Hobby-Eberly Telescope: a progress report

Sebring, Thomas, Ramsey, Lawrence

Thomas A. Sebring, Lawrence W. Ramsey, "Hobby-Eberly Telescope: a progress report," Proc. SPIE 2871, Optical Telescopes of Today and Tomorrow, (21 March 1997); doi: 10.1117/12.269069

Event: Optical Telescopes of Today and Tomorrow, 1996, Landskrona/Hven, Sweden

The Hobby-Eberly telescope: A progress report

Thomas A. Sebring
HET Project, McDonald Observatory, UT-Austin
RLM 15.308, Austin, TX 78712

Lawrence W. Ramsey
Dept. of Astronomy and Astrophysics, Pennsylvania State University
525 Davey Lab, University Park, Pennsylvania 16802

ABSTRACT

The Hobby-Eberly Telescope, nearing completion at McDonald Observatory in west Texas is an optical Arecibo-type telescope utilizing an 11-meter primary mirror and a 9.2-meter effective aperture. Innovative approaches have been employed to provide this large modern telescope at a total cost of $13.5 million. A joint project of the University of Texas, The Pennsylvania State University, Stanford University, the University of Munich, and the University of Goettingen, the telescope will be completed in mid 1997. First light is expected in mid 1996.

Keywords: Hobby-Eberly Telescope (HET), McDonald Observatory, University of Texas, segmented mirrors, large telescopes, Arecibo-type telescopes, cost-effective telescope designs, spherical mirrors

1. INTRODUCTION

The desire to have a large collecting aperture and enable improved signal to noise ratios as well as shortened image/spectrum acquisition times has spurred the development of several large telescopes in the last decade. Advances in technology which have made these telescopes possible include advanced optical fabrication technology, large mirror blank manufacture, advanced control algorithms and components, and optical technologies for sensing mirror position. In the case of most of the modern large telescopes the cost of these advanced technologies combined with the scale of the instruments themselves has led to near order of magnitude cost increases relative to the previous 2-3 meter telescopes.

The goal of the Hobby-Eberly Telescope (originally termed the Spectroscopic Survey Telescope) was to utilize an altered paradigm to provide a large telescope at a fraction of the cost of traditionally-designed telescopes. Originally proposed by Dr. Larry Ramsey and Dr. Daniel Weedman of PSU, the SST was to be an optical Arecibo-type, utilizing a spherical primary mirror and tracking the moving, focused image of the object via a moving tracker system at prime focus.

Several versions of the SST were developed over a period of five years employing different versions of segmented primary mirrors, tracker systems, and enclosures. In 1992 formal approval to construct the HET was provided by the University of Texas and legal agreements between the HET Partners achieved to secure the required funding. At that time a Project Team was formed and a major redesign of the telescope undertaken. Ground was broken in March of 1994. The HET is approaching first light in mid 1996, and several unique and novel engineering approaches have been developed to address the disparity between the scale and the desired cost for the HET.

2. GENERAL SPECIFICATIONS

As built, the HET will exhibit the following attributes:

Spherical Primary Mirror	77.6 m2
Pupil on Primary Mirror	9.5 meters
Central Obscuration	2..5 meters
Mirror Segments	91
Segment Phasing	25 microns/.0625 arc sec
Image Quality	.6 arc sec
Site Altitude	6800 feet

