Enhancing the Value of US National Participation in Giant Segmented Mirror Telescopes

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In the coming decade, a new generation of Giant Segmented Mirror Telescopes (GSMTs) will begin operation, with collecting areas an order of magnitude larger than those of today's 8-10m telescopes. Diffraction-limited GSMT observations with adaptive optics in the near- and mid-infrared will achieve unprecedented angular resolution, of order 5 times sharper than that of the James Webb Space Telescope (JWST) at similar wavelengths. These new observatories will enable transformative discoveries in nearly all areas of astronomy, from our solar system to cosmology. They will search for biomarkers in the atmospheres of extra-solar planets; study the structure and chemistry of protoplanetary disks and of ancient, pristine objects in our outer solar system; classify chemical signatures of primordial star formation in the oldest stars in our Milky Way; resolve and decode stellar populations in galaxies out to the Virgo cluster and beyond; map stellar dynamics within the spheres of influence of massive black holes in the centers of nearby galaxies; measure the structure, dynamics, and chemical evolution of galaxies across the visible universe at < 100 pc resolution (or better with gravitational lensing); execute tomographic studies of the intergalactic medium to map dark matter structure and trace the ecosystem of gas flows in and out of young galaxies; and follow up the faintest transient and variable objects detected by LSST, WFIRST, and other facilities.[2]

Three GSMTs are now proceeding into their construction phases. In the southern hemisphere, ESO's 39m European Extremely Large Telescope (E-ELT) and the 24.5m Giant Magellan Telescope (GMT) have begun construction in Chile. In the north, the Thirty Meter Telescope (TMT) will be built either on Maunakea in Hawaii or on La Palma, Canary Islands, Spain. These observatories will offer powerful synergies with the capabilities of other forefront ground- and space-based telescopes that will operate contemporaneously and at many wavelengths.

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[1] The authors are members of the US TMT Science Working Group (SWG), which represents US community interests in developing a model for potential US national partnership in the Thirty Meter Telescope International Observatory. The SWG was formed by NOAO in the context of a cooperative agreement between NSF-AST and TMT, and is comprised of scientists from institutions unaffiliated with TMT. The content of this white paper reflects, in part, the SWG's conclusions and recommendations presented in a report to NSF-AST. Many of those conclusions are not specific to TMT, however, and are presented here in the context of a US role in GSMTs in general.

[2] For much more information about science enabled by GSMTs, see the *TMT Detailed Science Case*, the *GMT Science Book*, and the *E-ELT Science Case Summary*.

International consortia are building the three GSMT projects. TMT and GMT were initiated in the US, and each has US university and institutional partners, but at present there is no national, federally funded participation that would ensure GSMT access for all US astronomers.

The 2000 and 2010 Decadal Surveys of astronomy and astrophysics, and a 2015 study of the ground-based optical/infrared (OIR) astronomy system, all highlighted the scientific and strategic importance of US national participation in GSMTs. The 2010 report, *New Worlds, New Horizons (NWNH)*, recommended federal participation in a GSMT at a level of about 25%, writing: "It is imperative that at least one of the US-led telescope projects have US federal investment. Such a federal role will leverage the very significant US private investment, will maximize the potential for the project's success, will help to optimize the US scientific return on other federal investments (ALMA, JWST, and LSST), and will position the NSF for leadership in future large-telescope projects beyond GSMT." GSMTs were described as part of "a program that will set the astronomy and astrophysics community firmly on the path to answering some of the most profound questions about the cosmos," and were judged to be "vital to US competitiveness in ground-based optical astronomy over the next two decades." *NWNH* also stated: "The benefits of such participation could go beyond making a fraction of the observing time available to the entire community of US astronomers. With a sufficiently early commitment from NSF, the broad US community would have input into GSMT governance and could play an important role in ensuring that the telescope and its instruments will meet the needs of the full US community of users and enhance the development and use of this facility by engaging the enthusiasm and experience of the entire community. This includes NOAO, which presumably would be identified as the public partner, with responsibility for representing the public interests during both the construction and the operation phases." The 2015 National Research Council report, *Optimizing the US Ground-Based Optical and Infrared Astronomy System*, reaffirmed these conclusions: "GSMTs will contribute critically to addressing the majority of the next decade's principle science questions and are required for five key science programs in *NWNH*, including the direct detection of giant exoplanets and the precise characterization of the Milky Way's central black hole, environments and progenitors of supernovae and GRBs, dark matter halos, and physical properties of the first stars." The report highlighted GSMTs as "critical complements to major new facilities, including LSST, ALMA, JWST, Gaia, WFIRST and Euclid."

