THREE CENTURIES OF ASTRONOMY

A PLAN FOR ACTION

HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

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Renovation and Restoration

of the

Historic Sears Tower and Great Refractor

to create a

Public Education and Information Center

at the

Center for Astrophysics

A Plan for Action

Harvard-Smithsonian Center for Astrophysics

60 Garden Street

Cambridge, MA 02138

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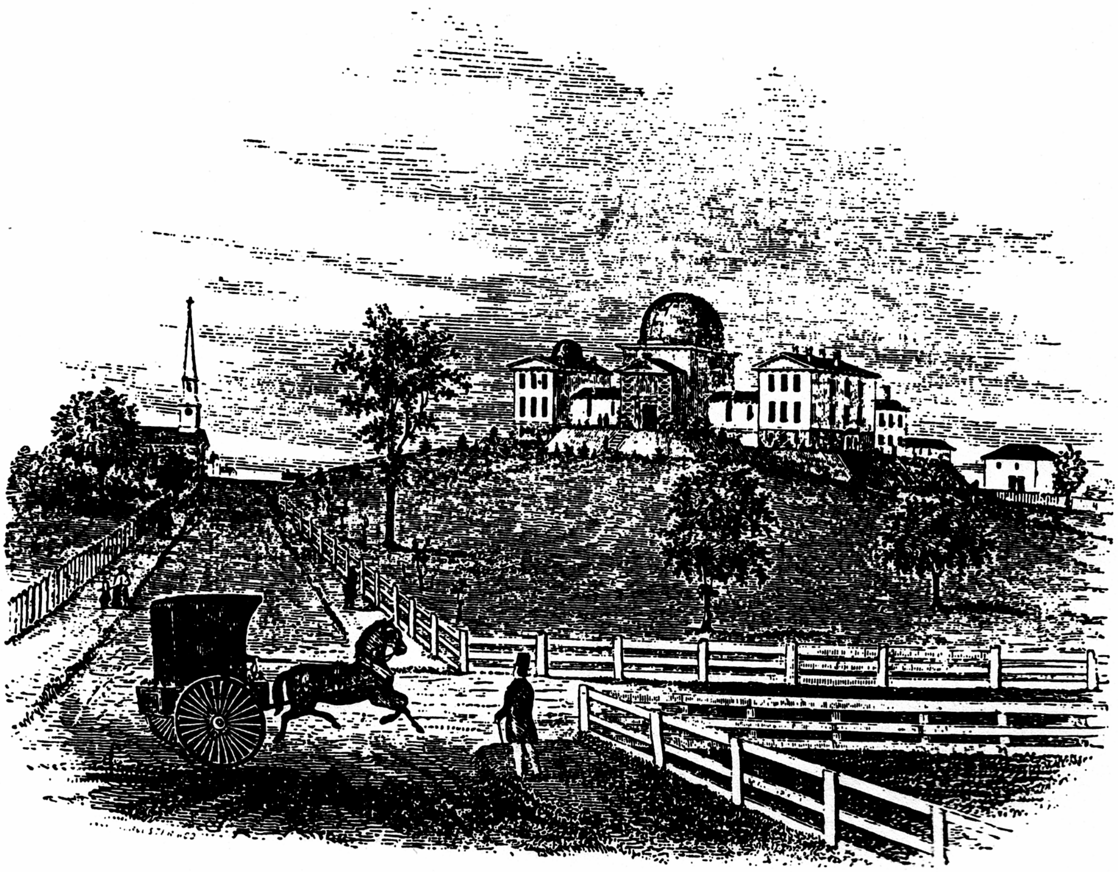
THREE CENTURIES OF ASTRONOMY

Abstract

This proposal describes a plan to design and construct a Public Education and Information Center at the Harvard-Smithsonian Center for Astrophysics (CfA) that will incorporate interpretive exhibits on modern astrophysics with a display of *in situ* instruments and artifacts linking current research with its historical roots--a panorama of astronomy spanning three centuries, from the 19th to 21st. The heart of this center will be the Sears Tower, a three-story structure housing the 15-inch "Great Refractor" of the Harvard College Observatory. Erected in 1846--the same year as the founding of the Smithsonian Institution--this building will be repaired and restored to its original operable condition. Once the building is deemed structurally sound and weatherproof, the interior spaces, including the observing room with its telescope, the "director's office," and the ground-level rotunda surrounding the telescope pier, will be developed as a unique introduction to the history of American astronomy as seen through the parallel and related research of the Smithsonian Astrophysical Observatory and the Harvard College Observatory. The exhibits and displays will be open to students, amateur astronomers, professional visitors, historians of science, and the general public, including attendees of the CfA's regular "Observatory Nights" and "Children's Nights." The estimated cost of the project, including all restoration work on building and instrument, is $513,000 of which $125,000 has already been raised through private donations.



Harvard College Observatory in 1851, as viewed from the corner of Concord Avenue and Bond Street in Cambridge.

INTRODUCTION

One hundred and forty years ago, the Harvard "Great Refractor" was the largest telescope in the United States. For the past decade, it has stood unused and immobile under the dome atop the three-story Sears Tower in Cambridge. The room directly below the telescope chamber, the former "observer's office," is now used as office and storage space. The first-floor entrance, a circular room surrounding the telescope pier and known as the Rotunda, presently contains four 1957-era exhibits and pictures of astronomical subjects. This room also serves as a rather dark passageway connecting two buildings. Over the years, several plans to refurbish the telescope and the exhibits have been suggested, but very little has actually changed.

This report describes a plan to renovate the building, the telescope, and the display areas to create a small, integrated, astronomy exhibit and public visitors center. The exhibits will emphasize both historical accomplishments and current projects at the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO), which jointly form the Center for Astrophysics (CfA). The potential audience to be served by this exhibit includes the several hundred visitors each month who attend the "Observatory Night" programs, as well as an estimated several thousand individual visitors each year who have an interest in the history of astronomy and technology. In addition, the facility would be available for visits by primary and secondary school groups.

The overall design concept for the public areas encompasses three distinct spaces, each with a distinct function, and each representing a distinct era in American science. The old building and the original telescope will give visitors a sense of history and an appreciation for the problems and techniques of astronomy in the 19th Century. The office, located midway on the stairs between the first floor and the dome, will be restored as the Director's Office as it might have appeared in the early 20th Century, complete with furniture and equipment used by local astronomers at that time. Exhibits illustrating modern astronomy and its potential for discovery in the 21st Century will occupy four alcoves surrounding the pier in the Rotunda. A second small office at the foot of the stairs leading to the dome will contain an interactive computer display.

This report details the necessary renovations and proposed exhibits and their associated costs.

THE SEARS TOWER

The oldest part of the complex now occupied by the CfA on Observatory Hill in Cambridge is the three-story-high "Sears Tower" housing Harvard's historic 15-inch (Great Refractor) telescope. The building was erected in 1846--the same year as the founding of the Smithsonian Institution--and the telescope was installed one year later. For the next twenty years, this beautiful, 20-foot-long, mahogany-veneered telescope was the largest in the United States.

Inside the tower, a granite pier supporting the telescope rises 43 feet to the observing floor under the dome. That pier is topped by an 11-ton solid granite block that carries the telescope and its mount. The 30-foot-diameter dome, weighing approximately 14 tons, was reputedly built by a whaling shipwright and is sheathed in copper. A velvet-upholstered observer's chair once moved around the telescope on circular tracks and could be raised or lowered by a pulley system, so the observer could be put into position at the eyepiece. The entire system--telescope, dome, and observing chair--was a prime example of 19th Century craftsmanship.

Among its many early scientific accomplishments, the refractor was used to discover the eighth satellite of Saturn and to make the first observation of Saturn's inner ring. The first photograph of a star (a daguerreotype of Vega) was made in 1850; and, within that decade, the first "wet plate" photographs of stars were also made here. Ironically, photography contributed to the demise of the Great Refractor as a useful research tool, since its color correction and clock drive were ill-suited to the new photographic methods. Gradually, the instrument and its magnificent observing chair fell into decay, as did the building around it.

The following plan emphasizes the development of interior spaces--the "exhibit areas" or "visitors center." The proposal assumes that all exterior repairs and restoration, and any structural reconstruction will be accomplished first, and that no interior work or exhibitry will proceed until the structure is stabilized and secure. (Appendix A.)

TELESCOPE AND OBSERVING ROOM

Beneath the huge dome of the Sears Tower, the top-floor Observing Room houses the telescope and its observing chair. To capture the spirit and style of the 19th Century builders, both the instrument and its surrounding environment will be restored as closely as possible to their original states, circa 1847-1866.

After external work has been completed on the rotating dome and the movable shutters, the first priority would be the telescope itself. A replica of the original clock drive has been completed, but installation will be postponed until the telescope is dismantled, repaired, and remounted. A metal section at the upper end of the telescope tube, installed as a repair some 35 years ago, will be replaced with a laminated mahogany veneer section; and the modern motor drive will be removed from the declination axis. These changes will lighten the instrument, return it to its proper balance, and allow removal of the lead counterweights added near the eyepiece end.

