MMT Observatory

Tucson, Arizona 85721-0065

This report covers the period 1 October 2001-30 September 2002.

1. INTRODUCTION

The MMT Observatory (MMTO) is a department of the University of Arizona and is jointly funded by the Smithsonian Institution and the University of Arizona. Its primary mission is to operate, maintain, and develop the 6.5 m MMT for use by the scientific staffs of the parent organizations. The MMT is located on the 2600 m summit of Mt. Hopkins, approximately 60 km south of Tucson, Arizona, on the grounds of the F. L. Whipple Observatory (FLWO).

2. PERSONNEL

As of 30 September 2002, the MMTO staff complement of 25 consisted of C. B. Foltz (Director), J. T. Williams (Conversion Project Engineer), S. Criswell (Conversion Project Manager), S. West (Associate Staff Scientist), T. Pickering (Assistant Staff Scientist), B. Russ (Administrative Associate), H. Lester (Business Manager), S. Callahan and C. O'Neal (Mechanical Engineers), T. Trebisky and D. Gibson (Computer Specialists), J. McAfee and A. Milone (Telescope Operators), W. Kindred (Staff Engineer), D. Smith (Staff Technician), P. Spencer (Electrical Engineer), M. Alegria (Engineer Associate/Telescope Operator), D. Clark (Electrical Engineer), K. Van Horn (Electrical Engineer), R. James (Instrument Maker/Designer), R. Ortiz (Engineer Associate), C. Knop and B. Comisso (Electronic Technicians), P. Ritz (Maintenance Mechanic), and G. Williams (Firestone Postdoctoral Fellow).

3. ASTRONOMICAL RESEARCH

Until its shutdown in early 1998, ninety-four percent of the scheduled time on the MMT was devoted to astronomical research, with the remainder going to telescope and instrument maintenance and improvement. Most astronomical research made use of the MMT facility instruments: MMT spectrograph-blue channel, MMT spectrograph-red channel, and echelle spectrograph.

On the morning of March 2, 1998, the chamber doors closed on the 4.5 m MMT. The telescope was decommissioned in preparation for the installation of the new 6.5 m instrument. The new telescope saw first light in May 2000 and was dedicated on May 20 of that year. Astronomical observations began shortly thereafter.

The MMTO maintains a web site containing documentation on the telescope and instruments, as well as information on the progress of the MMT Conversion Project. It can be accessed at the following URL: http://mmt.as.arizona.edu. (Address comments or queries to cfoltz@mmto.org.)

4. TELESCOPE INSTRUMENT DEVELOPMENT

4.1 Conversion of the MMT to a Single-Primary 6.5 m Telescope

As a result of the success of spin-casting of mirrors at the Steward Observatory Mirror Laboratory (SOML), the MMTO and its two parent institutions have replaced the six 1.8 m primary mirrors with a single 6.5 m diameter, *f*/1.25 paraboloidal borosilicate honeycomb primary mirror. Three secondary mirrors will be available: an *f*/9 classical Cassegrain to allow the use of existing instrumentation and high-resolution narrow-field imaging, an *f*/15 classical Cassegrain secondary for use in the infrared and for adaptive optics (AO) applications, and an *f*/5.27 Cassegrain, corrected to *f*/5.4 with a three-element refractive corrector with atmospheric dispersion compensation to produce up to a full one-degree field of view. The telescope is installed in the existing MMT building on the existing yoke. All observations during this reporting period were obtained at the *f*/9 Cassegrain focus.

Due to the space constraints both in the MMT building and on the summit of Mt. Hopkins, aluminization of the primary mirror is done in situ, i.e., in the telescope using a large steel belljar that mates to a flange on the primary mirror cell. The MMT is the first large telescope to attempt such a method and the first two attempts were less than satisfactory – they suffered from contamination by both tungsten and copper from the power cables' tungsten rod sources. This reporting period began with the telescope shut down in preparation to repeat the coating. This activity included the replacement of the filament system within the bell jar with coiled tungsten filaments, redesign of the power system to insure more uniform application of power to the filaments, and installation of a second large cryogenic pump to handle the pressure increase just prior to evaporation. The subsequent aluminization was carried out on November 11, 2001. The system performed flawlessly, depositing approximately 1000 Å of Al with a resulting reflectance within a few tenths of a percent of perfection, very low scattering, and excellent adhesion.