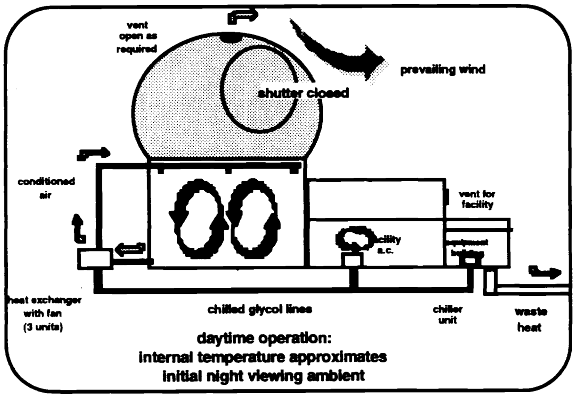
0277-786X/97/$10.00

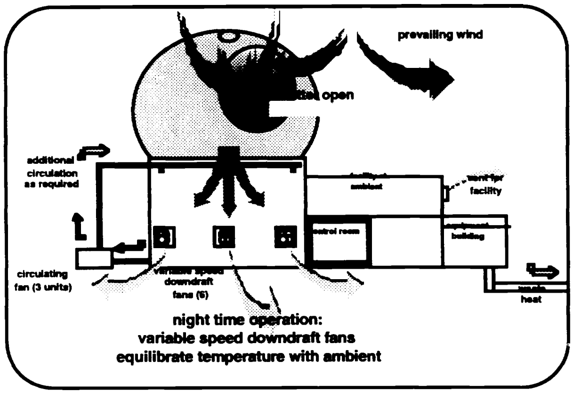
The HET telecentric axis is tilted 35 degrees off vertical, providing access to 70% of the sky as the telescope can be rotated 470 degrees in azimuth. The telescope is stationary during tracking providing a maximum track length of approximately 2 hours.

In the following section we discuss the engineering attributes of the major telescope subsystems and performance realized to date.

3. THE HET FACILITY

The HET Facility is designed to provide optimum seeing and to accommodate the fiber fed spectrometers in stable thermal environments. The facility is largely of concrete below ground and at ground level, and structural steel above. The foundations for the dome and the telescope pier are separated as individual cylindrical footings at what approximates bedrock atop Mt. Fowlkes in Texas' Davis Mountains. The cylindrical pier for the telescope forms the walls of a spectrometer room 40 feet in diameter by 16 feet high below ground level. Natural thermal swings of only a few degrees in this environment will be controlled within instrument enclosures to within .1° F year round to provide instrument stability.





The areas between the inner and outer piers are largely filled with loose dirt to provide insulation and vibration damping. The outer pier serves as the base for the structural steel cylinder which supports the dome. The floor of the enclosure is insulated as are the steel walls. The walls are sheathed externally with steel sheathing with vented airspace to allow convection cooling of sun-heated walls and to promote thermal equilibration. External finishes are Kynar polyamide with a projected 40 year life and total integrated solar absorptance of less than 2%.

During the day a glycol/water air conditioning system with two large chillers and vents which encircle the dome maintain temperatures below daytime ambient. In the period preceding initiation of observing, the interior temperature can be lowered to the anticipated ambient to allow equilibration and reduce the time needed for dome venting. Dome seeing during observation is addressed via down draft ventilation. The basic design for this system was taken from the Keck telescope and consists of six 48-inch diameter exhaust fans distributed approximately symmetrically about the enclosure wall at the base. Capacity is 20 full air changes per hour and the fans are fitted with variable frequency drives that permit them to be varied in speed.

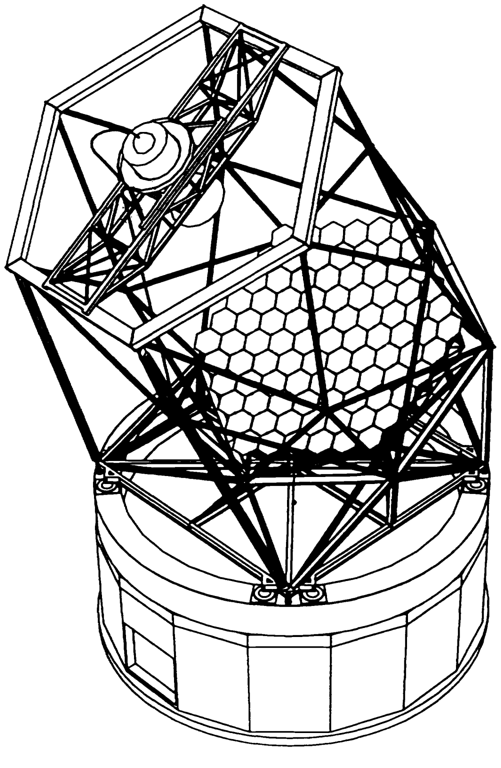
All aspects of the enclosure environmental system are under computer control via a Johnson Controls Intel 486-based commercial HVAC controller. Distributed temperature measurements from within the enclosure control the speed of fans to ensure maximum thermal uniformity at the lowest allowable fan speeds and turbulence. Air handlers for the air conditioning system can also be run without cooling to provide additional air mixing. All heat sources within the dome (electronics, motors, computers, etc.) are enclosed, insulated and cooled via a glycol water system and heat exchangers or heat exchange jackets.

