but serviceable wooden stand, such as the stand for this 4½-inch refractor. Such a crude option did not seem to be popular with school observatories — at least no description or illustration of one in that context has yet been found, but it may have found a market with budget-minded individuals. Source: Hannah M. Bouvier, *Bouvier's Familiar Astronomy ... for the use of Schools, Families, and Private Students* (Philadelphia: Sower, Barnes & Potts, 1855) p. 286. Courtesy: Astronomical Lyceum, Magdalena, New Mexico.

Fraunhofer's original 1824 clock drive for the Dorpat refractor was externally mounted on the inclined beam supporting the polar axis. So, the falling weights that powered the drive plus the rest of the mechanism were open to the air — and presumably also to bumps and dust.

At least as early as the USNO's 9.6-inch Merz refractor installed in 1844, U.S. builders fashioned piers having a vertical recess or channel to protect the falling weights. As problematic as such an external design must have been, it lasted well into the 1880s.

In the early 1880s, the placement of a telescope's clock drive changed. In 1881, when Warner & Swasey designed and built their first observatory telescope — having a 9 ½-in Clark lens for the John Smith Observatory at Beloit College in Wisconsin — they enclosed the clock drive and falling weights inside a hollow flared cylindrical iron pier. A metal door in the pier allowed access to the gravity-powered drive's centrifugal regulator.[14]

One of the first published write-ups describing Warner & Swasey's repositioning of the clock drive was a June 1884 account in *The Sidereal Messenger* of their installation of a second 9½-inch refractor, this one at the Hartford High School Observatory in Connecticut. For this instrument, a glass door allowed an observer to keep an eye on the centrifugal regulator; a handle outside the pier enabled an astronomer to raise the falling weights (necessary about every two hours) without disturbing the drive's ongoing operation.

At that time, Warner & Swasey were hoping to land the contract to mount the prospective record-breaking 36-in refractor at Lick Observatory. The Hartford instrument gave them a chance to combine all their improvements, as well as introduce the iconic rectangular pier that became Warner & Swasey's signature style.[15] Subsequently, they used images of the Hartford telescope in their advertising.

Ultimately, the Hartford instrument (plus a few other developments) so impressed the James Lick trustees with Warner & Swasey's capacity for engineering innovation and reliability that they were awarded the contract to design and mount the mechanics for the Lick 36-inch. [16]



Figure 7: This undated, colorized postcard image shows the eye end of the Lick Obs. 36-inch refractor (mounted in 1888) with handles of various control rods for moving and clamping the instrument. This telescope (and its obs. building) incorporated many innovations from Warner & Swasey. Source: Postcard in the collection of Trudy E. Bell.

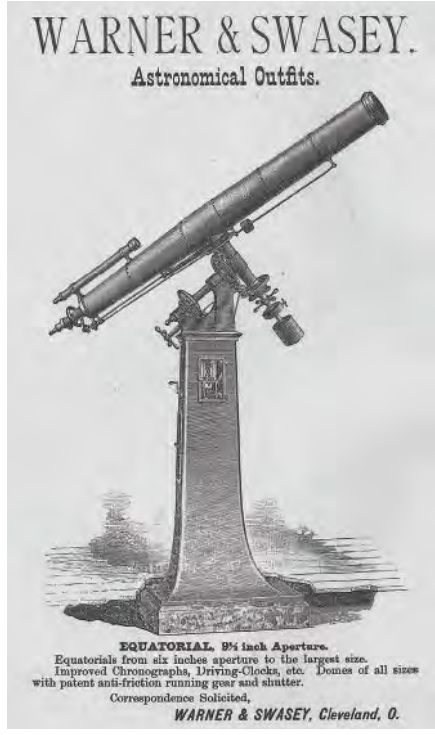


Figure 8: The 9½-inch refractor at the Hartford High School Obs. in Connecticut — about the same size as Fraunhofer's original Dorpat telescope — gave Warner & Swasey a chance to combine all their mechanical improvements, as well as introduce the familiar iconic rectangular telescope pier that became their iconic style. Credit: *The Sidereal Messenger*, March 1886, outside back cover.

