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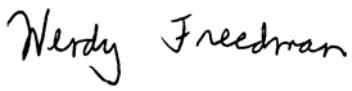
Dear Bill and Wayne:

The Giant Magellan Telescope (GMT) project has recently passed a major milestone, the completion of the GMT Founders Agreement. This document forms the legal basis of the GMT partnership, establishes procedures for governance and defines the means by which access to the telescope and related facilities are determined. A non-profit independent management organization, the GMTO Corporation, has been formed, bylaws drafted and an initial slate of officers proposed. We believe that this is an opportune time to explore expanding the GMT community to include a partnership with the NSF and AURA, as a representative of the broad US community.

To further this goal, the GMT Board has drafted a position paper that describes our perspective on the benefits to the community of a partnership between GMT and NSF/AURA, whether this is part of a system of extremely large telescopes, or as a stand-alone element in NSF's portfolio of astronomical facilities. On behalf of the GMT Board, I am transmitting this document to you and inviting you to consider it, to share it with your management and advisory committees, and to aid us in opening an effective and on-going conversation with the community. The attached document is neither a proposal nor a negotiating position; rather it is intended to be a clear statement of our interest in exploring pathways to a mutually beneficial relationship between the private and public sectors in the large telescope arena.

The GMT Board believes that this is a particularly important time to have such discussions in earnest as we head into the upcoming US decadal survey. We appreciate that the community must see tangible benefits to a large public investment in one or more extremely large telescopes and that this will require that they have a seat at the table when important decisions are taken. The GMT Founders Agreement enables the private partners to act with full institutional backing. We believe it is time to take concrete steps toward building an effective public-private partnership that will underpin not only the success of the GMT, but the future of ground-based astronomy in the US more broadly. I hope that you will take this opportunity to engage with us in bringing this goal to fruition.

Yours sincerely,



Wendy L. Freedman, Chair GMT Board
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A US National Partnership in the Giant Magellan Telescope Project

Executive Summary

A consortium of US and international institutions have set out to build a next generation optical-IR observatory, the Giant Magellan Telescope. This facility can satisfy the scientific goals set for the generic *Giant Segmented Mirror Telescope* that was identified as a top priority in the US decadal survey of astronomy and astrophysics (the 2001 Astronomy and Astrophysics Survey Committee (AASC)). This survey of astronomy and related fields called for a public-private partnership to build and operate such a facility. The Board of the GMT Project would like to begin the process of forging such a partnership by opening concrete discussions with the National Science Foundation, its representatives, and the broader community of US astronomers. The GMT Board believes that substantial benefits would accrue to both the public and private institutions by forming a strong partnership based on the common goals and aspirations of the scientific community and the diverse set of technical and management skills that would be brought together. We further believe that it is important to begin such discussions with the NSF and the broader community immediately, so that a successful path can be established once the 2010 Decadal Survey committee has completed its work.

Introduction

US Decadal Survey, National Priorities, and the Giant Segmented Mirror Telescope

Astronomers stand out from other scientific communities by the degree to which they organize themselves around decadal surveys of their scientific priorities. The National Research Council decadal surveys in the 1970s, 80s and 90s ultimately led to the successful development of the great space observatories (Compton, Hubble, Chandra, & Spitzer), the creation of world leading national radio astronomy facilities and the construction of the International Gemini Observatory. The 2001 AASC report laid out a compelling vision of growing connections between astronomy and other areas of science, particularly fundamental physics and the emerging field of astrobiology. This report, "Astronomy and Astrophysics in the New Millennium", identified a number of high priority scientific questions that were ripe for rapid progress in the coming decade. These questions span an enormous breadth of science – ranging from understanding the nature of dark matter and dark energy to exploring the properties of extra-solar planets and potentially habitable worlds.

Substantial progress toward these goals requires investment in a new generation of astronomical facilities with capabilities beyond those currently in operation. The survey committee's top priority for ground-based astronomy was a 30m-class optical/infrared telescope equipped with state-of-the-art adaptive optics. Its top priority in space astronomy was a large near- to mid-IR successor to the Hubble and Spitzer Space Telescopes. The *Giant Segmented Mirror Telescope* (GSMT) and the James Webb Space Telescope (JWST) were envisioned as the two pillars of optical/IR astronomy in the early

part of the 21st century. The committee recognized the long history of leadership from private observatories on the ground, but realized that the total costs (construction plus operations) of a GSMT were likely to be beyond the reach of individual, or even consortia of, private institutions. For this reason they called for a private-public partnership in the construction and operation of the GSMT.

