The Giant Magellan Telescope Project in 2026: Status and Plan Forward

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ABSTRACT

The Giant Magellan Telescope (GMT) is one of three planned ground-based optical/IR Extremely Large Telescopes (ELTs) that will provide a generational leap in ground-based Optical/IR capability. The GMT is part of the United States ELT Program (US-ELTP) which received the top ranking in the National Academies' ASTRO2020 Decadal Survey. The National Science Foundation (NSF) advanced the GMT Project to the NSF Final Design Phase in June 2025. The GMTO Corporation continues to proceed with GMT design, fabrication, and site construction. The overall development schedule responds to evolving programmatic factors related to the process of obtaining future US federal support for part of the construction and operations scope. Of the seven 8.4 m diameter mirror segments comprising the primary mirror, three have been completed and the remaining four segments have been cast and are in various stages of fabrication. One of the completed segments was used in a recently completed active optics test program that demonstrated excellent figure control with the GMT test mirror cell. Fabrication continues of the azimuth structures of the telescope mount. The first off-axis adaptive secondary mirror system has completed a second system level test program. A new enhanced capability adaptive optics and phasing testbed is building on the results from two earlier testbeds that demonstrated the GMT phasing strategy. A real time observatory control system prototype has achieved excellent initial results. The first generation science instruments continue development, from design to early fabrication. Construction documents and drawings are undergoing final quality checks as part of the preparations to create bid packages for telescope enclosure construction. Hard rock excavation of the foundations for the enclosure and telescope pier is complete, and residence buildings and other facilities and infrastructure needed to support construction at the Las Campanas site in Chile are complete and in operation.

Keywords: GMT, GMTO, Giant Magellan Telescope, ELT, Extremely Large Telescope

1. INTRODUCTION

The Giant Magellan Telescope (GMT) is a ground-based optical/IR Extremely Large Telescopes (ELTs) located on the property of the Carnegie Observatories' Las Campanas site in Chile. The GMTO Corporation ("GMTO") is a member of the United States ELT Program (US-ELTP) which received the top ranking in the National Academies' ASTRO2020 Decadal Survey.[1] The GMTO Consortium comprises 16 leading universities and research institutions from the United States, Australia, Brazil, Israel, South Korea, and Taiwan, and in partnership with our host country, Chile

The primary intent of this paper is to provide an overview and status update for the GMT Project since the previous update presented during the 2024 SPIE conference in Yokohama, Japan. For additional perspective on the history and evolution of the GMT design, please refer to References [2] through [11]. Special attention in this 2026 update is given to recent design progress and those areas of active construction and ongoing prototyping and qualification testing that continue to reduce technical risk and inform remaining final designs. In addition, high level context is provided as to how GMTO plans to complete the National Science Foundation's Final Design Phase (FDP) as the next step on the path to major construction as part of the NSF's Major Research Equipment and Facility (MREFC) portfolio.

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1.1 GMTO and the NSF Final Design Phase

Following the formal entry of the GMT project into the NSF Design Stage in early December 2022, the NSF convened a Preliminary Design Review that occurred in two parts in mid-December 2022 and early February 2023. The successful NSF PDR outcome included a finding by the PDR Committee that there were no technical or managerial concerns that could not be addressed during the NSF's Final Design Phase (FDP).

In July 2024, the NSF Director convened a review of the US-ELT Program's two ELTs (The GMT and the TMT) by a distinguished panel of experts experienced with the programmatic aspects of constructing and operating major research facilities that serve national science priorities. The Review Panel's charge was to assess the readiness of the GMT and TMT components of the US-ELT Program to move into the NSF's major facility Final Design Phase (FDP). Their report was released in December 2024, and the Panel summarized their GMTO/GMT findings as follows:

> "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."[12]

The NSF advanced the GMT Project into the NSF FDP as of June 11, 2025. Figure 1 shows conceptual renderings of the planned facility at the Las Campanas summit when construction is complete.

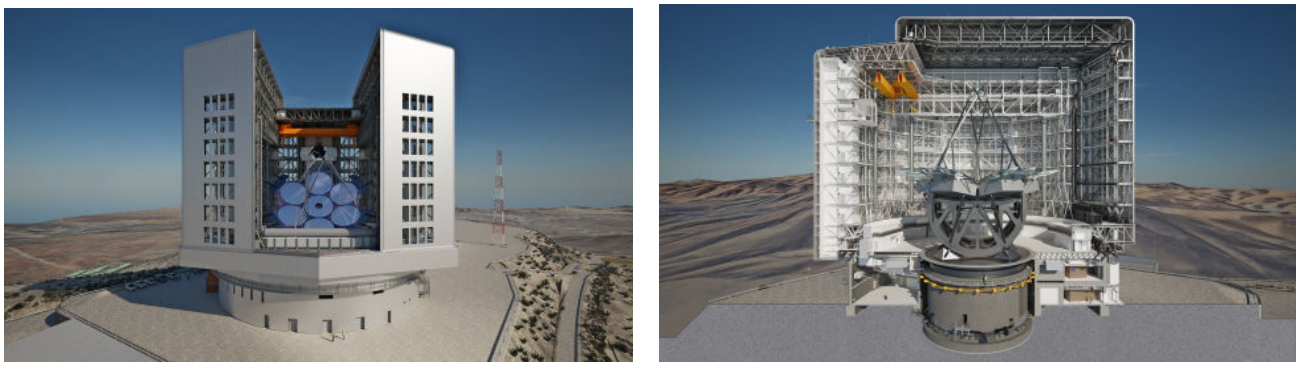


Figure 1. Conceptual rendering of a face-on view of the open enclosure (left), and a CAD section view showing the full extent of the telescope and pier structure (right). *(Renderings courtesy of IDOM)*

1.2 Final Design Phase Objectives and Timeline to Beginning Major Construction

GMTO is working closely with the NSF to move through the FDP as expeditiously as possible. This includes following the NSF's Research Infrastructure Guide (RIG) that clearly describes, e.g., the process and success criteria for the transition of an NSF MREFC project from the FDP to the Construction Stage.[13] The NSF and GMTO are working together to secure MREFC federal funding during (U.S.) Government Fiscal Year 2028 (GFY28) that begins Oct. 1, 2027. The schedule to achieve that goal includes passing an NSF-convened system-level final design review (NSF FDR) in mid-2027.

In addition to the FDR, the NSF requires a post-FDR Facilities Readiness Review (FRR) and a Director's Review Board (DRB) in order for awarded MREFC funds to begin flowing from the NSF to the GMT Project. The FRR and DRB are internal NSF reviews, and a successful FDR in mid-2027 will allow sufficient time for the NSF to complete their internal reviews and make an MREFC award to GMTO beginning with GFY28 funding. Use of the first tranche of GFY28 funds is currently assumed in the master GMT project schedule to begin between April 2028 and July 2028.

2. PROJECT MANAGEMENT AND ENGINEERING DEVELOPMENT

GMT project and engineering management always implement industry standard "best practice" methodologies and tools including risk management, configuration management, safety (both system safety and workplace safety), and quality control/assurance (QC/QA). Project cost and schedule are integrated into a Resource Loaded Schedule, and project execution performance is monitored and measured using earned value management (EVM) techniques.

2.1 Systems Engineering Management Processes and Current Status of GMT Subsystems and Interfaces

The general description of the GMT Systems Engineering management and the approach to characterizing performance are well described in References 11 and 14, including how the GMTO uses Key Performance Parameters grouped into the following four categories:

- Image quality (on-axis PSSN, PSSN across the field of view, Strehl ratio, PSSN spatial uniformity, and PSSN temporal stability across the field of view); PSSN is an IQ metric that GMTO SE uses instead of PSF,
- Throughput,
- Target acquisition time,
- Effective collecting area.

That discussion will not be repeated here, but instead the focus is on the system-level progress since June 2024 made or led by the GMT Project Systems Engineering team that has contributed directly to preparing for the NSF FDR. Of particular note, there have been significant advances in operations definition, verification planning, and continuing updates to the GMT Risk Register and Hazard Register. Systems Engineering has undertaken a coordinated effort to mature the operational concept, strengthen the requirements and verification framework, and steps made in the transition toward integration and execution readiness.

