



**NATIONAL
OPTICAL
ASTRONOMY
OBSERVATORY**

GSMT Annual Report FY 2008

September 1, 2007 – August 31, 2008

**SCIENCE WITH
GIANT
TELESCOPES:**
Public Participation in TMT and GMT

**JUNE 15-18
2008**
INTERCONTINENTAL HOTEL
CHICAGO, ILLINOIS

The Workshop will be the next major step in developing the private-public partnership envisioned in the 2000 Decadal Survey; its proceedings will be a supporting document for presentation—on behalf of the entire US astronomical community—to the new Decadal Survey. For further details see <http://www.gsmt.noao.edu/swgt.php>

Sponsored By
GSMT Science Working Group
National Optical Astronomy Observatory
Grant Magellan Telescope
Thirty Meter Telescope

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EXECUTIVE SUMMARY

During this reporting period, both U.S. projects, the Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT) have made progress on items considered on the critical path. Both have continued to seek additional partners and additional private funding. In particular, both projects have directly expressed their desire for NSF participation during the construction and operations phase.

At the end of FY08, both projects will have received nearly \$8 Million in direct and in-kind Federal support. Although relatively small compared to project total costs, this Federal support has been an important part of their respective programs and has enabled AURA/NOAO to remain fully engaged in their efforts.

AURA/NOAO, as Program Manager, has worked through the GSMT Science Working Group to enhance broader public engagement and to advance the Design Reference Mission concept. Two major meetings held in September 2007 and June 2008 have provided important input that will be relevant to the upcoming Decadal Survey discussions. NOAO intends to continue this important activity. In addition, a major meeting held August 1 of this reporting period has established an understanding on the need for and approach towards a community based independent review of the two projects.

Public Outreach has been an important part of the NOAO effort under SPO 10. Instructional materials on site testing and adaptive optics, and other hands-on materials have been prepared and are in use.

GSMT PROGRAM OFFICE ACTIVITIES

The GSMT Program Office (GSMTPO) continues to monitor the progress of both the Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT) projects on behalf of NSF. Both projects are actively engaged in their design and development phases.

This past year the GSMT SWG membership was modified to include a greater proportion of representatives not directly involved with TMT/GMT.

A workshop on Giant Telescopes was held in June 2008 that included approximately 100 participants from throughout the U.S. Astronomical Community.

The science use cases from that meeting can be found at:

<http://www.gsmt.noao.edu/swgt-suc.php>

In August 2008, AURA/NOAO hosted a meeting among the representatives of the National Science Foundation, the Thirty-Meter Telescope Project and the Giant Magellan Telescope Project.

The representatives affirmed the strong intention of the two projects to build these telescopes, and the interest of the NSF in supporting the science of the GSMT and access for the US community, provided that it retains a high priority in the upcoming Decadal Survey. Below is the link to the report from this meeting:

<http://www.aura-astronomy.org/nv/nuresult.asp?nuid=178>

Ongoing GSMT Program Office Efforts

- Identifying areas of commonality or overlap in technology with a view towards optimizing federal and non-federal budgetary commitments;
- Carrying out any appropriate independent technology efforts of importance to both programs and, ideally, to the OIR community as a whole, subject to available funding;
- Participating in development of instruments, adaptive optics systems, and similar projects intended for use on ELTs to which the community has access;
- Planning for the interfaces for community access, potentially including queue scheduling, as well as archiving and archive access;
- Assisting NSF in defining and realizing possible alternatives to a competitive down-select between TMT and GMT;
- AURA/NOAO will advise NSF on options for international collaboration at a governmental level.

SUB-AWARD SUPPORT ACTIVITY

Amendment No. 5, issued to SPO-10 AST-0443999 on July 25, 2008, provided for \$5,000,000 for continued support of the project entitled: "Enabling a Giant Segmented Mirror Telescope for the United States Astronomical Community." The period of performance was also modified through March 31, 2009. These funds continue to support operation of the GSMT Science Working Group and for sub-awards issued by NOAO on the two designs for the Giant Segmented Mirror Telescope: (1) TMT, Inc. on behalf of the Thirty Meter Telescope (TMT) and (2) the Carnegie Institution of Washington on behalf of the Giant Magellan Telescope (GMT).

Initial funding for SPO-10 in the amount of \$1M was received at the end of FY05, \$2M was received in FY06, and \$5M was received in FY07. These funds, in addition to the \$5M from Amendment No. 5 funds awarded under this SPO-10, now total \$13,000,000.