The control and service building provides 2500 square feet of space for the control room, engineering laboratories, storage, and other facilities. The control room will be an additional insulated space within the building, and no portion of the building other than the control room will be thermally conditioned. All venting of the building is on the predominantly downwind side. The large glycol/air heat exchanger which vents heat from the cooling systems for electronics and motors is further downwind. Total cost of construction was $2.3 million including paving, landscaping, and interior/exterior finishes.

The telescope dome was provided by TEMCOR of Los Angeles, California at a total cost of $850,000. It is a prefabricated aluminum-framed and skinned geodesic dome with a reinforced 11-meter opening. The dome weighs a total of 220,000 lb. with the shutter and rotation mechanism. Patented I-beams form the struts of the structure and pre-cut and bent panels are attached via a bolting system and silicone gaskets for waterproofing. The dome was manufactured and shipped to the site without pre-assembly. On site the dome was assembled without metrology, using only the precision of the components to control dimensions. The dome shutter was made 16 inches thick as it was too flat to have adequate shell stiffness to prevent unacceptable deformation under 120 mph maximum survival wind loads. Electro-mechanically driven clamps secure the shutter when the dome is stowed.

The dome is mounted on an 80-foot diameter steel ring formed of I-section steel 18 inches high and 12 inches across. This ring made up of 16 sections, was set up at the manufacturer's facility and drilled and pinned to allow precise on-site assembly. Additional fine tuning and site welding resulted in a beam flat to within 1/16 inch. The ring (and dome) rotate on 16 bogie assemblies featuring 8-inch diameter crown rollers as well as hold down rollers and radial runout rollers. Two drive assemblies featuring 5-horsepower motors driving through gear reductions and rubber tire friction drives rotate the dome. The dome rotates nearly without sound and only one drive is required providing redundancy in the event of failure. The dome was assembled on the ground and lifted, with 1/3 of the panels installed, atop the enclosure by a 300-foot crane.

4. TELESCOPE STRUCTURE



Illustrated here, the HET structure was conceptually design by Steven Medwadowski, the designer of the Keck Telescope structure. Detailed design was left to the contractor, Comsat/Radiation Systems Inc. of Dallas, Texas, which enabled them to design joints and sections to match their fabrication capabilities. The structure includes the pintle bearing assembly, base wedge (which supports the primary mirror) the telescope tube, and the top hex (which supports the tracker assembly). The structure exhibits a lowest natural frequency of > 6 Hertz when fully loaded with tracker and primary mirror.

The structure rotates on eight 36-inch diameter air bearings supplied by Aero-Go of Seattle, Washington. These custom-developed bearings operate at approximately 20 psi and are specially designed to minimize air usage. They operate on a 40-foot diameter by 40-inch wide concrete ring constructed atop the telescope pier foundation. The concrete was made flat within .0625 inches via the use of a laser level and steel forms. Flatness requirements were driven by the use of four telescope feet and the need to minimize racking of the structure when set for an observation. Drive for rotation is provided by two rubber-tired friction drives that operate directly atop the telescope pier. Azimuth location is encoder driven via a ring and spur gear arrangement off the pintle bearing. A 12-inch central hole through the pintle bearing provides access to the spectrometer room for the fiber optic cable which transmits photons from the focal plane to spectrographic instrumentation.

The structure operates with a total absence of perceived vibration. Lift-off and set-down for the air bearings create no jar, and acceleration profiles are well controlled. No vibration can be detected during rotation, and azimuth positions have been measured to be precise to within .1 arc sec; substantially exceeding the requirements set by pointing accuracy for target acquisition. The structure, including all structural steel, drives, controls, and software was completed for a total of $1.3 million.

5. PRIMARY MIRROR

The Primary Mirror consists of the Primary Mirror Truss, the Segment Support Modules, and the Mirror Segments. The primary objective in design was to maintain stiffness of the overall assembly to obviate wind shake. Segments are moveable in rigid body only, with figure not actively controlled.

The Primary Mirror Truss was designed, manufactured, delivered, and assembled by Mero Structures of Wurzburg, Germany. It is of patented bolted construction, 11-meters in major diameter, and has a lowest structural frequency of >10 Hertz when fully loaded with mirror modules. The truss exhibits three nodes for each mirror on the top surface and is reduced to three major mounting nodes on the back surface through two intermediate layers. Thickness and wetted surface aspect ratios of all members were selected to ensure identical thermal performance of all members, hence avoiding "bi-metallic" type bending.