During the past two years, significant emphasis has been placed on the maturation of the verification and validation (V&V) framework. Systems Engineering has continued a comprehensive scrub of the Observatory requirements to ensure that the requirements set is both complete and efficient, with particular attention to avoiding over-specification that could drive unnecessary cost, schedule, or risk. This activity is being carried out in conjunction with updates to verification planning, which serves as a grounding mechanism for validating the requirements architecture.[15] The combined requirements scrub and V&V planning effort began with seismic-related requirements and has continued across all system-level and cross-cutting requirements topical groupings.

The Systems Engineering team has also supported a wide range of subsystem and system-level reviews that contribute directly to verification readiness. These include Preliminary, Intermediate (~60% maturity), and Final design reviews, and Test Readiness Reviews for the NSF-supported risk reduction and demonstration/validation work that focuses on validation of requirements implementation and to improve verification strategies. The increasing frequency of subsystem reviews is driving systems engineering staffing resource allocations in the year proceeding the NSF FDR.

April 2025 GMT Operations Plan Review

A major milestone was the successful completion of the Operations Plan Review in April of 2025. This review provided a comprehensive evaluation of the Observatory's operational concept, and the balancing of technical performance, cost, and schedule. The review established a strong foundation for subsequent system-level design and verification activities and provided a clear path for continued maturation of the Operations Plan as the project approaches the NSF FDR.

Preparation for the Operations Plan Review required extensive Systems Engineering coordination across the project. A (temporary) GMT Project integrated product team (IPT) was formed to facilitate review planning and execution. The IPT included project management, systems engineering, and experienced observatory personnel who conducted detailed internal reviews of budgets, basis-of-estimate documentation, and the full set of operational and maintenance behaviors. This effort ensured consistency between the operational concept and the engineering design and enabled a complete assessment of key aspects of the GMT operational model including cost.[16]

A major part of the planning for Operations is the development of operational behaviors that are workflows defining the sequence of steps required to safely and efficiently conduct maintenance and operations tasks. These behaviors can be used as the first steps to define the detailed procedures followed by the maintenance and operations team. GMTO has developed a new and innovative video engine-based tool that we call "Builder of Observatory Behaviors" or "BOB" that has proved very effective in facilitating behaviors development.[17]

The Operations Plan was externally reviewed by a committee of internationally recognized experts in the operation of major observatories. Their finding was that for the expected level of maturity at this stage of the GMT project, GMTO has created a strong and realistic plan for operating the observatory with a good approach for continuing to mature the plan.

Integrated Modeling

Verification by analysis has been further strengthened through targeted investments in integrated modeling. This activity provides an independent benchmark for model fidelity and supports the use of these tools in requirements verification and compliance assessment. Additional analysis efforts, including Computational Fluid Dynamics (CFD) modeling of the subsystem FDR models of the Enclosure and Mount subsystems, are directly feeding system-level compliance assessments of Key Performance Parameters. (KPPs).[18, 19]

The integration of modeling, requirements, and verification activities is increasingly enabling closed-loop validation of the system design. Verification methods are being defined and refined in parallel with requirements evolution, ensuring that each requirement is associated with a credible and executable verification path. The addition of dedicated V&V expertise to the Systems Engineering team has further strengthened this capability and supports continued maturation of verification planning in advance of the NSF FDR.

Seismic Modeling

Explicitly incorporating system safety in all aspects of the GMT design is a perquisite to protecting and preserving the substantial capital investment in the seismic environment where the GMT Observatory will reside. To this end, GMTO is further advancing the capabilities of a suite of GMT seismic analysis tools. This work is a joint effort of the GMT Telescope Structures and Systems Engineering teams under the leadership of the Telescope Structures Lead Designer.

The GMT Enclosure and Mount include three primary and distinct earthquake mitigation systems, each at different points of the load path from the ground to the primary mirrors. Previous seismic analyses simulated these earthquake mitigation systems in isolation from the others. New and updated tools are being developed that realistically model the combination of these nonlinear earthquake mitigation systems, and the flexible structural bodies between them, as a single integrated model to better capture the coupled dynamics of the seismic response.

For the GMT Enclosure Seismic Isolation System (SIS) at the base of the telescope pier, new custom elements in each analysis tool are required to model the SIS friction pendulum bearings. These are being developed based on the link elements implemented in the SAP2000 commercial software package, and are verified against SAP2000 models developed by the IDOM enclosure designer. Initial results verify that these new custom elements closely match SAP2000's output.

Altogether, GMTO is developing three independent seismic analysis tools utilizing different software packages, nonlinear implementations (and solvers) to provide cross comparisons and analysis verification. For directly analyzing the effects of seismic-induced transients, GMTO has contracted Simpson Gumpertz & Heger (SGH) to develop one tool using ANSYS. This effort merges SGH's custom Ansys friction pendulum bearing element with the Ansys telescope model developed by GMT Mount contractor OHB Digital Connect. For creating the second seismic analysis tool, GMTO has contracted ATA Engineering to update a Nastran+MATLAB analysis capability previously developed by ATA and extended by GMTO. This tool enables coupled loads modal transient analysis using coupled loads techniques. GMTO is developing a third tool using Nastran+MotionSolve that uses multibody dynamics methods in transient analysis that provides an efficient nonlinear simulation capability to complement the other modeling tools.

These new integrated seismic modeling tools will be used to investigate and expand beyond the limitations of the previous analysis capabilities, perform design trades of critical parameters of the earthquake mitigation systems, and provide more accurate characterization of the seismic environments experienced by the telescope payloads. In particular, this will allow confirming the fragility analysis of the primary mirrors.

GMT Design Maturity Status as of June 2026

Over the past two years, GMTO has continued to focus engineering development on completing the "leveling" of the Project subsystem engineering design maturity to what is needed by the time of the NSF FDR. Progress in this regard has been steady and will continue with several reviews scheduled for the remainder of 2026 and 2027. Since June 2024, major subsystem gate reviews have occurred for the Commissioning Camera, MANIFEST, the Adaptive Optics Test Camera (AOTC), and the Summit Support Building (SSB).

In addition, for several of the subsystems that have already reached their final design maturity, GMTO is conducting post-FDR design optimization, value engineering, and/or advanced prototyping. This intentional engineering strategy keeps the GMT design adaptable to the evolving scientific needs and technologies that inevitably occurs over the long lifetime of a major project as well as continuing to reduce technical and manufacturing risk.

2.2 GMT Risk Reduction Development Sponsored by the National Science Foundation (NSF)

GMTO continues to reduce risk and validate segment phasing and wavefront control concepts with testbeds and prototype hardware demonstrations via two NSF awards. GMTO completed the Period of Performance (PoP) for its NSF Development subaward No NE0651C("NSF-Dev") as part of the Association of Universities for Research in Astronomy Inc. (AURA) NSF Grant No. 2013059. GMTO successfully completed all planned objectives in the subawards's three technical areas: (1) the manufacturing and testing of key components of the Adaptive Secondary Mirror (ASM), (2) the demonstration of the operational performance of the primary mirror active optics support control system (M1S) with a test cell and mirror mass simulator, and (3) using two adaptive optics testbeds to conduct an initial validation of the GMT wavefront sensing and phasing control strategy.

The GMTO received an additional award that began Oct. 1, 2023 to continue phasing risk reduction, prototyping, and broader impacts efforts. This NSF award focused on Optical Performance Risk Reduction ("NSF-OPRR") is supported by NSF Cooperative Agreement Award No. (FAIN) 2332336, and the PoP was successfully completed May 30, 2026. The three technical areas covered by the NSF-OPRR award were (1) the demonstration of active optics control of a GMT primary mirror segment, (2) the construction and demonstration of a Phasing Testbed (PTB) for the ASM, and (3) prototyping critical components of the adaptive optics Laser Tomography Wavefront Sensor.

The most recent NSF-sponsored work received by GMTO is the on Optical Control and Performance ("NSF-OCP") is Cooperative Agreement Award No. (FAIN) 2438477. The three technical areas covered by the NSF-OCP award are (1) the construction of an enhanced capability testbed compared to those developed as art of the NSF-OPRR award to further demonstrate GMT wavefront sensing and adaptive optics phasing techniques, (2) the creation of an end-to-end prototype of the GMT observatory control system (OCS), and (3) the design and prototyping of the real time computing platform for the OCS. This work is currently in progress with a planned completion of the PoP by the end of April 2027.

Much of the progress reported in this paper and elsewhere in this conference is the outcome of these NSF-sponsored NSF-OPRR and NSF-OCP efforts. GMTO takes this opportunity to express its deep appreciation to the NSF for their support.

