MMT Observatory

Tucson, Arizona 85721-0065

This report covers the period 1 October 2002-30 September 2003.

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 2003, the MMTO staff complement of 23 consisted of G. Schmidt (Director), J. T. Williams (Conversion Project Engineer), D. Blanco (Assistant Director for Operations), T. Pickering (Associate Staff Scientist), B. Russ (Administrative Associate), H. Lester (Business Manager), S. Callahan and C. Wainwright (Mechanical Engineers), T. Trebisky and D. Gibson (Computer Specialists), J. McAfee, A. Milone, and M. Alegria (Telescope Operators), W. Kindred (Staff Engineer), D. Smith and P. Ritz (Staff Technicians), D. Clark, P. Spencer, and K. Van Horn (Electrical Engineers), R. Ortiz (Engineer), C. Knop and B. Comisso (Electronic Technicians), and G. Williams (Firestone Postdoctoral Fellow).

3. ASTRONOMICAL RESEARCH

The MMT saw first light in its 6.5 m converted form in May 2000 and was dedicated on May 20 of that year. Astronomical observations began shortly thereafter. As systems and operations have improved, the fraction of time scheduled for observing has steadily increased, reaching approximately 90% by the fall 2003 trimester.

The MMTO maintains a web site containing documentation on the telescope and instruments. The site can be accessed at http://www.mmto.org. (Address comments or queries to gschmidt@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 replaced the six 1.8 m primary mirrors with a single 6.5 m diameter, *f*/1.25 paraboloidal borosilicate honeycomb primary mirror. The large primary is now complemented by no less than three secondary mirrors: an *f*/9 classical Cassegrain to allow the use of pre-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. The telescope is converted among the three configurations on an approximately 2-4 week timescale, as dictated by the combined considerations of observing pressure, instrument commissioning and availability, and operational efficiency.

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 lid that mates to a flange on the primary mirror cell. The MMT is the first large telescope to attempt such a method. The first fully successful aluminization of the primary, carried out in November 2001, achieved a coating with initial reflectance within a few tenths of a percent of ideal, very low scattering, excellent adhesion, and has proven to be as durable as traditional off-telescope coatings.

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.

Two technological milestones were attained during the reporting period: 1) closing the full-speed adaptive loop on the *f*/15 deformable secondary and the first scientific observations that this feat permitted; and 2) installing the *f*/5 secondary and its control system, followed the next night by first light with the wide-field wavefront sensor/science camera. These achievements are described in some detail below.

Attention continues to be paid to telescope pointing and tracking. While a simple eight-term model (six geometric terms and two elevation-dependent terms) can obtain rms deviations of 1.3 arcsec, the encoders are capable of better performance, and current efforts to better balance the encoder outputs should reduce the scatter substantially. At the same time, mount servo performance can be improved, particularly in terms of the cancellation of wind disturbance above about 20 mph. Hardware modifications in the servo electronics will be required to achieve this goal.

4.2 The *f*/15 Adaptive Secondary Mirror

The *f*/15 deformable secondary mirror was installed and operated on the MMT in November 2002 and in January and May 2003. The initial tests were very encouraging, reducing ∼3/4 arcsecond seeing-limited images to just over 1/8 arcsecond using an adaptive optics loop closed at 20 Hz and correcting 22 modes. However, the IR image exhibited a fair amount of astigmatism that was traced to curvature in the visible light pick-off mirror (dichroic) induced by excessive clamping in the mount. Once this was solved, the image became immediately much more symmetrical. Guide stars of faint magnitude were also tried but with modest success due to significant noise in the wavefront sensor camera. The last few nights of the run were dedicated to integrating the AO system with MIRAC/BLINC, the mid-IR imager and nulling interferometer.

The first full 550 Hz operation of the adaptive optics loop was achieved in January 2003, and resulted in Strehl ratios of 15-40% in H band observations (depending on guide star magnitude and conditions) and >96% Strehl in N band. These demonstrated that the mirror can be used over a broad range of wavelengths.

The May 2003 run was devoted to both development of the system and preliminary science observations with MIRAC/BLINC. Progress during the May 2003 run included:

- Demonstrating closed-loop operation on a V=13 star.
- Demonstrating image stability to <0.5″ over the airmass range 1-2.
- Demonstrating secondary shape stability in open-loop operation.
- Automating the wavefront sensor optics alignment.
- Guiding on an off-axis star while derotating up to 0.5 deg/s.

A key result of the May 2003 run was the demonstration of ‘‘routine’’ operation of the AO system. After setup at the beginning of the night, movement from one object to the next typically required no more than 5 minutes to move the telescope, acquire the object on the wavefront sensor, and close the loop on the new object. Much of the ongoing effort involves automating this procedure to allow operation by one person.