OF DOMES AND FLOORS

The four largest world's-record refractors were precision instruments of truly monumental scale. Although telescope objective lenses grew larger in aperture, their focal ratios remained roughly the same as that of Fraunhofer's Dorpat refractor, in the range of f/15 to f/18 (to use modern notation). Lick Observatory's objective lens mounted in 1888 was three feet across and had a focal length of 672 inches (56 feet) for a focal ratio of f/18.7.[17]

Thus, it required a tube 57 feet long. This unprecedented length posed at least two notable engineering challenges.

First, tube length determined the diameter of an observatory's dome to allow adequate clearance for the telescope to point in all directions. Larger domes meant more moving mass, thus affecting how much effort was needed to rotate the dome. Smaller observatories relied on minimizing friction in a circular track so a dome could be pushed or pulled manually using an attached handle. Slightly larger observatories used a hand crank and gearing. But for a dome big enough to house a telescope larger than 12 inches aperture, significant problems could arise, especially since over time domes tended to go slightly out of round, increasing friction.

Genuinely big domes, however, completely defied human power. The hand-cranked dome for the Dearborn Observatory 18½-inch refractor at its first site, for example, had a circumference of about 100 feet. "It requires 666 revolutions of the crank for one [revolution] of the dome," stated director George W. Hough (pronounced HUFF). He remarked wryly, "The physical labor involved in rotating such a dome … does not leave the observer in the best condition for making observations."[18]

Ever inventive, Hough devised a way of propelling the dome using a quarter-horsepower gasoline engine. "With this arrangement one can observe with ease and comfort in any region of the heavens on the same night," he wrote in 1883.[19] This motorized solution, which came to be known as "the Hough plan," was widely adopted in observatories.

Second, tube length determined the height of the pier. It thus also determined how low or high the telescope's eyepiece would be for observing a celestial object near the horizon (tube nearly horizontal) versus one near the zenith (tube nearly vertical) — the longer the tube, the more extreme the range. For visual observation of objects high in the sky, the astronomer might recline on a movable observing couch. For objects at lower altitude, the astronomer perched on a step of a tall, wheeled observing ladder.

For the Lick 36-inch, the difference in eyepiece height was far greater than reachable by any observing ladder. Telescope engineer Sir Howard Grubb in Dublin, Ireland, proposed making a large section of the observing floor movable up and down like an elevator, which could be raised and lowered as an observer needed. A central rectangular hole cut out of the floor center would clear the pier without touching.

To his disappointment, Grubb was not chosen to build the rising-floor system; the Lick trustees chose the more local Union Iron Works company from San Francisco. Using hydraulic power supplied by rainwater captured in a 30,000-gallon mountaintop reservoir, the completed circular elevating floor measured 61 feet in diameter and weighed 25 tons. Its range of travel was 16 feet. (Water power also rotated the massive, 100-ton 75-foot dome.)[20]

The rising observing floor system proved to be so successful that it was subsequently used in the Yerkes Observatory for the 40-inch refractor. Warner & Swasey built not only the mount and 62-foot-long steel tube, but also the mammoth 90-foot dome and the rising floor (75 feet in diameter with a 23-foot range of travel).[21]

ENGINEERING AESTHETICS

The physical beauty of the early refractors was a high priority of at least some makers, including Fraunhofer. Of the original Dorpat refractor of 1824, director Struve wrote that the "tube itself is 13 feet long, constructed of deal [soft pine resistant to both humidity and insects], in the strongest and safest manner, and overlaid with mahogany, so worked that it appears like a tube of highly-polished copper." [22]

When the instrument was finally assembled and installed, Struve recounted:

> I stood astonished before this beautiful instrument, undetermined which to admire most, the beauty and elegance of the workmanship in its most 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.[23]

Two decades later, on this side of the Atlantic, the tube of the Cincinnati Observatory's 11-inch Merz mounted in 1845 was made of wood, as were the Detroit Observatory's 12-inch Fitz for the University of Michigan, Ann Arbor, in 1857 and the Harvard College Observatory's 15-inch Merz. The Dearborn Observatory's 18½-inch refractor (with both optical and mechanical parts by Alvan Clark) at its first location in Chicago in 1866 also had a wooden tube, used until 1911.[24]