3. TELESCOPE MOUNT

As described in our 2022 and 2024 papers, GMTO selected OHB Digital Connect (ODC, formerly known as MT Mechatronics) of Mainz, Germany and Ingersoll Machine Tools (IMT) of Rockford, Illinois USA to supply the final design, fabrication, and installation of the Giant Magellan Telescope (GMT) Mount.[20, 21] This is the same partnership that designed and built the DKIST telescope structure. The Mount completed Final Design in 2023 and in this section we provide a detailed reminder of its key design features and highlight the construction progress since June 2024. Further details regarding Mount construction progress may be found in References 22 and 23. Some of the material in Section 3.1 is reproduced from Reference 11 although Reference 11 contains additional design details not included here.

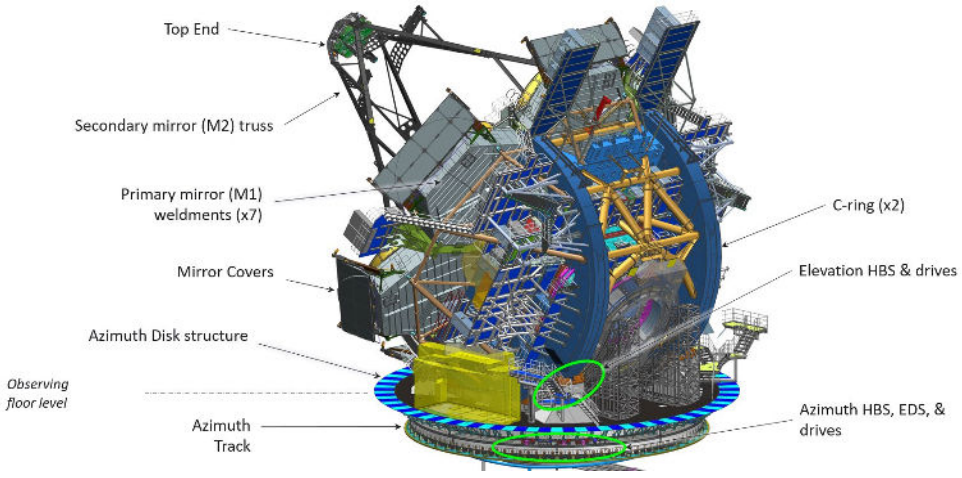


Figure 2. The major components of the GMT.

3.1 Design Overview of the GMT Mount

As shown in Figure 2, the GMT Mount is the structural, mechanical, hydraulic, and electronic system that is required to support, align, point, and track the telescope. The Mount is composed of the following assemblies: Optical Support Structure (OSS), Gregorian Instrument Rotator (GIR), azimuth structure, azimuth track, the Hydrostatic Bearings System (HBS), the mount drives, restrictors and locking pins, M1 conical baffle, primary mirror covers, instrument deployment mechanisms, and the azimuth, elevation, and GIR cable wraps. and is in the initial construction stage.

The design approach results in a compact final swept volume that helps minimize the volume of the enclosure needed to support efficient operations. A primary key and driving requirement of the Mount structural design is that it must mitigate the impact of the challenging seismic environment in Chile. As mentioned in Section 2.1 above, the continuing analysis of the Mount's dynamic response to seismic disturbances is informing maturing design refinements.

The Mount possesses 22 interfaces to other subsystems not part of the Mount. Some examples of these include the Mount interfaces to the Enclosure's telescope pier, M2, the Telescope Metrology System (TMS), the Acquisition, Guiding, and Wavefront Sensor (AGWS0, and to the five types of science instrument: Gravity Invariant Station (GIS), Auxiliary Port (AP), Instrument Platform (IP), Direct Gregorian (DG), and Folded Port (FP). Instruments mounted on the GIR are subjected to a gravity vector varying in two dimensions. The GIS is located on one side of the azimuth disk and is provided for an instrument that requires a stable gravity vector. The first instrument to occupy the GIS beginning at Science First Light will be the GMTO-CfA Large Earth Finder (G-CLEF). The DG and FP types of science instrument interfaces are located on the GIR. Three DG instruments, two large, and one small, can be stored on the GIR. Three FP instruments, identical in allocated volume and interfaces, can be mounted on the top surface of the GIR. Figure 3 shows more details of the locations of the DG and FP stations.

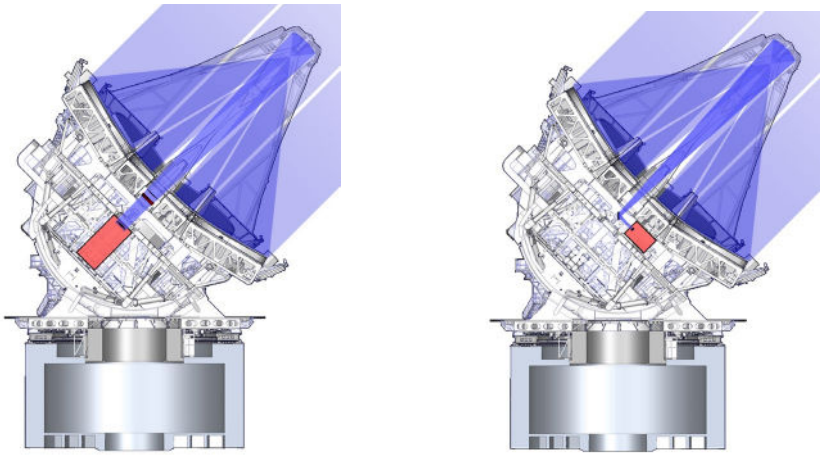


Figure 3. Highlighted in red are the Direct Gregorian (left) and Folded Port (right) instrument stations.

A high level decomposition of the Mount structures is shown in Figure 4 and serves as a starting point for presenting the current construction status in Section 3.2. The azimuth track and structures began construction in July 2023 and their construction is fully funded.

The Enclosure's telescope pier features a seismic isolation system (SIS) at its base to reduce the transmission of lateral seismic forces through the pier, but the interface between the top of the pier and the azimuth track must still accommodate significant loading. A key structural aspect of the azimuth track design separates lateral loads from vertical loads to limit stresses at the anchor bolts connecting the track to the pier. While the Enclosure SIS isolates and damps lateral accelerations, it transmits potentially large vertical accelerations. Vertical loads in the Mount are mitigated by means of an Earthquake Damping System (EDS) which is a proprietary damping system physically incorporated into the azimuth structure.[24]

The azimuth track has an approximately 21.5 meter outer diameter, a weight of 172 tons, a width of 2.4 meters, and is constructed in eight identical segments. The track segments feature both the axial and radial bearing raceways: surfaces in

two “orthogonal planes” that must be machined to flatness within 200 microns globally and 20 microns locally. The axial bearing raceway is also the load path for the EDS deployed in seismic, braking, and parked configurations.

The azimuth track is connected to the pier with a combination of anchor bolts, adjustable shim blocks (fixators), and flexures on intermediate base plates that are welded to the steel embedments in the concrete pier. The azimuth track also includes the azimuth encoder tape, azimuth drive magnet rotor forcers, hydrostatic bearing oil collection system (see Figure 5). The azimuth utility wrap is a separate, independently driven, corotating system.

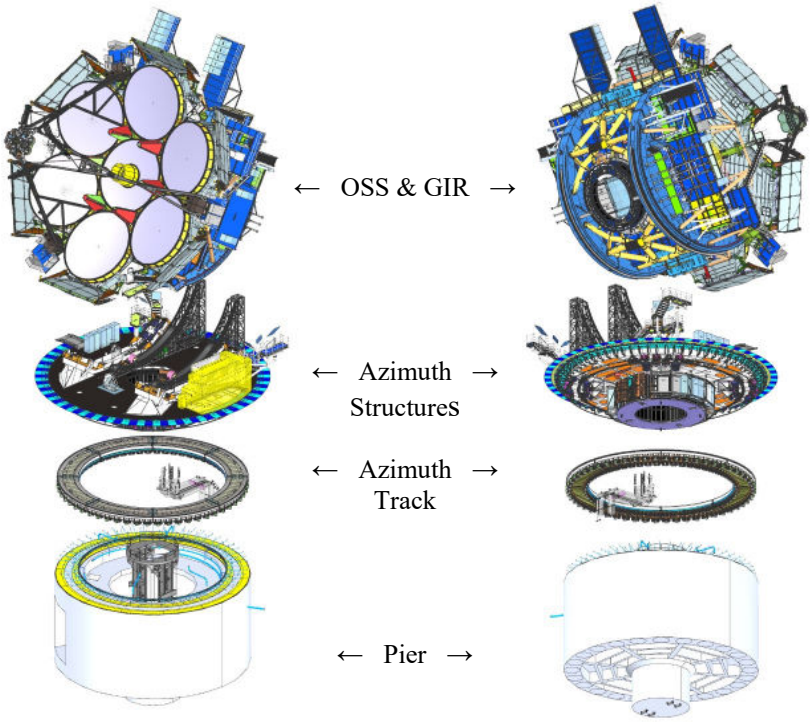


Figure 4. High level decomposition of the GMT Mount and telescope pier (the pier is part of the Enclosure scope, not the telescope).