In the years since the 2001 AASC report there has been substantial progress towards the development of telescope concepts that meet the goals of the generic GSMT. Two US-led international projects have evolved different concepts for the GSMT. Both have passed rigorous conceptual design reviews and have been shown to be technically feasible and capable of addressing the decadal survey goals. While there has been significant progress on the technical, organizational, and fund raising fronts within the private communities, there has been less progress towards realizing the goal of a private-public partnership in the construction and operation of the GSMT, whether it be a single telescope or a coordinated system of telescopes.

The NSF has instructed AURA (Association of Universities for Research in Astronomy) to coordinate community involvement in the development of Extremely Large Telescopes (ELTs) in the US through its GSMT Science Working Group. This group provides a forum for members of the US community at large and the two projects to exchange ideas and understand each other's scientific and technical aspirations.

The coming decadal survey will be faced with the challenge of reconciling the past survey's goals with the current landscape of extremely large telescope projects and the natural evolution in the forefront scientific questions. The GMT Board believes that the scientific drivers for the GSMT are as strong, if not stronger, than they were a decade ago. We believe that the GMT offers a low-risk and cost-effective approach towards realizing the goal of having one or more giant segmented telescopes open to the broad US community through a public-private partnership.

In this document we lay out a path towards a partnership with the NSF in the development and operation of the Giant Magellan Telescope. This provides a mechanism for the realization of the scientific goals of the decadal survey-defined GSMT and leverages the power of the public, private and international partners to raise capital and contribute to the technical and intellectual growth of astronomical facilities in the US.

Overview of the Giant Magellan Telescope

Organizational Structure: The GMT project is a consortium of US and international research and educational institutions committed to constructing and operating a 25m-class telescope using state-of-the art technology on a timescale that will reap maximum scientific rewards from synergy with ALMA and the JWST. The present partner institutions are:

- The Carnegie Institution of Washington
- Harvard College Observatory

- Smithsonian Astrophysical Observatory
- The Australian National University
- The Texas A&M University
- The University of Arizona
- The University of Texas at Austin

Discussions with other prospective domestic and international partners are ongoing. The partnership has formed a non-profit legal entity, the GMTO Corporation, and is in the process of obtaining tax-exempt status within the US. A Board of Directors governs the project with representatives from each of the partner institutions and observers from AURA, and other institutions. A Scientific Advisory Committee that has representation from each of the partner institutions provides scientific guidance. The project receives technical advice from the Project Scientists Working Group. The GMT Board has recently completed the *GMT Founder's Agreement*, and representatives of the founding institutions are expected to sign the agreement in the coming months. The structure of the agreement allows the founders to admit additional founders and to appoint members to the Board of Directors of the corporation from outside the founding institutions if they so choose.

Science Case: The scientific rationale for the GMT follows from the goals of the 2001 AASC report and is consistent with the broad goals defined by AURA's GSMT Science Working Group in their report "Frontier Science Enabled by a Giant Segmented Mirror Telescope". The GMT science goals are broken into several broad science themes: formation and evolution of stellar and planetary systems, the chemical evolution of stars and galaxies, the formation and evolution of black holes, galaxies and the IGM, the nature of dark matter and dark energy, and first light and reionization. Details can be found on the GMTO web site at http://www.gmto.org/sciencecase. The GMT Science Goals led to a set of scientific requirements and these were laid out in the documentation for the GMT conceptual design review. These are available on the web site at http://www.gmto.org/CoDRpublic and are described further below.

Status of the GMT Project

Conceptual Design: The status of the GMT partnership and its legal and organizational structures has been described above. Over the past few years the project has passed several key milestones. A conceptual design review was held in early 2005 and an international panel of experts gave the project a rigorous and positive technical review. They judged that the telescope and its related systems were capable of meeting the scientific goals defined for the GSMT by the 2000 decadal report. They concluded that the technical approach was sound and low risk, and that the budget estimate was reasonable. They recommended that the project proceed on the fastest possible timescale.

The Telescope and Enclosure: The concept for the Giant Magellan Telescope incorporates the largest possible rigid primary mirror segments and will provide the best performance in terms of image quality under realistic operating conditions. For this reason the GMT primary mirror is composed of seven segments, each 8.4m in diameter.

These segments are sections of a single ellipsoidal f/0.7 optical surface and thus six of the segments are off-axis elements. The telescope has an edge-to-edge span of 25.4m; a collecting area and diffraction performance equivalent apertures of 22m and 24.5m respectively. The secondary mirror is also segmented and there is a one-to-one conjugation between primary and secondary mirror segments. The telescope mount is compact, economical, and has excellent mechanical stiffness in the face of wind loading and gravity deflections.