The science case for US national participation in GSMTs remains strong and compelling, and is well aligned with the scientific priorities of the US astronomical community as outlined in *NWNH* and as they have evolved since that report. The giant telescopes will be essential elements of the observatory ecosystem in the next decade, and will have strong synergies with many other forefront facilities that US astronomers will be using for their science. National access to GSMTs will enhance the scientific return of federal investment in these other facilities. All US astronomers should have the opportunity to propose and carry out GSMT science programs, or they will be at a significant competitive disadvantage relative to scientists in other countries or at select US institutions with GSMT access. European astronomers, in particular, will undoubtedly make outstanding discoveries using the E-ELT, the largest of the three GSMTs.

Only fractions of GMT and TMT time will be available to US astronomers, and only to those at a few partner institutions, unless there is federal support for national open access.

National partnership in one or more GSMTs would offers substantial, long-term benefits for the US astronomical community, including steady, reliable access to observing time, a role in observatory governance and scientific planning, access to archived data, and the ability to lead and participate in key projects or survey programs (discussed further below). It would open opportunities for US teams to contribute to GSMT instrumentation development, or to bring visitor instruments to these observatories. The scientific aspirations of the US community justify the 25% GSMT participation share recommended in *NWNH*. At a minimum, a share of 10% (roughly 30 nights per year for one telescope) is necessary to enable a healthy program of principal investigator-led observing programs, as well as significant US community participation in international key projects. Maintaining US astronomical leadership and competitiveness also motivates a national share that is *at least* as large as that of other GSMT partners.

NOAO and NSF-AST should seek to maximize the scientific return to the US astronomical community from federal participation and investment in GSMTs. Here, we discuss a number of ways in which this may be achieved. Implementing these ideas requires a significant level of national participation in these observatories, in order that the US community has a role in shaping their governance, scientific planning, and operations.

A strategically managed balance of smaller and larger observing projects is important for a highly productive, high-impact GSMT science program. GSMT observing time will be in great demand by astronomers throughout the observatories' international partnerships. This could easily lead to segmentation into many small observing programs, and it may be difficult to carry out larger, coherent surveys within any one partner's share of observing time. A cross-partnership mechanism for proposing and executing large "key project" science programs would open opportunities for US astronomers beyond what might be possible or practical within a US national share alone, providing access to more observing time, data, and science. It would foster collaboration between US scientists and those in the international GSMT partners, and generate archival data sets with high re-use value. The US national community has broad experience with similar modes of operation at other ground- and space-based observatories, both as scientific users and as organizers. For example, NOAO manages time allocation for the Gemini Large and Long Programs (LLPs), and would be well-suited to organize similar collaborative science programs for the GSMT observatories.

The value of US national participation in GSMTs also would be substantially enhanced by a robust data management plan. GSMT data will be uniquely valuable, and federal investment should ensure that US scientists can make the best use of those data by enabling science teams to reduce, analyze and publish data from their observing programs effectively and expeditiously. National participation would also provide access to a body of GSMT data many times larger than that obtained through US community observing programs alone. A well-managed archive can multiply the value and usage of data by a much wider community, extending well beyond the original proposing science teams. A robust GSMT data management

plan should include data reduction software or pipelines, an archive suitable for long-term use and re-use of GSMT data, and user support. Some data management functions might be centralized at the observatories themselves, while others might be carried out by coordinated data centers in the partners, including a national GSMT data center to support US-based observers and archival researchers. US national participation could provide expertise and resources to enable a more extensive data management system than the observatories might implement themselves. One pertinent example is NASA's role as a partner in the W.M. Keck Observatory, which provided funding and data management expertise to create the Keck Observatory Archive (KOA), whose data holdings, software capabilities, and community use continue to grow. US partnership can also help to ensure that the GSMTs have carefully developed plans for observatory-managed instrument calibration, and for logging telescope, instrument and environmental metadata. This will be essential to ensure that users (both the proposing team and archival researchers) can reliably evaluate data quality and can accurately calibrate and analyze archived GSMT data at any time in the future.

We believe that full observatory membership/partnership offers the greatest benefit to the US astronomical community, as opposed to interim access to telescope nights through funding channels such as NSF's Mid-Scale Innovations Program (MSIP). Membership provides US astronomers with consistent, long-term access to observing time, and a seat at the table, alongside the other partners, for observatory governance and scientific planning (e.g., for future instrumentation, evolution of operations modes, etc.). In the long run, it is also likely to be the most cost-effective approach for community access to GSMT observing time.

US national participation in giant telescopes is fully consistent with NOAO's mission to provide open access to observing facilities and to serve as a gateway and coordinator for the US OIR system. GSMT operations and community science support is one of the major initiatives identified in the NOAO Strategic Plan. These activities engage nearly all the NOAO key competencies called out in the Strategic Plan, including "enabling community access and engagement, providing US research support services especially in the area of data management, hosting US-facing education and public outreach programs, and catalyzing consortia to develop, build, and deploy next-generation focal plane systems."