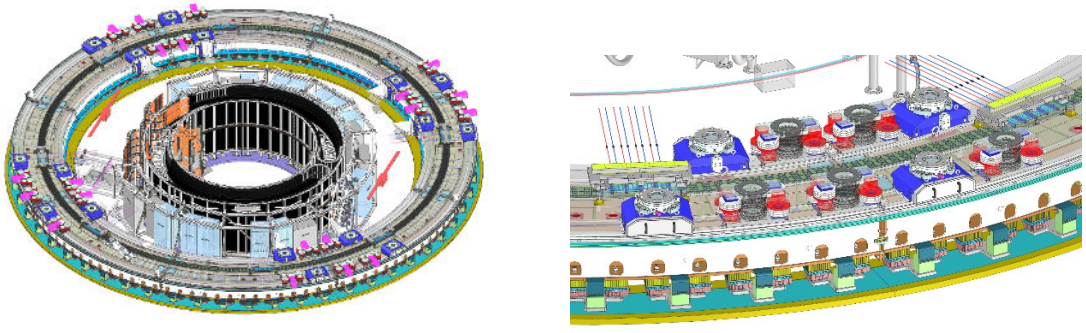


Figure 5. Azimuth track and bearings cross-section (left) and a closeup of the bearings (blue) and EDS (red) on the track (right).

3.2 Mount Construction Status as of June 2026

The telescope Mount began construction in July 2023. The factory construction is split into two phases, Phases 5A and 5B, to coincide with the construction of major sub-assembly groups. Phase 5A is the construction of the Azimuth Track and Azimuth Structures shown in Figure 3. Major components currently under construction include the fixed Azimuth Track base, the Azimuth Disk structure, the Azimuth Cable Wrap, the Hydrostatic Bearing System (HBS), the Direct Drive

System, and the Earthquake Damping System (EDS). The large steel weldments that comprise the Azimuth Disk have been fabricated. Five of the eight Azimuth Track segments have been built, with the final three segments under various stages of fabrication. Figures 6 and 7 show the progress that was made with the Azimuth Tack and Azimuth Disk between June 2024 and June 2026. Figure 8 shows a number of these steel sections in the IMT hall dedicated to the Mount assembly, The HBS pads, electric direct drives, and the EDS units are delivered and ready to be integrated at the IMT) factory. Figure 9 shows how the HBS pads and EDS unit will be configured on top of the Azimuth track.

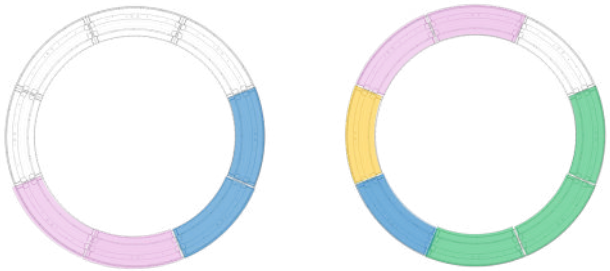


Figure 6. Progress of the Mount Azimuth Track between June 2024 (left) and June 2026 (right). Color code: Initial Welding/Assembly (white); Weldments In Progress (purple); Weldments Complete (blue); Machining In Progress (gold); Machining Complete (green).

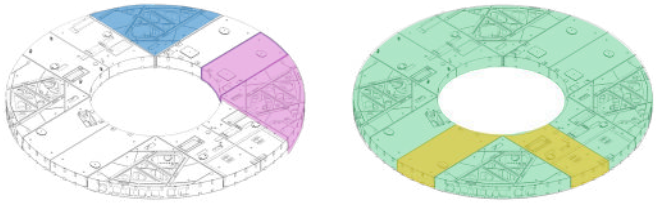


Figure 7. Progress of the Mount Azimuth Disk between June 2024 (left) and June 2026 (right). Color code: Initial Welding/Assembly (white); Weldments In Progress (purple); Weldments Complete (blue); Machining In Progress (gold); Machining Complete (green).

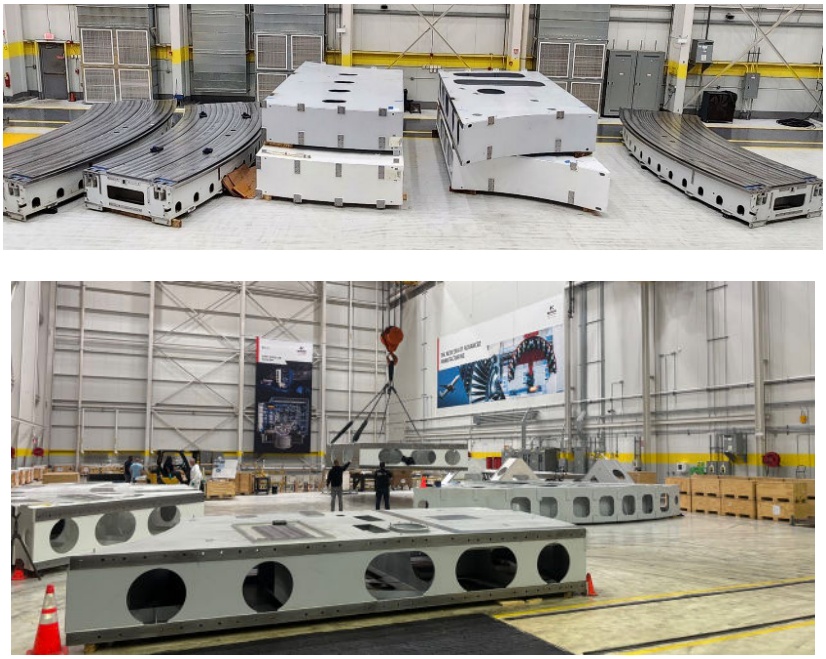


Figure 8. Azimuth Track and Azimuth Disk steel pieces at IMT (top) and IMT staff preparing to lift a steel weldment piece near IMT's assembly pit (bottom). The two IMT staff standing on the disk piece provide a sense of scale of these structures.

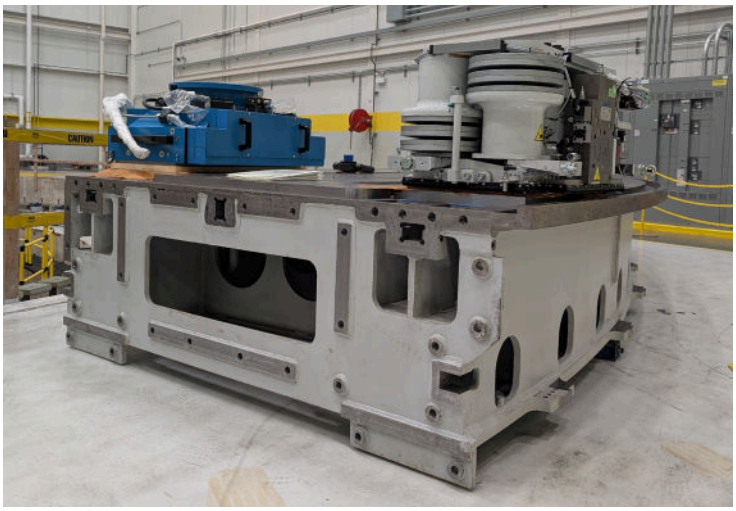


Figure 9. A Hydrostatic Bearing System pad (left) and an Earthquake Damping System component (right) arranged on top of an Azimuth Track section in the configuration they'll be once fully installed.