The GMT enclosure design is of the carousel type and will rotate independently of the telescope. A large number of retractable doors allow for a high ventilation rate while allowing one to control wind buffeting of the telescope mount. An overhead crane will remove primary mirror segments and lower them onto a cart for transport to the coating facility. A spare off-axis primary mirror segment will reduce downtime associated with recoating the primary mirror segments. The enclosure and related support buildings have been laid out on the site plan for Las Campanas peak.

Adaptive Optics: The GMT Science Working Group has identified the priorities for the first generation adaptive optics system as: 1) all-sky high-Strehl laser-guide star AO, 2) ground-layer correction, and 3) high dynamic range imaging around bright natural guide stars. At this time, the group recommends that more advanced forms of AO, in particular multi-conjugate and multi-object AO be further developed before they are adopted into the baseline plan. These AO modes are currently considered as part of the second-generation system, but we expect that the case for MCAO will be revisited in the next two years. The current AO system design allows us to incorporate MCAO in a straightforward manner.

The baseline telescope design includes thin-shell adaptive secondary mirror segments as the deformable elements in the natural and laser guide star adaptive optics systems. The telescope and its AO system will produce images with a resolution of 12 mas at 1 micron, with full sky coverage. The baseline AO plan involves a cold Offner relay to feed near- and thermal-IR instruments as well as visible (589nm) and near-IR wavefront sensors. The cold relay has an appropriate stop where a deformable element can be inserted, either as part of a multi-conjugate system, or as a temporary measure while the adaptive secondary is being developed and commissioned.

The GMT Site: The telescope will be sited at Las Campanas Observatory in Chile. LCO is an excellent site with a well-established reputation over several decades for excellent seeing and good weather. Carnegie owns the site and has access to water from wells on the property and draws electric power from the national grid. The cost of operating at Las Campanas is significantly cheaper than that at Paranal and similar sites in the north of Chile. Infrastructure costs for the GMT will be shared with other telescopes on the mountain.

Primary Mirror Fabrication: The technical and management team judged that the largest technical risk to the project lay in the fabrication and testing of the large off-axis primary mirror segments. For this reason, the Board directed the project to cast and polish the first

off-axis segment as a prototype. Primary mirror segment production is also the pace-setting item in the project schedule; thus the decision to cast the first segment was aimed at retiring both technical and schedule risk.

The first segment was successfully cast at the Steward Observatory Mirror lab in July 2005 and has undergone several stages of processing. At this time the front surface of the mirror is being figured and the mirror is expected to be complete in the first quarter of calendar 2009. The polishing of the first segment required the development of new infrastructure at the Steward mirror lab and the project has spent roughly $4M on upgrades to the polishing, testing and metrology systems. These upgrades, along with the addition of a second large polishing machine, will enable the mirror lab to produce one completed segment every 10 months once ramped up to full-scale production.

First Generation Instruments: The GMT science working group has defined a set of seven candidate first-generation instruments as part of the science requirements document. Conceptual designs have been developed that meet most or all of the scientific requirements. These concepts were presented at the GMT conceptual design review and the documentation is on the GMT web site. Since that time there has been substantial progress in understanding the best way to mount and support instruments, how to provide AO corrected beams, and development of facility wavefront sensor and guider packages. Three new instrument concepts have been developed since CoDR. These include a four-channel echelle operating from 3000A to 1μm, an AO-fed integral field spectrograph working in the near-IR and a precision radial velocity instrument targeting earth-like planets around nearby stars.

Final selection of the instruments that will be built for the first generation is still more than a year away. The project will shortly issue a call for letters of intent to propose concept studies for GMT instruments and these will be open to all institutions, subject to a small number of constraints. From the solicited and proposed concepts, a set of instruments will be selected for detailed design work and, subject to review, funding for construction. The GMT Board would like to engage the US community in this process through whatever channels are appropriate and has begun this process through the AURA GSMT SWG. The Board has also signaled its willingness to consider the first generation instrument selection of other ELT projects (e.g. TMT and EELT) in making the final selection of first generation instruments for GMT, if mutual agreements and assurances can be negotiated. Thus some degree of coordination or optimization is certainly possible.

Design and Development Phase: In April of 2007, the GMT Board approved the start of the detailed design and development phase of the project. Since that time the project has gradually expanded the team beyond the working groups involved in the conceptual design. Studies of wind-loading and dynamic response have been contracted with private engineering firms and scientists at the partner institutions have been contracted to carry out studies related to the phasing of the telescope and the implementation of key adaptive optics subsystems. Site characterization is continuing and the project has deployed a state of the art mid-IR radiometer to monitor precipitable water vapor above Las Campanas. SLODAR studies are being carried out to characterize the low altitude turbulence above

the site and understand its implications for ground-layer adaptive optics. MASS and DIMM measurements are being made nightly to characterize the seeing and weather stations record the ambient conditions at four prospective sites at Las Campanas.