The primary mirror thermal control system was installed in the spring of 2001. The design of this system is a departure from those used with other spin-cast borosilicate primaries and is a prototype for the thermal control system to be used with the Large Binocular Telescope. Instead of using distributed liquid-air heat exchangers and fans, the MMT system brings roughly 2200 cfm of conditioned air to the mirror cell from a large remote blower/heat-exchanger/chiller via underground duct to the primary cell. The air is then piped to a set of jet ejectors that mix with the air in the cell in a semi-recirculating system, which supplies 8 liters/sec of temperature-controlled air to each of the more than 1000 hex cells in the mirror. Although more complex than the liquid/air designs, this system is naturally well balanced. Initial tests showed that the primary could both be maintained nearly isothermal and at the ambient temperature with relative ease. The thermal control system went into routine operation following the aluminization of the primary mirror.

Progress was made on the *f*/15 and *f*/5 secondary mirrors during this reporting period:

The 70 cm diameter, 1.6 mm thick *f*/15 Zerodur ‘shell’ for the adaptive *f*/15 secondary was mounted on the telescope in June 2002. The results of the first run are described in more detail below.

Polishing of the 1.7 m diameter *f*/5 secondary is nearing completion at SOML. Polishing is being carried out with a 30 cm stressed lap, and the optic is tested with a computer-generated hologram written on a meniscus test plate. Extensive testing is currently underway in advance of the expected acceptance of the mirror in early November 2002. The mirror cell and support system are complete and await the polished blank. The blank will be integrated into the cell and tested together on the SOML small test tower. Aluminization will follow this final round of testing. The commissioning of the secondary on the telescope is expected in early 2003.

Pointing and tracking tests are ongoing. Using a simple eight-term model (six geometric terms and two elevation-dependent terms), the pointing at Cassegrain focus is accurate to about 0.8 arcsec rms. Mount servo performance is adequate although additional tuning is required to stiffen the elevation axis, which is still a bit soft. In the absence of wind above about 20 mph, the typical rms tracking errors in both axes are less than about 0.1 arcsec. The telescope slew rates in both axes are 1.5 degrees/sec, meeting specification.

4.2 The *f*/15 Adaptive Secondary Mirror

Technology for building large, fast deformable mirrors with comparatively low actuator density is not readily available and its development is one of the major undertakings of this project. A 640 mm diameter *f*/15 deformable secondary mirror has been built and characterized at Steward Observatory in the past couple of years and has performed very satisfactorily in the laboratory.

The main elements of the deformable mirror (DM) are: a support frame, three boxes of electronics hosting the 168 digital signal processors that implement position control of 336 actuators, a glass reference body and a deformable glass. A cold plate holds the actuators and removes their heat. A water circuit running through the cold plate and the boxes of electronics removes the heat generated by the actuators and their drive circuits. The reference body provides a stiff reference surface against which the 336 sensors associated with the 336 actuators measure the local position of the shell.

Between April 2001 and May 2002, the DM was tested and characterized optically in the laboratory by fitting it with the spherical shell as well as with the telescope-grade hyperbolic shell. Experience has shown that the alignment of the AO optics and the test bench is quite complex.

Static tests determined the best achievable optical figure with the shell mirror, and the trade-off between the optical figure and the amount of force required from the actuators to obtain it. The rms force required to produce the flat wavefront (and hold the weight) is 0.080 N/actuator using 150 modes.

Subsequent dynamic tests showed that the step response time of the DM using the shell (spherical or aspheric) is 1-2 ms depending on the mode applied, with the sloppy modes being the slowest. The AO loop dynamics are dominated by sampling time of the wavefront sensor (WFS) camera controller and the optical loop controller, which is a simple integrator. The response time is in the order of 10 ms at 550 WFS frames/s. The maximum rate of the WFS is 650 Hz, which can speed up the response by 10-15%.

The first commissioning run for the adaptive system took place during the last two weeks in June 2002. Integrating the AO system at the telescope is a major undertaking because major elements of the latter must be interchanged, in particular the secondary mirror. In addition, the hexapod secondary positioner is shared between the *f*/15 and *f*/9 secondaries and neutral structural beams must be removed from the telescope’s top end. The procedure is rendered even more challenging by the telescope’s having to be converted back to its *f*/9 secondary configuration at the end of the run. This operation is not only demanding from the manpower point of view, it is also risky. Since the MMT AO system is optimized for the thermal infrared, the secondary is the stop of the optical setup. Therefore, there is no mechanical structure around the secondary and the edge of the glass shell is totally unprotected. A protective cover was designed for all manipulation phases and it is only removed when the DM is ready for optical alignment or AO work. In practice, the installation of the DM into the hub turned out to be straightforward even if somewhat strenuous. Because of several cooling leaks and dust contamination between the shell and reference body, the DM was installed and removed from the hub a total of four times within ten days during the first-light mission without incurring damage to any part of the system or telescope.

