PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Hobby-Eberly Telescope: commissioning experience and observing plans

Glaspey, John, Adams, Mark, Booth, John, Cornell, Mark, Fowler, James, et al.

John W. Glaspey, Mark T. Adams, John A. Booth, Mark E. Cornell, James R. Fowler, Victor L. Krabbendam, Lawrence W. Ramsey, Frank B. Ray, Randall L. Ricklefs, William J. Spiesman, "Hobby-Eberly Telescope: commissioning experience and observing plans," Proc. SPIE 3349, Observatory Operations to Optimize Scientific Return, (3 July 1998); doi: 10.1117/12.316520

Event: Astronomical Telescopes and Instrumentation, 1998, Kona, HI, United States

SPIE.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020 Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

The Hobby-Eberly Telescope: Commissioning Experience and Observing Plans

J. W. Glaspey[a], M. T. Adams[a], J. A. Booth[b], M. E. Cornell[b], J. R. Fowler[a], V. L. Krabbendam[b], L. W. Ramsey[c], F. B. Ray[b], R. L. Ricklefs[b], and W. J. Spiesman[b]

[a]McDonald Observatory, University of Texas at Austin, P.O. Box 1337, Ft. Davis, TX 79734
[b]McDonald Observatory, University of Texas at Austin, RLM 15.308, Austin, TX 78712
[c]Dept. of Astronomy and Astrophysics, Pennsylvania State University, 525 Davey Laboratory, University Park, PA 16802

ABSTRACT

Experience in bringing into operation the 91-segment primary mirror alignment and control system, the focal plane tracker system, and other critical subsystems of the HET will be described. Particular attention is given to the tracker, which utilizes three linear and three rotational degrees of freedom to follow sidereal targets. Coarse time-dependent functions for each axis are downloaded to autonomous PMAC controllers that provide the precise motion drives to the two linear stages and the hexapod system. Experience gained in aligning the separate mirrors and then maintaining image quality in a variable thermal environment will also be described. Because of the fixed elevation of the primary optical axis, only a limited amount of time is available for observing objects in the 12° wide observing band. With a small core HET team working with McDonald Observatory staff, efficient, reliable, uncomplicated methodologies are required in all aspects of the observing operations.

Keywords: Hobby-Eberly Telescope, large telescopes, segmented mirrors

1. INTRODUCTION

The Hobby*Eberly Telescope (HET) is an innovative, low-cost implementation of a large, segmented-mirror, optical telescope[1, 2, 3]. Ninety-one hexagonal, spherical segments, each one meter across (flat side to flat side), are carried on a fixed-elevation, variable-azimuth pointing structure. An optical tracker carries a Prime Focus Instrument Platform (PFIP) along the spherical focal surface to follow star trajectories. The design parameters of the 4-element, all-reflecting, Spherical Aberration Corrector (SAC) will limit the effective aperture to a diameter of 9.2 meters, but, in combination with other systems, should provide 50% encircled energy within 0.6 arcsec in the absence of atmospheric seeing. All reflective surfaces are silver coated, which maximizes total throughput in the visible-red at the cost of very low throughput in the UV.

Because the telescope observes in a 12° broad band of the sky 55° from the horizon, operations will consist of mostly queue-scheduled, service observing[4]. There will be a Low Resolution Spectrograph in the PFIP plus two fiber-fed spectrographs in a thermally stable room inside the pier, a Medium Resolution Spectrograph, being built by the Pennsylvania State University, and a High Resolution Spectrograph, being built by the University of Texas at Austin.

The HET is an international collaboration involving The University of Texas at Austin, The Pennsylvania State University, Stanford University in the United States, and the Ludwigs-Maximilians-Universität München and the Georg-August-Universität Göttingen in Germany.

First light was achieved in December 1996, and some science observations have been attempted through the second semester of 1997 and early 1998. A temporary, 2-element reflective corrector (the Surrogate Spherical Aberration Corrector, or SSAC) was used with a fiber-fed, bench-mounted, low resolution, echelle spectrograph furnished by Pennsylvania State University. This paper reports on some of the results and experiences of this commissioning phase

Part of the SPIE Conference on Observatory Operations to Optimize Scientific Return • Kona, Hawaii • March 1998

