U.S. National Science Foundation

# **US ELT** External Evaluation Panel Report

*December 9, 2024*

*— Embargoed until 11 am EST December 9 —*

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# EXECUTIVE SUMMARY

In July 2024, the Director of the US National Science Foundation convened an external panel to assess the readiness of the Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT), parts of the US Extremely Large Telescope (US-ELT) Program, to move into the major facility Final Design Phase (FDP). The panel examined eight key aspects, including scientific merit, risk management, public engagement and governance, as well as the financial impact on NSF of supporting these projects.

Realization of at least one ELT is deemed essential for maintaining U.S. leadership in astronomy and education, as access to international alternatives is limited, particularly for early-career researchers. Both GMT and TMT have strong leadership, partnership and financial commitments but require $1.6 billion in NSF funding to proceed. Without this support, significant delays or project cancellations may result. The panel emphasized the critical need for congressional support, noting that without additional appropriations, NSF may face challenges balancing these projects with other national priorities, risking U.S. competitiveness in fundamental research.

# INTRODUCTION

The NSF Director convened a special Evaluation Panel (hereafter referred to as "panel") of unconflicted experts in management and oversight of large facilities to provide an independent review of the US-ELT projects: the GMT and TMT. Guidance to the panel, which met in person July 8-10, 2024, with the GMT Organization (GMTO) and TMT International Observatory (TIO) leadership teams, was provided in a document dated May 21, 2024, from the NSF Director. The following report addresses topics raised in that guidance and is intended to assist the Director in making the decision to move either, both or neither project into FDP.

## Review Panel Charge

The NSF Director asked the panel to consider the eight detailed questions listed below, to which the GMTO and TIO leadership teams were invited to respond in oral briefings.

1. Considering both the light gathering apparatus and planned instrumentation, to what extent does the proposed telescope present a scientific reach that is highly complementary to the ESO ELT, which is designed to come online in 2030 and will have at least four years of operation prior to the tentative beginning of operations for the U.S. telescope?
2. Are the partnerships that are contributing to the construction and operation of the telescope secure —that is, are there firm commitments in the resources matrix as of today, such that NSF can have assurance that the overall effort will be successful? What are the missing contributions, if any, and how critical are these to the overall success of the project?
3. Are there any risks in the risk matrix for the proposed project that could potentially cause a significant delay in completion or render it altogether infeasible? If such risks exist, are there mitigation plans already in place that could offset this risk? What would be the scientific, financial or societal impacts of implementing these mitigation plans?
4. Does the project offer well developed opportunities for junior and early-career U.S. scientists to have access to and utilize the telescope?
5. Does the project offer significant potential for formal and informal engagement of the general public (K through gray), and are there specific plans in place that would ensure this?
6. Is the proposed governance model that incorporates NSF's involvement equitable and compatible with NSF's role as the major funder and provider of open access to the U.S. astronomy community? Have the partners agreed in principle to the proposed governance terms to the extent that a framework for refinement during the FDP is in place?
7. Considerable time has passed since the Preliminary Design Review (PDR) took place. The project team has not been idle during that time. At NSF's request, the project has provided an update in response to the concerns left open by the PDR. Does the reported progress fully address the concerns raised in the PDR report? If not, has sufficient progress been achieved to provide assurance that the remaining questions can be addressed in the FDP?

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8. Looking at the proposed funding plans provided by NSF would the proposed needs and the plan to meet those needs have such a significant effect on the estimated availability of resources — e.g., require an extensive reduction in support of research programs or limit availability of Major Research Equipment and Facilities Construction (MREFC) funding to any project other than this — as to render the investment infeasible? If meeting the needs of the plan requires a redirection of resources beyond those proposed, what is the most compelling argument for taking this step?

The panel was not charged with evaluating the scientific merits of the two projects, as those had been established earlier in the major facility design stage process. It was, however, encouraged to engage deeply with each project team and ask any additional questions that came to mind, including tasking each project team to respond to written questions after the first day of meetings. Thus, over the course of the three-day meeting, the panel met with each project team twice. It also met with the NSF Director and heard presentations from NSF staff on project governance and agency funding plans.

## Members

The panel was chaired by Dan Arvizu, Ph.D., former Chancellor of New Mexico State University, former Director and Chief Executive Officer of the U.S. Department of Energy National Renewable Energy Laboratory, and former Chair of the National Science Board (NSB). The NSB establishes the policies of NSF and serves as an advisor to Congress and the President. Arvizu's expertise is in mechanical engineering, renewable energy, education, risk management and the planning, execution and governance of large multidisciplinary, multi-sector projects. Other panelists included, in alphabetical order:

- Persis Drell, Ph.D., Provost Emerita, James and Anna Marie Spilker Professor of Engineering; Professor of Materials Science and Engineering and Professor of Physics, Stanford University; former Director of the SLAC National Accelerator Laboratory; with an expertise in high energy physics, particle astrophysics, education and the planning, execution and governance of large multidisciplinary, multi-sector projects.
- Kelvin K. Droegemeier, Ph.D., Professor of Climate, Meteorology and Atmospheric Sciences and Special Advisor to the Chancellor for Science and Policy, University of Illinois at Urbana-Champaign; former Vice Chair of the NSB; former Acting Director of NSF; and former Director of the White House Office of Science and Technology Policy and Science Advisor to the President of the United States; with an expertise in atmospheric science and meteorology, policy, education and the planning, execution and governance of large multidisciplinary, multi-sector projects.
- Rick Farnsworth, Ph.D., (Col. U.S. Army Ret.), Senior Science Advisor, Oak Ridge Associated Universities; former Senior Associate in the NSF Large Facilities Office; former Associate Director of the NSF National Radio Astronomy Observatory; and former Senior Program Manager for the NSF National Ecological Observatory Network at Battelle Memorial Institute; with an expertise in biology, strategic planning, construction and management of large multidisciplinary, multi-sector projects and quantitative risk management.
- James Hurrell, Ph.D., Professor and Scott Presidential Chair in Environmental Science and Engineering, Colorado State University; former Director of the NSF National Center for Atmospheric Research, a Federally Funded Research and Development Center; with an expertise in climate science, executive leadership, education, and the planning, execution and governance of large multidisciplinary, multi-sector projects.

### Resources

The panel's work was informed by the following documents: TMT and GMT PDR reports, TMT and GMT responses to the PDR reports, TMT and GMT documents describing progress since PDR, TMT and GMT Project Execution Plans (PEP), Directorate for Mathematical and Physical Sciences (MPS) Blue Ribbon Panel report, NSF Astronomy Division (AST) Internal Management Plan and AST Implementation Plan. Extremely valuable to the panel's work was being able to meet in person with the GMTO and TIO leadership teams. This allowed the panel to ask numerous questions, follow up to seek clarification and validate findings and assess intangibles, including how members of each organization interacted with one another and worked as a cohesive team.