The adaptive control loop was not closed on starlight during this first run. The principal problem was an undiscovered fabrication error in the DM package that positioned the shell 12.5 mm too close to the primary. This was beyond the range of the hexapod’s motion. However, the DM was optically figured and the telescope was pointed at various azimuth and elevations. The system was run in this mode for several hours, and the position error of the actuators as well as the forces put in by the 336 position controllers were recorded. In addition to this demonstrating the capability of the DM to operate in the telescope environment with wind and dust, it showed that the DM figure was only deformed by ± 30 nm peak-to-valley by windshakes (10-20 nm rms wavefront).

Below is a list of the major lessons that were drawn from the first mission to the telescope:

- It is possible to mount, operate, and dismount the adaptive secondary without breaking it! This sounds trivial but is actually not so. The DM is an instrument of formidable complexity from the optical, electronic, and metrology points of view. Devising safe and effective procedures for installation and operation was a significant challenge.
- There is evidence that the all-important gap between reference body and shell becomes contaminated by airborne particles from the side of the shell. The DM

seems to be able to operate for extended periods of time without the wind pushing particles into the gap. To prevent gap contamination in future missions, a hood is being designed around the DM and handling procedures are being modified to improve the cleanliness in the integration and installation phases.

- Efficient tools and procedures are needed for the handling of the DM package. Special tools for the removal of the shell on the telescope (i.e., with the DM pointing horizontally) have been produced and tested. In addition, connection of the DM power and coolant lines, which proved to be time consuming and prone to errors, has been simplified and rendered safer by use of keyed connectors.
- The DM is operable even with a significant number of failed actuators. Unlike traditional piezo-stack deformable mirrors, the technology used in the deformable secondary can ignore failed actuators. In the former type of system, if an actuator fails, it creates a local hard point at its location that will create a sharp bend in the mirror and can lead to breakage. In the latter case, a failed actuator creates a local soft point that will average the position of the surrounding actuators. Excellent closed optical loop results were obtained in the lab with six actuators shut off; during the MMT mission, we lost another two with minimal impact on the figure and no impact on the response.
- The experience gleaned during the first run led us to realize that the required cooling of the actuators is modest with the number of modes used by the reconstructor during the on-telescope tests.

A second run is scheduled for November 2002. The goals are twofold. First, the primary/secondary spacing problem will be corrected. Second, the depth of the real-time telemetry will be augmented so that many minutes of WFS and mirror data can be stored in real-time. This should be enough for typical science exposure and offers the possibility of using the WFS data for the deconvolution of images. In addition, a procedure to permit the measurement of the interaction matrix on the sky is being developed and will be implemented. This technique is potentially useful to compensate for the fact that, unlike in a traditional AO system, the secondary system cannot be illuminated with an artificial star in order to calibrate the interaction matrix.

4.3 The *f*/5 Optics and Instruments

In the past year, several important milestones for the Converted MMT's *f*/5 wide-field optics and instruments have been reached. In mid June 2002, the large refractive corrector for the *f*/5 focus was delivered to the MMT offices in Tucson. When the *f*/5 secondary is completed and prepared for commissioning, the refractive corrector will be moved to the MMT site. The corrector optics were polished at B.F. Goodrich Optical Systems in Danbury, Connecticut and coated with Sol-gel antireflection coatings by Cleveland Crystals. Smithsonian Astrophysical Observatory (SAO) engineers assembled the large coated lenses and ADC prisms (typically 0.8 m in diameter) into a cell of SAO design.

The hexapod secondary actuator for the *f*/5 secondary was constructed by ADS International s.r.l. This is basically a larger scale version of the hexapod used for the *f*/9 and adaptive secondaries with some modifications based on knowledge accrued from experience with the smaller unit. Prototype driver electronics have been tested and the final circuit boards are being constructed.

In late August, two large tractor-trailers arrived at the MMT from SAO carrying the Hectospec and Hectochelle bench spectrographs. In September, the two large optical benches for these instruments were craned into the MMT building, along with the 1 m Hectochelle camera mirror and its refractive corrector lenses. As of early October, the Hectospec optics had been aligned and excellent images had been obtained. Alignment of the Hectochelle spectrograph optics is underway.

In January 2003, the robotic fiber positioner that positions the optical fibers common to both Hectospec and Hectochelle will be delivered to the MMT, along with the 300 optical fiber probes. At the same time we anticipate the delivery of a Shack-Hartmann wavefront sensor for the *f*/5 focus. Later in 2003, the large optical imager, Megacam, will be delivered to the MMT. Megacam contains an array of 36 CCDs, each with 2048 by 4608 pixels, a 340 megapixel array.

4.4 Public Access Time on the 6.5 m Telescope

A significant amount of observing time on the 6.5 m telescope of the MMT Observatory is made available to the astronomical community through the NOAO proposal process. Under an agreement with the National Science Foundation, a total of 162 nights of observing time will be allocated to the astronomical community. This Public Access time will be distributed over the phases of the moon and the seasons of the year in the same proportion as the scientific observations scheduled for the staffs of the MMT Observatory's parent institutions, the Smithsonian Astrophysical Observatory and Steward Observatory. Roughly twenty-seven nights per year will be allocated for national access.