SPIE Vol. 3349 • 0277-786X/98/$10.00

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

2. TRACKER PERFORMANCE

Details of the tracker design and performance are given in Booth *et al.*[5], however we shall discuss some of the issues relevant to pointing and to tracking. The tracker will carry the PFIP along a three-dimensional trajectory on the spherical focal surface of the primary mirror at a velocity appropriate for the target being observed (which may not move at strictly sidereal rates.) The trajectory depends on parameters that must be carefully determined, such as the true azimuth and elevation angles of the optical axis, the radius of curvature of the focal surface, and several terms that represent the imperfections in the mechanical systems, *e.g.* the flatness and inclination of the pier, sagging or warping of the linear stages, *etc.* The precision of positioning the structure in azimuth is typically 0.002 degrees, certainly adequate to place most objects near the center of the acquisition camera field-of-view. The elevation angle of the optical axis appears to be within one arc minute of the nominal value of 55°. Initial studies of pointing and tracking were severely hampered until most of the mechanical terms were included in the pointing model. As of this writing the absolute pointing error is 11 arcsecs rms. Tracking is 0.01 arcsec/sec or better, adequate for normal guiding and requires only occasional intervention of the telescope operator. Automatic guiding will be implemented in the near future.

More tests will be required to optimize the tracker hexapod performance, especially for the guiding corrections. The hexapod, or Stewart platform, provides the Z linear motion and two rotational motions for the instrument package during the trajectories. During the earliest tests the acceleration of the motors when guiding or focus corrections were added to the trajectory were quite high, leading to unacceptable shaking of the payload and concerns about long-term damage on the mechanical components. This has since been reduced considerably, but we believe that additional reductions can be made to protect the mechanisms without degrading the scientific performance.

3. MIRROR CONTROL SYSTEM PERFORMANCE

As built there is no closed-loop control of the mirror segment positions, so thermally induced changes in the mirror truss effectively deform the primary. The dominant term is one equivalent to defocus, *i.e.* a bending of the truss that inclines the mirror segments away from their ideal orientations. It is expected that a reasonably simple model (with relatively few terms) will keep the “un-stacking” of the mirrors within the optical image quality requirement of the total system. During the initial test runs no attempt was made to implement a thermal model, which admittedly made mirror alignment quite difficult, especially at the beginning of the night when temperatures were changing most rapidly. Subsequent introduction of a first-pass thermal model shows promise but at the time of writing we lack quantitative data to discuss the effectiveness of this approach.

The truss struts and nodes are bolted together, not welded, so we have also noticed misalignments induced by workers climbing on the truss to perform mirror installations or maintenance. When no one climbs on the truss the alignments are quite stable, except for the thermal effects. Furthermore, the structure rotates very smoothly on air bearings while changing azimuths, and no degradation of the alignment quality has been detected due to lifting the structure, rotating, then setting the structure down.

Little effort has yet been put into establishing or maintaining piston alignment, *i.e.* focus of individual segments. Rough piston can be established using a simple spherometer. Once in operation it has been estimated that the piston of individual segments must be held to .025 mm, otherwise the statistical probability that one (or more) of the segments will be far enough out of focus to degrade the optical image quality is unacceptably high. With the SSAC this effect has not yet been noticed.

Most of the development work and alignment prior to science observations has made use of the Center of Curvature Alignment System (CCAS) laser system. A laser beam from the center of curvature of the spherical mirror returns to the point of origin. Using one mirror as a reference, the relative angles between the images from other segments to the reference mirror gives the tip/tilt corrections needed to co-align the images. Once the segments are roughly aligned, a shearing interferometer provides more precise error measurements, but the return beams from the segments must be directed into a 0.2 mm aperture over 26,000 mm from the mirror. Under very windy conditions this has proven to be difficult. The CCAS sits on a steel tower that is inside a slightly larger diameter access tower. Although this dual tower combination provides some thermal insulation, right after sunset we have still seen changes in the position of the interferometer relative to the mirror. Most of this is probably due to bending of the tower from differential heating of the side that is exposed to strong sunlight for much of the day.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

On-sky alignment using star images is also possible. The tracker complicates this process since it blocks, totally or partially, starlight going to some of the mirrors (as it does with the laser beam when using the CCAS). A two-step procedure will be needed, the first step being with the tracker covering one part of the array and the second observing a different star that puts the tracker over a different part of the array. Bright stars are not suitable objects with 1 meter aperture segments since they saturate the CCD detector in the imaging camera for exposure times of acceptable length, so fainter stars, 8-9 magnitude, are preferable and on-line catalogs must be used. Long exposures, such as 20-30 seconds, may also be needed to average out short-term tip/tilt seeing variations that could bias centroid determinations during the alignment procedure.