WORK IN PROGRESS

Additional significant design modifications were made to both the optics and mechanics of later 19th century refractors as well as throughout the 20th century. For example, third lenses were fashioned for retrofitting a visual refractor to focus bluer "actinic" rays for photographic use (at a shorter focal length). Connectors were added to the eye end and adjustable counterweights to the sky end of a telescope tube to allow the installation and removal of massive spectroscopes and spectrographs. Electricity was introduced to illuminate eyepiece crosshairs (replacing the fumes and flammability of kerosene lamps), to power a clock drive instead of falling weights, and to slew a telescope, rotate its dome, and raise or lower an observing floor.

Together, Fraunhofer's fundamental design plus others' important modifications evolved into the German-mounted refracting telescopes used today. Moreover, the engineering advances laid foundations for the building of the even larger giant record-setting ground-based reflecting telescopes of the 20th and 21st centuries.

Gratitude is expressed to John W. Briggs (Astronomical Lyceum, Magdalena, New Mexico), Bart Fried, Kenneth Launie, Horace H. Smith, and the late Paolo Brenni — all members of the 35-year old international Antique Telescope Society — for helpful suggestions and illustrations. Thanks also go to engineer Dan Sweeny for insights about materials.

Selected References listed on page 39.



Figure 9 (above): The 57-foot length of the segmented steel tube for the Lick Observatory 36-inch refractor was accommodated by making most of the circular floor rise and lower like an elevator. This engraving shows the floor at its lowest position for observing objects high in the sky. At the floor's highest position (for observing objects at low elevation), the floor could rise to the mezzanine level (where two figures stand). Source: Library of Congress.

Figure 5 (middle, p.8): Lewis M. Rutherfurd's 6-inch equatorial refractor with optics by Henry Fitz, installed in 1848, was mounted by Gregg and Rupp on a brick pier. Note that it differed from the Dorpat refractor not only in having no full-length inclined beam, but also in having only three legs instead of four. Moreover, Fraunhofer's short straight cross-braces were also replaced with a continuous curved piece of wood echoed by the supporting bricks. Source: Hiram Mattison, *A High-School Astronomy...*, (New York: Mason Bros., 1859), p. 226.



Figure 10: The Dearborn Observatory telescope, installed in 1866 at its first site in Chicago, was the largest refractor in the U.S. to have a wooden tube. The wooden tube was also used until 1911 at its second site on the campus of Northwestern University in Evanston. At that time, the objective lens was given a new steel tube and mount by Warner & Swasey. The wooden tube and its original brass mount by Alvan Clark & Sons have been preserved and are on display in the Adler Planetarium and Astronomical Museum in Chicago. Photo credit: Trudy E. Bell, June 2025.

WHAT INSPIRED FRAUNHOFER?

This article is strictly on influence of Fraunhofer's pioneering German equatorial mount for the Dorpat refractor on follow-on astronomical refractors in 19th century America. For those interested in European predecessors to Fraunhofer's design, on YouTube there is an excellent 84-minute Harvard-Smithsonian colloquium presentation by Dartmouth historian Richard Kremer recorded in 2016 (*https://www.youtube.com/watch?v=103DoEMYepI*).

Finding evidence for what exactly inspired Fraunhofer's innovative design for the mount and clock drive is difficult, Kremer found, because artisans rarely wrote down such things, much less published their writings, in part because they regarded such information as competitive trade secrets. The same is also true, I found, for many subsequent alterations discussed in this article. Often illustrations were more eloquent than any accompanying text — a picture is indeed worth a thousand words.

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... Evolution of Giant Telescopes ... Continued from page 11.

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22. [W. Struve], reference 3, page 95.

23. [W. Struve], reference 3, pages 93-94.

24. Whitesell, p. 59; W&A: pp. 87-89; Ian R. Bartky, "Chicago's Dearborn Observatory: a study in survival," *Journal of Astronomical History and Heritage*, 3(2): pp. 93–114. December 2000.