The observing chair has recently had its fractured members replaced, but it requires new upholstery. In conjunction with restoration of the chair, the floor needs to be refitted, and the iron rails on which the chair moves must be re-anchored.

Although the telescope and observing chair will be restored to operating condition, the chair probably would not stand up to constant use by every visitor. The restoration, therefore, is really for "limited operation," perhaps used only for demonstrations by trained operators, or available for observing only on special occasions. It is not intended for use on a regular basis, or by the public on "Observatory Nights." (The telescope could be equipped with a CCD-detector providing video images to a dedicated monitor, so small groups of visitors could "observe" with the instrument.)

Two alcoves on the northeast and northwest sides of the dome will be cleaned out and fitted with indirect lighting and special high-security plexiglas doors for exhibits of astronomical artifacts drawn from the Harvard University Collection of Historical Scientific Instruments. One alcove might feature instruments representative of astronomy in the 19th Century; the other will feature a clock, chronograph, and transit instrument illustrative of work accomplished by William Bond during that period. One staff member has promised some original drawings of Donati's Comet, made at the 15-inch telescope, which would be appropriate in the northeast alcove. In addition, the Smithsonian Institution has a set of astronomical drawings by Trouvelot, who worked with the 15-inch telescope, and it would be appropriate to hang some on the walls of the dome, if the temperature extremes do not pose a problem for the lithographs.

After renovation, the Observing Room will be equipped with an automatic, visitor-activated sound-and-light program that will spotlight various parts of the telescope and exhibits in synchronism with a short soundtrack.

THE DIRECTOR'S OFFICE

Immediately below the Observing Room and just off a landing on the spiral staircase to the ground floor, there is a small room called the "Director's Office." This will be refurbished as a typical astronomer's office of the early 1900s, circa 1905-1920. The room's centerpiece will be the famous "rotating desk" of E.C. Pickering. As fourth director of HCO, Pickering had a special lazy-susan-style desk constructed so he could work concurrently on several different projects, rotating the desk to move the separate piles of paper in front of him each time he switched subjects. The desk was later used by Harlow Shapley, and is now in the hands of his son, Alan Shapley, in Boulder, Colorado, but has been promised to the CfA when the Sears Tower is restored. There will be shipping fees for this and also for two chairs from the former Director's Residence, which were salvaged by Harvard astronomer Bart J. Bok and are now stored in Tucson. In addition, the CfA recently received from Annie J. Cannon's family home a candelabrum with prisms which inspired her to think about stellar spectra. The candelabrum and other artifacts of the era will be in this room. A glass or plexiglas barrier will be constructed to allow unobstructed viewing, but also provide protection for items displayed.

THE ROTUNDA

The Rotunda is a circular room 28 feet in diameter set within the square walls of the Sears Tower at ground level. The granite pier supporting the telescope is at the center of this chamber. The Rotunda serves as a passageway between two buildings of the CfA which join the Tower on the east and west sides. It also serves as the entry to the historic telescope for public visitors during the monthly Observatory Nights and the twice-yearly Children's Nights.

Four alcoves fill the space between the walls at the corners of the building. These presently hold outdated exhibits on Halley's Comet, x-ray astronomy, optical tracking of meteors, and radio astronomy. Two of the alcoves have hoods that protrude into the walk space. Light boxes with faded transparencies line portions of the wall. Although some of the exhibits are moderately interesting, the overall impression is of a dark, cluttered place with dust-filled corners. It is an embarrassment to the CfA and unrepresentative of current or planned research interests.

This most public of spaces will be remodeled to create a large, accessible, well-lit area. The stone pier, a feature of interest and beauty, will fill the center, and will not be obstructed by attachments. The light boxes and alcove hoods will be removed, leaving the structure closer to its original configuration. Four exhibits, one in each alcove, will illustrate the work of the CfA, provide an educational experience for the public, and represent the thrust of astrophysical research for the 21st Century.

The Rotunda exhibits will be designed to impart to visitors the multi-faceted research approach of both modern astronomy and the CfA through the general theme of the distribution of matter and radiation in the universe. In addition to current investigations at CfA, the exhibits will include the historical contributions of both SAO and HCO. The four alcoves will follow a common style so the Rotunda as a whole is consistent and pleasing. The three-dimensional displays in each alcove will be semi-permanent (10-year estimated life) and relatively maintenance free, but the accompanying graphics and text will be arranged so that they can be changed and updated with minimal effort.

To express the concept of modern multiwavelength astronomy, the Rotunda will be lighted by a strip of lights mounted seven feet above the floor along the circumference of the outer wall. The fascia concealing these lights will form a continuous band passing above the alcove windows and just above the doors. The four-foot sections of this fascia will be used to illustrate the broad range of the electromagnetic spectrum--from very long radio wavelengths to extremely short gamma rays. The fascia will be slightly translucent acrylic with opaque letters specifying wavelength and wave band.

One section, at the center of the band, will show the colors of the visible spectrum.

A few unobtrusive pictures, probably line drawings, will be placed on or close to this band to illustrate the types of astronomical instruments used at the various frequencies, especially those instruments employed by CfA projects. Other drawings might show some common objects associated with the various wavebands, such as a TV set or dental x-rays.

The four alcoves will show four different aspects of modern astronomy. Although the exact content is now under development, possible themes might be The Solar System, Stars of our Solar Neighborhood, Evolution of the Milky Way, The Local Group, and Large-Scale Structure in the Universe. As an illustration, one theme is described in Appendix C.

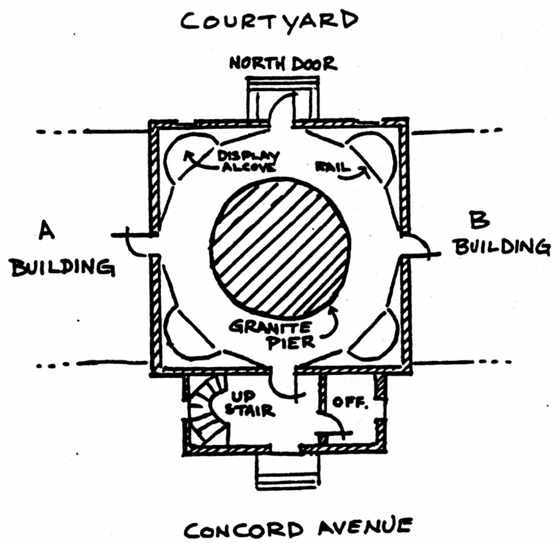


Diagram of the Rotunda

EDUCATIONAL GOALS AND AUDIENCE

In keeping with the public service mission of the Smithsonian Institution and the educational traditions of Harvard University, the Center for Astrophysics (CfA) conducts extensive public information and education programs. Among the various activities serving the residents of the Greater Boston area are monthly "Observatory Nights," featuring lectures, films, and telescopic observing; twice-yearly "Children's Nights" designed specifically for primary-school students ages 6 to 12; an annual "Science Saturday" open house for children; and "Dial the Sky," a 24-hour recorded telephone message about naked-eye observing for amateurs. Booklets, pamphlets, posters, and other printed materials are also produced for the benefit of teachers and students and in answer to mail requests.

Despite these varied programs, the CfA lacks any formal "Visitors Center," a place where casual visitors can be received or school groups can tour during normal daytime business hours. The natural site for such a center is the Sears Tower, a beautiful example of 19th Century architecture and technology that forms the physical and philosophical core of the sprawling modern CfA complex on Observatory Hill.

The renovation and restoration of this structure, and the development of its interior with exhibits and displays, will create a natural attraction for diverse audiences.

The primary audience envisioned by the developers is the student population of the Greater Boston area, ranging from undergraduates at Harvard University and other institutions of higher learning to students in primary and secondary schools. Indeed, the exhibits and displays will be designed as introductory, intended first to inform general science classes about the role of astronomy and astrophysics in modern science and the relationship to physics and mathematics. A second goal is to provide visitors, and especially students, with an understanding of the linkage between past and present science, stressing the long cumulative process of scientific understanding as seen through the historical contributions of the Harvard and Smithsonian observatories. A third goal, as expressed through displays and descriptions of current and planned projects of the CfA, is to create an awareness of the CfA's contributions to national research goals and, by extension, the intellectual life of Cambridge, thereby engendering among our neighbors a heightened sense of community pride.

Another important audience will be the amateur astronomers. Few other fields of science have such a rich tradition of amateur participation. From the independent scholars of the 19th Century, to the volunteer satellite trackers of the 1960s, to the comet hunters of today, amateur contributions have benefitted greatly both Harvard and Smithsonian research. The Amateur Telescope Makers of Boston, a local group, also plays a vital role in the CfA's public programs, providing observing support and presentation assistance at the regularly scheduled Observatory and Children's Nights. This constituency will not only be served by our Visitors Center, but will also participate in its operation and in the associated interpretive and education programs.