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## Context: Overview and Importance of a US-ELT Program

The U.S. currently supports a diverse range of ground-based optical and radio telescopes, each with unique capabilities. These sophisticated and sometimes massive instruments have not only inspired generations of scientists and the public but also driven groundbreaking discoveries and led to hundreds of publications and numerous prestigious awards, including the Nobel Prize. They have also been used to educate thousands of students and have thereby placed the U.S. in a global leadership position for astronomy, cosmology and astrophysics.

The proposals for which the panel was convened are concerned with the development of optical telescopes. Mirrors on existing U.S. optical telescopes range from on the order of 1 meter to 10 meters in diameter. Advances in instrumentation and data processing allow these systems, some of which are decades old, to continue providing observations of scientific and educational value. However, fundamental limitations in light-gathering capability have led to the need for a next generation of telescopes, termed “extremely large telescopes.”

Having primary optics on the order of 30 meters in diameter, these systems are poised to dramatically advance the understanding of the deep universe, including exoplanets and the possibility of extraterrestrial life, supermassive black holes and dark matter. Additionally, ELTs offer the promise of extraordinary synergy with numerous existing ground- and space-based observing platforms, including the James Webb Space Telescope. By virtue of their enormous size and complexity, especially the use of adaptive optics, ELTs require extraordinary levels of engineering. They are correspondingly extremely expensive and thus require creative funding approaches to support their design, construction and operation.

Historically, optical telescopes, such as the Hale Telescope at the Palomar Observatory in California and the Keck telescopes at the W.M. Keck Observatory in Hawaii, have been funded largely by non-federal sources. For ELTs under consideration by NSF, total project costs range from $2.6 to nearly $4 billion. Large portions have been paid from non-government funds, some of which already have been expended for design and fabrication of key components. The panel views NSF funding for either GMT or TMT as essential if the projects are to succeed. Indeed, these ELT systems are so expensive that NSF may be required to augment its existing major facility construction processes or create an entirely new set of processes to account for both the large cost and the considerable expenditure of funds prior to the request for government support.

### Giant Magellan Telescope

GMTO currently has 14 partners. It employs approximately 110 people, many of whom reside outside the U.S. but travel to the U.S. for extended periods of work. The total GMT project cost is estimated to be approximately $2.6 billion, for which $850 million has been formally committed by the partners to date, mostly in cash. Commitments from new partners are actively being sought that will bring this total to $1 billion, thus requiring approximately $1.6 billion from NSF. GMT operation and maintenance (O&M) costs are projected to be approximately $60 million per year, increasing over the project’s estimated 50-year lifetime. GMTO has expended over $500 million to date and has completed three mirrors, along with other components of the system. The site at Las Campanas Observatory in Chile is available and no issues exist with regards to construction permitting. GMTO has in place a comprehensive risk management structure and utilizes a California firm to manage enterprise risk.

### Thirty Meter Telescope

TIO currently has five partners with an estimated total project cost of $3.9 billion, of which $2 billion would come from partners (cash and in-kind) and $1.6 billion from NSF. To date, partners have committed $1.7 billion, with another $300 million in commitments from new partners actively being sought. So far, $700 million has been expended on the project. The large differential in cost between GMT and TMT — according to TIO leadership — results from the considerably larger size of TMT, with a primary mirror diameter of 30 meters compared to GMT’s 25.4 meters. The panel was told that 84% of subsystems are in final design, ready for production or in production. TMT O&M costs are projected to be approximately $60 million per year, increasing over the project’s estimated 50-year lifetime.

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The desired site for TMT is on U.S. soil (in an EPSCoR jurisdiction). The telescope also strongly leverages experiences from the Keck telescopes, causing TMT to sometimes be referred to as Keck 2.0. Technically, its design is more traditional than that used in GMT and thus TMT has a relatively low technological risk. The TIO risk management framework focuses solely on project-level risk at this point and does not yet include an enterprise-level risk management.

## PANEL RESPONSES TO CHARGE QUESTIONS

The sections below provide the panel's findings in response to each of the eight charge questions.

## QUESTION 1: COMPLEMENTARITY TO THE EUROPEAN SOUTHERN OBSERVATORY'S ELT

The highest priority recommendation for ground-based astronomy in the Committee for a Decadal Survey of Astronomy and Astrophysics 2020 report *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* is participation in the US-ELT Program. The three components of the US-ELT are GMT, TMT and NSF's National Optical Infrared Astronomy Research Laboratory's (NOIRLab) program office. If implemented as envisioned, the US-ELT Program would provide an all-sky observing capability with unprecedented spatial resolution and sensitivity, accessing a much larger volume of space and looking back farther in time than current capabilities allow. The new technological capabilities of the US-ELT would result in discoveries that cannot be made with existing 10-meter class telescopes and would be an important complement to existing U.S. investments in space-based observations. The US-ELT would ensure the U.S. remains a global leader in ground-based optical astronomy for many future decades: in its absence, the U.S. would cede leadership to other nations.

The recommendations made in the Decadal Survey – also known as Astro2020 – are the outcome of two decades of investment by the U.S. astronomy and astrophysics community in both the development of the technology and the maturation of the understanding of the scientific questions. Over that time, the GMT and TMT collaborations made distinctly different design choices for light-gathering apparatus, control systems and planned instruments. Importantly, both combinations of choices have been validated by the scientific community as meeting the scientific objectives of the US-ELT Program, and both projects have been recommended to advance to the FDP of the NSF major facility construction process. NSF's investment in the US-ELT would be consistent with the NSB's *Vision 2030* report, which calls for NSF to lead by providing U.S. researchers with leading-edge scientific facilities.

In considering NSF's investment in a US-ELT Program, however, it is critical to assess the complementarity of the program to the European ELT, also known as the ESO-ELT; ESO's members include all the major European countries. The ESO-ELT is under construction on Cerro Armazones in the Chilean Atacama Desert, with the goal of achieving first light in 2028. The primary mirror is 39 meters in diameter, and the telescope will be fitted with six first-generation instruments to make observations from the visible to infrared (IR) with high-spectral resolution. Both GMTO and TIO made compelling cases for how their telescopes and instrument suites will provide U.S. researchers with several unique observational capabilities, allowing pursuit of science that otherwise would not be possible. However, some capabilities of the US-ELT Program may be viewed as redundant with those that ESO-ELT will provide to European researchers. Redundancy in scientific observations is advantageous and necessary. For instance, redundancy helps confirm the accuracy and reliability of scientific findings, and it allows for error detection and correction.