The most significant manufacturing milestone to date is that the first assembly of three Azimuth Track sections has been bolted together, aligned, and is in process for the final precision machining of the top bearing surface (see Figure 10). This operation utilizes IMT's giant gantry mill, which is the largest in North America. The Azimuth Track is composed of 8 separate segments which must act as one seamless flat surface to carry the full weight of the telescope via the HBS pads. A set of three segments are machined together such that every seam is match-machined with its neighbor. This is one of the critical processes which highlights IMT's precision machining capability of large scale steel structures.

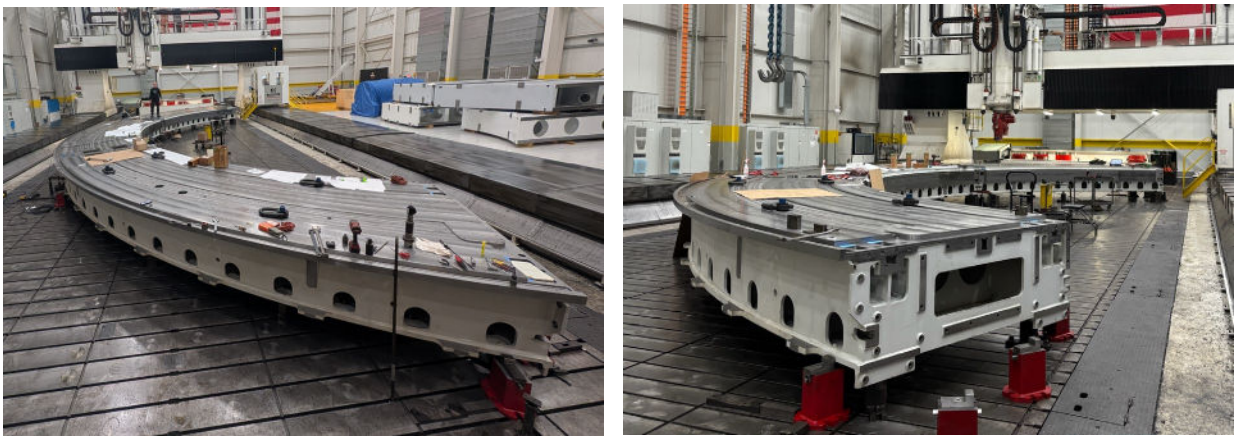


Figure 10. Three Azimuth Track sections joined on the IMT gantry mill for precision machining to achieve the track flatness specification.

4. PRIMARY MIRROR OPTICS (M1) AND SUPPORT SYSTEM (M1S)

4.1 Primary Mirror Segment Production

Since June 2024, GMT primary mirror segment production at the University of Arizona's Richard F. Caris Mirror Lab (RFCML) has been focused on the following:

1. Active Optics demonstration using mirror segment S3,
2. Completion of front surface generating and the start of polishing of mirror segment S5 (see Figure 11),
3. Preparing to reuse of the Rubin primary mirror's transportation and storage container for S3 (see Figure 12).

The University of Arizona RFCML completed Active Optics testing in March 2025. The test demonstrated the GMT M1 Subsystem (M1S) ability to control the primary mirror position and bending modes. The test was performed under the RFCML test tower using S3 integrated with the M1S Test Cell (see Section 4.3 below for additional details).

S3 will be placed in its Segment Transportation Container and will join S1 and S2 in storage. The STC design for S3 has been upgraded to replace rubber shear bushings used to support the mirror with wire rope isolators. The rubber shear bushings were not designed for long term storage and creep beyond their allowable limit over time. The redesigned GMT STC has eliminated the creep issue associated with the rubber shear bushings.

The NSF-DOE Vera C. Rubin Observatory has approved transferring the Rubin STC to GMTO, and UA will refurbish the container and integrate the new wire rope isolator design upgrade. Figure 12 shows the Rubin STC in storage at Cerro Pachón waiting to be returned to UA in June 2026.



Figure 11. Segment S5 undergoing front surface polishing on the RFCML Large Polishing Machine (LPM). *(Photo courtesy of University of Arizona RFCML)*



Figure 12. NSF-DOE Vera C. Rubin M1/M3 Mirror Shipping Container *(Photo courtesy of University of Arizona RFCML)*

4.2 Optical Procurement Status

The GMT OOM team has issued two study contracts for the Primary Mirror Coating and Stripping Subsystem (CSS). European suppliers Von Ardenne GmbH and AGC PTS will deliver their CSS concepts with a FFP proposal by early October. One supplier will be selected to design and build the GMT CSS, with an expected start of December 2026.

The next procurement GMTO intends to issue will be for the Fast-Steering Secondary Mirror Subsystem (FSMS). The seven-segment secondary mirror subsystem will be used for GMT commissioning operations and when the Adaptive Secondary Mirror Subsystem (ASMS) has been removed for servicing or maintenance. The FSMS positioners will

compensate for large telescope structural gravity- and thermal-induced deflections, while fast tip-tilt actuators will compensate for low-frequency telescope vibrations and wind shake, enabling natural seeing-limited observations. The FSMS call for tender is expected to be released by mid-summer.

4.3 M1 Support System (M1S)

The GMT requires active optics control to position the primary mirror (M1) segments, actively support the M1 Segment weight, and control low-order M1 Segment figure error using active optics corrections. Mirror seeing and thermal figure error are controlled by actively regulating the M1 Segment temperature to track the ambient air temperature. The M1 Subsystem (M1S) includes the static support, active support control system, and thermal control system of the M1 segments. The active support control system lifts the M1 Segment off the static supports and precisely controls the M1 figure and position. It consists of triple-axis and single-axis pneumatic support actuators that counter the M1 segment gravitational forces and control the mirror figure. The 5-dof bulk position and orientation is controlled by linear actuators known as hardpoints. The mirror segment is cooled by a closed-cycle forced air convection system using air handler units with CO2-based refrigeration to circulate and condition the air.

Since the Safe for Glass Review and Test Cell Tilt Test reported in 2024, the M1S team relocated the Test Cell to the Richard F. Caris Mirror Lab (RFCML) at the University of Arizona (UA), integrated mirror segment 3 (S3) with the Test Cell, and completed the active optics demonstration as part of the NSF-OPRR award (see Figure 13). The primary objectives of the optical performance testing were to demonstrate that the active support system can optimize the mirror surface figure, and the predicted support and bending forces match the measured results. Results show that the surface optimization is within 5 nm of our 30 nm RMS goal with temperature compensation (see Figure 14). Optical testing was performed using the RFCML ventilation system which was used during mirror polishing. The measured lateral and axial bending modes both match well with the FEM predicted analytical. See reference 25 for more details about this work.

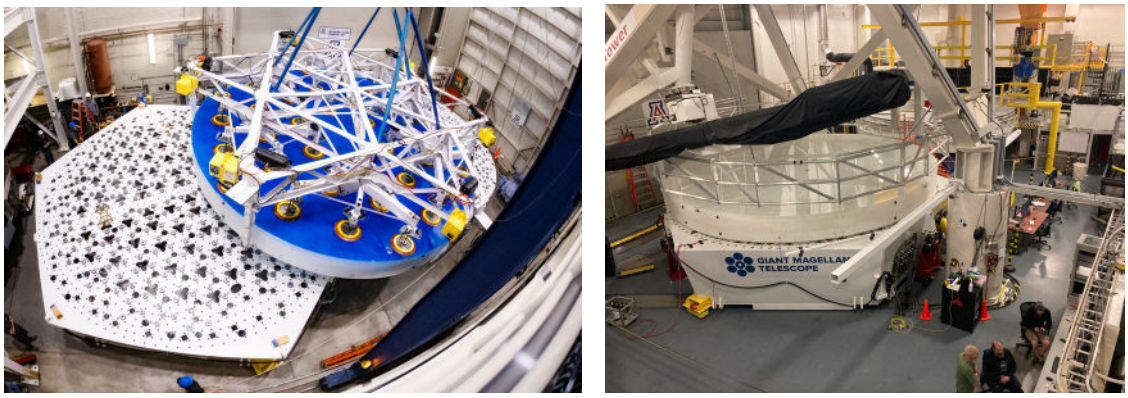


Figure 13. GMT S3 being integrated with the M1S Test Cell (left) and the integrated S3+Test Cell under the RFCML ready for active optics testing (right). *(Photos courtesy of University of Arizona RFCML)*

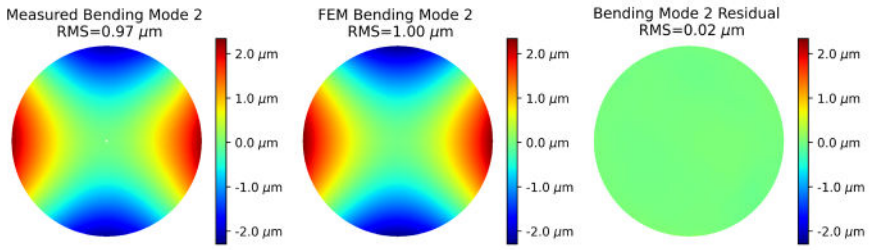


Figure 14. A surface map of the measured deflection of bending mode 2 created by the M1S actuator support system (left), a surface map of the predicted deflection by the GMT Finite Element Model of the same bending mode (center), and the surface map of the (measured – predicted) residual with RMS = 0.02 μm (right) .