Both sub-awardees are presently undergoing contract negotiations to: (1) Amend the period of performance to extend through March 31, 2009; and (2) Increase funding utilizing the recently provided funds. The table below shows the cash and "in-kind" support for both projects.

	In Kind TMT	Direct TMT	Direct GMT	GRANT AURA EPO	AURA Indirect	SPO 10 (Grant)	Total Support
FY 05	879	513	416	57	15	1000	1879
FY 06	2406	1031	820	106	43	2000	4406
FY 07	358	1461	3444	0	95	5000	5358
FY08		1343	3312	247	99	5001	5001
FY09							
Total	3643	4348	7991	410	252	\$13,001	\$16,644
Grand Total		7991	7991				
Difference through FY06			3594				
Difference through FY07			1969				
Difference through FY08			0				

TMT, Inc was originally awarded a sub-award for the TMT on March 8, 2006 in the amount of \$440,280. Subsequent cash amendments have increased funding to a total of \$3,005,296. The amendment currently under negotiation will add an additional \$1,343,000 bringing the total sub-award amount to \$4,348,296 through March 31, 2009. This history is shown below in Table 1:

Table 1

FY 06	440,280
FY 07	1,104,016
FY 08	1,461,000
FY 09	1,343,000
Total	4,348,296

The Carnegie Institution of Washington likewise was awarded a sub-award on October 6, 2006 in the initial amount of \$1,235,419. Subsequent amendments increased funding to a total of \$4,679,419. The amendment currently under negotiation will add an additional \$3,312,000 bringing the total sub-award amount to \$7,990,419 through March 31, 2009. This history is shown in Table 2:

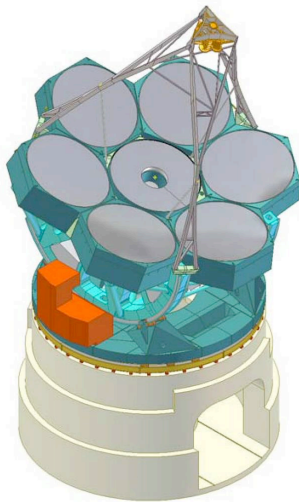
Table 2

FY 06	410,541
FY 07	824,878
FY 08	3,444,000
FY 09	3,312,000
Total	7,991,419

Due to the current cooperative agreement expiration, and the negotiations of a another 5 year agreement, AURA/NOAO will be working with the NSF to request a “no-cost extension” to the current design and development award in order to match the original SPO 10 budgeting schedule.

GMT Management Report

On November 9, 2007 AURA executed an amendment to its sub-award with Carnegie Institution of Washington on behalf of the Giant Magellan Telescope (GMT) project. At the time of the amendment, the institutions participating in the GMT included Carnegie Institution of Washington, Harvard University, Smithsonian Astrophysical Observatory, University of Arizona, University of Texas at Austin, Texas A&M University, the Australian National University, and Astronomy Australia Ltd. During FY 2008, the Korean Astronomy and Space Science Institute announced its intention to join the project on behalf of the Korean national astronomy community.



[figure caption] Engineering model of the GMT concept showing the arrangement of seven 8.4-meter circular mirror segments acting as a single primary mirror.

The GMT concept shown above calls for a primary mirror made up of 7 circular segments, each of 8.4-meter diameter. Only the central segment is on-axis; the other six are off-axis and must be optically identical, to within very tight tolerances, in order for the telescope to meet its performance and scientific goals. The production of the 7 segments is the pacing technical item for completion of the project. In order to demonstrate the feasibility of making and verifying the off-axis segments, and in order to protect the construction schedule, the GMT project is proceeding with the fabrication of the first off-axis segment.

In order to promote the goals of SPO10, AURA's funding to Carnegie under the amended sub-award is directed towards reduction of risk in the most critical areas of development, mainly the fabrication of the first off-axis segment and the testing methods for the off-axis segments. Carnegie is applying the funds received from AURA under the amended sub-award to fund completion of two contracts with the University of Arizona, Steward Observatory Mirror Laboratory (SOML). The first contract is for the grinding and polishing of the first segment, and the second is to develop four different testing methods for the off-axis segments and to procure the equipment necessary for the testing.