The panel agrees with previous evaluations that found that the light-gathering apparatuses and instruments of the US-ELT Program are highly complementary to those of the ESO-ELT. Specifically, the proposed GMT will be sited in the Atacama Desert and would therefore provide U.S. researchers with the same sky coverage as ESO-ELT. While the GMT primary mirror (25.4 meters) is significantly smaller than that of ESO-ELT, its innovative optics design is claimed to have some competitive advantages. GMT's sensitivity extends further into the UV (320 nanometers compared to 400-450 nanometers for ESO-ELT) with high spectral resolution. In addition, GMT has a significantly wider field of view than ESO-ELT over much of the wavelength range of interest. Similarly, TMT claims greater sensitivity than ESO-ELT in the UV and claims to outperform ESO-ELT in the near IR as well, although ESO-ELT will have the best capability in the mid-IR. See Tables 3.2 and 4.2 in the AST Internal Management Plan for more detailed properties of the TMT and GMT instrument suites. Overall, we conclude – as have other assessments – that US-ELT could provide performance that both complements and equals or exceeds that of ESO-ELT.

The proposed TMT, whether at the primary Maunakea, Hawaii, site or at the alternate site in La Palma, Spain (Canary Islands), also has the obvious complementarity to ESO-ELT of looking at the northern rather than the southern sky. At the latitude of either the primary or alternate site, TMT would be able to see approximately 80% of the sky, comparable to the GMT or ESO-ELT coverage from the Atacama Desert. This would mean that roughly 60% of the sky would be seen by telescopes in both hemispheres, with 20% seen uniquely by each of the Southern and Northern Hemisphere telescopes. The performance would be somewhat different, as telescopes have the best resolution for the sky directly overhead, and they lose resolution near the limb. There are competing arguments for which part of the sky is more important: The southern sky contains the center of our galaxy while the northern sky contains more of the nearby galaxies, and some of these would be missed without a Northern Hemisphere telescope. Transient events (such as novae) are randomly distributed without preference for either hemisphere.

First light for either TMT or GMT is not anticipated until 2032 at the earliest, compared to 2028 for ESO-ELT. There is no question that the inauguration of ESO-ELT will open exciting new scientific frontiers, and the U.S. community will be relegated to the sidelines at that unique and exciting moment. However, the exploration of the important science objectives laid out in Astro2020 will be an effort of many decades, and while there is a unique excitement when the campaign starts, stunningly important science will be done by these telescopes over a 50-year period. The US-ELT Program is a marathon and not a sprint. An approximately five-year delay in the full access of the U.S. research community to 30 meter-class telescopes is unfortunate, but the community is already benefitting from lessons learned in the construction of ESO-ELT and the eventual science will be better as a result.

It is crucial that, at some point soon, the U.S. astronomy and astrophysics community has a chance to lead the important and unique scientific observations that ELTs will enable. As a result of the ESO funding model, U.S. scientists can collaborate with European researchers using ESO-ELT, but they cannot independently compete for telescope time. This puts the U.S. scientific community, and especially early-career researchers, at a significant disadvantage, with potentially long-term negative consequences for U.S. scientific leadership. This topic is discussed in more detail in the response to Question 5 in the section "Review Panel Charge" in this report. In addition, the demand for time on this new class of telescopes will be very high, so having more than one will enable additional opportunity to produce novel science. Finally, education and outreach (E&O) activities underpinned by an ELT will be dramatically fewer in number and shallower in scope if only ESO-ELT is available.

## QUESTION 2. SECURITY OF PARTNERSHIPS AND RESOURCE COMMITMENTS

The panel's review of written materials provided by TIO and GMTO and discussions with the leadership of both organizations revealed various strengths and weaknesses regarding the security of partnerships and resource commitments. Both TIO and GMTO have strong partnership commitments, with each demonstrating robust financial backing and diverse support from both domestic and international partners. However, both projects face challenges related to securing remaining funding and managing the risks associated with dependence on NSF contributions. TIO's strength lies in its diversified, in-kind contributions and unified partner support, while GMTO benefits from substantial cash contributions and a stable fiscal foundation. Ensuring the continuation of these commitments and addressing funding gaps will be critical to the success of both projects.

### TMT International Observatory (TIO)

TIO includes a diverse partnership base with prestigious universities like Caltech and the University of California, as well as international partners from Canada, India, Japan and, initially, People's Republic of China (note that the PRC withdrew amicably from TIO in early 2024). This diversity brings a wealth of expertise and resources to the project, which has already secured and costed $700 million, comprising $500 million in cash and $200 million of in-kind contributions. These in-kind contributions cover critical components such as the telescope structure, primary mirror blanks and production from Japan, the enclosure and adaptive optics facility from Canada, and optical fabrication from India. All partners have signed binding agreements, demonstrating a strong commitment to the project. This legal backing provides a measure of security and assurance of continued support. Furthermore, the partners, with demonstrated financial strength, are unified in their commitment to ensuring adequate funding for TMT.

However, the project's continuation heavily relies on securing the requested $1.6 billion from NSF. The panel has noted concerns about the political risks and potential impact on the international commitments if NSF funding does not materialize. Even if NSF provides the requested funds in addition to the existing strong commitments of the partners, a $300 million funding gap remains for project construction. Active discussions with potential collaborators to fill the funding gap are underway.

### GMT Organization (GMTO)

GMTO has secured over $850 million in legally binding contributions, with $810 million in cash from its 14 founding partners. This financial foundation offers significant flexibility for the project's execution. The project includes major U.S. institutions, such as the University of Arizona, Carnegie Institution for Science and Harvard, alongside international partners from South Korea, Australia, Brazil and Israel. These partnerships bring both financial and intellectual resources. The project's fiscal stability is underscored by its partners, which are world-class institutions with deep financial resources, ensuring a solid base for ongoing and future contributions.

GMTO acknowledged a shortfall in funding and is in active discussions to secure more. They also presented two options for the NSF contributions to offer flexibility. In one option, NSF would provide $1.6 billion – the entire amount needed to complete construction – and GMTO would pay a larger share of future O&M costs until its total contributions equaled those of NSF, after which O&M would be shared equally. In the second option, NSF would contribute $1.3 billion for construction, and the project would raise an additional $300 million. In this scenario, future O&M costs would be shared equally by NSF and the GMTO partners. In either case, securing the remaining funds is crucial. The tiered contribution structure, with different levels of partners (major, partner and smaller partner), could potentially complicate decision-making and project management if votes are weighted by size of contribution.

## QUESTION 3: RISK MANAGEMENT AND MITIGATION PLANS

Both TMT and GMT have articulated Risk and Opportunity Management plans in their respective PEPs that are consistent with the requirements of the NSF "Research Infrastructure Guide" to advance the projects from PDR into FDP. At PDR, both projects presented an acceptable level of technical and programmatic risk and had appropriate mitigation plans. Neither project presented a technical risk that would prevent the infrastructure from being completed. In the 17 months since PDR, both projects have continued to manage their risk profiles. TIO's risk management has focused efforts at the project level, and largely toward the risk of not being allowed to utilize the Maunakea site. GMTO's risk management has dealt with risks across the portfolio at both the enterprise and project levels and has continued to mature.