Access for visiting observers through the Public Access Program began in June 2000. Proposals are submitted through NOAO using the standard NOAO proposal form. The NOAO TAC reviews proposals, and those approved are forwarded to the MMTO for scheduling. Procedures and forms to apply for telescope time can be found at http://www.noao.edu/noaoprop/noaoprop.html.

During this reporting period 18.5 nights of Public Access time were allocated.

PUBLICATIONS

Claver, C. F., Liebert, J., Bergeron, P., Koester, D., 2001, ‘‘The Masses of White Dwarfs in the Praesepe Open Cluster,’’ *ApJ*, **563**, 987.

Dietrich, M., Hamann, F., Shields, J. C., Constantin, A., Junkkarinen, V. T., Chaffee, F. H., Foltz, C. B., 2002, ‘‘Continuum and Emission Line Strength Relations for a Large Active Galactic Nuclei Sample,’’ *ApJ*, **581**, 912.

Foltz, C. B., 2001, ‘‘AAS Annual Report, *BAAS*, **35**, 208.

Goldberg, D., Mazeh, T., Latham, D. W., Stefanik, R. P., Carney, B. W., Laird, J. B., 2002, ‘‘A Survey of Proper-Motion Stars. XV. Orbital Solutions for 34 Double-Lined Spectroscopic Binaries,’’ *AJ*, **124**, 1132.

Impey, C. D., Petry, C. E., Foltz, C. B., Hewett, P. C., Chaffee, F. H., 2002, ‘‘LBQS 0015+0239: A Binary Quasar with Small Angular Separation,’’ *ApJ*, **574**, 623.

Koranyi, D. M., Geller, M. J., 2002, ‘‘Kinematics of AWM and MKW Poor Clusters,’’ *AJ*, **123**, 100.

Lacy, C. H. S., Torres, G., Claret, A., Sabby, J. A., 2002, ‘‘Absolute Properties of the Main-Sequence Eclipsing Binary Star WW Camelopardalis,’’ *AJ*, **123**, 1013.

Mazeh, T., Carney, B. W., Laird, J. B., Morse, J. A., 2002, ‘‘A Survey of Proper-Motion Stars. XVI. Orbital Solutions for 171 Single-Lined Spectroscopic Binaries,’’ *AJ*, **124**, 1144.

Sakai, S., Kennicutt, Jr., R. C., van der Hulst, J. M., Moss., C., 2002, ‘‘Discovery of a Group of Star-Forming Dwarf Galaxies in Abell 1367,’’ *ApJ*, **578**, 842.

Schmidt, G. D., Smith, P. S., Foltz, C. B., Hines, D. C., 2002, ‘‘An Extraordinary Scattered Broad Emission Line in a Type 2 QSO,’’ *ApJ Letters*, **578**, L99.

Schmidt, G. D., Hines, D. C., Swift, S., 2002, ‘‘The Nascent Bipolar Nebula Surrounding the Carbon-Rich Variable CIT 6: Transition to Axisymmetry,’’ *ApJ*, **567**, 429.

Stepanian, J. A., Green, R. F., Foltz, C. B., Chaffee, F. H., Chavushyan, V. H., Lipovetsky, V. A., Erastova, L. K., 2001, ‘‘Spectroscopy and Photometry of Stellar Objects from the Second Byurakan Survey,’’ *AJ*, **122**, 3361.

Torres, G., Neuhäuser, R., Guenther, E. W., 2002, ‘‘Spectroscopic Binaries in a Sample of ROSAT X-Ray Sources South of the Taurus Molecular Clouds,’’ *AJ*, **123**, 1701.

Wegner, G., Thorstensen, J. R., Kurtz, M. J., Brown, W. R., Fabricant, D. G., Geller, M. J., Huchra, J. P., Marzke, R. O., Sakai, S., 2001, ‘‘Redshifts for 2410 Galaxies in the Century Survey Region,’’ *AJ*, **122**, 2893.

West, S. C., 2002, ‘‘Interferometric Hartmann Wave-Front Sensing for Active Optics at the 6.5-m Conversion of the Multiple Mirror Telescope,’’ *Applied Optics*, **41**, 3781.

Wildi, F. P., Brusa, G., Riccardi, A., Allen, R. G., Lloyd-Hart, M., Miller, D., Martin, B., Biasi, R., Gallieni, D., 2002, ‘‘Progress of the MMT Adaptive Optics Program,’’ *SPIE*, **4494**, 11.