The work under the sub-award is progressing satisfactorily. AURA representatives have taken part in quarterly reviews of the progress on construction of the first primary mirror segment, which include reviews of the development of testing methods. SOML has completed the optical surface generation on the first segment and has begun loose abrasive grinding. This stage of fabrication is largely on schedule after some delays early in FY 2008 to resolve minor back-surface cracks that appeared in earlier processing steps. SOML also has completed the design, fabrication, and integration of the first off-axis mirror testing method, the "Laser Tracker Plus" system for surface profilometry. At the time of this writing, this system was being commissioned at SOML. Measurements with this method will be used to guide the loose abrasive grinding work. SOML has completed design and is well along in fabrication of the second testing method, the interferometric test using a large computer-generated hologram. The implementation of this test has been delayed several months by several problems with achieving the required assembly tolerances on a number of the components. The third testing method, known as the scanning pentaprism test, went through a successful critical design review on April 23, 2008. The fourth test, known as the shear test, is conceptually very similar to the second (interferometric) test and requires only the creation of additional analysis software.

AURA representatives have also taken part in GMT scientific and technical meetings aimed at defining the intended suite of instrumentation and the planned operational modes for the observatory. AURA takes part to ensure that the interests of the broader US astronomical community, as defined so far by the GSMT Science Working Group, are presented to the GMT partners for consideration in their planning. Also, AURA worked with the GMT project to name a community representative to the GMT Science Working Group. In March 2008 Dr. Megan Donahue of Michigan State University became the community representative. In that capacity, she will be a permanent voice for the interests of the US community on the GMT Science Working Group. Finally, AURA representatives have also attended meetings of the GMT Board since the execution of the original sub-award.

TMT Management Report

In November 2007, the sub-award to TMT was amended to extend the period of performance to 30 September 2008 and provided funding in the amount of \$1,461,000. Funding was provided in four equal payments, of which three have been made and the fourth is being processed.

The sub-award funds have been applied entirely to support efforts in TMT science and operations design, observatory software, system engineering and modeling, and telescope system management and optics design. The supported personnel include crucial leadership in these efforts. These efforts have all been subject to external review, and these reviews have been attended by AURA oversight personnel and NSF officials.

System Engineering:

George Angeli continued to lead the Systems Engineering efforts for TMT. A major ongoing effort that he guided was updating the top level system requirements as well as their flow down to subsystem Design Requirements Documents. He also led the major efforts of modeling and design verification work, which culminated in the very successful TMT Image Quality Performance Review 15–16 April. Optical, thermal, and dynamic simulations were integrated into a consistent Monte Carlo environment to provide stochastic estimates for the overall TMT performance. Planning is now underway for the systems engineering efforts leading up to the project PDR in June, 2009.

Additional personnel supporting the System Engineering effort and funded in whole or in part by the sub-award were K. Vogiatzis and M. Cho. The work by the systems engineering group resulted in 10 papers at the SPIE Symposium on Astronomical Instrumentation 2008 in Marseille, several of which were presented by people supported by this sub-award.

Telescope Science Operations:

David Silva served as the Observatory Scientist and interim head of the Operations Design (DEOPS) department for the TMT Project through the end of June, 2008, at which time he left TMT to become NOAO Director. Key accomplishments during the period were: TMT outreach at the January AAS meeting in Austin; planning and development of observatory software architecture and requirements documentation, including Design Requirements Documents (DRDs) for Common Software, Executive Software, and Data Management System within the Observatory Software project; participation in the on-site construction review; out-briefings on DEOPS and budget planning; participation in TMT SAC and Board meetings and in meetings with a delegation from University of Hawaii, Hilo, including the chancellor, Dr. Rose Tseng; and attendance at the NSF Large Facilities Operations workshop in Boulder, CO. Silva also wrote and presented SPIE papers about TMT observatory software and operations planning for the SPIE Astronomical Telescopes and Instrumentation symposium in Marseilles, France.

Segmented Primary Mirror Design:

Activities for L. Stepp, Telescope Department Head, and E. Williams, Optics Group Leader for Segmented Primary Mirror Design Support, included: supervision of department/group staff and contracts; teleconferences and visits to several contractors and potential contractors for progress meetings and facility tours; and numerous technical meetings and

reviews for the Controls, Optics and Structures groups. Efforts included planning for Telescope Department activities for the design and construction phases; and development of statement of work, requirements documents and specifications for primary mirror segment fabrication.

Subsequently, they reviewed baseline design reports from four study contracts: two for design of the secondary mirror system and two for design of the tertiary mirror system and visited suppliers to tour their optical shops and discuss fabrication and testing of the TMT secondary mirror. They also visited suppliers to review their progress in polishing the first TMT prototype segments. They wrote a statement of work for a study by the System Engineering Group to evaluate the sensitivity of the relative image positions in the focal surface to changes in telescope optical parameters. Stepp developed a revised organization for the Telescope Structures Group, in response to resource problems at the design contractor. They visited Gemini, Keck, and Subaru observatories in Hawaii to learn about their mirror coating facilities and procedures, and met with suppliers to develop designs for the corresponding facilities for TMT. They participated in a series of technical interchange meetings with engineers from the European Southern Observatory working on the European Extremely Large Telescope project, and with engineers from the Southern African Large Telescope (SALT) project on the subject of segment edge sensors.