The refurbished telescope, and the other research artifacts of the 19th Century, will be of special interest to historians of science and technology. The "Great Refractor" was considered the most advanced telescope of its type when constructed, and its pioneering use of photographic techniques marked a major milestone in astronomical history. Like the refurbished Meridian Circle Telescope at the Greenwich Observatory in England, a faithfully and fully restored instrument would attract scores of professional and amateur historians.

Another class of professionals (and aficionados) who are not necessarily students of astronomy are architectural historians who recognize the Sears Tower's many unique structural features. Among these features is the unusual construction of the dome roof interior, where a shipwright created what almost appears to be a concave version of a Yankee Clipper's bow.

In short, the Sears Tower, combined with the associated exhibits, represents a rich educational resource that has lain fallow for many years. Most important, its renovation and expansion will stand as a prominent example of the Harvard-Smithsonian Center for Astrophysics' leadership and excellence in modern science.

PERSONNEL

<u>Sears Tower Committee</u>

Fred Seward, Astrophysicist, Smithsonian Astrophysical Observatory (Chair)
Will Andrewes, Curator, Historical Instrument Collection, Harvard University
James Cornell, Publications Manager, Smithsonian Astrophysical Observatory
Owen Gingerich, Professor of Astronomy and the History of Science, Smithsonian Astrophysical Observatory and Harvard University
Edward Haack, Designer, Museum of Comparative Zoology, Harvard University
Nathan Hazen, Engineer, Division of Applied Sciences, Harvard University

(For vitas, see Appendix E)

<u>Consultants</u>

Pamela Lodish, Associate Director for Administration, Harvard College Observatory
David Latham, Senior Astronomer, Smithsonian Astrophysical Observatory
Charles Hickey, Facilities Manager, Harvard College Observatory
Arthur L. Brown, Jr., President, Boston Building Consultants

The committee would like to thank the following colleagues who contributed to this report: Gayle Anderson, Nat Carleton, Martha Hazen, Peggy Herlihy, John Huchra, Edward Imbier, Edward Lilley, Caroline Lupfer, Susan Roudebush, Irwin Shapiro, Peter Smith, Barbara Welther, and Charles Whitney.

SCHEDULE AND PRIORITIES

This schedule lists different phases in order of priority and gives approximate time required to complete. Some phases can be done concurrently, e.g. the dome interior and the telescope, if funding is available. However, no interior renovations, or exhibit fabrication, are recommended until all exterior work is completed and the dome is stabilized and waterproofed.

Phase		Cost (000s)	Time
Building Repairs			
Roof		$195.0	6 mos.
General exterior		40.0	6 mos.
Dome interior		20.0	4 mos.
Rotunda floor		15.0	4 mos.
	Subtotal	$270.0	
Public Education/Information Center			
Telescope and pier		34.0	18 mos.
Dome exhibits		44.5	6 mos.
Director's office		25.5	6 mos.
Rotunda repair		29.5	6 mos.
Rotunda exhibits		24.0	12 mos.
Interactive exhibits		15.0	6 mos.
Administration		50.0	
Annual Operations (2 years)		21.0	
	Subtotal	243.5	
	TOTAL	$513.5	

APPENDIX A

DOME AND BUILDING REPAIRS

Dome and Roofing

The cornices, gutters, and flashing on the Sears Tower exterior are in need of immediate attention, for they are currently and precariously shored in place. The wood has rotted so that there are gaps between the metal sheathing on the roof and on the sides and bottom of the cornice. This gap is open to wind and rain and, while there is evidence of leakage in only one part of the interior at present, the project's first priority is to repair the roof. The condition of the copper sheathing on the stationary roof and the dome is satisfactory, but a prudent approach would be complete replacement of all copper sheathing as part of the process of restoring the structure and "weather proofing" the dome. (The amount indicated in the budget attachment reflects the best current estimate for complete replacement.)

Dome Shutter Doors

In classic observatory style, the Sears Tower dome has an "observing slit" that runs from "horizon to zenith" and allows telescopic views of the heavens. The slit is sealed by shutter doors that slide up and down in the fashion of a roll-top desk. The current shutters are of two types. The upper doors are relatively recent and are built with fiberglass skins over wooden frames. The lower three doors, quite a bit smaller, are original: copper-sheathed, counter-weighted, and sash-mounted in a curved triple frame. These are caulked closed at present.

This proposal recognizes that a fully operation door system, and one that anyone could open at will, is probably impractical. Indeed, such a situation would allow possible damage to the instrument and the dome interior, create substantially larger ongoing maintenance costs, and present the risk of damage to the shutters themselves by inept operators. However, a fully operation door system which achieves full weather-tightness is desirable, with actual operation restricted to special occasions. The budget estimate represents the cost of shutter rehabilitation.

The chain drive system for the doors is largely intact, but some rehabilitation has already begun. The attachments from the chains to the upper shutter doors should be strengthened, and the winch gear/clutch assembly should be taken apart and overhauled. The fastenings holding the drive frame to the dome must also be tightened or renewed.

In normal operation, the dome turns in azimuth so that telescope, observing slit, and target objects on the sky are aligned as the Earth rotates. The dome drive now occupies the southeast alcove on the observing level. Much of the drive train is original, but it was fitted with an electric gear-motor in more recent times. The renovation strategy calls for removal of the electric drive and associated steel work, building a replica hand-wheel and pinion, and restoring of the remaining parts to a functional display condition. Some pictorial documentation exists and the frame is original.

Observing Level Floor

The floor at the observing level is structurally sound, but needs refurbishment. The old linoleum covering needs to be removed, the underlayment consolidated, a new surface installed, and the chair tracks refastened. This floor does not now meet the structural requirements of a "public space" (i.e., unlimited numbers of people); and, to do so would require historically damaging work. Thus, once the observing room is renovated and opened to the public, visitor group sizes will be controlled. (Of course, other good reasons also support such policies, including security of the instrument and displays.)

Rotunda Floor

The Rotunda (first level) floor represents perhaps the most difficult problem in the Sears Tower renovation. This is because of its original cantilevered design, the substantial piping and machinery load added in recent times, its current compromised structural condition, present building code requirements relating to public space and passages, and the desire to limit the destructive impact of renovation on its historical content. The budget item reflects the highest estimate proposed, but a careful review and definition process will be necessary for any final work statement.

Other Exterior Work

Various details need to be addressed by this restoration. The upper level Observing Room (outer) doors are deteriorated wood and need replacement. In addition, the hinges and bolts of the room's iron security doors (interior) need refitting.

The south entry, an attached peak-roof structure, needs masonry and carpentry repairs. Some additional minor masonry work may be required around the balcony on the north face. The balcony itself is the only remaining one of the original three and as such needs careful cleaning and protection.

The entry into the dome from the Building B roof is a recessed stairwell that collects debris. This leads to deterioration of the door frame and should be remedied.

APPENDIX B

RESTORATION OF THE TELESCOPE AND OBSERVING ROOM

Observer's Chair

The badly deteriorated Observer's Chair has now been stabilized and can easily be refurbished to its original functional condition. However, given its historical value, it is not appropriate to plan substantial use of the chair. It was designed and built to be used by a few skilled observers, not the general public, thus the renovated chair will be considered a part of the exhibit, limited to demonstrations by guides.

Alcoves

The northwest and northeast alcoves on this level, currently used for active storage, will be enclosed with secure glass fronts and fitted with display lighting and fixtures. The cost estimates for this feature pre-supposes construction in place, following high-quality residential standards, and based on pre-existing architectural drawings.

15" Telescope (General):

Many elements of the telescope and its mount will require substantial work to bring them to a reasonable display condition, to ameliorate the effects of a 1955 modernization, and to stabilize ongoing deterioration. The most cost-effective approach is to disassemble the instrument and mount totally, distribute the parts to various skilled craftsmen, and then to reassemble the entire renovated telescope system. In short, work will proceed much more efficiently and with more care than trying to do repairs in place. Full disassembly also allows a more careful evaluation of the telescope's condition as well as an examination for historical markings and artifacts. The necessary mechanical and rigging skills are available within the university. (The original instrument arrived from Germany in parts and was assembled by the Director and his staff; modern astronomers should be able to do as well.)

The telescope work is estimated to take four months and should precede any work on the observing level floor. The Observer's Chair restoration would proceed in parallel, while the telescope was out, as would the work on the dome and dome door drives. Scaffolding used during the telescope disassembly could be reconfigured for the dome work and again for the telescope reassembly.

Telescope Tube

The main problem is the damage sustained to the upper end in 1955, and its resultant replacement with a metal tube extension. To restore the telescope to its original state, the tube will be stripped of all external hardware, leaving a net weight of less than 500 lbs. It will then be moved to another site for the wood and veneer work. This latter task will probably set the pace of instrument renovation.