In parallel with the active optics demonstration, the thermal control system component level testing was completed, and a test readiness review was conducted. When the optical performance testing was completed, the thermal control system

was integration with the Test Cell and S3 to conduct thermal control system testing with optical feedback. The primary objective of the thermal control system testing is to demonstrate that the mirror temperature can be uniformly controlled. Optical surface figure testing was used to measure the thermal print through which indicated heat was migrating into the upper plenum. This result was an anticipated risk and was mitigated by installing 3D printed thermal enclosures in one quadrant of the cell which significantly reduced the thermal print through. The thermal control system operated as expected, maintaining a stable uniform temperature. See reference 26 for more details about this work.

The actuator calibration system (ACS) served as a valuable tool throughout the Test Cell integration, functional, and optical testing. When a support actuator required maintenance, a spare actuator was used to replace the actuator requiring service which enabled the maintenance to occur in parallel with optical testing, optimizing the timeline. The ACS is a novel design implementing a hexapod linear actuator system the moved the stage in 6-DOF to exercise the full range of motion of a support actuator. See reference 27 for more details about this work.

5. SECONDARY MIRROR OPTICS (M2)

In the GMT optical design, each ASM segment provides the secondary optical surface for one primary mirror segment. The ASMS provides adaptive optic's correction and rigid-body segment phasing so that the seven primary/secondary optical paths behave as a coherent telescope pupil.

The phasing function is a system-level performance requirement. The ASMS phasing requirement is to maintain relative segment piston at less than 62 nm rms while the telescope is subjected to tracking motion, wind disturbances, structural vibration, thermal effects, sensor noise, and control-loop latency. In addition, the ASM segment positioner must meet segment position precision requirements of less than 10 nm rms over 20 seconds and less than 50 nm instantaneous precision error.

From an engineering perspective, the M2 Adaptive Secondary Mirror System (ASMS) represents a key enabling technology due to the GMT AO requirements requiring a new generation ASM relative to the adaptive secondary mirror systems currently in operation. GMTO has contracted with AdOptica, a consortium of ADS International and Microgate, to create what will become the 4th generation of operational adaptive secondary mirror systems that will possess significantly enhanced capabilities compared to the previous generations (see Figure 15).

To further inform this technology development, GMTO has been conducting an ASMS Manufacturing and Phasing Risk Reduction program supported by a combination of funding from the NSF-Development subaward, the NSF-OPRR award, and GMTO internal funds. The primary objectives of this program are (1) to conduct, assess, and mitigate manufacturing risks as early as possible in the development life cycle, and (2) to use full scale "First Article" hardware to validate and qualify the ASMS design. Additional details are described in references 28 and 29.

For the first objective, and specific to the 4th generation ASM for the GMT, the off-axis, parabolic Thin Shell and Reference Body were the first off-axis ASM components to be built. Previous generations of ASMs have had on-axis parabolic shapes. The off-axis optical contour adds complexity to the manufacturing and testing to identify and maintain the vertex through the manufacturing process.

Thin Shell fabrication begins with a ~100 mm Zerodur blank supplied by Schott that is then ground and polished by Safran-Reosc. The final Thin Shell is a 1.05-m concave of-axis optic with a thickness of 2 mm. The manufacturing process removes 98% of the original material to yield the deformable surface for the ASM. The deformable surface can be shaped by voice coil motors to create a diffraction limited image for the telescope. The two Thin Shells completed to date are shown in Figure 16.

GMTO and AdOptica developed the Segment Phasing Testbed (SPT) shown in Figure 17 to reduce phasing risk before full ASMS integration. The testbed was designed to demonstrate the phasing process using operational ASM hardware, except the 1.05 m face sheet is replaced by 3 pseudo shells, each 72 mm in diameter. The surrounding reference frame takes the place of three adjacent segments, which is the number of adjacent segments for each off-axis ASM. There are two control systems: (1) a 7 Hz M2 positioner hexapod and (2) a 2100 Hz pseudo shell control system. The M2 positioner is used for tracking, slewing, offloading and to inject wind disturbances. Each pseudo-shell controller uses three operational voice coil motors and three operational capacitive sensors. The combined set of pseudo-shells simulates piston-tip-tilt control of the operational face sheet.

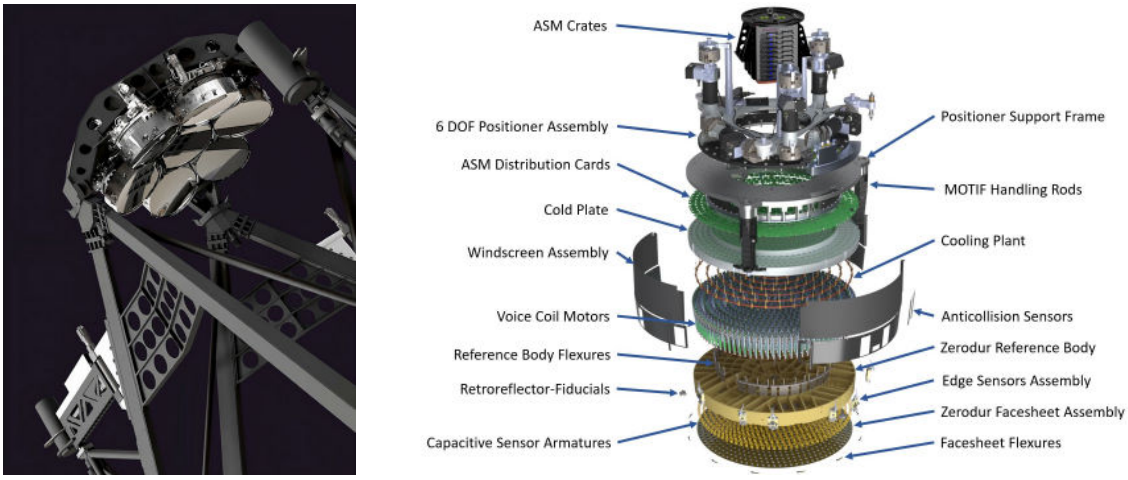


Figure 15. The seven GMT Adaptive Secondary Mirror Systems (ASMS) installed on the Mount's upper truss (left) and an exploded view of a single ASMS (right).

