THE 15-INCH GREAT REFRACTOR of the HARVARD COLLEGE OBSERVATORY

A Study of its History, Current Condition
and Future Utilization

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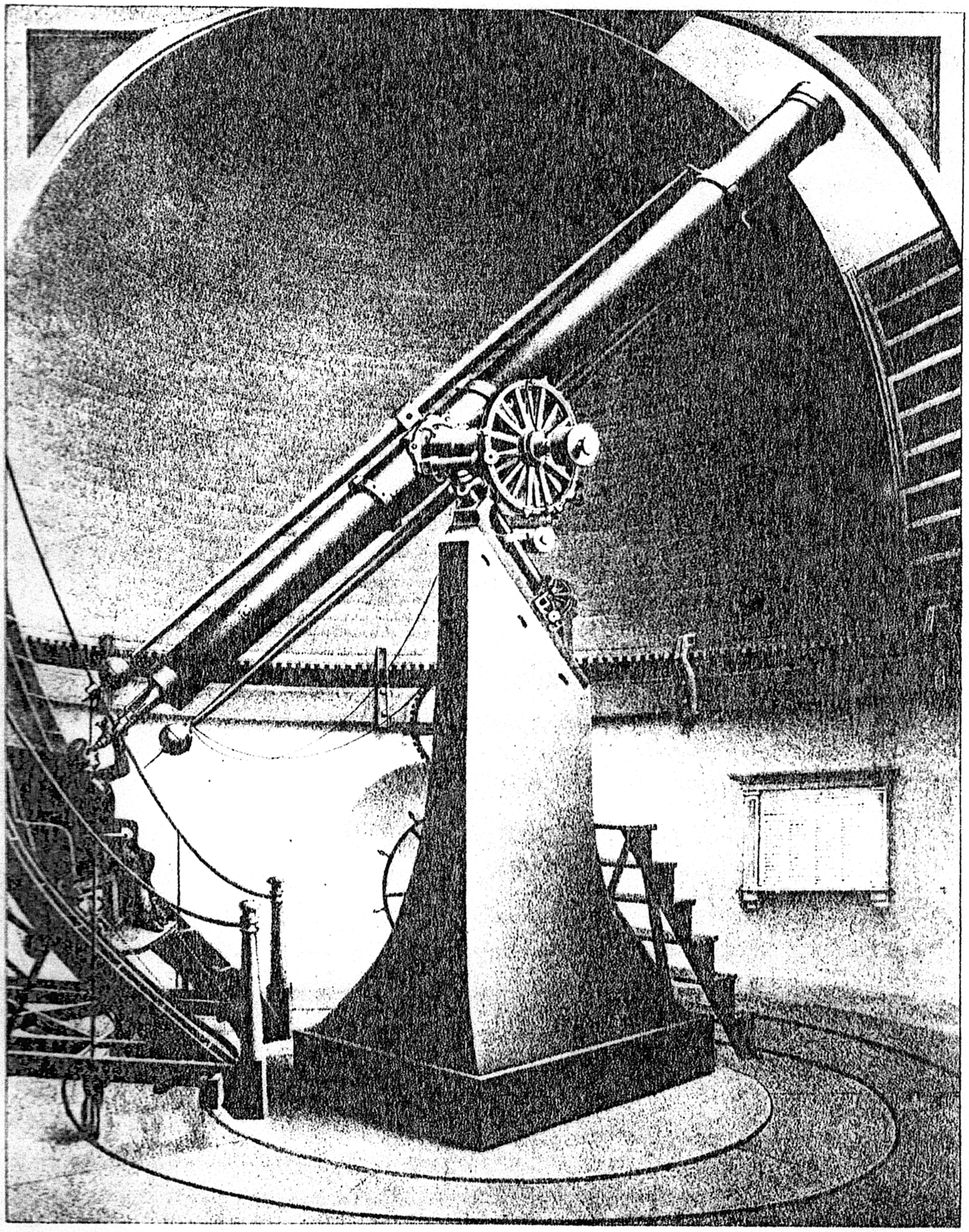

The HCO 15-Inch Refractor

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INTRODUCTION

The 15-inch telescope has been established at the Harvard College Observatory for nearly 123 years. After an active life of 70 years the instrument ceased to be generally used and during the last half century has been devoted to occasional observing associated with public open nights, freshman seminars, and irregular student use. The electrical drive system installed on the right ascension axis in 1955 has persistently given trouble, and by the spring of this year had become so erratic that it prevented any effective use of the telescope. This prompted a study to be undertaken in May 1969 to determine the condition of the telescope and possible future courses of action, including financial requirements. Three broad approaches were initially considered: a) restore the telescope to operation; b) alter its status to that of a static exhibit; or c) close up the area because of possible safety considerations or financial limitations on maintenance.

Early investigation quickly revealed the surprising fact that very little information was collectively available on the telescope's origin, historical significance, use at the Observatory, and maintenance, repair, or rebuilding. Hence, it has seemed appropriate to spend somewhat more time and effort than was originally planned to learn about and interpret this instrument so that its future could be planned with the greatest understanding. Because a study of the instrument itself must also consider the building and dome that surround it, these too have been examined and reported upon.

It is the purpose of this report, therefore, to bring together information from many scattered sources, not only to support the conclusions that have been drawn, but hopefully to serve as a point of departure for any later work on or interest in the telescope.

EARLY HISTORICAL BACKGROUND

The significance of the 15-inch refractor at Harvard among historical astronomical instruments is manifold. Although no one aspect is so predominant as to overshadow any other, all together they yield a decisive endorsement of the historical value of this instrument. This conclusion can be drawn from a consideration of the lineage of the telescope, its place in the formative stages of American astronomy in the mid-nineteenth century, and the original contributions to astronomy derived from painstaking work with this instrument.

Lineage

The Harvard 15-inch telescope is a primary example of the early great refractors of the nineteenth century. During a period of nearly 75 years, the achromatic astronomical telescope was developed from the earliest effective example--the Dorpat instrument completed in 1824--through what is still the largest instrument--the 40-inch refractor at Yerkes, completed in 1897. The first half of this period was dominated by instruments of the same character as the Harvard telescope, while the second half was almost wholly the result of innovations by the American firm of Alvan Clark (see Figure 1). All of these developments were prompted by two major factors: practical difficulties in the further development of speculum reflectors, and the availability of high-grade optical glass.