In late 2007, the project posted job listings for several senior engineering positions and a large number of applications are in hand. The project expects to bring 6-8 people on board in the coming months. The project staff is projected to ramp up further in late 2008 and early 2009.

Budget and Schedule: The current schedule calls for the start of the construction and commissioning phase in early 2010. This will mark the start of major construction, although work on the primary mirror segments will continue during the design and development phase as will preparatory work on the site. The currently projected start of scientific operations is in 2017, with some limited science operations possible in 2016. The primary mirror segments are on the critical path, but the construction of the telescope mount and enclosure are not far behind. The currently projected cost to completion is $555M in 2004 US dollars.

Operations Model: The GMT science working group, in consultation with the project and groups at the partner institutions involved in operating Magellan, MMT, HET, and other large telescopes, has developed an operations model for the GMT facility. This is described in detail, including estimated costs and number of FTEs, in the GMT CoDR documentation described above. The operations philosophy is based on maximizing the scientific return of the facility and led to a model called "flexible assisted observing." This observing model contains a mix of queue schedule service observing, classical PI observing, and interrupt modes driven by targets of opportunity and changing conditions. Some observers will travel to the telescope where local staff will assist them in obtaining their data, while others will choose to have their programs executed as part of a service queue. Approved time- and condition-critical observations will be given priority at the required time and some observers will need to be flexible in their plans.

The operations model developed by the SWG called for 116 FTEs. Most of these are based in Chile, either on the mountain or at the sea level facility. The base operations budget projection is $17M in 2004 dollars. In addition to this, the SWG recommended a $13M per year development fund, $8M of which is directed at new instrumentation with the remaining $5M being for facility upgrades. Thus the total projected operations cost is $30M per year, with ~45% of this being somewhat flexible in terms of year-to-year fluctuations.

Data Archiving: The current GMT operations plan and projected costs do not include a fully supported data archive. The GMT SWG recognizes the need for a data archive but it acknowledges uncertainties associated with appropriate implementation and realistic cost estimates in light of the rapidly-evolving national and international virtual observatory plans. The GMT project and its Science Working Group would like to engage the community as we work toward developing an archiving plan. Our initial planning suggests that a simple data archiving system with a minimal staff would cost roughly

$500K per year with a small up-front investment in hardware. A more elaborate integrated archive with advanced user interfaces and user support could cost an additional $1-$2M per year to implement.

Second Generation Instruments, AO System and Upgrade Paths: The GMT project and its Science Working Group are in the process of identifying attractive upgrade paths and options for second-generation instruments and AO systems. The group is aware that it would be unwise to be too definite in planning ten years into the future, but it is also mindful of the need to identify emerging technologies and to budget with an eye towards the future. Areas of particular interest are OH suppression, either via filter or Bragg fiber gratings, photon-counting IR detectors, advanced approaches to wave-front sensors, such as curvature sensing, and energy resolving detectors. We expect rapid development in next-generation AO systems, in terms of hardware, software and algorithms. The GMT project looks forward to engaging the rest of the US community in long-range planning for the second generation of GMT instruments.

US National Engagement and Participation in the GMT Project

Involvement in the GMT project by the US community at large will be most effective if it occurs on many levels. At the grass roots level, engagement by the community of active optical/IR astronomers across the full range of US educational and research institutions is needed to ensure that scientific and technical decisions are fully informed as to the goals and aspirations of the likely users. At higher levels, the standing committees within the GMT project and the NSF and its delegates, such as AURA, need to communicate regularly and should have representatives of both the private partners and public users wherever possible and appropriate. At the highest level, the GMT Board would like to engage senior leadership at the NSF and AURA to understand their desires and constraints as we look towards funding the construction and operation of the GMT as part of a public-private partnership.

In the short term, the GMT can continue to augment its committees with representation from the US community. The GMT Board would like to see further activity on the part of the GSMT SWG, both as a forum for community input and as a channel of communication between the project and the community. The GMT project has initiated greater contact with the community by sponsoring a project booth at meetings of the American Astronomical Society and by widely advertising upcoming science meetings. The project continues to update AURA via its various advisory committees and would look forward to more frequent and direct contact.

As we look towards the next decadal review, the GMT community seeks to communicate to the survey committee the great excitement that we share regarding the scientific opportunities offered by this facility. Participation by a broader community will only strengthen the scientific case for the telescope and can help cement a lasting foundation for operations and technology development. The sooner this process is begun in earnest, the more likely it is to succeed.