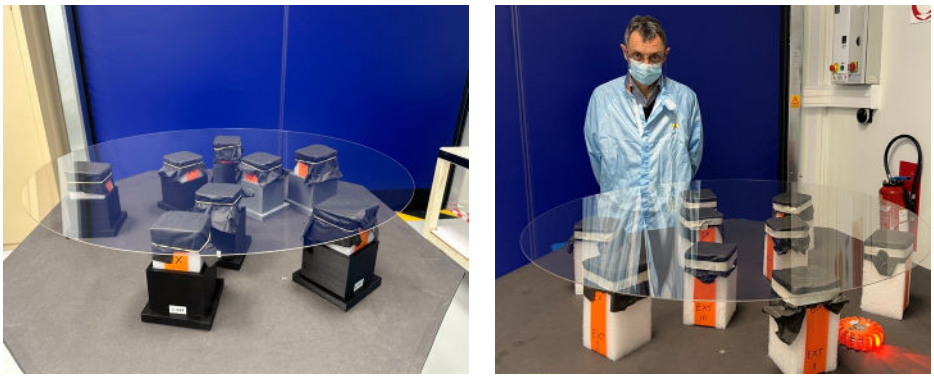


Figure 16. ASMS Thin Shell #1 mentioned in the 2024 GMT Overview (left) and the more recent ASM Thin Shell #2 (right). *(Photos courtesy of Safran-Reosc and AdOptica)*

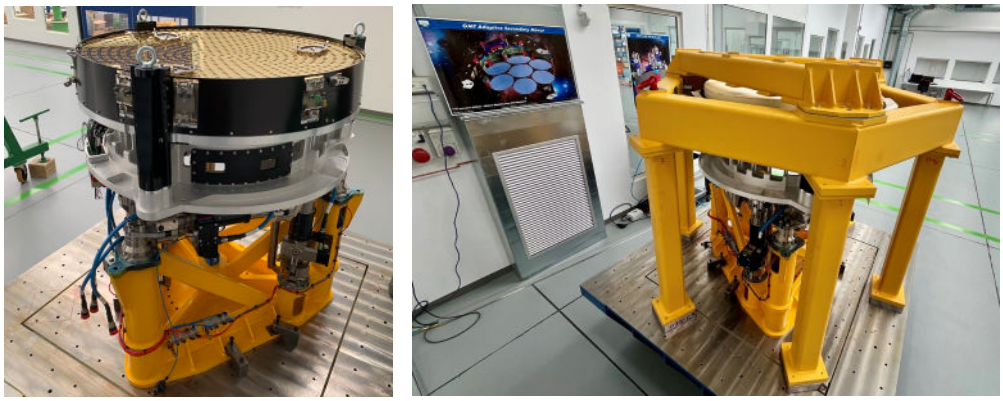


Figure 17. The ASM Segment assembled for Phasing Test (left) and the ASM Segment integrated into the Phasing Testbed Frame (right). *(Photos courtesy of AdOptica)*

The SPT contains two sets of interferometer sensors, the operational edge sensors and the test-only truth sensors. The six pairs of edge sensors measure the relative distance between the reference body and the hexagon ring which represents the 3 adjacent ASM Segments. The nine truth sensors measure the relative distance of each pseudo-shell to the triangular frame. Reconstruction matrices convert these measurements respectively to reference body and face sheet positions. Figure 18 shows the schematic of the SPT and illustrates the simulated 3 adjacent Segment and on right shows the

operational Edge Sensors installed on the Reference Body to the right and mounted to the Hexagonal frame to the left, with beam lines indicated. Figure 19 shows additional configuration details with the Reference Body, Pseudo Shells, and Truth Sensors.

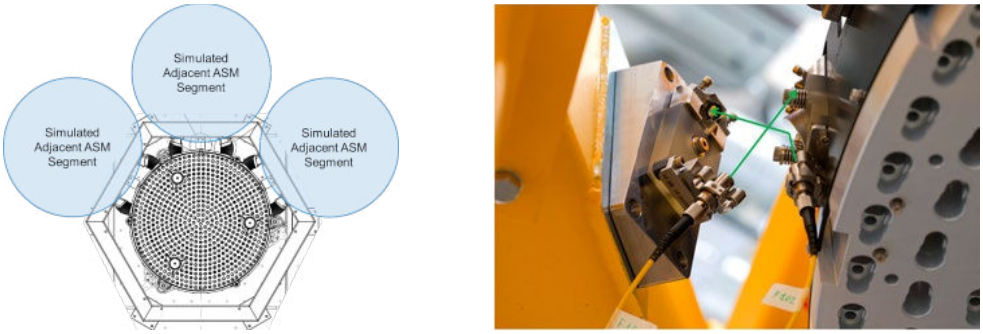
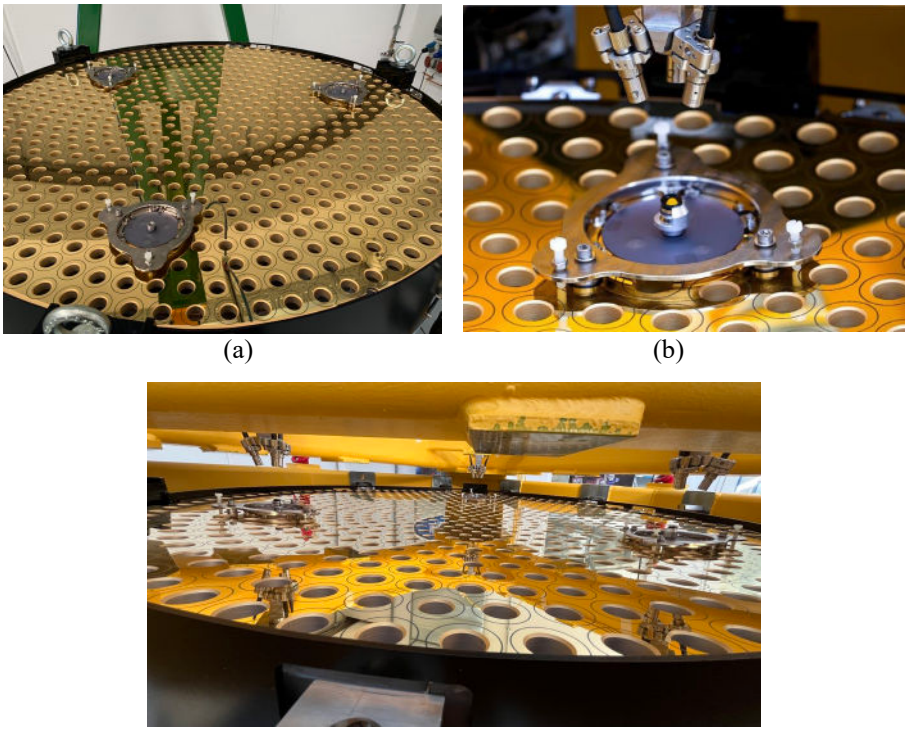


Figure 18. Schematic view of the Phasing Testbed showing the location of the simulated adjacent segments and Edge Sensor (left), and the operational Edge Sensors mounted to the Hexagonal frame to the left and to the Reference Body to right (right).

The phasing test uses the M2 positioner to inject wind-induced motion of the reference body, and without any wavefront control the face sheet would have the same motion. The wavefront controller local to the ASM uses the edge sensors to measure the Reference Body position, and then using a feedforward network, commands the face sheet with the conjugate motion. Ideally this results in zero face sheet motion due to the wind disturbance, and more practically the goal is to meet the 62 nm relative segment piston phasing requirement. The edge sensors, the reconstruction algorithms, and the wavefront controller using the edge sensors are all at operational readiness. Detailed results of the test plan and test results are contained in reference 29.



(a) (b)

(c)

Figure 19. (a) The ASM Segment Zerodur Reference Body (RB) showing Pseudo Shells locations. The RB holes allow VCM pass through. (b) A Pseudo Shell mounted to the RB and showing Truth Sensor with 3 Attocubes mounted to a frame above Pseudo Shell. (c) The RB with 3 Pseudo shells which simulate the Face Sheet and 3 Truth Sensors above the Pseudo Shells.

6. WAVEFRONT SENSING AND ADAPTIVE OPTICS

GMTO has achieved significant progress in the development of wavefront sensors and control algorithms for the three AO observation modes on the Giant Magellan Telescope since June 2024. The GMT wavefront sensing and control suite of subsystems comprises three wavefront sensors, an Adaptive Optics Test Camera (AOTC) for verification of AO system performance, and a laser guide star facility for carrying out laser tomographic atmospheric correction. Please see references 30–37 for additional details.

6.1 GMT Adaptive Optics and Phasing Sensor (GAPS) Testbed

We have invested strategically in testbeds and prototypes to de-risk the designs and the control strategies. As part of the NSF-OCP award, GMTO recently built the GMT Adaptive Optics and Phasing Sensor GAPS) testbed in a new Adaptive Optics laboratory located close to GMTO headquarters in Pasadena, CA (see Figure 20). The NSF-OCP GAPS objective is to test and verify performance of the diffraction-limited NGAO (Natural Guide Star AO) observation mode in a realistic environment. Following a successful Assembly Integration and Test Readiness Review in September 2025, the assembly and integration of the GAPS testbed was conducted by the WFSC team in collaboration with the INAF Arcetri AO team (see references 31, 32, and 33 for further details).