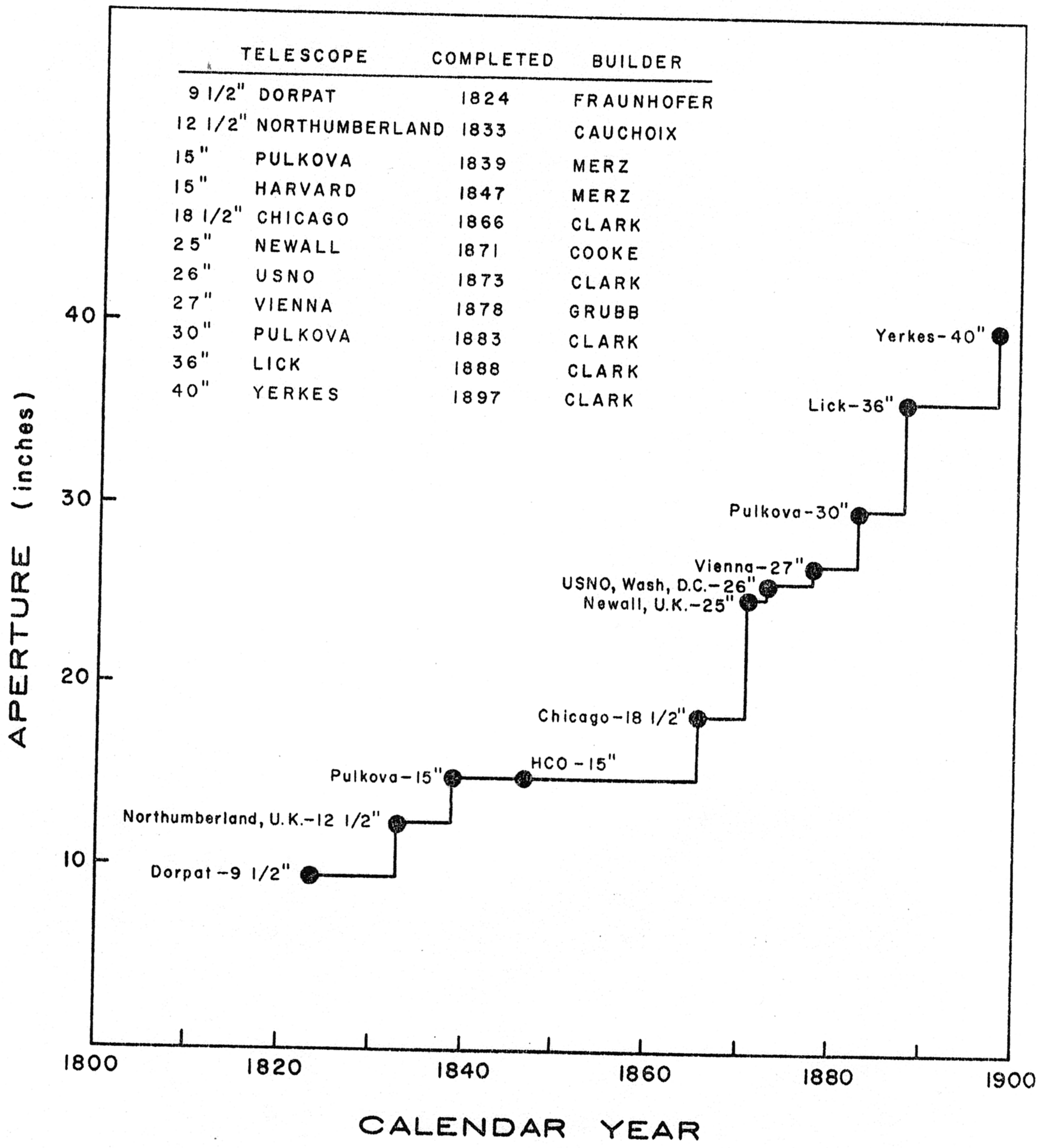


Figure 1. The Largest Acromatic Refractors

The latter part of the eighteenth century was characterized by the development and use of larger and larger reflecting telescopes with speculum metal mirrors. The culmination of this activity was the completion of a 48-inch diameter, 40-foot focal length reflector by Sir William Herschel in 1789. Although this instrument resulted in the discovery of the sixth and seventh satellites of Saturn, it proved less than satisfactory for the same reasons that applied to all reflectors of the time. The metal mirrors, or specula, were cumbersome to mount because of their great weight, and more important, the techniques of manufacturing and figuring large mirrors in speculum were not adequate to the task of producing a high quality optical surface. The real preeminence of reflectors would not come until nearly a century later, after the development of the silvering process by Liebig and its astronomical application in 1856 by Steinheil and Foucault which allowed the use of glass as a mirror substrate material. Even Lord Rosse's 6-foot speculum telescope, completed in 1845, suffered from the same difficulties encountered with the earlier metal-mirrored instruments and was thought less than successful.

The second factor leading to the "Great Refractors" was the development of techniques for producing high quality optical glass in large sizes. C.M. Hall is generally credited with discovering the principle of the achromatic

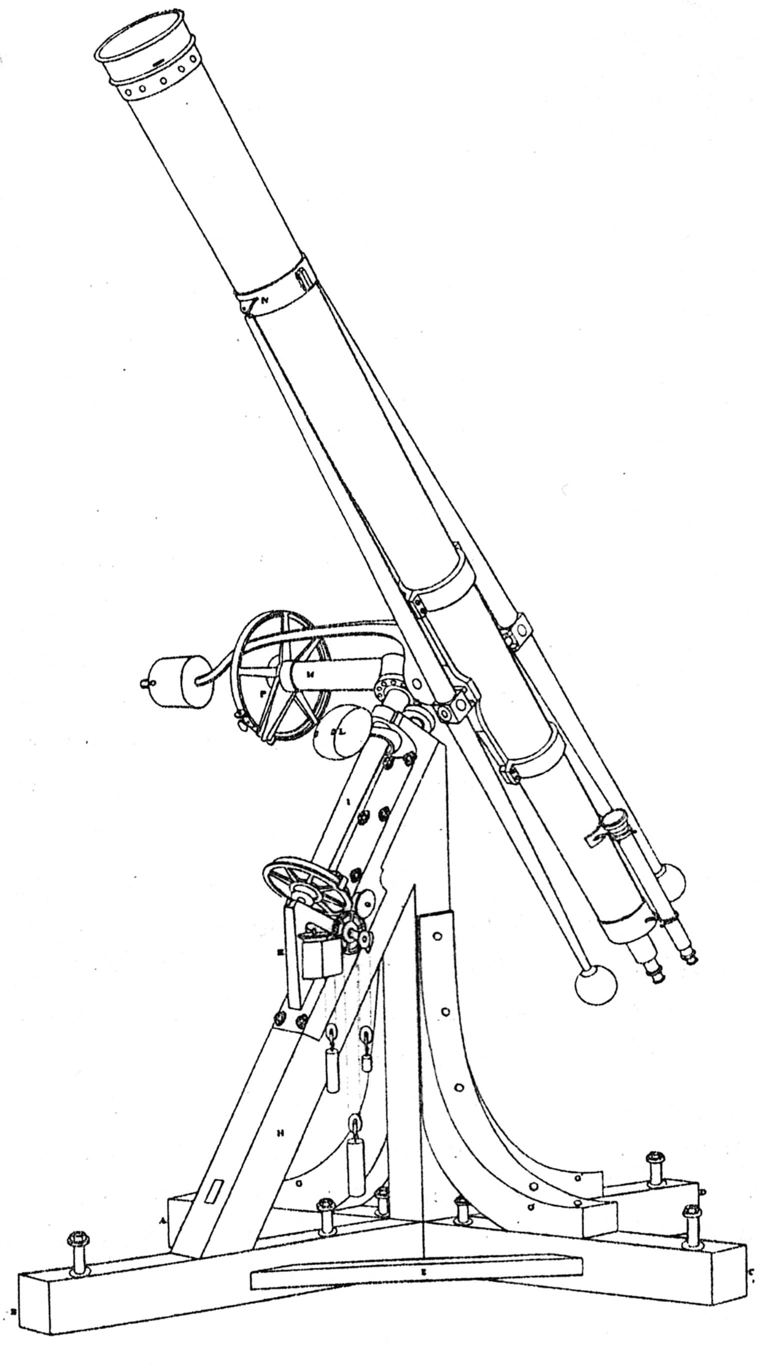


Figure 2. The Dorpat 9½-Inch Refractor

lens in 1729. This concept was developed and elaborated upon by John and Peter Dollond in the last half of the eighteenth century but was severely limited by the scarcity of high quality optical glass.

The advancement of the technology of optical glass manufacture started with Guinand in 1783. His success was considerable, and in 1806 he was asked to join the Munich Optical Institute where he met the young Fraunhofer. Fraunhofer had likewise come to the Institute that year after an abortive apprenticeship in ornamental glass cutting. In 1809 Fraunhofer was given sole charge of the glass works and by arrangement was instructed by Guinand in his methods. He became Director of the Optical Institute in 1820. Fraunhofer's further development of glass making and lens manufacture progressed quickly and culminated in the world's first major achromatic telescope of large aperture and high quality--the 9½-inch Dorpat Equatorial (Figure 2). This telescope was installed in the Observatory at Dorpat, Imperial Russia, and entrusted to Wilhelm Struve who rapidly expanded the knowledge of double stars using this excellent instrument.