4. OPTICAL PERFORMANCE

Since the optical beam at prime focus entering the spherical aberration corrector is fairly fast at f/1.4, maintaining proper focus will be critical to total image quality. Once the mirror segments were co-aligned, the Full-Width at Half Maximum (FWHM) of the guide star or acquisition fields images were measured as a function of corrector height and the best value was used to select the focus position. In the long-term temperature sensors on the steel support beams of the prime focus tracker will be read by the Telescope Control System (TCS) computer and used to adjust the focus component of the target trajectory in real time. At a distance of 13082 mm from the primary mirror vertex to the entrance of the corrector, a 0.5°C temperature change would introduce roughly 0.5 arcsec of defocus, so focus compensation will be critical to meeting total image quality specifications.

For the test runs using the SSAC[5], the image quality with a single mirror segment was slightly better than 2 arcsecs FWHM, approximately the performance limit of the diamond-turned, metal mirrors of the SSAC. The best measured FWHM for aligned mirrors was 1.9 arcsecs, so the alignment quality was better than the SSAC image quality. The entrance aperture of the fiber feeding the spectrograph was 0.4 mm, approximately 2 arcsecs on the sky, an acceptable match to the image quality of the 21 mirrors in use at that time.

The major limitation on image quality has been the difficulty in co-aligning the mirror segments while the truss was undergoing temperature changes. The automatic dome environment control was not implemented at that time, so the air-conditioning system was usually only operated during the late-afternoon and early evening, not always leaving enough time to get the truss temperature close to the outside air at sunset, when the dome would be opened. As mentioned above, the thermal control algorithms for adjusting mirror tip/tilt/piston to compensate for expansion/contraction of the steel members of the truss had neither been developed nor implemented, so the truss was usually changing while we were trying to align the mirror segments. We estimated that the image quality, while close to 2 arcsecs at the start of a star trajectory immediately following a mirror alignment at sunset, was sometimes noticeably worse by the time we were ready to observe 20-30 minutes later. During the night six large "downdraft" fans run continuously, providing 20 volume changes per hour. Once temperatures stopped changing so rapidly after midnight, the extent of the misalignments from thermal drifting of the truss reduced considerably in amplitude to the point where the SSAC intrinsic image quality was dominant.

5. COMMISSIONING PHASE OBSERVING CONSTRAINTS

The open-loop nature of the mirror segment control system requires frequent examination of the quality of the mirror alignment. The system is required to hold the image quality performance specification for temperature changes of up to 0.5° C per hour as a normal operating condition. With a 0.5°C global temperature change the effective radius of curvature of the truss can change by 0.15 mm, requiring tip/tilt adjustments of the segments of just over 0.2 arcsecs for mirrors at the edge of the truss. If the response of the truss to thermal changes is not well enough behaved to be removed by simple analytical formulae, it may be necessary to realign the mirrors before every target. The telescope performance specifications state that no more than 6 minutes per hour, or 10% of observing time, may be used for mirror alignment. This time must include rotating the telescope structure to point to the CCAS tower, measuring the alignment errors, and applying the corrections, making this requirement a challenge to meet.

Once all 91 segments are fully integrated into the mirror alignment scheme the system will behave like a single mirror. While developing the control software and user interfaces, which includes the early testing period, it has been decided not to try to control all 91 segments, but to work instead with a subset of the mirrors. Twenty-one mirrors arranged in an "X" along the two directions of shear of the CCAS interferometer have been used for most of the hardware and software development work. The other 70 mirrors were tipped many arc-minutes off-axis, but not with great precision. As a result the acquisition

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

camera sees the on-axis science field of images provided by the 21 aligned mirrors plus whatever part of the nearby (not usually blank) sky towards which the unaligned 70 mirrors happen to point. Faint target objects are quite difficult to identify with this kind of background confusion. Also, the SSAC does not have a central baffle, so any additional stray illumination from the dome may fall directly on the detector.

6. OBSERVING PLANS

The telescope can only track objects for an hour at the southern declination limit, which is typically the longest exposure times observers accept with CCD detectors, and up to 2.5 hours at the northern limit. As a result observers do not have the luxury of searching very long for their target, so for optimal efficiency the targets must have very well known coordinates. This will require extra work on the part of the Principal Investigators in preparing observing lists with accurate coordinates and, where appropriate, finding charts, the more so because up to 80% of the observations will be made in "service" mode by the Resident Observer/Astronomers.