The truss is kinematically mounted to the structure utilizing commercial linear bearings and custom made ceramic pivots which operate in oil baths to preclude contamination and ensure longevity. These mounts can impart no more than 5-foot pounds of torque to the truss regardless of motions of the structure mounting points. All truss component surfaces inside and out are hot dipped galvanized and powder coated, resulting in life time corrosion resistance.

Testing of the truss bolted connections featured at each node indicated that the pre-stressed bolted connections exceeded the bulk stiffness of the members in both compression and tension. Torqueing during assembly ensured uniform stress within the structure. Node position accuracy for the completed truss was verified to be better than 4 mm as provided by the precision of component manufacture. Mero utilizes a custom built state-of-the-art laser metered strut manufacture robot and high quality CNC node machining stations. All components were manufactured in a three week period by approximately four personnel. The truss was assembled and measured in Germany and subsequently disassembled and shipped. Broken down the truss easily fit in a single ship board container and on a single tractor trailer rig for road transport. Total cost for the truss assembled at the HET site was $400,000.

Primary mirror segments are hexagonal of 1 meter minor diameter and 50 mm thick and are low expansion Zerodur glass ceramic. With a radius of 26.18 meter, there is only approximately 10 mm of sag in the optical surface. The backs of the segments are plano. Initial investigation of fabrication options with vendors revealed several options. The chosen approach was continuous polishing (planetary type) followed by ion-figuring. The planetary polishing approach was an extrapolation of the technique used by several vendors to provide flat mirrors and windows. Following an Internal Research and Development effort, Eastman Kodak determined that they could successfully manufacture the mirrors to near net shape via this process. Residual surface deformation produced by the nine-point mounting of our modified Hindle approach also needed to be accommodated during final figuring, and Kodak's ion figuring process was deemed suitable for this. Kodak's award of the fabrication effort was won by a bid of $1,650,000.

The mirrors are mounted via a modified Hindle mount, which utilizes three tetrahedrons manufactured from 1/2-inch invar bar to support the segment. These tetrahedrons are in turn supported by compound levers providing a 10:1 reduction. The levers are actuated via commercial motor micrometers and the entire assembly is extremely stiff to obviate wind shake. Given the fixed gravity vector of the HET (no elevation change) the mirrors can be figured to good optical quality at the use angle in the presence of fixed mount induced deformation. The mirrors are figured to better than 1/15 wave (6328 a) rms and tested via a close, non-contact transmission sphere. Testing against a master sphere provides a straightforward means of accurate radius matching.

6. TRACKER SYSTEM

The tracker system is designed and manufactured by Orbital Sciences Corporation of Phoenix, Arizona. Lateral motions are provided by recirculating ball linear bearing systems driven by roll screws. Focus and tip/tilt of the instrument package at prime focus are achieved via a hexapod or Steward platform formed of three pairs of extensible bipods. Rotation of the instrument package to null field rotation is provided by a circular rail/bearing system driven by a cable drive.

Positioning is accurate to 6 microns in linear dimensions and to .1 arc sec in tilts. The payload capacity is 250 kg. and with the payload in place, the lowest natural frequency is >10 Hz. The tracker itself provides a total obscuration of less than 3%, as the instrument package and the mounting stage reside within the central obscuration defined by the central hole of the tertiary mirror. All motors are enclosed, insulated, and cooled via glycol/water heat exchangers.

All cables, hardware, and software are tested in the use attitude at the manufacturer's facility, disassembled into major subassemblies, and shipped via truck. Installation at the site is via crane through the dome aperture. The entire tracker system is manufactured at a cost of $1,250,000.

7. PRIME FOCUS INSTRUMENT PLATFORM

The Prime Focus Instrument Platform (PFIP) provides correction of the spherical aberration inherent to the primary mirror, incorporates acquisition camera, guider, fiber instrument feed, and a low resolution spectrometer. The Spherical Aberration Corrector (SAC) itself is a four-element Gregorian design, utilizing three conics and one general asphere. The mirrors are of ULE and are mounted via an Invar metering structure. The SAC is mounted kinetically to the PFIP structure via a gimbal arrangement which precludes any stress induced misalignment of corrector elements. Within the corrector at an intermediate pupil a moving baffle system is fitted to occlude the portion of the system pupil which roves off the primary mirror during tracking. This obviates any need for any baffle at the primary mirror. There is a conical stray light baffle at the entrance region of the SAC.