The objective for the Dorpat telescope, completed in December of 1817, had an aperture of 9½ inches and a focal length of 14 feet. The telescope was installed and operating at the Dorpat Observatory late in 1824. In addition to its role as the first major achromatic refractor, the telescope embodied several other features that made it unique. It was the first installation to make effective use of a clockwork drive on the right ascension axis. It was the first practical use--possibly the first one ever--of the classical "German" mount attributed to Fraunhofer. Also, as can be seen by comparing the frontispiece and Figure 2, the Dorpat refractor was the prototype of the telescope mountings used by Fraunhofer and his successors through at least 1850. Study of the literature shows that many of the mounting and constructional features of the Harvard 15-inch telescope were identical, except in scale, to this first important large refractor. Although Fraunhofer died in 1826, his assistant since 1808, George Merz, continued with the glass works and telescope manufacture at the Munich Optical Institute, eventually purchasing the entire enterprise in 1839 with the financial help of his friend Mahler. Mahler died in 1845, but the glass works continued to exist under Merz and his family until 1884, and under others well into the 20th Century.

Fraunhofer and the successor firm of Merz and Mahler built a large number of telescopes, but the three principal ones--two of which were the largest of their time (as indicated in Figure 1)--were the original Dorpat refractor, the 15-inch refractor built for the Pulkova Observatory and completed in 1839, and the 15-inch telescope delivered to the Harvard Observatory in 1846. The Dorpat telescope apparently still exists in a museum in the USSR, although only the objective of the Pulkova instrument survived World War II.

The 12½-inch refractor completed in 1833 is not of the Fraunhofer lineage. It was built by R. Cauchoix for Sir George Airy at the Royal Observatory and had an objective constructed of glass produced by Guinand after his separation from the Munich Institute. This instrument is said to be still in existence although there is a scarcity of information about it. The original mount was of the English form.

With only two exceptions the remaining telescopes in the list of the largest refractors (Figure 1) were made by Alvan Clark and Company in Cambridge, Massachusetts, and all represent a later design era than that of the telescopes mentioned previously. Hence, the Harvard telescope is a primary example of the early achromatic refractors made by the Fraunhofer group, and may well be the only major example extant or in nearly its original form and surroundings.

Historical Position in American Astronomy

The position of the Harvard Observatory and the 15-inch telescope in the rapidly developing field of American astronomy in the nineteenth century is not easy to fix. Although the instrument's role had several unique aspects, it certainly was not the first major telescope nor was it a part of the first observatory in the United States.

The climate for public funding of astronomical ventures was not favorable in the early nineteenth century, but instruments and observatories were nonetheless built. The first known permanently fixed American instrument was installed in 1828 at Yale College. It was a 5-inch diameter refracting telescope by Dollond, set up in a church steeple on a simple altitude-azimuth mount. In 1836 a modest observatory (ascribed to be the first in the United States) opened at Williams College under Professor Hopkins and included a "Herschellian telescope of 10 foot focus" (Ref. 2) on an equatorial mount within a revolving dome. This observatory also included a transit instrument and a Molineaux clock. 1836 also marked the year in which Wesleyan College acquired a 6-inch Lerebours refractor. In 1838 observations were initiated at Western Reserve College in Ohio with a 4-inch diameter Simms refractor mounted in a rotating dome. This observatory also included a transit circle by Simms and a Molineux clock.

Perhaps the most significant telescope installation of this decade was completed at the High School Observatory of Philadelphia where, in 1840, a 6-inch equatorial by Merz and Mahler was installed in a rotating dome. According to Loomis (Ref. 2), this telescope was "mounted like the celebrated telescope at Dorpat" and "formed an epoch in the history of American astronomy in consequence of the introduction of a superior class of instruments to any hitherto imported." During the 1850's the USNO and this observatory, which included a meridian circle by Ertel and an astronomical clock, was mentioned a number of times by Bond in the context of establishing standard meridians in the United States.

The West Point Observatory was in operation in the early 1840's with a 6-inch diameter Lerebours refractor on an equatorial mount by Grubb, and the National Observatory at Washington was making observations in early 1845 with an equatorial of 9.6-inch diameter by Merz and Mahler. (An old picture--1874--reproduced in February 1956 issue of _Sky and Telescope_ reveals strong similarities among the USNO, Dorpat, and Harvard College instruments.) This major observatory housed numerous instruments including a meridian circle and a prime vertical.

The Cincinnati Observatory appears to have commenced operations in 1845 with an equatorial by Merz and Mahler of 12-inch aperture, and several smaller observatories reached completion within the next year or two.

Hence, the Harvard Observatory, which achieved operation with its 15-inch telescope on June 24, 1847, was in the middle of a considerable amount of astronomical activity in America.

Interest in astronomy at Harvard dated from much earlier, however. In 1761 Professor Winthrop gathered up some instruments and sailed to Newfoundland to observe a Venus transit. Professor Williams was encouraged in 1780 to proceed to the Penobscot area for the observation of a solar eclipse. Some of the equipment used in these expeditions still exists in the Harvard collection of historic scientific instruments.

On May 10, 1815, the President and the Corporation of Harvard voted to form a committee to "consider upon the subject of an observatory, and report to the Corporation their opinion upon the most eligible plan for the same, and the site" (Ref. 3a). This is reputed to be the first corporate act in the United States toward the establishment of an observatory. A committee was appointed which wrote to William C. Bond (a prominent Boston clockmaker and later the first director of the Harvard Observatory) in Europe in June, 1815, "to undertake comprehensive inquiries in Europe and

England concerning the construction of the required instruments and buildings" (Ref. 3a). A review of the information returned by Bond revealed that the cost of a first-class observatory far exceeded previous estimates, and the plans were suspended for lack of support. A similar fate befell a revival of the idea in 1822 and another in 1823, the latter by John Quincy Adams.

Finally, however, in 1839 the Harvard Corporation voted to engage Mr. Bond and his apparatus and install it in the Dana House which then stood on the present site of the Lamont Library in Harvard Yard. This structure was modified and various instruments installed in late 1839, with the first transit measurement accomplished on December 31, 1839. In April, 1840, the American Academy of Arts and Sciences voted to provide additional magnetic and meteorological instruments for installation in this observatory. Various clocks were mounted along with several barometers. A transit circle by Troughton and Simms was installed (with a stone tower meridian mark on the Great Blue Hill in Milton, Massachusetts) along with various other instruments, including a 5-foot reflecting telescope by Short. (This last instrument still exists at Harvard.) Two additional small refractors from previously owned college equipment were placed in use.

Although this early observatory was rather makeshift, it was not until 1843--with the appearance of a great comet in March--that public interest was sufficiently aroused to permit the subscription of funds for a truly first-class observatory. The College then purchased the present site of the Observatory--Summer House Hill of the old Craigie Estate between Concord Avenue and Garden Street--and a building and dome were erected (Sears Tower) with a donation from David Sears. The "Great Refractor" was ordered in 1843, and the object glass arrived on December 4, 1846. Assembly of the instrument took place in June, 1847, with the first brief observations on the 24th. The central tower and dome cost $5000 and the telescope $19,842, the latter sum donated by a number of institutions and individuals whose names are preserved on the marble plaque in the dome. A variety of other instruments, including a transit circle by Simms, a comet seeker telescope by Merz and Mahler, various clocks, and a $4\frac{1}{4}$-inch equatorially mounted refractor, were assembled through the period up to 1851 when the remaining major structures on the property were completed.

The Observatory's formative years through 1855 are very richly and thoroughly described by William Bond in Volume I of <u>The Annals</u> (Ref. 3a). It might be rewarding to have that material, along with other published but obscure historical sources, available for wider circulation.

Although it has been shown that the Harvard Observatory with its 15-inch telescope was certainly not the first such astronomical institution in this country, several important points can be made. The 15-inch telescope was certainly the largest telescope in the United States from the time of its installation in 1847 for some 19 years until Clark's completion of the $18\frac{1}{2}$-inch refractor for the University of Chicago in 1866. It was also the most significant American instrument during this period, being the cornerstone around which the Harvard College Observatory was formed and yielding ample return on the clear purpose of having an instrument equal to the finest in the world at that time.

Finally, the Harvard Observatory earned an enviable international reputation during this early period through the devoted and foresighted work of William C. Bond, accomplished in considerable measure with the 15-inch telescope.