### Risk Identification

GMTO manages risk and opportunity[1] at two levels: enterprise and project. The key enterprise risks are: achievement and timing of fundraising goals, management of the NSF partnership and funding requirements, management of relationships with Congress and federal agencies, and recruitment and retention of talent. Key project risks are focused on technical aspects of the project. It was clear to the panel that GMTO has actively managed its risks and risk register since the PDR. Also, GMTO continuously updates its PEP and the associated Risk Management Plan. Risk and opportunity management utilizes a risk register, consistent with guidance in the NSF "Research Infrastructure Guide." It is notable that GMTO manages its project risk register as a dynamic database that actively accounts for 88 independent variables. The project currently has 197 active risks and conducts quarterly reviews with risk owners.

The impacts of the GMTO key risks are variable. The single largest project risk is "achievement and timing of fundraising goals," which currently relies on NSF support. Should the risk be triggered, a lack of NSF funding will significantly impact the start of the FDP and, ultimately, construction.

1 GMTO Project Execution Plan (June 2024), Chapter 6, Risk and Opportunity Management

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TIO manages risk and opportunity[2] at the project level only. The most impactful identified risks are: availability of construction funding, site access, in-kind delivery delays, enclosure classification and attrition. TIO actively manages risks through a risk register that is maintained by the project manager as a static document, with a dashboard that uses a commercial software tool. This is fully compliant with NSF requirements and provides project participants with high-level visibility. However, in FDP, adoption of a more robust management tool for use in the Construction Stage would be recommended prior to Final Design Review (FDR). It is notable that, while there have been updates to the risk register since PDR, the PEP and associated Risk and Opportunity Management Plan have not been updated. The project currently has 79 active risks.

The three most significant risks to TMT are availability of construction funding, site access and in-kind delivery delays. Triggering any of these risks would likely be an existential threat to the project. The leadership team is wholly reliant on NSF funding to complete the FDP. Should the project not be allowed to build on Maunakea, a decision about whether to proceed would be needed. The mitigation strategy for a lack of site access is to pivot to the alternate site (La Palma, Canary Islands), but the panel did not feel that plans for use of this site were developed to the same level as those for Maunakea. Risks related to in-kind contributions deal primarily with impacts on schedule, although the complete failure of a partner to deliver is also a risk that must be managed.

Both projects have compliant[3] and robust Risk and Opportunity management plans that serve to identify potential threats and opportunities, rate their probability and potential impact, and develop appropriate mitigation plans for those deemed high to moderate risk. There were a few key differences in the maturity level of the projects' risk management approaches. As stated earlier, GMTO manages risks at both the enterprise and project levels, while TIO manages at the project level only. This positions GMTO to manage very high-level risks to the organization that could prevent project completion. Without a comparable enterprise-level strategy, TIO may not be paying the appropriate level of attention to these higher-level risks. It is also notable that GMTO is tracking 197 active risks, while TIO is managing 97 active risks, having previously mitigated 15. Although direct comparison of active risk counts may not be appropriate, the large difference in number suggests that TIO has defined risks at a higher, less granular level or may be missing some project risks. Moreover, GMTO has a very robust suite of tools for management of project risk and opportunity, which is a considerable strength.

Nowhere have any risks associated with the participation of NOIRLab[4] in the US-ELT Program been documented. While this is understandable, as each project manages its own internal risks and opportunities, participation of NOIRLab is critical for the success of the US-ELT Program, and these risks should be identified and managed and should be included in Chapter 11 of the AST Internal Management Plan.

## Mitigation Strategies

Both GMTO and TIO manage their risks and opportunities through well-developed risk registers, with mitigation strategies developed for risks rated to have "high" and "medium" impacts. The methodology is consistent with that expected for management of large research infrastructures and should result in limitation of risk exposure.

Generally, TIO presented mitigation strategies that were compliant for this stage of the project but in the panel's opinion, require maturation. TIO has two high-level risks that, if triggered, would have severe impacts to the project.

> Site access. TIO has been actively managing the risk of not being able to build on Maunakea. All completed steps to date have focused on adjusting the project schedule and have not actually mitigated the risk of lack of site access. In-progress efforts include continued comprehensive Maunakea site acquisition activities and moving the Project Manager to Hilo for extensive community engagement. While these activities are commendable and the panel was very impressed by how

2 TMT Project Execution Plan (October 2022), Chapter 6, Risk and Opportunity Management

3 NSF 21-107 Research Infrastructure Guide, NSF (Dec 2021)

4 NSF NOIRLab is a Federally Funded Research and Development Center (FFRDC) managed by Association of Universities for Research in Astronomy (AURA)

much has been done, it isn't clear how these efforts have impacted this specific risk. The mitigation strategy also includes identification of the La Palma site, with site characterization in progress, permits in hand and acceptance by all TIO partners. The project leadership communicated to the panel that the project would progress through FDP focused on Maunakea. If it became apparent Maunakea was not going to be available, TIO would switch to adapting plans for TMT to the Canary Islands site. There was no timeline associated with these decision points. While it is possible to enter FDP with this level of uncertainty, it is impossible to participate in FDR before site selection has been fully resolved. The panel finds TIO's mitigation strategy for this risk, taken as a whole, to be inadequate.

Availability of construction funding. The mitigation plan for this risk has been actively managed, but it hasn't impacted its probability or potential severity and largely focuses on developing a plan for NSF and AURA to join TIO. This is not a mature or appropriate mitigation strategy. Further, the risk itself focuses on availability of construction funding rather than the proximate risk of funding for FDP. In addition, TIO's senior leadership communicated to the panel that, should NSF funding not be forthcoming, there was no plan for continuing the TMT project.

GMTO's single largest risk is availability of funding from NSF, and the impact to the project – should this risk be realized – is severe. The mitigation strategy largely focuses on relationship building with donors, founders, Congress and NSF, but it does not directly address the possibility of no NSF funding at all. Although GMTO has plans to address the approximately $300 million shortfall in identified funding, those would be severely impacted by delays in NSF funding or no funding being made available at all.

Resolution of the construction funding plans for either project is not required to move into FDP. However, even though the NSF "Research Infrastructure Guide" expressly states that entrance into FDP is no guarantee of advancing to the Construction Stage, there is a community expectation that if a project proceeds into FDP, it will be approved for construction after a successful FDR. The idea of advancing both projects into FDP without a clear path for future funding presents risk to NSF's reputation within the community. Additionally, NSF faces risks should the projects' budget shortfalls not be eliminated, potentially having to cover the shortfall from the MREFC budget or to exercise scope reductions.

## QUESTION 4: OPPORTUNITIES FOR TRAINEES AND EARLY-CAREER SCIENTISTS

The most precious experimental resource for the field of astronomy is time on the telescope. Scientific discovery relies on coordinated nights of observing in excellent conditions. Once the new generation of ELTs is operational, the competition for observing time will be fierce. If only ESO-ELT is built, the U.S. community will be at a crippling disadvantage, as it will be able to access observing time on that telescope only as part of an international collaborative team. This creates a particularly important barrier for early-career U.S. scientists who have not yet developed such collaborations. Further, U.S. educational benefits from ESO-ELT, both formal (primary, secondary and postsecondary) and informal (K through gray), will be even more limited, which is particularly troubling because astronomy has long been, and continues to serve as, a mechanism for generating broad interest in STEM.