The combination of queue-scheduling and service observing[4,7,8] implies that at the telescope the observer will select objects from a computer-generated target list. The scheduling software will have to take into account not just which objects are available at a given moment, but also the priority of the target as a function of the fraction of time each partner in the consortium has accumulated up to that moment relative to the contractual fraction *and* the relative priority of a particular program within each partner's total list of accepted programs. The observer may have to reject targets in real-time depending on the current weather conditions and whether or not the current operational status of the particular scientific instrument requested might have an impact on the quality of the desired data. The scheduling program may have to be run prior to the end of each observation to select the next target so that the amount of time spent acquiring science exposures during the night will be maximized.

Target selection software taking into account the telescope pointing restrictions is available to view lists of potential targets. The lists show how much time is left in a trajectory for each object, or how long it would be before the object would enter the observing zone of the telescope. The optimum track for each object has the trajectory passing through the middle of the tracker range, which only occurs at one azimuth directly related to the declination of the object. Although the optimum trajectory for a given declination requires moving in azimuth so that the telescope central optical axis intersects this declination circle, for short exposures it is possible to observe objects at non-optimum azimuths, saving time by not having to rotate the telescope structure.

Focussing a 9.2 meter telescope cannot be done with bright stars, since exposure times must be long enough to average out seeing variations. For a given target the tracker will have to be pointed at a region of sky of the same declination but several minutes of hour angle ahead of the science target. Enough time must be allowed to permit the Telescope Operator to find an appropriate faint star for focussing, carry out the focus procedure, then to move the tracker into position for the science target before it arrives. Focus stars as faint as 15th magnitude will be required.

The full primary mirror array is stationery but the pupil moves across it during long exposures, so the scientific quality of some of the data will depend how many and which mirrors make up the pupil. Since the Low Resolution Spectrograph sees the actual pupil (as opposed to the fiber fed spectrographs), some observations might be affected by data acquired when the pupil consists of mirrors near the edge of the array, since the pupil would not fill the collimator or the grating. The FITS headers will contain sufficient information to either allow the PI to take this into account or at least to ask for more detailed information about the configuration when the data was being taken.

ACKNOWLEDGEMENTS

We wish to acknowledge the valuable assistance of Niall Gaffney, Grant Hill, Craig Nance, François Piché, Brian Roman, William Wren, as well as numerous others for their contributions in carrying out the tests and observations necessary in starting to commission a major telescope like the HET.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

REFERENCES

1. Ramsey, L.W., Sebring, T.A., & Sneden, C., 1994, "The Spectroscopic Survey Telescope Project", S.P.I.E. Vol. 2199, *Advanced Technology Optical Telescopes V*, p. 31.
2. Sebring, T.A., Booth, J.A., Good, J.M., Krabbendam, V.L., and Ray, F.B., 1994, "Design and Status of the Spectroscopic Survey Telescope", S.P.I.E. Vol. 2199, *Advanced Technology Optical Telescopes V*, p. 565.
3. Sebring, T.A. and Ramsey, L.W. 1997, "The Hobby-Eberly Telescope: A progress report", S.P.I.E. Vol. 2871, *Optical Telescopes of Today and Tomorrow*, p. 32.
4. Gaffney, N.I. and cornell, M.E., 1997, "Planning and Scheduling Software for the Hobby*Eberly Telescope", in *Astronomical Data Analysis Software and Systems VI, A.S.P. Conference series*, Vol 125, p. 379.
5. Booth, J.A., Ray, F.B., and Porter, D.S., 1998 "Development of a star tracker for the Hobby-Eberly Telescope", S.P.I.E. Vol. 3351, *Telescope Control Systems III*, (in press).
6. Ramsey, L.W., Adams, M.T., Barnes, T.G., Booth, J.A., Cornell, M.E., Gaffney, N.I., Glaspey, J.W., Good, J.M., Fowler, J.R., Kelton, P.W., Krabbendam, V.L., Long, L., Ray, F.B., Ricklefs, R.L., Sage, J., Sebring, T.A., and Steiner, M., 1998, "Early Performance and present status of the Hobby-Eberly Telescope", S.P.I.E. Vol. 3352, *Advanced Technology Optical/IR telescopes VI*, (in press).
7. Gaffney, N.I. and Cornell, M.E., 1998, "The Phase II Language for the Hobby*Eberly Telescope", in *Astronomical Data Analysis Software and Systems VII, A.S.P. Conference series*, (in Press).
8. Gaffney, N.I., Cornell, M.E., 1998, "Scheduling and executing Phase II observing scripts on the Hobby-Eberly Telescope", S.P.I.E. Vol. 3349, *Observatory Operations to Optimize Scientific Return*, (these Proceedings).

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 15 Jul 2020
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use