Specifically, in the near term the GMT Board is interested in the possibility of forming a partnership with the NSF, or its designate, equal to the partnership among the current founding institutions. The NSF, or its designate, could play a strong role in defining the process of time allocation, involvement in instrument development, and participation in and access to data from key scientific projects early in the life of the facility. Other areas of particular interest to the NSF, and potentially the National Optical Astronomy Observatory, are the development and maintenance of a GMT science archive as part of the NVO.

Possible Scope of NSF Involvement: The goals of the current GMT partners, in terms of shares of the project, amount to nearly 100% of the total. The GMT Board, however, feels that national participation in the US is of such a high priority that it is willing to scale back on the aspirations of the individual partners to allow NSF participation at the 25% level. This will go a long way towards realizing the goal of a 50% share in an ELT outlined in the US decadal survey report. The Board is also mindful of the historical precedent that not all private, or public, institutions are able to meet their goals and so there may be room for a larger public share in the GMT. The Board is open to discussion with the NSF on this issue.

The cost of a 25% share in the GMT capital cost amounts to approximately $138M in 2004 dollars, or $155M in 2007 dollars. In addition to this, an annual contribution to operations costs of $7.5M (2004; $8.4M 2007), split between base operations and development as described above, would be needed to secure 25% of the available observing time. The GMT agreement is structured such that partners can contribute unevenly towards capital and operations and thus a 25% public share of observing time could be ensured by a range of possible combinations of construction capital and operations.

A 25% public stake in GMT would provide approximately 83 nights per year to the NSF supported community (after Chilean time and engineering time are removed), or roughly 900 hours of queue scheduled observing time. In terms of total photon collecting area, a 25% share of GMT is equal to 620 8m-telecope nights, more than twice the light gathering power of the US Gemini nights.

Timing Constraints within the NSF: The GMT Board is aware, thanks to helpful discussions with the NSF and AURA, of the constraints on the MREFC and AST division budgets in the near term. The understanding of the Board is that large contributions to construction capital are not likely before 2013, late in the planned construction schedule for GMT. The Board would like to work with the NSF and AURA to craft a plan that will allow us to go forward with a partnership with the NSF despite these constraints and to chart a path towards completion of the facility in a timely manner.

Steps Toward a System of Large and Extremely Large Telescopes

The power of the GMT will be greatly increased if it is used in concert with 8m class telescopes. Preparatory and supporting observations on these large telescopes will allow

more efficient use of the GMT and can expand the scope of science that can be addressed with the specialized instrumentation on the largest aperture. The US national community has access to the Gemini telescopes; Gemini South in particular could be vital in providing synergy with the GMT. The 6.5m Magellan telescopes are also well suited to this role. At present the broader community has only limited access to the Magellan telescopes through TSIP. When the GMT begins operations, there will likely be opportunities for the NSF and AURA to obtain additional access to these facilities. This could provide a more powerful and versatile suite of capabilities to the full US community and ease the oversubscription on the Gemini telescopes.

Even in the best-case scenario, the number of GMT nights available to AURA is not likely to satisfy demand in the US community, or to provide a strong competitive position with respect to Europe. This will be particularly true if the NSF share is on the order of 25%. The NSF could address this with joint participation in the GMT and TMT, either as part of a two-telescope system of ELTs (or a larger system of large and extremely large telescopes), or as completely decoupled partnerships. Some degree of cooperation between the two projects, enabled by the NSF and managed by AURA, could lead to coordination in instrument suites and specialization in AO systems and observing modes.

We do not intend this discussion to be exclusive of other US or European efforts. We are continuing to have discussions with other telescope projects to explore various options. However, we believe that it is imperative that serious discussion about ELTs with the NSF occur promptly, and this document signals the readiness of the GMT project to enter into a discussion and partnership with the NSF.

Starting the Process of Building a Partnership

Every journey starts with a single step. Forming a partnership between the NSF and GMT will require a first step that leads to the many that will follow. The process could begin by working with AURA and its GSMT SWG to define scientific conditions and the scope of the partnership. Working groups can be established or expanded as needed and the process of building community consensus can begin in earnest. On another level, GMT project personnel and Board members can engage staff at the NSF to discuss the status of the project and the goals that each partner sees in building such an arrangement. The GMT Board is enthusiastic about starting this process immediately and is particularly eager to begin discussions while the decadal survey is in the early stages of its work. A solid partnership will provide a clear path to realization of the goals of the previous decadal survey as recast in the coming review.