Early Contributions to Astronomy

A substantial amount of original work has been done with the 15-inch telescope through the years. Although comprehensive treatment of such contributions may be found in Bailey's History and Work of the Harvard Observatory (Ref. 7), a few popular high points can be mentioned. The eighth satellite of Saturn was discovered on September 19, 1848 (independent of a nearly simultaneous sighting in England). In the first successful attempt to photograph a stellar image, Vega was recorded by daguerreotype on July 17, 1850, yielding a technique for which "the advantage would be incalculable" (Ref. 3a). Also in 1850, on November 15, Bond discovered Saturn's dusky, or inner, ring with the 15-inch telescope.

The early years of the telescope's existence were devoted predominantly to the measurement of stellar positions and separations, while later years were almost wholly given over to stellar photometry by Wendell under Pickering. Abundant details can be found in the Annals (Ref. 3) and in the Annual Reports of the Observatory (Ref. 15).

Although original observations are more a function of the observer than they are of the instrument, suffice it to say that a number of significant and unique observations and programs have been accomplished with this telescope from the very first.

LATER SERVICE AND ALTERATIONS

After its acquisition and installation, the 15-inch telescope continued to be used actively by selected observers for nearly three-quarters of a century. The first 30 years of work were characterized by the determination of stellar positions and by visual observations of planets, variable stars, comets, and nebulae. Stellar photography was explored, for which purpose a new and more accurate clock drive was installed in 1857 by Alvan Clark. Although traces of surface deposits ("efflorescence") on the objective began to be discernible before 1860, these never became objectionable. The old "West Equatorial" of $4\frac{1}{4}$-inch aperture was remounted as the finder for the 15-inch telescope in 1868.

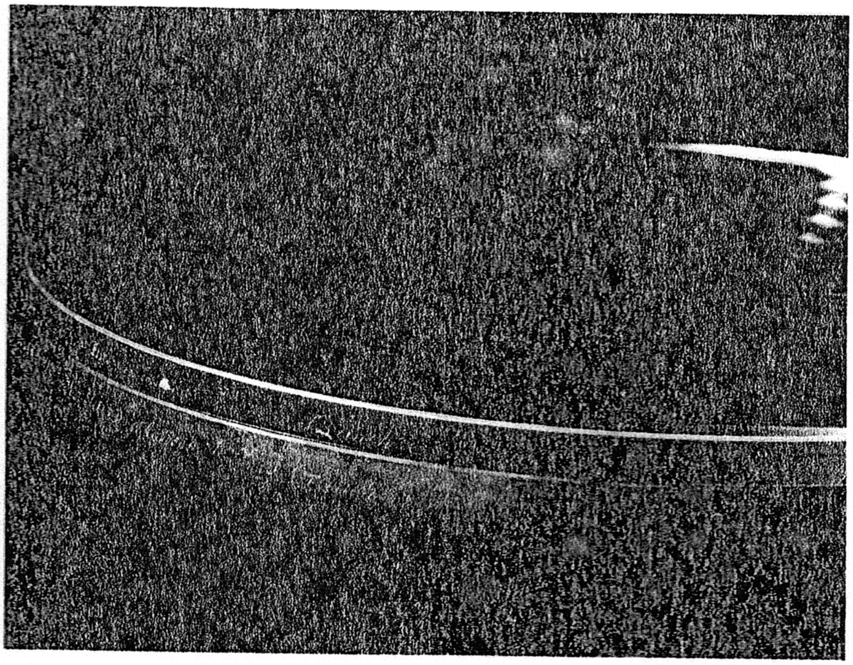
After being appointed Director of the Harvard College Observatory in 1877, E.C. Pickering proposed in his first annual report a new program emphasis for the 15-inch telescope--the field of photometry, which was to be its principal occupation for the remaining active years. O.C. Wendell joined the Observatory in 1879 and was the foremost, and later the only, observer on the telescope. His work included the determination of stellar magnitudes, variable star observations, stellar spectroscopy, comet observations, and eclipse studies of Jupiter's satellites. He was joined in this occasionally by Dr. Pickering. With Wendell's death in November 1912, active use of the telescope ceased.

During Harlow Shapely's directorship from 1921 through 1952, reference to the 15-inch telescope is nearly absent in the Annual Reports (Ref. 15) and other sources. Nonetheless, it appears that the telescope was used regularly for public "open houses" and also occasionally by students. Certainly many people, including the writer, have recollections of going into the darkened dome at night and observing one of the planets through the eyepiece.

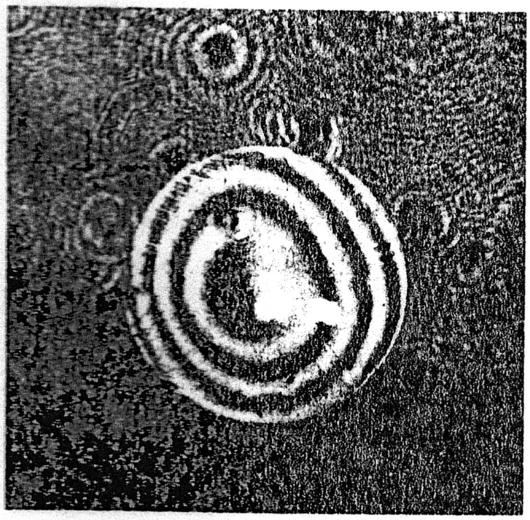
As one of the few recent uses, brief mention is made in the 1951 Annual Report of Richard Dunn, then a graduate student, installing a birefringent filter of his own construction on the "ancient 15-inch refractor"(Ref. 15) to observe solar spicules and prominences.

In 1953 the Observatory Council determined to "modernize the 100-year-old telescope into an important research instrument" as part of a larger observatory revitalization program (Ref. 15, 1956). An optical system was designed by Dr. James Baker and constructed by Chester Cook and James Gagan at the Observatory. (It was a Schupmann catadioptric system and was taken to Sacramento Peak by Dunn for testing. Of less than satisfactory performance, this system is thought by Dunn to be in a box at Sacramento Peak to this day.) The telescope tube and mounting were disassembled and stripped of their paint and dirt (they had previously been painted black or gray). An accident occurred during this dismounting which destroyed the objective end of the wooden tube (although the objective itself was unharmed) and did minor damage to the dome. The mechanical clock drive on the right ascension axis was removed and discarded, and a new electrical drive with clutch was added to that axis. Also, a clamp and electrical drive were added to the declination axis. These operations, including the painting of the dome and installation of a new floor covering, were concluded in 1955. Meanwhile the first floor of the rotunda was completely stripped and rebuilt into its present form in the period from 1954 to 1956 to provide a display area for models, transparencies, and other interesting material. In the following year the old prime vertical room (attached to the north wall of the tower) was redecorated as a chart room. This small annex no longer exists, having been removed when Building B was constructed. Also associated with this period was the replacement of the copper sheathing on the top half of the dome.

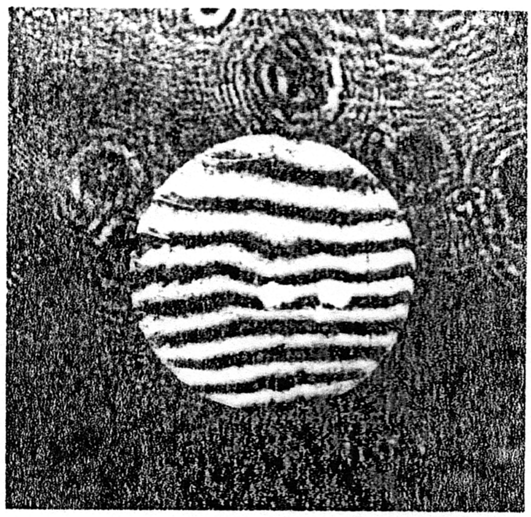
The telescope is used to the present day by occasional students and for public "open houses." This has been limited somewhat by the generally poor performance of the right ascension clutch--the problem that gave rise to this study.



(a) Inscription on the edge



(b) Interferogram at null



(c) Interferogram away from null

Figure 3. The HCO 15-Inch Refractor Objective Lens

PRESENT STATE OF THE INSTRUMENT, EQUIPMENT, AND BUILDING

A detailed study of the Harvard 15-inch telescope was undertaken in May 1969. In addition to unearthing the early history of the instrument, dome, and tower, individual components were critically examined and evaluated. The nature and results of the latter work are described in this section of the report.