A U.S.-based ELT with significant NSF funding for construction and operations will have a substantial fraction of its observing time dedicated to U.S. scientists through an open and competitive process. The difference for the U.S. community will be dramatic. Not only will U.S. scientists be able to lead observing campaigns, but programs from NSF will provide special access to developing talent in the field, including early-career scientists from under-resourced and historically disadvantaged communities. The GMT collaboration is committed to dedicated telescope time for graduate students, postdocs, staff and faculty from the U.S. Founder institutions, while both GMT and TMT will be open to all U.S. scientists in the share of time accorded to NSF. Data from both would also be accessible to all U.S. researchers after a proprietary period. In combination with open access to telescope time available through NSF or its designee, likely NOIRLab, these aspects would provide a critical pipeline for scientific talent in the U.S. with long-term benefits to the national and economic security of the country.

Both GMTO and TIO propose innovative training and mentoring plans for supporting early-career scientists on their telescopes. Some components of these plans are already being executed, such as waived conference fees and travel support to annual GMT community science meetings; training for both instrumentalists and software engineers; and TMT science forums, conference series and hands-on workshops in instrument design and operations. Moreover, both projects have thoughtful plans to expand their offerings, including outreach to engage the public in the excitement of the science delivered from ground-based telescopes. The TMT team was particularly eloquent in describing their outreach to and engagement with the Indigenous populations of Hawaii, including the new Mauna Kea Stewardship and Oversight Authority. Such outreach and meaningful dialogue with native Hawaiian communities is essential, since the construction of TMT on Maunakea hinges on continued engagement with, and ultimately the approval of, the local communities.

The link between U.S. scientific leadership in astronomy and astrophysics and the access of U.S. scientists to ELT observing time is clear. But there is another benefit to the U.S. scientific community from having a U.S.-based ELT that is less obvious. The telescope collects light and delivers it to instruments that are specially designed to match the unique features of a particular telescope's design. Instruments are built by consortia of scientists and engineers, often at universities, with the engagement of many students, postdocs and other early-career researchers. The U.S. does not have the ability to propose and construct instruments for ESO-ELT; that is a privilege reserved for members of ESO. As a result, without TMT or GMT, a generation of U.S. astronomers and astrophysicists will not be engaged in the cutting-edge technology development that will be required to fully exploit this new class of telescope. Because the ability to design and build these scientific instruments is often the gateway to a STEM career, it both benefits the field of astronomy and astrophysics and helps to build the scientific workforce of the nation.

## QUESTION 5: PUBLIC ENGAGEMENT AND EDUCATIONAL OUTREACH

Both GMTO and TIO have long-standing E&O programs that formally and informally engage audiences at multiple levels of relevance and interest. Although their approaches and in some cases their audiences are notably different, both organizations show a strong commitment to excellence, breadth and impact. They also pledge to expand their activities through prudent, specific actions that were articulated during discussions with the panel, should they be selected to go forward to FDP. Generally, E&O programs are not formally budgeted as part of the major facility construction process. GMTO and TIO currently operate their E&O programs independently, though in some cases in collaboration with NOIRLab, using internal funds as well as external grants from various sources, including NSF. NOIRLab is an important component of the overall US-ELT Program, and both GMTO and TIO will potentially involve it more extensively as a coordinating body.

### Formal Engagement Programs (K-12, Undergraduates, Graduates)

The GMTO formal education programs involve six Carnegie R1 universities as well as several observatories, the Smithsonian Institution and the Carnegie Science Organization. Additionally, six organizations in Chile serve as partners, along with the U.S. Inter-American Development Bank. The international engagement brings an important dimension to the program that is unique to GMTO. GMTO utilizes a co-creation approach in its E&O activities, especially with international partners, to ensure buy-in, effectiveness and programmatic stability.

The GMTO E&O programs are framed within a pipeline construct that proceeds from K-12 through higher education and then bifurcates into early-career workforce and continued public engagement. The goal of the former is to build a diverse and competitive STEM workforce while also increasing the participation of underrepresented minorities in STEM. Formal education programs include K-12 curriculum development and teacher training, a next-generation leadership fellowship program that focuses on undergraduates and broadening participation and a cross-institutional undergraduate mentorship program that seeks to build linkages to a diverse array of institutions. The thread linking these programs together is the natural pathway traveled by students as they progress through their education careers. A comprehensive E&O plan was delivered at PDR and continues to be refined and enhanced.

The panel felt that, as GMTO expands its E&O programs, it would be well disposed to engage other institutions as core partners, especially those from EPSCoR jurisdictions, tribal communities and emerging research and minority-serving institutions. The map showing GMTO's current E&O impact depicts a concentration of institutions in the U.S. Northeast, Southwest and West Coast, but nothing in the rest of the country apart from Chicago. Additionally, emphasis on the skilled technical workforce, which is critical for S&T research, should be included in the GMTO framework and activities. GMTO recognizes these issues and noted they are committed to addressing them.

TIO has in place a comprehensive, multiphase E&O program centered in Hawaii. Currently, this program is almost exclusively focused on Indigenous Hawaiian populations, though not to the exclusion of broader audiences. TIO has launched 20 pilot programs during the past three years and plans to continue focusing on Hawaii for the next two years, before expanding into other parts of the U.S. TIO's co-creation E&O strategy has involved considerable efforts directed toward building trust and understanding with local communities, which also is a key issue for the site location and the ultimate workforce for TMT. Importantly, building trust and partnership with the local communities in Hawaii could potentially benefit from other STEM projects not directly associated with TMT.

The first phase of the TIO E&O program involves active listening and extensive dialogue with the local community. This effort has engaged more than 1,000 community members, including elders, protectors and teachers, and has set the stage for the second phase involving the co-creation of various programs to meet the unique needs of local communities. Topics range from education and workforce development to Indigenous culture learning, environmental protection and conservation. Also included is professional development for TIO staff, which is viewed as integral to success regarding trust with the many stakeholders in Hawai"i".

As was the case for GMTO, the panel felt that TIO should, during its next phase of its E&O efforts, expand as quickly as possible, especially to other EPSCoR jurisdictions beyond Hawaii and other emerging and minority-serving institutions. This will allow TIO to promote lessons learned to a broader national audience that deals with similar challenges in broadening participation and building trust with various communities. It is noteworthy that some of those who formerly protested the siting of a telescope on Maunakea and wanted TIO to leave Hawaii are now asking them to stay, owing to the impact of E&O activities on their children and communities. This is quite extraordinary and the sort of progress that needs to be made for science and Indigenous communities to work in harmony.