The tube is constructed of three layers of longitudinal "staves" of light fir or pine, covered with a thin mahogany veneer, laid up in staggered fashion, totalling one inch in wall thickness. The primary renovation goal is to restore the damaged end to its former appearance and function, by:

(1.) Removing the existing metal tube extension and surveying the condition of the tube and the nature of the original materials;

(2.) Building a plug to serve as an internal model during the renovation;

(3.) Laminating the tube end using materials and dimensions similar to the original and scarfing it into the existing tube wall; and,

(4.) Applying new veneer over the repaired section and back to the upper brass clamp ring, which will serve to camouflage any disparity between original and replacement sections.

Objective Lens

The objective lens will be removed and stored in a secure location during renovation of the tube. This has already been done once before, in 1970, when the air-spaced lens was also disassembled. Some work may be required to adapt it to the renewed telescope tube. It is apparent that the internal fittings are not original, with some modifications adapted to the metal tube repair; and these may have to be revised. (An appropriate approach will be established during the tube assessment.)

Tailpiece End

Some parts of the tailpiece do not seem to be of a quality consistent with the original telescope. After documentation and disassembly, the parts will be inspected, compared to historical records, and a strategy defined for renovation. Some new parts will probably be required to emulate those lost. The emphasis will be to recreate an accurate representation of its probable configuration in 1847.

Finder Telescope

The finder telescope (a small wide-field instrument attached to the main tube and used to train the larger telescope on target objects) currently in place has no relationship to the original or any early variant, except in its general size. Lacking any remaining contemporary material, the strategy here is to simply clean the present finder, which is brass and matches the general appearance of small instruments from that era.

Mount

The "German" mount for the 15" telescope is in reasonable condition except for normal dirt and grime--and the effects of a "modernization" initiative in 1955. The thrust of a historically sensitive refurbishment will be to reverse both of these circumstances. A reasonable, and the most economical, approach is simply to take apart the whole mount, clean and restore the individual parts, make a limited number of display-quality parts to emulate those lost earlier, and reassemble the renovated system. Obviously, all the work will be documented photographically, and no approaches will be used that are not reversible.

Right Ascension Axis

The plan is to restore the right ascension (celestial longitude) axis to its form at the time of its delivery in 1848. This is because a) it is simpler than the 1855 drive, and b) a replica of the original drive exists (see below). Although the Clark drive added in 1855 is really more representative of the telescope's early productive period, no detailed documentation exists regarding that drive, and to construct a replica would be very time-consuming and costly. In other aspects, this axis is in reasonable shape, except for damage done to the graduated circle in 1955.

The right ascension circle will be cosmetically restored and fitted with dummy verniers and eyepieces during the general refurbishment described above. The main worm gear drive will be cleaned, and the worm re-shafted (it was cut off in 1955) to match the replica drive and the original drawings.

Drive Systems

The 1955 electrical drive has already been removed from the telescope. (Removal revealed the original right ascension circle!) An excellent operational replica of the original Merz and Mahler governor drive has been built in Florida, and, with the addition of shaft adapters, it simply needs mounting on the telescope and pier.

Declination Axis

Restoration requires construction of a replica declination clamp, cosmetic restoration of the graduated circle, and the fitting of dummy verniers and eyepieces. This will be planned in detail during disassembly based on examination of the parts. (The hub of the original declination circle apparently survived and was used to form the ring gear for the electrical drive. How it will be adapted to this restoration remains to be seen.)

Upper Pier

The 11-ton granite block that holds the telescope and mount above the central pier shows some of the ravages of time and the zeal of eager experimenters. The remains of the electrical cabling will be removed and the holes filled with simulated granite. The pier as a whole will be cleaned with non-invasive techniques. Any adaptions for the governor drive will be restored.

APPENDIX C

ROTUNDA REPAIRS AND EXHIBITS

Walls and Ceiling

The lights and wiring currently attached to the central stone pier will be removed. The two east alcoves (formerly with hoods) will be modified to the same configuration as the others, with the addition of floor, wooden wall, and window (so the alcove is sealed and dust free). The ceiling and walls will be painted a light color. New lighting and signage will be installed for the exhibits. Heavy-duty carpeting will cover the floor.

The black ceiling with stars and the murals over the east, west, and south doors would be painted over. The Sun mural depicted over--and on--the east door could be preserved, if desired. The Milky Way mural over the north door is on a plywood panel that will be removed and stored.

Alcove Exhibits

The Rotunda is essentially a round room in a square space, and the otherwise wasted areas at the four corners form natural "alcoves" for exhibits.

The actual subjects of the four exhibits have not yet been fully defined, but the following description of an exhibit concerning The Local Group of Galaxies will illustrate what might be done:

The so-called Local Group consists of two massive galaxies, the Milky Way and M31 (the Great Galaxy in Andromeda), plus a few smaller systems. One alcove will contain a scale model of this region of space. The backdrop will be dark, but not black, with a few painted, distant galaxies. The larger galaxies of the Local Group will be suspended in the space within the alcove. Each will be an acrylic disk, covered with a color transparency overlay of the actual object and illuminated from within by a small light, so the viewer will see the luminous spiral arms and nuclear regions. On this scale, M31 and the Milky Way are each three inches in diameter, and separated by seven feet. The visitor will stand at the window and look down to see the Milky Way with attendant Large and Small Magellanic Clouds nearby. M31, M32, and M33 will be above the visitor's head.

Below the alcove window and to the sides, words and pictures will present related modern and historical observations. The CfA's Image Processing Laboratory has digital images of M31 in radio, infrared, visible, and x-ray wavebands. A set of color pictures, each scaled to the same orientation and size, will illustrate the different appearance of M31 in these wavebands. Another panel will present measurements made at HCO in 1885-1886 on the supernova in M31, thus demonstrating a link between past and present astronomy.

Supernovae in the Local Group provide an opportunity for an interactive feature illustrating both historical astronomy and an event prominent in current research. In 1885, a supernova was observed in M31. In 1987, one occurred in the Large Magellanic Cloud. Bright supernovae were also observed in the Milky Way in 1006, 1054, 1572, and 1604. The model galaxies may contain very small bulbs that will light when visitors press a button. A simple circuit will regulate the light intensity to illustrate a supernova light curve, with a rapid rise to maximum brightness and a slow decay.

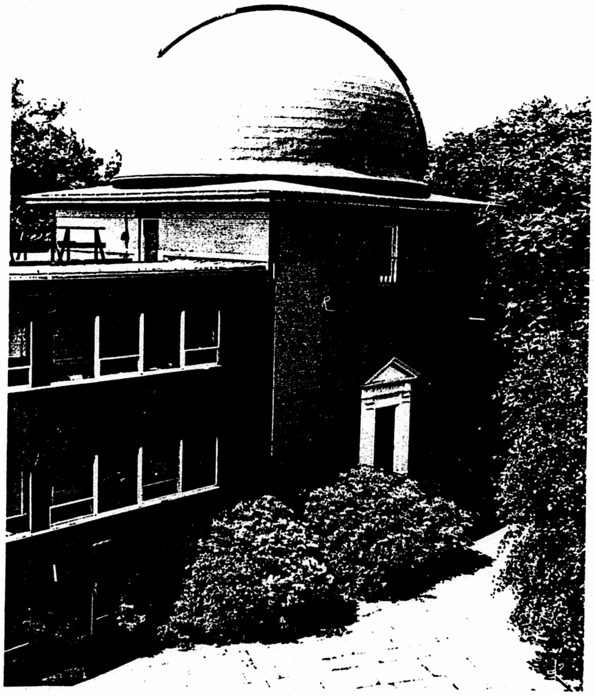
<u>Interactive Exhibits</u>

A small office is available adjacent to the rotunda and at the base of the stairs leading to the 15" telescope. This space may be used as a guide's room, a sales area, a video viewing area, or for interactive exhibit. Possibilities for interactive displays include:

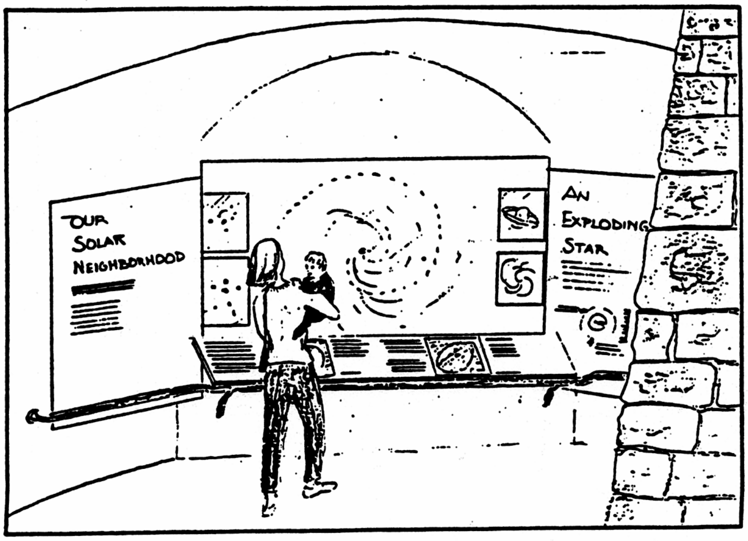
1. A small computer with digital image display programmed so visitors may call up astronomical images (such as regions of the sky recorded at different wavelengths) and zoom in on any area desired.