Objective

Because of its vital character and historical interest, the objective lens of the telescope received considerable study. It is of conventional "Fraunhofer" form consisting of a biconvex crown element followed by a concave-plano flint element, with nearly equal radii on the first three surfaces. This objective, one of two prepared for the Pulkova 15-inch telescope in 1838, was rejected by Professor Struve for being of inferior quality at that time. It was refigured as one of two objectives for Harvard in 1846 and after testing was held by Merz as being "very much better" than the Pulkova objective.

Initial inspection for this study revealed that the inter-element lead spacers were not aligned with the external pressure pads in the lens cell. (This may account for reports of inferior performance by users during this last year. The lens was last disassembled 1½ years ago by others.) After removal of the cell from the telescope, a Ronchi test was performed with inconclusive results. The lens elements were then removed from the cell, and it was rewarding to find the original inscription, "Harvard College W.S.J. Cranch Munich May 15, 1846," on the edge of both elements, verifying their authenticity (see Figure 4). Measurements were taken of the surface radii and spacings, and the indices of refraction were determined indirectly. The elements were qualitatively inspected for strain, and the size and number of the bubbles and seeds were evaluated. The four surfaces were examined under an electron microscope to determine the quality of surface finish and the degree of deterioration that had occurred over their lifetime.

After cleaning, the elements were reassembled with new lead spacers, and the objective was tested through the courtesy of the Perkin-Elmer Corporation in their modern interferometric equipment. The data show that the maximum wavefront distortion produced by the objective is approximately $\frac{1}{4}$ wave at λ 6500 Å. Figures 4b and 4c are two representative interferograms taken with the lens mounted in Perkin-Elmer's lens test chamber in the autocollimation (i.e., two pass) mode. Figure 4b is the interference pattern between a plane reference wavetrain and the spherical wavetrain produced by the lens, observed at the null point. Figure 4c is the same pattern, but observed away from the null yielding nearly straight fringes. In both cases the fringes are superimposed on the image of the objective so that the distribution of irregularities can be identified. The irregular background ripples and the two light spots are artifacts from the interferometer. Finally, achromatism, or color correction, was evaluated before the objective was replaced on the telescope.

Since it is intended to report the detailed results of these various tests separately, they will not be discussed further here. Suffice it to say that the objective is quite good for a visual element by modern standards. Its shortest focus is at approximately λ 5700 Å, and it is somewhat over-corrected for color as is customary in visual objectives.

The lens mountings are quite conventional although the axial restraining ring does not seem to be original and is somewhat cruder than expected. There are conventional, but internal, adjustments for squaring the cell on the tube, thereby requiring the cell to be removed for each trial adjustment.

Tube and Mount

The tube is constructed of a light fir-type wood of about one-inch total wall thickness, tapering from about 16½ inches diameter at the objective end to 12 inches diameter at the tail piece. The one-inch wall thickness is composed of strips, each approximately ⅓-inch thick and one-inch wide, laid down in three layers with staggered joints. The outer surface is veneered with mahogony, and the inside is covered with a cardboard-cloth laminate. A number of internal metal rings down the length serve as aperture stops and tube stiffening members. They are cut to yield an unvignetted field of view of about 3 inches, or 0.6 degrees. The upper part of the tube, damaged during the disassembly in 1955, has been replaced with a 3½-foot length of steel tubing slipped over the 15-inch butt end of the wooden tube, wedged, and through-bolted in place. The extra weight of the steel has required approximately 85 pounds of lead to be affixed externally at the tailpiece end; the lead maintains balance but alters the deflections of the tube and optical axis.

The condition of the wooden tube appears to be excellent although shrinkage over the years has resulted in looseness of the various clamp bands and a crack that extends approximately two-thirds of the length of the tube from the tailpiece end. The crack has been partially filled with a graving piece of mahogony. Because of the tube's shrinkage and taper, it appears that it may slip out of the yoke if the objective end were depressed. This should be carefully checked before any work on the objective is attempted in this manner.

Considering the age of the telescope, the yoke, axles, and bearings of the German mount appear to be in reasonable condition in all respects. The lubrication appears to have been adequate, and no damage is evident. Similarly, the counterweight systems, which reduce the deflections of the tube and reduce the loads on the axle bearings, are also in good condition with the exception that one of the tube counterweight shafts is bent approximately 4 inches from straight (resulting from the same accident that damaged the tube itself). All of these mount parts were carefully disassembled and cleaned during the rebuilding in 1955.

The configuration at the tailpiece consists of a heavy brass ring through-bolted to the wooden tube and carrying a crude steel sole plate to which the removable brass end piece and focusing slide are attached. Considering the number of pieces of equipment that have been adapted to this end over the years, it is hard to verify the age of most of the parts. However, I think the main pieces are original.

There is a position circle for moving and reading out the rotation of the eyepiece carrier, but it is not original as it does not conform with the original description of that device. No other auxiliary equipment known to belong to the telescope has been unearthed at Cambridge or the Agassiz Station.

Drive Systems

The existing recent electrical drives on the declination and right ascension axes have serious design deficiencies that render them unsatisfactory in service. They both date from the same period--1955--at which time the right ascension drive replaced an earlier clock-regulated segment drive, and the declination system supplemented a previously undriven axis.

Historically, the first right ascension drive was the one provided by Merz and Mahler with the original telescope. This was unsatisfactory from the beginning being "disproportionate to the other parts of the telescope and in cold weather requires frequent adjustment" (Ref. 1). It was replaced in 1857 with a better system made by Alvan Clark to provide precise regulation for astro-photography. It seems probable that the clock-regulated drive system removed in 1955 (illustrated in Ref. 7) is this Clark system. Its whereabouts is unknown, but it is being traced.

The present polar drive consists of two synchronous motors driving into a differential unit, thereby providing tracking and setting rates derived from a variable frequency oscillator. This unit provides the input to the apparently original worm and worm gear on the polar axle. Clutching is accomplished with a (genetically unreliable) complex system of motors, lead screws, linkages, brake shoes, and timers. If the electrical drive is to be retained, the clutch should be replaced with one of simpler and more straightforward design. In addition to being more reliable, it would occupy less space and be easier to maintain. The motors and differential gear box are adequate and can be retained. By its very nature, however, this drive system will never be extremely precise because of the small diameter of the worm gear. The Clark mechanical drive avoided this difficulty by using a segment gear of much larger radius clamped directly upon the polar axle. A slip clutch, set to release at a torque low enough to prevent damage to the drive system, should be included in any modification of this drive system.

The declination drive, although crudely built, is largely satisfactory. It does seem unnecessary, however, and because of the small face width on the main brass declination gear, is liable to damage when the declination clutch is engaged. Two teeth have already broken from this gear and a number of others are badly worn. If the system is to be retained, the final gear should be replaced with one of greater strength, and a slip clutch should be installed to prevent overloading. The main declination gear appears to be of recent origin, perhaps 1955, although the details are unknown.

The electrical control console, consisting of a variable frequency oscillator and a variety of control switches and indicator lights, is in satisfactory and workable condition although of obsolete design. The lack of any significant design information, however, makes maintenance difficult, and a modest amount of time should be spent tracing its wiring and recording its plan so as to permit future maintenance. For the same reason the wiring on the telescope, including the remote control paddle and junction boxes, should be traced.

The original hour circle provided with the telescope was 18 inches in diameter, divided on silver, and read with two verniers to one second of time. It was very difficult to use, however, and was supplemented in 1867 with a small finding circle which is still mounted on that axis. The original hour circle was later removed but its whereabouts is presently unknown.

It appears that the declination axis had only manual adjustment clamping prior to 1955. The original declination graduations were divided on a 26-inch diameter circle and read to four seconds of arc with four verniers. Like the R.A. axis, this circle was supplemented with a more easily read circle, and the precise circle was later removed completely. Its present location is also unknown.

Eyepieces

At the present time, there is a box containing 15 apparently old eyepieces of various magnifications and constructions. There are also a half dozen miscellaneous eyepieces of various ages (including new) by various makers. Some of them are homemade. None was inspected in any detail except to determine the general absence of historical markings. The telescope is fitted with a recent clamp-type eyepiece holder that will accept any of these eyepieces.