### Informal Public Engagement

GMTO's informal education programs involve 11 different organizations in the U.S. and Chile, including the Exploratorium, California Science Center and Braille Institute of America. As for the formal education programs, the informal programs also engage observatories and the Carnegie Science Organization and proceed from K-12 through higher education with the goal of increasing public engagement and STEM literacy as well as the participation of underrepresented minorities in STEM. The K-12 component includes two programs geared toward students in Chile, while the higher education component includes a community engagement program, a major exhibit and documentation of GMT's construction as it progresses. The panel was only provided information on the exhibit, an immersive, inquiry-based traveling activity designed in collaboration with the Exploratorium, with a target reach of 1.4 million annually through networks and partnerships. A major goal is to advance equity through implementation in U.S. and Chilean communities that otherwise have limited access to high-quality informal STEM learning.

Given the nature of challenges in Hawaii, as described previously, and efforts directed toward building trust, TIO's informal education programs are interwoven throughout its broader E&O portfolio. Specific programs, including STEM Workforce Development with Hawai'i Community College, the TIO Mirror Assembly Lab Plan in Hilo, Astronomy Outreach with Maunakea Observatories, NOIRLab, the University of Hawai'i and 'Imiloa Astronomy Center, the Maunakea Forest Restoration Program, 'Ohana Stargazing and the 'Ale Lau Loa Global Youth Ambassador Program. All these activities engage Indigenous communities and seek to integrate Indigenous knowledge and lore with modern astronomy. As noted before, this degree of direct and continuous engagement is critical for building trust, with lessons learned exportable to other programs and institutions across the U.S.

*— Embargoed until 11 am EST December 9 —*

# QUESTION 6: GOVERNANCE MODEL AND NSF INVOLVEMENT

The standard in the astronomy community is that telescope observing time is owned and allocated by the consortium that paid to build the telescope. A tradition of private investment is at the root of this model. Private funding is a major source of investment in the design and construction of TMT and GMT and can be credited with the projects' readiness for FDP. Moreover, there is expectation among the consortium of investors that there will be commensurate allocation of observing time to them once the telescope is operational.

Significant investment from the federal government is needed, however, to bring either project to fruition. The critical importance of NSF's role in providing both construction and future operations funding is well understood by both teams, and both expressed openness, and indeed eagerness, to have more detailed discussions about how NSF would be incorporated into their existing governance models. Agreements on the framework and overall structure for NSF participation will be important considerations for entering FDP. The appropriate time to define and refine the details of the governance model to include NSF participation will be in FDP, and full agreement on the governance model is necessary to pass FDR.

As NSF approaches the governance discussion, there are a few key points to keep in mind:

1. Considering the substantial investment that NSF might make in these telescopes — potentially exceeding the contributions of any other stakeholder — it is reasonable for NSF to control at least the majority of the observing time on the telescope under the current funding model. If NSF contributes more of the construction costs, then a larger proportional share of the observing time would be appropriate.
2. NSF should expect to fund the annual operating costs of the telescope at a fraction proportional to its contribution to the construction.
3. NSF must be able to exercise oversight of both the project and the O&M of the facility in a way that is consistent with its requirements as a government agency.
4. NSF needs to assess the costs of NOIRLab's role in the US-ELT Program and include those operating costs in its future budget projections. The role of NOIRLab in the operations phase needs to be fully defined.
5. NSF needs to evaluate the different options it has for governance organizations. Initial discussions with the project teams focused on NSF becoming a part of the existing consortia, which are structured as 501(c)(3) corporations. However, NSF's Office of the General Counsel has identified significant limitations to the participation of any federal employee in such an organization, which would significantly weaken NSF's role in decision-making. The panel thinks that NSF should propose to the projects an approach that ensures that NSF has decision-making authority that is at least proportional to its investment share, if not a clear majority position.

In any construction project or operating facility, new challenges will emerge. Any governance model must anticipate those challenges and have robust mechanisms for addressing them that are consistent with NSF's mission and status as a government agency. There are many lessons that can be learned from other projects, both in AST and possibly other fields such as high energy physics, that should be incorporated into any new agreements.

# QUESTION 7: PROGRESS SINCE PRELIMINARY DESIGN REVIEW

## Updates and Progress

The PDR for the US-ELT Program recommended that both GMT and TMT be advanced to FDP, with recommendations for consideration by both NSF and the individual projects. In the 17 months since PDR, TMT and GMT have each advanced their plans and refined their processes.

GMTO has continued to refine the preliminary design, the cost details and the required funding profile and has updated all project documentation since PDR. They continue to develop site infrastructure at Carnegie's Las Campanas Observatory. Though these activities are occurring at the level they would have had the project advanced into FDP already, GMTO has made steady progress and has largely addressed the concerns of the PDR panel.

— *Embargoed until 11 am EST December 9* —

In response to the PDR panel's specific concerns about the funding model, GMTO has secured increased financial commitments from existing partners and brought new partners into the GMTO consortium. They have decreased overall risk exposure through continued development of key technology and through active management of their risk register. The PDR panel recommended that NSF ensure that its contributions are counted in a manner commensurate with the contributed scope's value during the operations phase. GMTO has addressed this issue with its consortium members, resulting in an agreement with NSF to allocate observing time in direct proportion to the fraction of construction cost provided.

TIO has continued to refine the preliminary design, the cost volume and the required funding profile. Though the project is actively managing its risk exposure through the risk register, TIO does not appear to have updated the formal project documentation (Risk Management Plan, PEP, etc.) since PDR. The largest project risk identified by the PDR panel was site selection. TMT has invested significant time and resources since PDR in working with the local community in Hawaii to mitigate any potential community influence that would prevent construction. They have also developed plans to move production of some telescope elements to Hawaii and have created a workforce development plan. TIO has also better fleshed out the plans to utilize the alternative site (Canary Islands) since PDR, although, as noted in Question 3 in "Review Panel Charge" of this report, more needs to be done.

Neither project has presented a technical risk that would prevent the infrastructure from being completed.

### Assessment of Remaining Concerns

The PDR panel found that initiation of NSF funding for remaining design work and advancement into FDP was required for the projects to progress. There has been a delay in that funding, and both projects have continued to refine their plans, albeit at a reduced level of effort. GMTO has largely executed project tasks as if it will begin construction in the future and continued to refine plans accordingly. GMTO has addressed the PDR findings for which they were responsible. TIO has also continued development and refinement. The partner nations have continued to produce elements of the infrastructure as in-kind contributions, while the project's focus has been on efforts to secure the support of Indigenous Hawaiians.

The PDR report noted that the NOIRLab component is a critical element of full life cycle planning for the US-ELT Program. The PDR panel recommended that NSF identify the development and operational roles they would like NOIRLab to perform, and that costs for these components should be clarified. Both projects stated that they have worked with NOIRLab, but as neither is responsible for this effort, progress toward the panel's recommendations could not be evaluated.