2. A VCR/TV to show short videos produced by CfA on subjects such as Einstein and gravitational lensing, the formation of the Moon by a collision between Earth and another small planet, or large-scale structure in the universe.

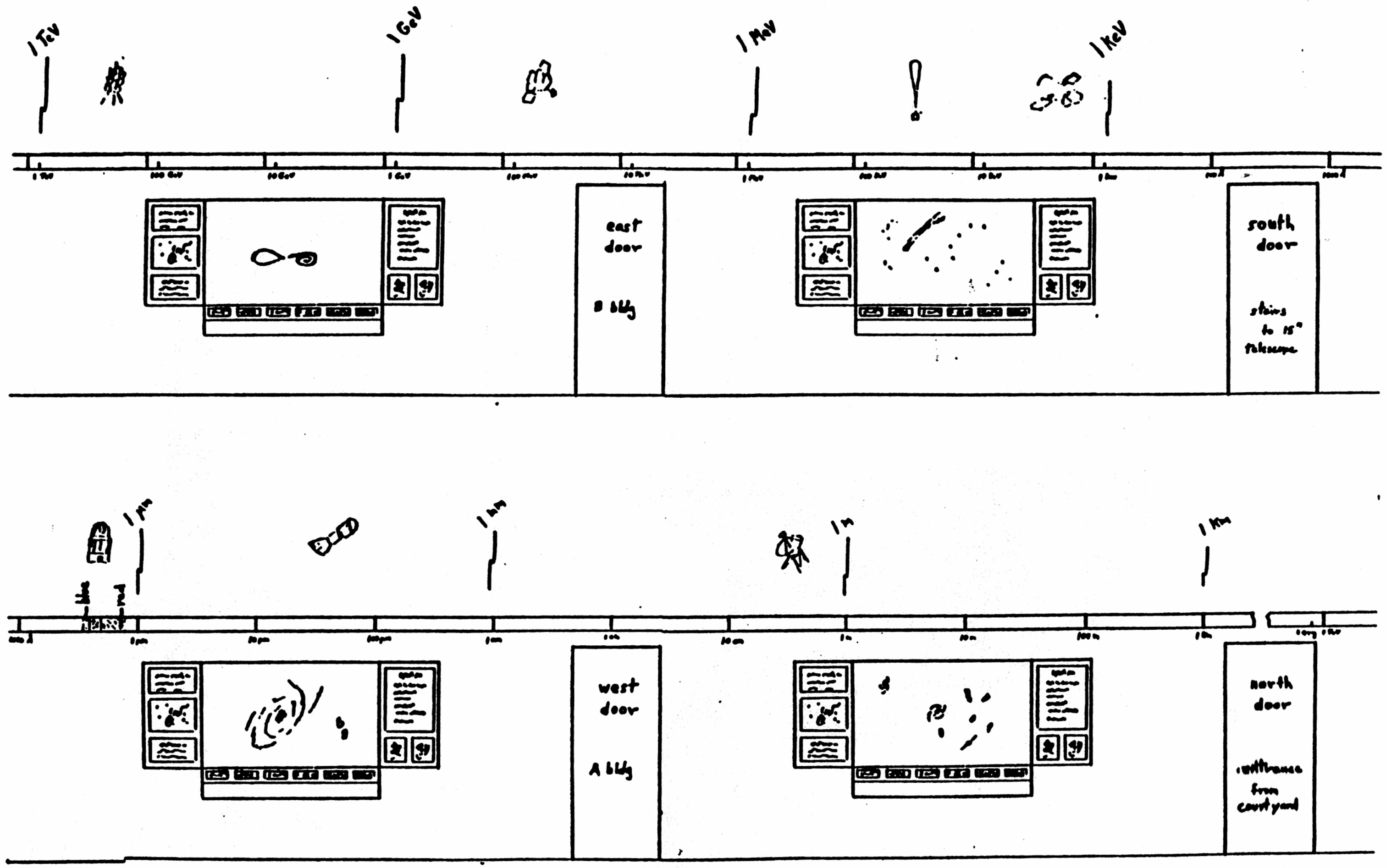
3. A slide projector which automatically cycles through a set of 35mm slides illustrating current CfA research projects with a voice-over narration.



Left, Sears Tower, north entrance, with balcony.



Layout of an exhibit in one of the Rotunda alcoves.



Astronomy throughout the electromagnetic spectrum. This panorama of the Rotunda outer wall shows the four alcoves and the fascia/illuminating light strip which has a wavelength scale inscribed. Illustrations of astronomical instruments sensitive to different wavelengths are located at appropriate spots above the fascia.

APPENDIX D

DETAILED COST ESTIMATES

Cost estimates for repair and restoration of the Sears Tower dome and exterior are based on an analysis by Boston Building Consultants (Report to Harvard University Planning Group, September 20, 1991) and represent the option for repair and restoration accepted by the Harvard College Observatory and assumes full operation of both dome and shutters. Costs of the "public areas and exhibitry," including the 15-inch telescope restoration and repair, are based on estimates by consulting engineer Nathan Hazen (telescope), designer Edward Haack (exhibits in Rotunda), and historian Will Andrewes (observing room displays and Director's Office). All figures are in thousands.

I. BUILDING AND DOME REPAIRS

Dome Exterior

Staging	8.0
Copper Dome: Removal of existing and recladding with 16 oz. copper	56.0
Lead Counterflashing: Backup with neoprene and repair or replace lead	3.0
Gutters, Soffits, and Rainleaders: Remove existing and replace with copper	30.0
Apron Cladding: Remove and replace with copper	16.0
Portico Roof Cladding: Remove and replace with copper	12.0
Shutters: Recladding and flashing	12.0
Exterior Track: Repair, cleaning, and painting	3.0
Carpentry	4.0
Internal gutter arrangement	3.0
Fees (architect, consultant, university)	28.0
Insurance, etc.	5.0
Contingency	15.0
Subtotal	$195.0

General Exterior

Painting	10.0
Masonry	23.0
Window/door replacement	7.0
Subtotal	$40.0

Interior

Rotunda floor	15.0
Dome Interior	20.0
Subtotal	$35.0

Building and Dome Subtotal	$270.0

II. PUBLIC EDUCATION AND INFORMATION CENTER

15" Telescope and Pier

Scaffolding	4.5
Disassembly	3.5
Rebuild telescope tube woodwork	9.5
Polish and protect brass	3.0
Refurbish RA and Dec axes	7.0
Adapt replica Mertz drive	2.0
Refit objective cell	1.0
Reassembly	3.5
Subtotal	$34.0

Dome (Interior) Exhibits

Reset track for observing chair	2.0
Refurbish Observer's chair	
Carpentry	4.0
Paint	1.0
Upholstery	3.0
Hand rail	1.0
Aperture door drive, mechanical	3.5
Dome drive, mechanical	5.5

Exhibit cases	10.0
Interior paint	5.0
Lighting fixtures	1.0
Display fixtures	0.5
"Sound and Light Show" fixtures and controls	5.0
Alarm	3.0
Subtotal	$44.5

Director's Office

Painting	1.0
Graphic material	2.0
Protective barrier	2.0
Furnishings	20.0
Shipping	0.5
Subtotal	$25.5

Rotunda

Steam clean central pier	0.5
Plaster repair	1.0
Paint	5.0
Sprinkler system	5.5
Rebuild alcoves	4.0
Electrical, remove existing wiring, new wiring	7.5
Carpet	2.5
Lighting fixtures	2.5
Fascia to conceal lights	1.0
Subtotal	$29.5

Rotunda Exhibits

Silkscreens	2.5
Photos	2.5
Typesetting and Signs	0.5
Graphics production artist	3.0
Light boxes or light panels	2.5

Four alcove models	12.0
Plaques (donor and historic markers)	1.0
Subtotal	$24.0

Interactive Exhibits

Circuitry	3.0
VCR/monitor	2.0
Computer terminal and disk	6.0
Graphics material	0.5
Slide projector/screen	1.0
Software/programming	2.5
Subtotal	$15.0

Administration

Writer	10.0
Preservation consultant	5.0
Designer	20.0
Contingency	15.0
Subtotal	$50.0

Annual Operations (First 2 years)

Alarm fee	1.0
Guide expenses	2.0
Insurance	4.0
Maintenance	10.0
Utilities	4.0
Subtotal	21.0

Education/Information Center Subtotal	$243.5

SUMMARY

Building and dome repairs	270.0
Education/Information exhibitry	243.5
TOTAL	513.5
Donations received to date	125.0
TOTAL REQUIRED	$388.5

APPENDIX E

CURRICULUM VITAE

SEARS TOWER RESTORATION COMMITTEE

William Andrewes

Biographical Sketch

William Andrewes is the David P. Wheatland Curator of the Collection of Historical Scientific Instruments and Preceptor in the History of Science at Harvard University.