The telescope was originally fitted with 18 eyepieces, some with crosshairs, with powers ranging from 100 to 2000.

Various references mention the addition of new eyepieces from time to time. It has not been determined whether any of the original eyepieces are among the existing collection.

Observer's Chair

William Bond took considerable pride in the design of the observer's chair to complement the telescope. It incorporated many of his original ideas and was described in as great detail as the telescope itself in Volume I of the Annals (Ref. 3a). The device is still in remarkably sound condition. The basic framework has been inspected and found to be entirely sound and tight with only minor fastening and gluing required at this time. The undercarriage, including wheels, axles, and bearings, shows very little wear, and the azimuth and elevation drives are basically sound although in need of adjustment and maintenance.

The chair proper needs more attention. The framework is weak and should be disassembled and reinforced before further deterioration occurs. Reupholstery is also necessary.

Finder Telescope

There have been at least three finder telescopes used on the 15-inch instrument over the years. During this study, the existing one was removed and disassembled for inspection. The objective is of 5.37-inch clear aperture and 69-inch focal length and is an airspaced achromat with fairly strong curvatures. When the glass was removed from the cell for cleaning, the inscription "John Clacey, maker, 1906" was found on the edge. From the makeshift nature of its fitting, it is obvious that the objective cell was not originally part of the existing telescope body. No further identification has been found on the body, although it was at one time an independent instrument as evidenced by a series of holes appropriate for attaching such a mounting. The instrument has been fitted with a modern large-field eyepiece, although this is not ideal because of the small eye relief and lack of crosshairs.

As a point of information, the original finder telescope was of 3-inch aperture and 45-inch focal length. This was removed in 1868 in favor of the old West Equatorial (Munich objective, mounting by Simms, 4¼-inch aperture, 5-foot focal length) which was mounted in its place. A new West Equatorial was purchased in 1869 from Alvan Clark (5¼-inch aperture, 7½-foot focal length), and the old finder from the 15-inch instrument was mounted independently on an equatorial stand and loaned to the Harvard Physics Department. Although of approximately the same dimensions, it is unlikely that the "new" West Equatorial has any relationship to the present finder telescope because of dissimilarities in their appearance.

As a whole, the finder is adequate in its present condition although it would benefit from routine maintenance, some of which it received during this study.

Dome

The dome on Sears Tower is of frame construction which, legend has it, was built by a whaling shipwright. Vertical ribs of approximately 3x9-inch section on 14½-inch centers at the bottom carry 5/8-inch thick sheathing, 3 to 4 inches wide on the inside, and sheathing of undetermined thickness on the outside. The framing rests on a sill of built-up construction, approximately 9 inches thick (radially) and 15 inches high. This is held together with through-bolts that also serve to hold the cast-iron track and gear rack on the underside. The whole dome, including copper sheathing, is reported to weigh approximately 14 tons.

A limited inspection of the framework was performed after removal of a small amount of the internal ceiling. The wood of the frames, sheathing, and sill all appeared generally sound although a small amount of rot has started where the sill has frequently become wet. As testimony to the integrity of the original construction and its stability for over a century, the trueness of the dome as a body of revolution when rotated against a fixed generating point inside at half height was found to be within ¼ inch of concentricity. The only exception was within 3 feet of the aperture door pulleys where the radial load component of the chains had pulled the dome in by ½ inch. Another observation was that the weight of four men at the top center of the dome during an external inspection produced no perceptible effect.

Although the sheathing on the corners of the building roof and on the dome's lower portion is thought to be original, the top half of the dome was resheathed in copper about 1955. This was done because of the continued need for repairs; the Harvard Buildings and Grounds Department estimates that the rest of the original sheathing will need similar replacement in 10 to 15 years. There is a recurrent need for attention to pinhole leaks, and the chemical attack on the sheathing is well advanced. The Buildings and Grounds roofing consultants report that copper sheathing is no longer a satisfactory roofing material in Cambridge because of recent atmospheric pollutants. It appears that one good solution to producing a relatively permanent, truly water-tight roof without detracting from the appearance of the dome would be to use a green-colored silicone rubber membrane roofing material applied directly over the copper. This has been tried elsewhere in the University and has been quite satisfactory. The product is made by General Electric.

The leakage problem has been and continues to be chronic and must be halted before further deterioration of the dome structure occurs and to avoid further deterioration of the instrument and the exhibits on the lower floor from water damage and high humidity. Already the rotunda ceiling shows areas of peeling paint due to water damage.

The dome is presently supported on twelve modern roller truck assemblies fixed to the lower track. These were installed sometime shortly before 1946, replacing the 8-inch diameter iron spheres previously used. Also at about that time an electric motor drive replaced the handwheel used for turning the dome. The original drive reduction gears are still in use except that the handwheel has been replaced by an electric motor. Both the support bearings and the motor drive system are well made and in good condition although some of the through-bolts holding the upper track are loose and need attention. The lower track, unused because of the fixed roller trucks, has rusted somewhat from the water leakage and has produced the rust stains apparent on the inner wall of the observing floor.

The aperture doors consist of a lower set of three mounted in a conventional window sash arrangement with sash cords and weights, and an upper, considerably larger pair mounted on steel tracks and driven by chains from the observing floor. The two upper doors plus their hardware are completely new within the last 10 years. They are of fiber-glass construction with wooden frames and are in excellent condition. The lower doors are of copper sheathing on wooden frames and appear to be in adequate condition. When positioned properly, these doors seal the aperture even in a heavy rain. However, they must be set rather carefully to accomplish this. During a heavy storm, water that appears to be coming from the doors is actually coming from leaks in the roof adjacent to the aperture and through fittings associated with the doors. As mentioned earlier, this leakage and that of the roof must be eliminated to prevent further deterioration of the dome and the building as a whole.

The chain and gear drive for the upper aperture doors is in its original configuration, although the chain was replaced in 1955 and the door attachments modified at that time. (These fittings are less than satisfactory and should be replaced.) The brass drive pinions on the winching device are badly worn and should be replaced. Also, one of the main gears has a broken tooth that should be repaired. The drive mounting frame is bolted to the sill of the dome with through-bolts and lag screws, some of which are loose or missing. This should be corrected.

It is interesting to note that originally the dome had upon it a "stout glass ball, quick silvered inside" (Ref. 11) mounted on a rod approximately $1\frac{1}{2}$ feet above the outer surface. This was directly over the telescope axes and served to precisely identify the latitude and longitude of the Observatory for external observers. This ball is shown still in place in the frontispiece of Harvard College Observatory - The First Century (Ref. 11), so I suspect it was removed during the roofing operations in 1955. It would be fitting to restore it to its rightful place.

Tower

The Sears Tower is a brick building 32 feet on a side with walls of brick and mortar 2-feet thick resting on a granite foundation. The inner wall is brought to circular form, with alcoves in the corners on the first and second floors, so as to adequately support the dome and track. The first floor originally had windows, and the northeast alcove was fitted with a chair lift to the observing floor; these have since been eliminated. The central pier rises independently a total of 43 feet to the observing floor from its base 26 feet below ground level. It is constructed of granite carefully laid up on a massive 22-foot diameter footing and is surmounted by an 11-foot high, 11-ton granite "tripod" (with three feet tooled into the underside) that carries the telescope mount.

Structurally and in interior finish, the Tower appears in quite satisfactory condition although several details need attention. As mentioned earlier, the roofing over the four alcoves (not covered by the dome) leaks occasionally, and this has caused water damage inside the building. This roofing should receive the same membrane treatment as the dome.

The observing floor consists of a wooden framework and plank subfloor supported from the outer shell of the building. To this are screwed the rails (one-inch diameter iron bars bent to shape) on which the observing chair rides. A spacer layer of plywood supports the linoleum floor covering. This floor needs some attention, particularly the observing chair rails whose fastenings have failed. The rails should be through-bolted to the floor and the broken parts of the linoleum repaired. A more satisfactory solution would be to lift the linoleum and plywood, reset the rails at the proper gauge, and replace the plywood and linoleum on top of a waterproof membrane. This would reduce the possibility of any further water damage to the rotunda ceiling below. Additional work required at the observing floor level includes the normal maintenance of washing, patching plaster, and painting. Deterioration here has been hastened by the water problem mentioned earlier. For display purposes, a more effective lighting arrangement would be very desirable.