Currently, the primary limitation in the system is a vibration causing ∼20 mas jitter in closed-loop images at a frequency of ∼20 Hz. During the May run accelerometers were placed on the mount, spider arms, and secondary hub to analyze the vibration. The AO group is currently analyzing the data to better understand the vibration and how best to deal with it.

Science application of the AO system during May 2003 included nulling interferometry with BLINC as a technique to search for zodiacal dust around Vega, the prototype of IRAS-excess stars. These stars exhibit a far-infrared excess thought to arise in a circumstellar shell similar to our own Kuiper belt. Whether they have a dust disk at mid-IR wavelengths is currently unknown due to the much brighter emission from the star. The AO system achieved a null level of 3% with a stability of 0.5-1%, limited by the vibrations mentioned above. No dust was detected around Vega with an upper limit approximately 4× more stringent than previous observations. We hope to improve this performance as the interferometer is refined and the vibration issue is addressed.

High-resolution (FWHM=0.3″), very high Strehl (∼0.98) images with unprecedented PSF stability were also produced for the AGB stars AC Her and RV Boo and the symbiotic variable CH Cyg. No significant difference was found between AC Her’s morphology and the PSF calibration stars (μ UMa and α Her) at 9.8, 11.7, and 18 μm (Close *et al.* 2003). This is surprising since previous (seeing-limited) 11.7 and 18 μm Keck images suggested the presence of a resolved ∼0.6″ edge-on circumbinary disk for AC Her. The observations do not confirm any extended structure >0.2″ around AC Her, and represent a nice example of the advantage of a stable PSF for mid-IR observations. In the case of RV Boo a ∼0.15″ FWHM dust disk was detected at PA=120° (Biller *et al.* 2003). The disk has a radius of ∼40 AU and is aligned with the previously known CO disk. Taken together these observations strongly suggest RV Boo is the best example yet of a dusty disk around an AGB star.

Based on engineering progress made and the initial scientific observations, the MMT AO group has solicited proposals for observations with MIRAC/BLINC during the fall trimester, and plans to carry out engineering and test observations with ARIES, the adaptive imager/spectrograph of D. McCarthy.

4.3 The *f*/5 Optics and Instruments

A major milestone was reached with the completion of the *f*/5 secondary system and its first light on the telescope on April 19, 2003. This marked the culmination of more than two years’ effort by most of the MMTO engineering staff, and followed the completion of the secondary mirror by the UA Mirror Lab and its aluminization in December 2002. During the intervening few months, the mirror was mounted and integrated into its cell at the UA Sunnyside coating facility by MMTO staff. Like the *f*/9 and *f*/15 systems, mirror control is achieved by an actuator hexapod. Position sensing for the *f*/5 mirror is achieved directly by a set of Linear Variable Differential Transformers (LVDTs) whose outputs are used to close a digital servo loop operating in firmware at 75 Hz. The result is that the secondary can be commanded to any position over a range greater than 30 mm in a few seconds with a precision of 3 μm. This is faster and more accurate than the *f*/9 system. A variable-gain algorithm is used to overcome stiction as the unit reaches its target position.

Baffles for the *f*/5 system have been designed, but fabrication has been briefly postponed pending a decision on attachment points, which in turn impacts the choice of a new primary mirror cover. Finally, secondary mirror cooling lines were designed and fabricated to service both the *f*/15 and *f*/5 cells. These lines were installed just prior to the May AO run.

The *f*/5 Shack-Hartmann wavefront sensor was used for first light with the new wide-field secondary in April 2003. Collimation and focus tests with the wavefront sensor science camera and 30-inch diameter *f*/5 corrector were carried out over the ensuing engineering runs, culminating in images measured at 0.5 arcsec FWHM simultaneously over the full 1-degree diameter spectroscopic field.

In summer 2003, the robotic fiber positioner that positions the optical fibers common to both Hectospec and Hectochelle was delivered to the MMT, along with the 300 optical fiber probes. During late July and the summer shutdown period, the massive fiber positioner was attached to the Cassegrain focal station, the fibers were plumbed, and procedures were tested for deploying the positioner and retracting it when not in use. First light with the spectrographs is scheduled for October 2003, and at approximately the same time the 340 megapixel optical imager, Megacam, will be delivered to the MMT.

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 the original agreement with the National Science Foundation, a total of 162 nights of observing time was to be allocated to the astronomical community. (An addendum to this MOU dated September 2003 extends this commitment by 27 additional nights.) This Public Access time will be distributed uniformly over lunar phase and season of the year in the same proportion as enjoyed by the staffs of the MMT Observatory's parent institutions. Roughly 27 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 27 nights of Public Access time were allocated.

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