NOAO Sub-contracts:

Work was performed under contract at NOAO related to design of the secondary and tertiary mirrors and the design of the laser guide star facility (LGSF). Thermal modeling of the telescope optics was also carried out; this activity involved two University of Arizona students contracted by NOAO on behalf of TMT. Additional staff supporting the Telescope Group effort and supported in whole or in part by the sub-award were E. Williams (Optics Group Leader) and M. Cho.

GSMT Science Working Group

Funding from the award was used to provide partial support for the GSMT Science Working Group, specifically non-payroll costs associated with the SWG meeting in November 2007 and the Chicago GSMT Science Workshop in June 2008.

The workshop, entitled "Science with Giant Telescopes: Public Participation in TMT and GMT was intended to provide an opportunity for members of the community who were not affiliated with either of the two projects an opportunity to learn more about the opportunities that they will present, and to present scientific programs that would require access to such facilities. The advertisement for the workshop stated that,

"Both TMT and GMT have expressed a strong commitment to participation by U.S. scientists from non-member institutions in the building and use of their facilities. The National Science Foundation, AURA, and NOAO fully support the goal of U.S. public participation in at least one, and possibly both, of these ambitious projects. Although the designs of these two telescopes are well advanced, the opportunity for public involvement in planning and executing science programs, specifying and constructing instrumentation, modes of operation, time allocation, integration into and coordination with the full system of US astronomical facilities, and the processing, archiving, and public distribution of data products are all topics that now require strong involvement from the full US astronomical community. At the

Workshop the GMT and TMT Projects will offer their thinking on these topics. Invited speakers outside of these projects will express their views and wide audience participation will be encouraged. Examples of “science use cases” covering various subjects and a wide range in scope will be developed and presented to help identify the issues, and there will be much time for discussion.”

The workshop drew close to 100 participants, largely astronomers without TMT or GMT affiliations. Links to a list of attendees and copies of material presented at the workshop can be found at the NOAO GSMTPO website, <http://www.gsmt.noao.edu/swgt.php> .

Speakers presenting science cases were also asked to write these up in a form suitable for use in the developing the community Design Reference Mission. These written cases are also posted as the speakers provide them.

GSMT Education and Public Outreach Report

Task 1-Instructional Materials Development: Site Testing

Task Summary: Design, development, testing and evaluation of online educational modules aimed at middle and high school students – Key personnel: S. Croft and S. Pompea

The educational materials developed in this task are in support of the design and development phase of the Giant Segmented Mirror Telescope project. At present there are three giant telescopes in development: the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT), and the European Extremely Large telescope (E-ELT). Although the science objectives for these telescopes are well defined, it will be several years before “First Light” and the beginning of scientific data gathering for any of these projects. Consequently, the first educational modules in this project address engineering aspects of telescope design and development.

Two topics were selected for the modules: Astronomical Site Selection and Observatory Enclosure Selection. These modules involve issues of weather and climate, air flow, and topography as well as more technical ideas such as turbulence and seeing. Consequently, these modules can be tied in with national science content standards for middle school as well as for high school. They emphasize science process and problem-solving as well as inquiry skills.

A. The first module is titled *Astronomical Site Selection*. It is based on the successful educational pedagogy used in the award-winning *Astronomy Village* and *Exploring the Environment* educational products developed at NASA’s Classroom of the Future in Wheeling, WV. The module’s pedagogy is open-ended, problem-based learning:

- Students are presented with a real-world problem to solve and provided with authentic information and data relevant to the problem.
- Both the problem – selection of a site or an enclosure for a giant telescope – and the data presented to the student are the same as that encountered by project scientists.
- Students are provided with guidelines on how to reach a solution, but there is no “correct” answer. As in real-world engineering problems, the validity of the students’ conclusion is based on the completeness and accuracy of the data they have gathered and the rigor of the supporting analysis they present. Thus any solution is only as good as the data and evidence suggest.