Mr. Andrewes was born and educated in England. He began an apprenticeship in clockmaking in 1966, and worked under the guidance of the celebrated watchmaker George Daniels between 1969 and 1972. During this period, he also studied three-dimensional design at Kingston College of Art, where he received his degree in 1972. In 1973, he became the first recipient of the British Crafts Advisory Committee Award, and he began teaching design and metalwork at Eton College. In 1974, Mr. Andrewes was commissioned by the Royal Mint to design and model a set of three medals to commemorate the 300th anniversary of the Old Royal Observatory at Greenwich. In the same year, he became responsible for the conservation and restoration of the clocks at the Old Royal Observatory and the National Maritime Museum. A clock he made is now on permanent display there. He was elected a Freeman of the Worshipful Company of Clockmakers in 1977.

In the same year, Mr. Andrewes was appointed Curator of The Time Museum in Rockford, Illinois. During his ten year term of office, The Time Museum's collection tripled in size and became recognized as being the most comprehensive collection of its kind in the world. Mr. Andrewes was also responsible for launching The Time Museum's catalogue project.

In 1987, William Andrewes was invited to become Curator of Harvard University's Collection of Historical Scientific Instruments, one of the three largest university collections of its kind. He is currently involved as Project Director of a series of illustrated catalogues of the Collection, the first of which will be published in January 1992. He also serves as Co-Director of a joint project between M.I.T.'s Center for Educational Computing Initiatives and Harvard's Collection of Historical Scientific Instruments to develop multimedia applications for teaching and research.

Mr. Andrewes has given many lectures in the United States and Europe, and has appeared on the BBC, NBC, CBS and PBS as an expert on the history of time measurement. He has published articles in both popular and scholarly journals and is currently contributing articles to the Encyclopedia of Astronomy and Astrophysics, the Encyclopedia of Time and the Encyclopedia of the History of Astronomy.

JAMES CORNELL
Harvard-Smithsonian Center for Astrophysics
60 Garden Street
Cambridge, MA 02138
617/495-7461

James Cornell is Publications Manager of the Harvard-Smithsonian Center for Astrophysics, Cambridge, Mass., where he is responsible for programs of both technical information and public education.

A graduate of Hamilton College (BA 1960) and Boston University (MS 1968), he worked for the Worcester (Mass.) Telegram and Gazette before joining the Smithsonian staff in 1963. His articles on astronomy, science, and travel have appeared in Smithsonian, Harvard, Science World, Sky and Telescope, the New York Times, the Boston Globe, and other periodicals. He contributes regularly as a book reviewer for the Quincy (Mass.) Patriot-Ledger.

Mr. Cornell is the author or editor of more than a dozen books, including THE FIRST STARGAZERS (Scribner's, 1981), THE GREAT INTERNATIONAL DISASTER BOOK (Scribner's, 1982), REVEALING THE UNIVERSE (MIT Press, 1982), ASTRONOMY FROM SPACE (MIT Press, 1983), INFINITE VISTAS (Scribner's, 1986), BUBBLES, VOIDS, AND BUMPS IN TIME (Cambridge University, 1989). He has produced and written several audio-visual shows for the Smithsonian Institution, including "The Electronic Sky" and "Visions of Einstein;" and he produced the exhibit "Light Paths" at the Whipple Observatory.

He is President of the International Science Writers Association and a member of the National Association of Science Writers, American Association of Museums Committee on Public Relations and Communications, and the AAAS. From 1976 to 1985, he was also a Lecturer in Science Communication at Suffolk University, Boston.

OWEN GINGERICH
Biographical Sketch

Owen Gingerich is a senior astronomer at the Smithsonian Astrophysical Observatory and Professor of Astronomy and of the History of Science at Harvard University. Beginning in February (1992) he will chair Harvard's History of Science Department.

Professor Gingerich's research interests have ranged from the recomputation of an ancient Babylonian mathematical table to the interpretation of stellar spectra. He is co-author of two successive standard models for the solar atmosphere, the first to take into account rocket and satellite observations of the sun; the second of these papers has received over 500 literature citations.

In the past decade Professor Gingerich has become a leading authority on the 17th-century German astronomer Johannes Kepler and on Nicholas Copernicus, the 16th-century cosmologist who proposed the heliocentric system. The Harvard-Smithsonian astronomer has undertaken a personal survey of Copernicus' great book *De revolutionibus*, and he has now seen over 550 16th-century copies in libraries scattered throughout Europe and North America, as well as those in China and Japan. His annotated census of these books will eventually be published as a 700-page monograph. In recognition of these studies he was awarded the Polish government's Order of Merit in 1981, and more recently an asteroid has been named in his honor.

Not all of his historical researches concentrate on the Renaissance. He has co-edited *A Source Book in Astronomy and Astrophysics, 1900-1975* and currently he is editing the 20th-century part of the International Astronomical Union's *General History of Astronomy*, with the first volume published in 1984.

Professor Gingerich has been vice president of the American Philosophical Society (America's oldest scientific academy) and he has served as chairman of the US National Committee of the International Astronomical Union. He has been a councillor of the American Astronomical Society, and helped organize its Historical Astronomy Division.

Besides over 300 technical articles and reviews, Professor Gingerich has written more popularly on astronomy in several encyclopedias and journals. In 1989 he published *Album of Science: The Physical Sciences in the Twentieth-Century* with Macmillan. Early in 1992 two anthologies of his essays will appear, *The Great Copernicus Chase and Other Adventures in Astronomical History* from Cambridge University Press and *Eye of Heaven: Ptolemy, Copernicus, Kepler* in the American Institute of Physics' "Masters of Modern Physics" series. At Harvard he teaches "The Astronomical Perspective," a core science course for non-scientists, and in 1984 he won the Harvard-Radcliffe Phi Beta Kappa prize for excellence in teaching.

EDWARD HAACK

Current Position

DIRECTOR OF EXHIBITS June 1979 to Present
The MUSEUM OF COMPARATIVE ZOOLOGY
Harvard University
Cambridge, MA 02138

Responsible for all activities related to the public exhibits: planning and design of new exhibits; label production for exhibits; maintenance of existing exhibits; monitoring of exhibit specimen condition (facilitates treatment of specimens); supervision of departmental staff; work schedules; purchase of materials and contract services.

Special Project

INSTALLATION COORDINATOR
HARVARD ART MUSEUMS June through October 1985

Responsible for the exhibit design and the installation of the nineteen galleries of the Fogg Art Museum during the complete renovation and reinstallation.

Relevant Experience

EXHIBIT CONSULTANT 1976 to present

Isabella Stewart Gardner Museum; Boston Museum of Fine Arts; the Old State House (Boston); Boston Zoological Society; the Paul Revere House; State Street Bank; Shreve Crump & Low Co.; Mineralogical Museum; Peabody Museum; Semitic Museum.

Education

B.A. American Studies - Pennsylvania State University 1969

Special Skills & Knowledge

Exhibition design, project administration, concerns of conservation, graphic design and production, construction, and manufacturing processes.

NATHAN L. HAZEN
50 Radcliffe Road
Weston, MA 02193
(617) 235-0712

Mr. Hazen is a mechanical engineer with over 30 years experience, 28 of which have been in the design and development of scientific instruments for astronomy, astrophysics, and atmospheric photochemistry. His specialties include conceptual design of new equipment, system and detail design, follow through in fabrication, integration, test and field application.

For the last 8 years, he has been Head Project Engineer with the Division of Applied Sciences of Harvard University, responsible for the above phases of a number of projects requiring flight instruments for stratospheric scientific balloons and high-altitude (ER-2) aircraft. In this work he has developed many novel systems and elements and has spent considerable time in the field on successful flight campaigns in Texas (NSBF), California (NASA ARC), Chile (Antarctic Ozone Hole) and Norway.

Prior to 1978 and a 2-year stint as Program Manager at Itek Optical Systems Division managing NASA-oriented new business areas, Mr. Hazen was with the Harvard College Observatory for 17 years. Here he was project engineer for a variety of satellite, balloon-borne, and ground-based instruments. In 1969, while a member of the observatory staff, he prepared a detailed engineering and structural analysis of the Sears Tower and its contents, with recommendation for the repair and restoration of the 15-inch telescope.