Acquisition is via a camera utilizing five optical elements and featuring a TEK1024 x 1024 CCD at its focal plane. The guider system utilizes three fiber optic probes which relay images to a second CCD system identical to that of the acquisition camera. Atmospheric dispersion correction is provided by a two element prism of fused silica and LLF2 glass, 3.15 inches in diameter and mounted in a rotation stage to maintain the prism dispersion along a great circle through zenith and the object being tracked. A sliding mirror arrangement provides for image routing to either the acquisition camera, fiber handling system, or the low resolution spectrograph. The fiber handler can provide either single or multi object capability and handle multiple bundles of object and sky fibers to address varied scientific missions.

8. FACILITY INSTRUMENTS

The $13.5 million capital cost for the HET does not include instrumentation. The first generation HET facility instruments have been under development for the past three years and are now entering the final design and construction phase. All are fully funded constituting an instrument program of about $4 million.

8.1 The Low Resolution Spectrograph

The Low Resolution Spectrograph (LRS) is the only first generation instrument that will reside at the HET focal plane. It is designed to achieve a resolving power ($R = \lambda/\Delta\lambda$) between 500 and 1000 with a 1 to 1.5 arcsec. slit over the wavelength range 400 nm to 1.0 μm. Two exposures will be required to cover the entire wavelength range on the CCD at $R \sim 1000$. The dispersing element will be a grism in all cases. Multi-object spectroscopy (MOS) capability will be enabled with 15 slitlets covering the 4 arcmin. HET science field. Automated removal of the grism and slit assembly will allow broad and narrow band imaging over the science field of view. This basic configuration is scheduled to be deployed in January 1998. The LRS PI is Dr. Gary Hill, UT-Austin.

8.2 The Medium Resolution Spectrograph

The Medium Resolution Spectrograph (MRS) is a fiber-fed dual beam echelle spectrograph that functions in three modes; single object with sky, 1/2 arc minute long slit and 10 MOS probes remotely positionable over the 4 arcmin. science field of view. Fibers sizes of 1.5, 2 and 3 arcsec. are selectable. The preliminary design covers the range from 350 nm to 1.0 μm in a single exposure at resolving powers from $3{,}600<\lambda/\Delta\lambda<2{,}0000$. A fiber slicer is utilized to achieve the highest resolution on single objects. The spectrograph utilizes a white pupil design to maintain throughput and obtain good sky subtraction and precision radial velocity capability. More details are discussed by Ramsey.[1] The first beam is scheduled to begin commissioning in February 1998. Dr. Larry Ramsey at PSU is the PI.

8.3 The High Resolution Spectrograph

Like the MRS, the High Resolution Spectrograph (HRS) will be fiber-fed from the HET corrected prime focus. The HRS design will work in the resolving power range $30{,}000<\lambda/\Delta\lambda<120{,}000$ over the 400 nm to 1.1 μm spectral region. Two fiber size selections will be available; 1.2 and 1.8 arcsec. In each size there will be a source fiber and up to four sky fibers. Image slicers will be used to maximize throughput at the higher resolutions. The HRS is essentially a single object instrument which is being optimized for high wavelength stability (<10 m/sec) low scattered light (<1%) spectroscopy. It employs a white pupil design. The HRS will be a single beam version of the instrument described in detail by Tull.[2] The HRS is scheduled to be in commissioning during the second half of 1998. The PI is Dr. Robert Tull at UT-Austin.

9. SUMMARY

The HET provides a fundamental paradigm shift for large astronomical telescopes. By accepting less than full sky capability and the somewhat limited field of view implied by the optical design, substantial savings have been realized. Innovative engineering approaches which have relied significantly on construction technologies not previously applied to optical telescopes have further reduced cost. Finally, the development of concept and preliminary designs within the HET Project Team followed by detailed design and construction by vendors under firm fixed price contracts has resulted in strict control of cost growth. The HET will be commissioned in mid 1997.

10. REFERENCES

1. L.W. Ramsey, "The Hobby-Eberly telescope medium resolution spectrograph" in *Proceedings of SPIE Conf. 2476, Fiber Optics in Astronomical Applications,* Orlando, FL, April, 1995, p. 20.

2. R.G. Tull, "High Resolution Spectrograph for the Spectroscopic Survey telescope" in *Proceedings SPIE Conf. 2198, Instrumentation in Astronomy VII,* Kona HI, Mar. 1995, p. 674.