Originally the tower had upper doors on the east, north, and west faces leading to small iron balconies on which portable telescopes were mounted for comet seeking and other temporary purposes. Only the north balcony remains, and it is probably original. The east and west balconies were replaced in 1881 with wooden structures that have since been removed. The door and framework on the north is in satisfactory condition, but the west glazed door is weak and needs repair. On the east side, the iron door needs some repair work on the bolt. As a matter of interest, the heavy iron doors at all the entries to the dome were originally installed to protect the interior of the Tower and the telescope from external fires--testimony to the value then attributed to the instrument.

CHOICES FOR THE FUTURE

Broadly speaking, there are at least four possible courses of action for the 15-inch telescope and the Sears Tower.

A. Demolition or complete rebuilding of the tower's interior for other purposes, for example, additional office space or laboratory areas. In this and option B (below), the instrument might be preserved and displayed elsewhere or perhaps sold.

B. Replacement of the existing telescope with one better suited for student use and training. To increase the effectiveness of this option, a modern and efficient dome would be desirable.

C. Continuation of the present situation where the instrument is available for general informal use, and maintenance is held to the essentials necessary for immediate survival. A harsh alternative here is elimination of general access and use to reduce the rate of deterioration.

D. Initiation of a positive program to preserve and enhance the historical value of the instrument and the building. This is logically the principal part of a program with a more general goal--to make the history of the Observatory and its equipment more visible and available to Observatory staff, the University, and the general public.

These four options are widely separated in attractiveness, but the first two have some common points: both involve the elimination of the present telescope and the expenditure of substantial capital funds.

Option A, the demolition or rebuilding of the tower, is unusually cumbersome and expensive because of the massive character of the building. The space within the building (700 square feet per floor for each of the two floors) would be reduced by the necessity of allowing passage between Building B and Building A. Therefore, even with the removal of the central pier, the maximum space that could be obtained would be 1200 square feet, exclusive of the vestibule, which is already used for office space. Demolition, of course, would require new construction to rejoin Building B and Building A. The estimated cost of rebuilding the interior into offices or other space would be at least as expensive as new construction, considering the nature of the building, and might well be in excess of $70,000.

Option B, in addition to being expensive, is functionally unproductive. Other telescopes exist at 60 Garden Street for student use, and these are not fully utilized. In addition, the local environment (thermal turbulence, background light, and atmospheric contamination) is so bad as to negate any but the most rudimentary utilization. With respect to the cost, a modern 16-inch telescope would be approximately $35,000, and a new 30-foot dome has been priced at $30,000 installed. Of course, peripheral equipment would increase the capital expenditure, and there would be significant maintenance expense. If projected future utilization requires this kind of investment, it would be far better made at a more favorable site.

Hence, these first two options seem clearly impracticable from an economical and functional point of view (i.e., value gained for money invested) and may be dismissed out of hand. The desirable ends of more office or laboratory space or further student training opportunities can be obtained less expensively by other means, such as adding a new wing, incrementally increasing the new building, installing a student telescope in its own small building, and so on.

The choice between the last two options, or their blending to some middle ground, is more difficult. Option C is obviously the least expensive with a direct cost approaching zero. It does, however, imply continued deterioration of the historical value of the instrument and the building. I consider this to be the greatest objection to this course of action. As a minimum, the alterations to the clutch and electrical system, which are required for reasonable function and trouble shooting in the future, should be accomplished as essential maintenance. This involves a direct cost of approximately $3000. As an indirect cost (to the building maintenance fund), the dome leakage problem mentioned in the previous section should be resolved so as to avoid further damage to the building. All in all, option C has only the lack of major expense to recommend it as it serves few other constructive purposes.

The last option--to undertake a continuing program of historical preservation and exposition--is highly constructive, but its final evaluation depends heavily on a subjective judgment of the intrinsic historical value of the telescope and, more broadly, the value of history itself to the Observatory.

History can be thought of as having two closely allied functional purposes: on one hand there is its power to revive the past and to stir feelings of personal identification with it; on the other, it enables us to recover relevant elements from the past for the enrichment of present and future activities. The first is more personal and subjective; the second, more utilitarian and objective.

Similarly, the study of people and their accomplishments takes us back into the past and is, in large measure, personal and contemplative, whereas the history of technological design points to present and future use and is objective and constructive in its directions. Significant instruments are as much the documents of scientific history as are the tales of the discoveries themselves; often, discoveries have only been possible through technological advances.

To consider another point, it is now quite generally accepted that museums have educational functions and responsibilities extending beyond the mere display of the artifacts in their collections; in fact, these may well be their primary assets. Hence, a natural place for such activity is within an educational institution. Conversely, for an educational institution to be complete, it should not only preserve historical material but present and interpret it. The Observatory has within its domain a rare opportunity for such activity in the existence of the 15-inch telescope, a unique major instrument that is still functional and housed in its original building.

A third and more practical aspect of historical study and exposition is its value in promoting good relations with the outside world. This would seem to have particular application to the area of fund raising, where an enhanced awareness of the Observatory's work and effective use of gifts might encourage new contributions.

In its fullest development, option D might consist of the following steps:

First, the telescope would be refurbished and restored as much as possible, consistent with the recovery of such presently missing parts as the mechanical clock drive, and the declination and R.A. circles. Its routine operational use would be terminated or at least limited to be consistent with its historical value. The observing chair would likewise be refurbished and reupholstered.

Second, the building and dome would be renovated, initially by repair work to the roofing, walls, and doors, and later through the introduction of proper display lighting, historically accurate furnishings, and interpretive material.

Third, a coordinated historical exhibit would be planned and implemented for the rotunda level, taking advantage of such resources as available literature, the University collection of scientific instruments, and various sources of photographic material. Later, a complementary exhibit of modern astronomy would be planned for the display areas of the new building.

Fourth, the exhibits would be publicized through such outlets as presently cover other University displays and exhibits, and an information office would be set up near the exhibits to receive visitors, handle daily tasks, and distribute interpretative materials. This office could be the part-time occupation of someone located adjacent to the rotunda.

Fifth but by no means least important, studies of the many aspects of the Observatory's history would be continued. Areas that would benefit from such attention might include identification of astronomical instruments presently preserved by the University; identification and preservation of additional material and instruments of historical or expositional value; interrelationships between the Observatory and the community (such as the time service and meteorological activities of the 19th Century); cooperative ventures with other observatories; and so on. These activities could be coordinated with other interested University groups and might, in part, be undertaken by them with subsidiary funding.

The full development of option D would require initial capitalization on the order of $30,000 and annual operating funds of up to $15,000; these figures could vary widely, depending on the details of implementation. A suggested budget for implementing option D is being submitted separately.

RECOMMENDATIONS

Based on the study and the material discussed in this report, five recommendations are submitted:

1. That a resolution be taken to preserve the 15-inch refractor and building and to enhance its historical and display value.
2. That the Sears Tower as a whole be devoted to a coordinated exposition of the historical aspects of the Observatory, its people, and its equipment. Also that the display areas of the prospective new building be devoted to complementary exhibits focused on modern aspects of the Observatory's astronomical endeavors, and that both areas be made accessible to the public.
3. That initial capital funds be obtained and allocated (according to a detailed budget submitted separately) to accomplish the repair, restoration, and display work described under option D. Also that certain non-direct cost work, such as the roof renovation, be actively pressed to completion.
4. That an annual budget be established, first to continue systematic studies into the history of the Observatory and the identification, preservation, and exposition of its significant equipment, and second, to assure that preventative maintenance and repair on the 15-inch telescope, its building, displays, and other historic equipment at the Observatory proceed on an orderly basis. (A proposed annual budget is submitted separately.)

5. That a standing committee be formed for the purpose of implementing these recommendations and reporting periodically on its activities.