His experience also includes project management areas such as proposals, cost budgeting and analysis, schedule management including PERT, and subcontract management. He is the author or coauthor of 15 published technical papers and numerous studies, reports and proposals. He graduated from MIT with a BS in mechanical engineering, is Registered Professional Engineer in Massachusetts and a member of several professional societies.

FREDERICK DOWNING SEWARD

Astrophysicist

Education:

Princeton University, A.B., Physics (1953)
University of Rochester, Ph.D., Nuclear Physics (1958)

Positions Held:

1953-1958	Research and Teaching Assistant, University of Rochester
1958-1966	Research Scientist, Lawrence Livermore Laboratory
1967-1975	Group Leader, High Altitude Physics Group Lawrence Livermore Laboratory
1975-1976	Senior Visiting Fellow, University of Leicester and Mullard Space Science Laboratory
1977-	Astrophysicist, Harvard-Smithsonian Center for Astrophysics
Summer 1982	Guest Research Fellow of the Royal Society Institute of Astronomy, Cambridge, England
1984-	Harvard University - Lecturer

Professional Duties:

AEC/USAF Vela Satellite Scientific Overview Committee, 1961-67
NASA HEAO Instrument Proposal Review Committee, 1970,1973
NASA ASTP Instrument Proposal Review Committee, 1973
NASA Spacelab II Instrument Proposal Review Committee, 1977
NASA XTE Instrument Proposal Review Committee, 1978
NASA Spacelab Instrument Proposal Review Committee, 1979
NASA Einstein Observatory Guest Observer Proposal Review Committee, 1978-81
Einstein Observatory Users Committee, Chair, 1979-88
NASA High Energy Astrophysics Management Operations Working Group, 1984-86
Executive Committee, High Energy Division American Astronomical Society, 1984,5
SI Scholarly Studies Proposal Review Committee, 1985,6
ROSAT Users Committee, Member, 1985-
Executive Committee, Astrophysics Division, American Physical Society, 1987-89

Professional Societies:

Fellow, American Physical Society
American Astronomical Society

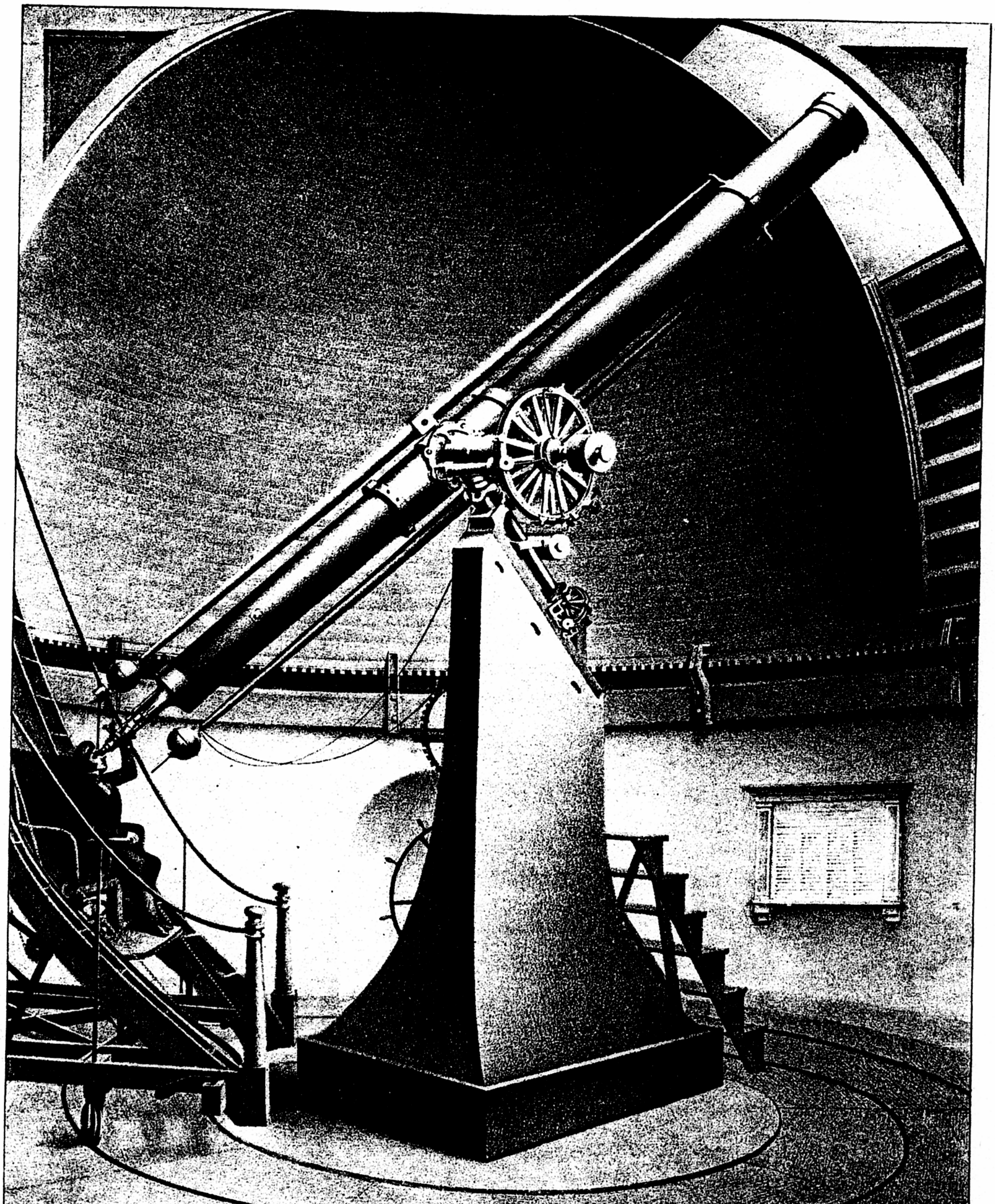
General Fields of Investigation:

Low Energy Nuclear and Photonuclear Reactions
Space Physics
X-ray Diagnostics of Laser plasmas
X-ray Astronomy

APPENDIX F

"The 15-Inch Great Refractor of the Harvard College Observatory"

(Excerpted from a study done by Nathan Hazen, Harvard College Observatory, February 1970.)



The HCO 15-Inch Refractor

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.