### Readiness for FDP

The PDR panel found that both GMT and TMT were sufficiently ready to advance to FDP. As the design plans progress, there will no doubt be elaboration and identification of more technical and programmatic risk, but the plans as presented are sufficient. The current panel believes both projects have met the requirements to proceed to FDP once a governance framework is agreed on.

This is not to say that both projects are at the same level of programmatic readiness. The GMT team has progressed steadily toward development of the final design (at a reduced rate), and the panel has confidence that GMT will progress through FDP to a successful FDR and construction, if approved. The TMT team has also progressed and has largely addressed the PDR panel's concerns. This panel has no significant concerns with moving TMT into FDP but restates that FDP cannot be completed until a specific site has been identified. Siting the infrastructure drives a myriad of design, infrastructure, contracting and other critical choices. Because the time scale for resolving the siting issue is uncertain, NSF should monitor progress closely and recognize that advancement without resolving this issue risks an extended FDP, with all the associated costs.

## QUESTION 8: IMPACT ON BUDGET

The Astro2020 report recommended that NSF invest no more than $1.6 billion in a US-ELT Program, a ceiling reinforced by a recent NSB resolution. Those funds would come from NSF's MREFC account, which is the agency's primary source of support for construction or acquisition of research infrastructure. According to information provided to the panel by NSF, the average yearly appropriation for the MREFC account was $187 million over the past 10 years, or 2%-3% of the total NSF budget. The $1.6 billion in construction funding that each project would need from NSF would necessitate an MREFC investment that significantly exceeds the 10-year average. GMTO projects a construction cost of over $200 million per year for at least five years, considering possible delays between PDR and initiation of construction. TIO projects a construction cost of over $200 million per year for at least seven years, assuming the same delay. This annual amount represents approximately two-thirds of the Fiscal Year 2025 MREFC budget request of $300 million and roughly half of the aspirational FY 2030 MREFC budget request of $500 million.

Although these costs arguably could be met if either of the two projects entered the Construction Stage, their inclusion would effectively exclude, or at best seriously delay, any other major MREFC investments until construction is completed, unless a significant and sustained congressional augmentation of the MREFC budget took place. Without such an augmentation, other high-priority projects recommended in the Astro2020 and 2023 Particle Physics Project Prioritization Panel reports would be imperiled, notably the next-generation Very Large Array, fourth-generation Cosmic Microwave Background, the next-generation Gravitational Wave Detector and the next-generation IceCube Neutrino Observatory. Investment in construction of one of the ELTs without additional appropriations would also significantly hinder the agency's capacity to manage construction projects outside MPS, such as the Antarctic Research Vessel, which is already in FDP. Additionally, it may impact the agency's ability to provide strong support for the Midscale Research Infrastructure Track 2 program and the Antarctic Infrastructure Recapitalization program, both of which are funded by the MREFC account.

Two other points related to the budget impact of the US-ELT Program are worth mentioning. First, as noted in responses to other charge questions, the costs projected above do not reflect any contribution to the design or construction of the NOIRLab component that would accompany either TMT or GMT, which would include much of the data processing, observation scheduling and outreach components of the completed facility. Because this component has not been costed, the above figures reflect the minimum to be anticipated for construction. The budget for future O&M must also be considered within the context of the AST budget.

The second point concerns the challenge of meeting necessary costs for FDP for either telescope, which are listed in the GMT and TMT proposals as $103 million and $144 million, respectively. These resources would be drawn from the same account that funds AST research awards, including support for researchers, students and postdocs. Funding the FDP costs of either telescope would exceed the budgeted research component of AST, which is $79 million in the FY 2025 budget request. Meeting these costs, even when spread over the two to three years of the FDP effort, would have a deleterious effect on AST and MPS budgets and could seriously impact the research and education components of their programs.

## FINDINGS AND SUMMARY

In July 2024, NSF convened an external panel to evaluate the readiness of GMT and TMT, components of the US-ELT Program, to advance into FDP. These two projects had previously passed PDR and were reviewed by a Blue Ribbon Panel convened by MPS. The NSF director commissioned the current panel to gain an independent assessment as part of his decision process to move either, both or neither project into FDP. Entering FDP is not a commitment by NSF to fund construction; however, the community expectation and the past precedent is that no project has entered FDP without ultimately being built. Furthermore, the NSB has recommended that the US-ELT Program be funded at no more than $1.6 billion, and although support for funding the US-ELT Program is expected, it has not yet been appropriated by Congress. The panel's findings emphasize that the success of this program critically depends on acquiring the necessary resources from Congress to enable NSF funding that is vital for both projects.

The panel was tasked with addressing eight questions provided by the NSF director, covering the scientific reach and complementarity to ESO-ELT, security of partnerships' commitments, risk management details, opportunities for junior scientists, public engagement, governance plan with NSF, update on progress since PDR and impact of the proposed projects' financial commitments on NSF's budget and other priorities.

*— Embargoed until 11 am EST December 9 —*

The panel finds that a U.S.-managed ELT is extremely important for access to cutting-edge capabilities by U.S. researchers — not only to keep U.S. astronomy at the frontier of science but also to reap the associated benefits to formal and informal education. ESO-ELT will be quite capable (though arguably less so than either system being proposed to NSF) and will come online some four years before a U.S. system, if current schedules hold. However, U.S. researchers' access to ESO-ELT appears to be limited to collaborations with colleagues who can directly request time on the system. This creates a particularly important barrier for early-career U.S. researchers who may not yet have developed such collaborations. Further, educational benefits to the U.S. from ESO-ELT, both formal (primary, secondary and postsecondary) and informal (general public) K through gray), will also be limited, which is troubling because astronomy has long been, and continues to serve as, a mechanism for generating broad interest in STEM.

A US-ELT with NSF as a major partner will alleviate most of these challenges, particularly regarding access, because U.S. researchers can request access to ELT observing time directly through a process likely to be managed by NOIRLab. NOIRLab is positioned to facilitate a US-ELT Program, including its educational components. The panel wishes to note, however, that funding for the NOIRLab component of the US-ELT Program, should that be formally established, was not reflected in budgets shown to the panel.

Both GMTO and TIO have been in place for several years and have strong and cohesive leadership teams, though notably different in character; the GMTO team has more of a corporate orientation, while the TIO team has more of an academic orientation. Both organizations also have cultivated important funding, scientific and educational relationships with domestic and international partners; secured financial commitments and obtained both cash and in-kind support from their partners; created and are executing impactful formal and informal E&O programs; and expended considerable funds toward fabricating key components of their respective systems. In short, the panel was very impressed with the breadth, depth and collaborative strength of both the GMTO and TIO teams.