The Observatory, as the University as a whole, is rich in the history of its works, its people, and its equipment. It is only right that this historical wealth be preserved and made readily available to future astronomers, students, and the public.

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Key to Pictorial Material

Although the number of illustrations used in this report has been limited for the sake of economy, a modest collection of pictorial material was identified in the literature or originated during the study that might be of future interest.

The telescope in its earliest form is best depicted in a Ref. 1 lithograph (reproduced here as the frontispiece and on file at the HCO Photo Lab as negative #6909-22B) and in a Ref. 3a drawing. Photographs of the instrument prior to 1954 appear in several sources: the best is Plate II in Ref. 7 showing the whole Clark drive; another is in both Refs. 10 and 12; Ref. 11 contains a third (though poorer) view. Two modern (1962) photos are on file at the Photo Lab, numbers 6201-10 A and B, the latter in color.

Several 35 mm pictures taken during the course of the investigation are also on file at the HCO Photo Lab. Film strips 6909-16 A through E show details of the telescope, objective, and dome; studies of the objective glass appear in 6909-16 G through J and 6908-25 A through E. Interferograms of the objective are on strip 6909-16F, and electron photomicrographs of the surfaces are filed as 6912-23 A through Q.

Although a few drawings of the building exist in Refs. 1 and 3a, the most complete early illustrations are in Ref. 3b (Plates I-III). Later photos can be found in Ref. 7 (Plates III, XIV) and Refs. 11 and 12. Other photographs and illustrations of both the telescope and the building undoubtedly exist, but a search for them, per se, was not undertaken.

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THE 15-INCH GREAT REFRACTOR OF THE HARVARD COLLEGE OBSERVATORY

BUDGET SUPPLEMENT

THE 15-INCH

GREAT REFRACTOR

of the

HARVARD COLLEGE OBSERVATORY

A Budget of Costs
To Restore And Maintain The Instrument
And Building And To Continue Further
Historical Studies

Nathan Hazen
Harvard College Observatory

March, 1970

INTRODUCTION

This supplement to the study report on the history, current condition, and future utilization of the 15-inch telescope at the Harvard College Observatory presents the estimated cost of carrying out the program recommended in the main document. After reviewing the significance of the 123-year-old great refractor to the stature of the University and American astronomy during the 19th Century and evaluating the present state of the instrument, ancillary equipment, and original building -- Sears Tower --, the report concludes that with modest effort and expenditure, the historic telescope could continue to play an important educational role within the Observatory, University,and community at large.

In support of this general recommendation, the various costs of initiating and maintaining a program to preserve and enhance the cultural value of the instrument and building have been organized into two separate though related budgets. One allocates the capital funds required to restore the great refractor and Sears Tower for permanent exhibition and student use; the other provides for yearly basic maintenance and display activities.

The items in the Capital Funding budget follow closely the sequence of topics discussed on pages 19-32 of the main report. The Annual Support budget outlines the cost of a continuing program of reasonable proportions for preservation and historical exposition as formulated on pages 35-38 of that document.

ALLOCATION OF FUNDS

The major difficulty in establishing a cost basis for the various tasks and activities lies in defining the scope or magnitude of the optimum program. For this program one alternative was to gradually assign funds for certain basic repairs, thus gradually reversing the present trend of deterioration; at the other extreme was the immediate appropriation of large sums of money for all major renovations, thus achieving in the shortest possible time a permanent educational facility for academic as well as public use.

The approach actually adopted in preparing the budgets follows an intermediate course based on underwriting a substantial portion of the recommended work through initial capitalization, with provision for continued improvements through annual support. The costs in the budgets were derived from a variety of sources, but mainly from direct vendor quotations (for example, the telescope tube restoration) or working experience within the Observatory engineering service group, since most of the required work would be accomplished either by our engineering and model shop staff or outside contractors.

The allocations should be viewed with a certain degree of flexibility, especially in accomplishing individual tasks. For example, recovery of the presently missing Clark clock drive would probably eliminate the need for rebuilding the electrical drives but, on the other hand, could entail restorative work of another kind, incurring more or less comparable costs. However, while unforeseen changes in the nature of the work may alter some items, the overall cost of the program should not be materially affected.

The cost of some budgeted items could be reduced or defrayed appreciably by other means. Although no solicitations have yet been made, some vendors might welcome the chance to exchange their materials or services for appropriate publicity or "good will". Such arrangements are quite common in modern museums. Recognition for support in the restoration of the 15-inch telescope could be acknowledged as part of the proposed displays or in one of the special publications. Moreover, the cost of producing these publications would in time also be reduced or even returned through public sales and subscriptions, eventually making this annual support item self sustaining.

PROGRAM SCHEDULE

Since fine weather is required for exterior work and it is inappropriate to heat the observing floor of Sears Tower, it will be necessary to make most of the repairs on the telescope, dome, and roof during the summer months. However, some work on telescope equipment (such as refurbishing the observer's chair and testing optical components) which will be done elsewhere in the Observatory could be initiated without regard to season. Designing the display area and planning the scope and nature of the exhibits could also be independently started. If funds were available in mid-1970, these latter activities could be conducted during the fall and winter months of 1970-1971, with major renovations scheduled for the following spring and summer. In this case, the entire program would be completed and the area opened to visitors by the beginning of the academic year in September, 1971.

This staggered schedule provides ample opportunity for planning and orderly procedures. An earlier target date might be met but would not allow the fullest time for organization, and the rush to completion would unquestionably prove detrimental to the ultimate value of the program.

CAPITAL FUNDING

Objective		
Additional dispersion, homogeneity and strain tests		$ 500
Tube and Mount		
Rebuild wooden tube	$1,200	
Strip, refurbish, reassemble mount	1,500	
Fix counterweight shaft, refit bands, etc.	800	3,500
Drives		
Rebuild or restore present R.A. drive and clutch	2,000	
Rebuild or restore present declination drive	700	
Refurbish and document drive and control electronics	900	3,600
Observer's Chair		
Refasten and paint frame	400	
Refit and adjust drives	300	
Rebuild and reupholster chair	600	1,300
Finder Telescope		
Replace eyepiece and refit hardware		200
Dome		
Sill: repair bolts and apply preservative (includes removing some ceiling, jacking up dome)	1,000 *	
Restore ball tracks and install balls	1,200	
Make and install handwheel	250	
Repair and refit lower sash frames and doors	400 *	
Replace upper door fittings	100	
Refasten door drive frame	200	
Refit door drive winch, including new gears	300	
Make and install external position ball	200	
Prepare roof and install silicone membrane roofing	2,500 *	
Repair ceiling, as required	400 *	6,550

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* Areas normally covered by building maintenance reserves and therefore probably not requiring independent funding

<u>Tower</u>		
Strip and rebuild observing level flooring (includes refastening chair rails and installation of water proofing)	$1,500 *	
Repair west wooden door and east iron door	150 *	
Repaint interior, including dome, at observing floor level	500 *	
Install improved lighting at observing floor level	400	
Install equipment storage cabinets - northeast alcove	500	
Install double door entry to observing floor (to permit winter entry with minimum heat loss)	300	$3,350
<u>Displays and Exhibits Material</u>		
<u>Observing Floor</u> (furnishings largely from available material)		
Install protective rails	200	
Pictorial and explanatory material	1,000	1,200
<u>Rotunda Level</u>		
Display and explanatory materials		2,000
<u>South Vestibule</u>		
Display cases and explanatory material		1,000
<u>Publications</u>		
Reprint (offset) initial quantities of certain significant documents for resale to public - proceeds to cover additional printings (i.e. Vol. I - Annals, 2000 copies, and others)		3,000
Subtotal (without asterisks)		$19,750
Subtotal (asterisks)		6,450
Total		$26,200

ANNUAL SUPPORT

Continuing Studies and Projects		
Senior Research Assistant (1/2 time)	$6,000	
Publications: material and services	2,000	$ 8,000
Routine Operations, Maintenance and Improvement		
Research Assistant (1/4 time) for daily activity	2,000	
Instrument technician (1/4 time)	2,500	
Direct materials	500	5,000
Total Appropriation/yr.		$13,000