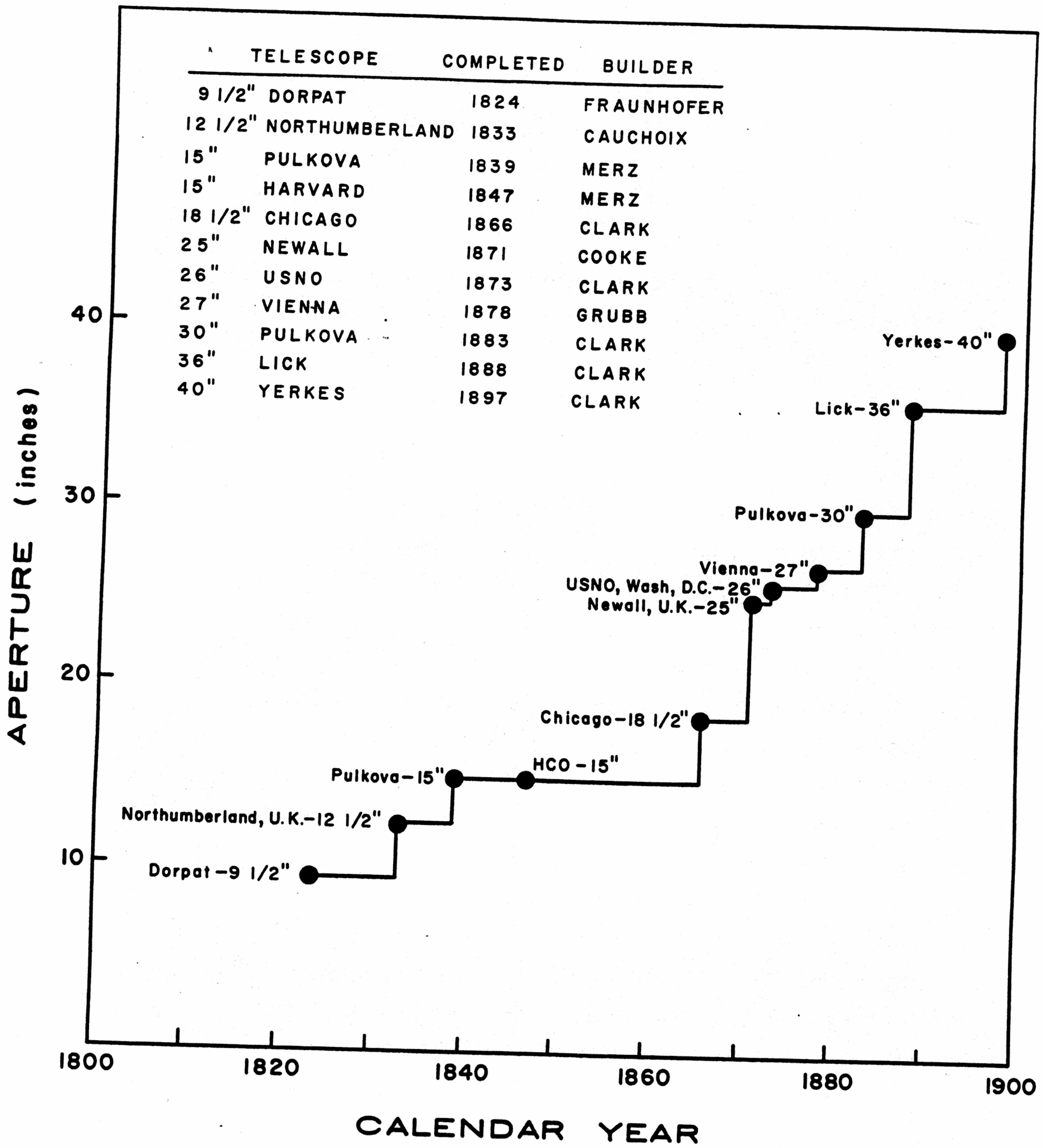


Figure 1. The Largest Acromatic Refractors

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

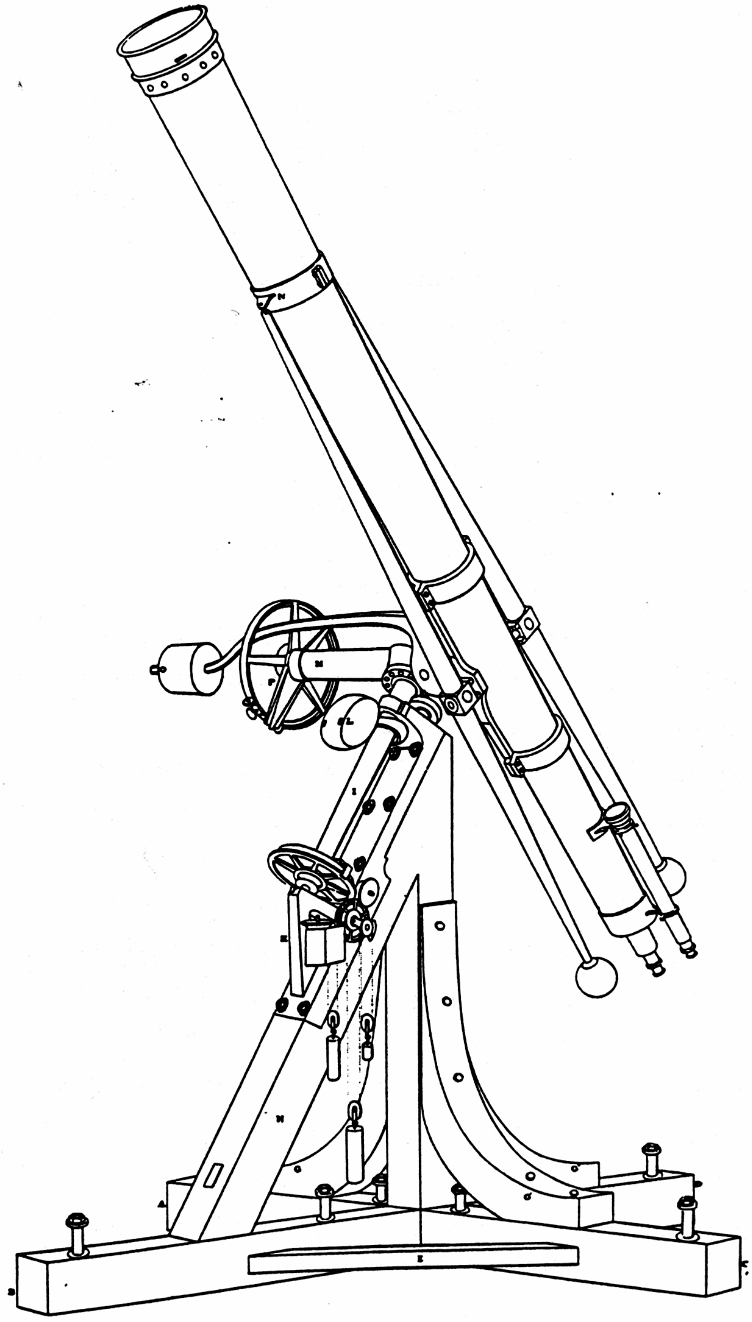


Figure 2. The Dorpat 9½-Inch Refractor

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 4¼-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 18½-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.

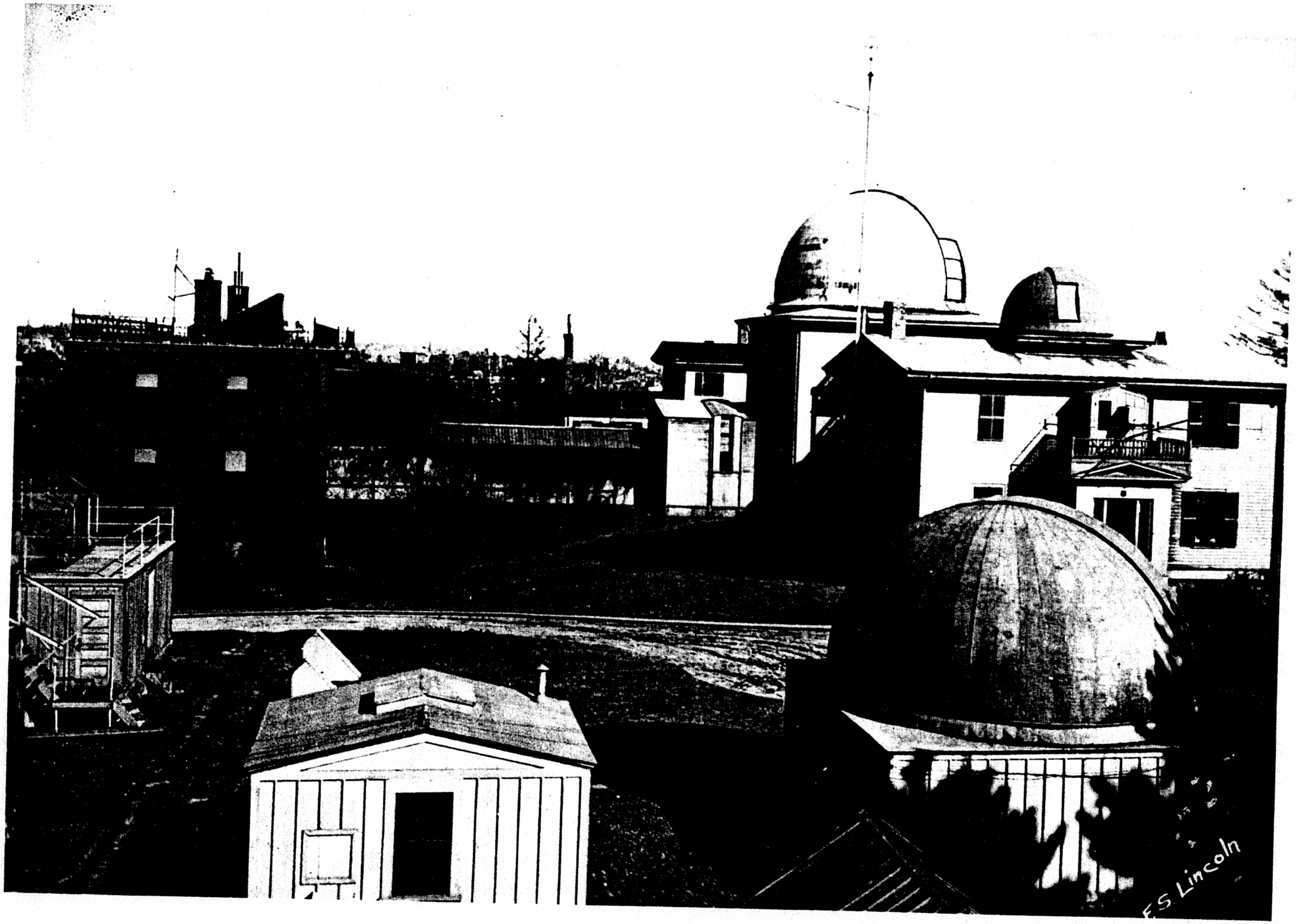
After being appointed Director of the Harvard College Observatory in 1877, E.C. Pickering proposed in his first annual report a new program emphasis for the 15-inch telescope--the field of photometry, which was to be its principal occupation for the remaining active years. O.C. Wendell joined the Observatory 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.



Observatory Hill circa 1910, with Sears Tower at rear right. (Harvard University Archives.)