Both GMTO and TIO have indicated that $1.6 billion of NSF funding is necessary to proceed with construction of either telescope. Both organizations have raised considerable funds to date and have indicated they have good prospects to raise more. Without NSF construction funding, however, both projects face significant delays, at a minimum, and the very real possibility of not moving forward at all. The panel noted that NSF's funding contribution is crucial to the overall success and sustainability of either project and that the role of NOIRLab must be considered and included in the funding discussions, for it is an integral part of success for the US-ELT Program. Without NSF's support, there is a risk of not only project failure but also detrimental impact on the U.S.'s position in global astronomy.

The GMT project's strengths include a strong and cohesive leadership team with a corporate orientation, substantial cash contributions totaling over $850 million, a comprehensive risk management structure with a significant focus on enterprise-level risks and extensive formal and informal E&O programs. The TMT project's positives include a diverse partnership base with significant financial contributions already secured, lower technological risk due to leveraging experiences from the Keck telescopes and a strong focus on education, outreach and engagement with Indigenous Hawaiian communities.

Regarding the security of partnerships and resource commitments, GMTO has secured significant cash contributions and strong domestic and international partners but still requires NSF support to cover the construction funding gap. TIO has a diverse partnership base and significant in-kind contributions but also faces a substantial construction funding gap and is critically dependent on NSF funding.

GMTO has a mature approach to risk management and mitigation at both enterprise and project levels, while TIO's risk management focuses on project-level risks but requires further development in mitigation strategies, particularly concerning site access. Both projects indicate that obtaining the required funding resources is their top risk yet hiring and retaining qualified personnel and supply chain delivery are among other significant risks. One important issue for TMT that is yet to be resolved is the major risk associated with site selection, and specifically with unresolved issues regarding the primary site on Maunakea. The panel notes that until this issue is resolved, it would be impossible for TIO to complete FDR.

Both GMTO and TIO have longstanding E&O programs that formally and informally engage audiences at multiple levels of relevance and interest. Both projects offer extensive training and mentoring programs for early-career scientists, emphasizing the importance of access to telescope time and instrument development. GMT's public engagement and educational outreach programs involve a range of domestic and international partners, focusing on a pipeline from K-12 to higher education and workforce development. TMT's programs are centered in Hawaii, with a strong focus on Indigenous communities and broader educational outreach plans. Although their approaches and in some cases their audiences are notably different, both organizations articulate a strong commitment to excellence, breadth and impact. They also pledge to expand their activities through prudent, specific actions that were articulated during discussions with the panel, should they be selected to go forward to the FDP.

Both projects recognize the importance of NSF's role in governance, with a need for NSF to have significant decision-making authority proportional to its investment. Both projects have indicated a willingness to negotiate support for NSF governance requirements, and the panel suggests that NSF ensure that it retains the majority of the telescope observing time for either project.

Beyond the technical, financial and program impacts considered by the panel, the NSF Director must consider the broader context of the US-ELT Program, including its impacts on maintaining U.S. leadership in astronomy, the need to balance this substantial NSF funding request with those for other high-priority projects within the agency and the current fiscal realities and domestic policy concerns.

It is very important to recognize that funding either, and especially both, of the US-ELT proposals will have a significant negative impact on the NSF budget, and on U.S. science more broadly, unless Congress is able to significantly augment the MREFC budget as well as that of the Research and Related Activities (R&RA) account for the reasons described below.

First, numerous costs beyond construction funded by the MREFC account (e.g., for research grants in AST on all topics, including use of US-ELT, along with E&O activities, O&M and US-ELT coordination support for NOIRLab) must be considered for the expected operating lifetime of the telescope(s). Because these funds come from programmatic budgets in AST, failure by Congress to also provide these additional non-MREFC funds would substantially reduce the AST research and education budget for many years to come, potentially requiring a significant reallocation of resources within NSF to make up the difference. Such reallocation would then have a cascading, deleterious impact on several NSF programs, including those of particular national interest (e.g., those within the Technology, Innovation and Partnerships Directorate and for emerging industries such as artificial intelligence, quantum computing and advanced telecommunications).

Second, without substantial additional funding to the MREFC account, were one or both of the US-ELT proposals to be funded, several other scientifically critical MREFC projects, which are in various stages of planning and review, may be substantially delayed or even cancelled, as detailed in the panel's response to Question 8.

Third, NSF has for many years been fortunate to receive significant bipartisan support and related authorizations from Congress. Unfortunately, these have not been followed by commensurate appropriations. The Panel is extremely concerned about the risk to NSF and to the nation's research and education enterprise more broadly if this trend continues in the context of an US-ELT award. One strategy to reduce or remove this risk would be for Congress to appropriate the bulk of US-ELT MREFC construction funding up front and likewise augment the R&RA account to ensure robustness of the astronomy research and education portfolio.

Finally, the performance of fundamental research is foundational to the economic and national security of the U.S. and is a unique responsibility of the federal government. Indeed, fundamental research funded by NSF decades ago in structural biology, computational modeling, communications technologies, high-performance computing, data visualization and supply chain management played a pivotal role in the country's ability to develop, manufacture and distribute a COVID-19 vaccine in record time. Availability of adequate funding for fundamental research continues to pose significant challenges, owing to fiscal constraints and growing national debt. Yet, such funding must be protected if the U.S. is to remain competitive in today's challenging geopolitical climate. Consequently, failure by the U.S. to support a US-ELT will have a domino effect and exacerbate the already problematic funding in the country for fundamental research.

In conclusion, the success of the US-ELT Program hinges on securing the necessary resources from Congress, with NSF funding being critical to both projects. Both GMTO and TIO have strong proposals with distinct strengths and challenges, and the panel recommends careful consideration of their Risk Management Plans and the security of partnership commitments as decisions about advancing either project are made. The panel advises the Director to optimize the use of taxpayer funding to ensure that both projects have the opportunity to succeed in FDR.

## LIST OF ACRONYMS FOUND IN US ELT EXTERNAL EVALUATION PANEL REPORT

AST – NSF Division of Astronomical Sciences.

E&O – education and outreach.

ELT – extremely large telescope (this is separate from the US-ELT Program acronym).

ESO – European Southern Observatory.

ESO-ELT - European Southern Observatory – Extremely Large Telescope.

FDP – Final Design Phase.

FDR – Final Design Review.

GMT – Giant Magellan Telescope.

GMTO – Giant Magellan Telescope Organization.

IR – infrared.

MPS – NSF Directorate for Mathematical and Physical Sciences.

MREFC – Major Research Equipment and Facilities Construction.

NOIRLab – NSF National Optical-Infrared Astronomy Research Laboratory.

NSB – National Science Board.

O&M – operation and maintenance.

PDR – Preliminary Design Review.

PEP – Project Execution Plan.

R&RA – Research and Related Activities.

TIO – TMT International Observatory.

TMT – Thirty Meter Telescope.

US-ELT – U.S. Extremely Large Telescope (in this report, US-ELT refers to the grouping of the Thirty Meter Telescope, Giant Magellan Telescope and NOIRLab).

UV – ultraviolet.