The issues of site selection are introduced by an activity comparing the sites of the best observatories of the 19th and 20th centuries. Students are then presented with the challenge of selecting the best site among three premier sites being investigated by the GMT and TMT projects: Las Campanas, Mauna Kea, and San Pedro Martir. Students are provided with science content describing the issues and preferred characteristics of: Seeing, Light Pollution, Geography, Weather, and Logistics. Students are then provided with data in each of these topics specific to each site. The selection of the specifications, the sub-topics within each, and the supporting data were derived from TMT and GMT

project publications and data archives. Students work in teams to reach their choices, and then present and defend their results in a classroom “Science Conference” with their student peers. Additional assessment strategies are provided to teachers on a separate web page. As an extended application, students are then invited to compare their “best site” with Yerkes, a premier site of the 19th century, using the same techniques and types of data, tying the students back to the introductory activity.

The module is Internet based. It is designed for grades 8 – 12, but can be used with advanced younger students in formal classroom settings. It may also be used for more informal settings such as home schooling. The module can be used as part of GMT or TMT project teacher workshops. It can also be used as a hands-on activity by local amateur astronomy clubs (they can gather their own data!), or in conjunction with educational materials from the International Dark Skies organization.

STATUS: Module 1 is completed and is available for use by TMT and GMT via the Web at www.noao.edu/education/gsmf/.

B. The second module is *Observatory Enclosure Selection*, geared toward the engineering problem of determining the best enclosure shape for a large telescope. This module is for high school students. We are working closely with George Angeli on the characterization of the enclosure engineering issues for large telescopes. The module will be build around 3-D hydrodynamic calculations. The computer-generated movies of wind flow and turbulence are for three enclosure types: carousel, dome-shutter, and calotte.

STATUS: The movies are being created by TMT project personnel and will not be available until mid-October 2008 at the earliest. Students will be provided with science content about laminar and turbulent flow, and how these parameters affect seeing, telescope vibration, and dome cooling. They will then use the movies to investigate the most favorable enclosure design. We anticipate that a basic module will be on the web on November 15.

Task 2-Instructional Materials Development: Adaptive Optics

Task Summary: Design, development, testing and evaluation of educational units aimed at high school students emphasizing basic principles of adaptive optics – Key personnel: R. Sparks and S. Pompea.

We have been developing activities and demonstrations to illustrate the key concepts in adaptive optics. The activities are outlined in a teacher’s guide that includes instructions and equipment lists to do all of the activities with students. Student handouts and worksheets are included where appropriate. The teacher’s guide contains the series of activities outlined below.

Basics of Image Formation

This hands-on activity briefly reviews the concept of image formation. Students will form images of an object using lenses and measure the focal length of lenses. They will explore how the shape of the lens relates to its focal length and learn that converging lenses produce inverted images.

Bubbles in the Air

This demonstration shows students how our atmosphere can distort the image of a star. Using a fake atmosphere made using mineral oil and an eye chart, students will observe how the resolution of a telescope is degraded by atmospheric turbulence.

Tip and Tilt

Students will learn about tip/tilt mirrors in this activity and game. Tip/tilt mirrors are designed to keep the image of a star at the same point on a CCD chip. Tip/tilt mirrors were the first form of image stabilization, and these correctors are available to amateur astronomers. Students use a laser to simulate a star. The image of the star is reflected onto a target. When the "atmosphere" is introduced, students must tip and tilt the mirror to keep the star on the target.

The Shack-Hartmann Sensor

In order to correct images for atmospheric distortion, we must first measure the distortion. One way to measure the distortion is a Shack-Hartmann sensor. This demonstration uses a scaled up Shack-Hartmann sensor to illustrate how we measure atmospheric distortion. We provide plans for construction of a S-H sensor.

It's Done With Mirrors

Reflecting telescopes use mirrors. In this demonstration, students learn how a curved mirror forms an image. They also make their own spherical mirrors out of flexible Mylar and test them to find the focal point.

The activity book is provided as a pdf file. An equipment list as well as where to purchase the items used in the activities will be available as well.

STATUS: We have built a 4x4 array of lenses for the S-H sensor. These lenses can be used to focus the image of a distant object onto a screen. A pan of mineral oil is inserted into the optical path to simulate Earth's atmosphere. When the tray is gently shaken to simulate a moving atmosphere, the images of the light are observed to move. The movements of the images can be used to calculate the atmospheric distortion in a S-H sensor.

We are building an initial run of 10 adaptive optics kits. These kits contain all of the materials needed to conduct all of the activities and demonstrations in a classroom setting. These kits will be used in our outreach programs and available to GSMT partners for use in outreach. We may build more kits as requests justify and funds permit. The project (including kits) should be completed on September 30, 2008.