The GAPS testbed integrates the pre-existing Natural Guide Star Wavefront Sensor Prototype (NGWS-P) funded by the NSF-Development subaward with a new GMT telescope simulator leveraging the operational experience obtained under the subaward. The GAPS telescope simulator is an accurate scaled-down engineering model of the Giant Magellan Telescope optical system that feeds the NGWS-P with the GMT F/8.3 beam. The beam is shaped by a precise GMT pupil mask over a wavelength range of 600-920nm.

The behavior of the GMT Adaptive Secondary Mirror (ASM) is reproduced using a BMC deformable mirror (DM) and custom-built piston/tip-tilt (PTT) array furnished by SAO. The NGWS-P incorporates both a Pyramid Wavefront Sensor (PWFS) to precisely measure low and high order spatial modes and a Holographic Dispersed Fringe Sensor (HDFS) to measure segment piston modes over a range as large as 10 microns. The HDFS captures large initial segment piston errors and reduces them to within the unambiguous capture range of the PWFS. Then, in the steady state mode, the PWFS provides fine piston control and correction of low and high order wavefront error while the HDFS preempts and minimize segment piston ejections.

In preliminary closed loop testing the GAPS testbed has corrected 140 segment spatial modes including tip, tilt and initially large segment piston offsets using synchronous feedback from both the PWFS and HDFS resulting in a diffraction-limited PSF having a Strehl Ratio of 75% at 630 nm (see Figure 21). This testing was carried out in the presence of ambient laboratory turbulence. In the next phase of testing, realistic GMT turbulence will be injected using the DM.

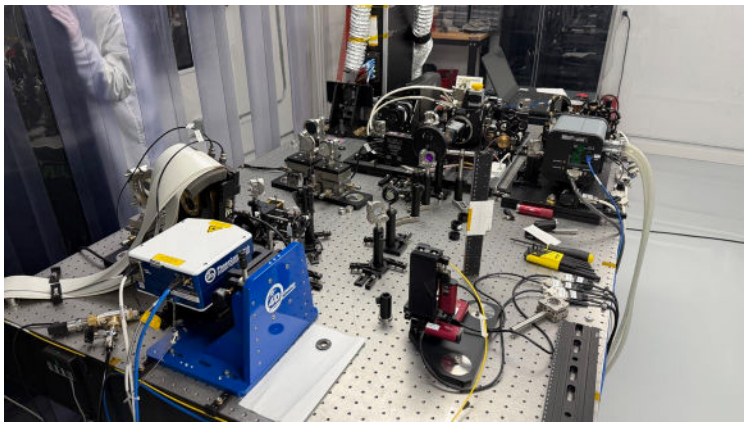


Figure 20. Photo of the current GAPS Testbed in operation at the new GMTO Lab in Pasadena, CA. The testbed incorporates a Giant Magellan Telescope simulator, an interferometer diagnostic and a full scale wavefront sensor prototype.

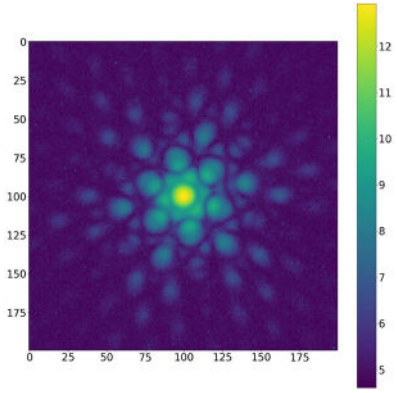


Figure 21. Photo of the current GAPS Testbed in operation at the new GMTO Lab in Pasadena, CA. The testbed incorporates a Giant Magellan Telescope simulator, an interferometer diagnostic and a full scale wavefront sensor prototype.

6.2 Laser Tomography Wavefront Sensor (LTWS) Prototyping

The Laser Tomography Adaptive Optics (LTAO) observation mode uses laser guide stars (LGS) to enable diffraction-limited observations over a large fraction of the sky. The laser guide stars provide a means to measure the high-order atmospheric wavefront error in the direction of an on-axis science target. The Laser Guide Star Facility hardware can be decomposed into the Laser Guide Star Subsystem (LGSS) and Laser Tomography Wavefront Sensor (LTWS) subsystem.

In February 2024, the Australian National University (ANU) and GMTO began updating the ANU 2013 preliminary design of the LGSS and LTWS. This design refresh culminated in a delta-Preliminary Design Review held in October 2024. This update was a prerequisite to beginning the prototyping of LTWS critical components and resulted in important changes to both the LGSS and LTWS designs (see reference 30, 34, 35, and 36 for further details). The prototyping work itself was funded by the NSF-OPRR award.

Using the updated LTWS design, ANU assembled, integrated and tested both a single-channel camera prototype and a full scale mechanical prototype to demonstrate the synchronous translation and rotation motions with cable and coolant hose wrapping mechanisms (see Figure 22). The single-channel camera prototype was tested using an optical setup that simulates the Giant Magellan telescope and the LTWS collimator optics. The prototype camera was compliant with performance requirements and revealed valuable lessons to be implemented in the final design phase.

The mechanical prototype was built to validate the design with respect to motion control requirements on accuracy, speed, total range of motion and life cycle reliability for both linear and rotational mechanisms. The LTWS requires a focus translation stage to compensate for the changing distance to the sodium layer as the telescope changes elevation, and a rotation stage to cancel the pupil rotation of the GIR. The mechanical design must accommodate the wrapping and unwrapping of electronic cables and cooling hoses as the stages move back and forth. The mechanical prototype was measured to be fully compliant with eight of ten motion control requirements. The two partial noncompliances are expected to be resolved in the final design phase. For the life cycle reliability test, the system was operated for a total of 114 hours without any observed deviation of performance. This was roughly equivalent to 40 months of operation on the GMT.

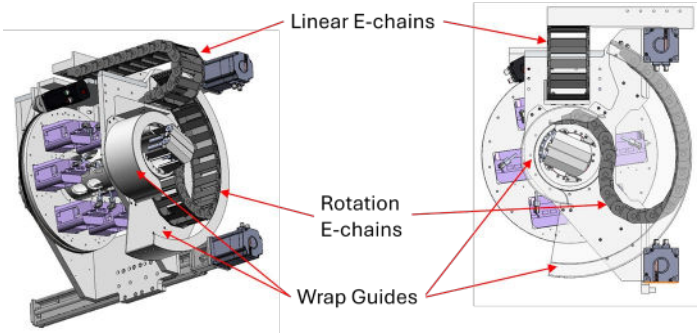


Figure 22. Photo of the current GAPS Testbed in operation at the new GMTO Lab in Pasadena, CA. The testbed incorporates a Giant Magellan Telescope simulator, an interferometer diagnostic and a full scale wavefront sensor prototype.

6.3 Acquisition and Guiding Wavefront Sensor (AGWS) Instrumentation

The Acquisition and Guiding Wavefront Sensor (AGWS) consists of four identical probes located just ahead of the Direct Gregorian focus, and enables the first stage of wavefront control for all instruments and control modes (see Figure 23).[37] The AGWS makes the measurements required to maintain coalignment and phasing of the telescope optics, corrects segment pointing, and preserves the correct mirror shape by simultaneously sensing the light of three or four off-axis natural guide stars. The final design phase for the AGWS , led by SAO, is underway with expected completion in the first quarter of 2027. The primary design tasks will include (i) a trade study evaluating new low noise visible cameras for the visible camera channel, (ii) the addition of a visible focus mechanism that does not exist in the AGWS prototype, (iii) the addition of a mechanism to inject atmospheric dispersion (iv) modification of the coolant and (v) update of all electrical, mechanical and safety interlock interfaces.

The AGWS will be used early in the telescope commissioning stage before all of the M1 mirror segments are installed on the telescope. The AGWS is required to functionally operate without the full complement of M1-M2 segment pairs. A study has been conducted to analyze how AGWS performance is impacted by the number of available segment pairs. The analysis showed that when some segment pairs are absent, all of the active optics still function as designed with degraded performance that is roughly consistent with the reduced optical collecting area. The GLAO performance is slightly degraded for four or fewer segments. Coarse phasing using the dispersed fringe sensor can operate with a minimum of two adjacent segments.

In addition to the design of the AGWS, a new Instrument Mounting Frame (IMF) has been designed for installation or exchange of AGWS probes. The IMF design has a payload capacity of two AGWS probes, significantly reducing the time required to install two probes on the telescope or to exchange a probe needing servicing. A rotary fixture in the IMF enables a space-constrained swap of probes from a stow position to an installation position.

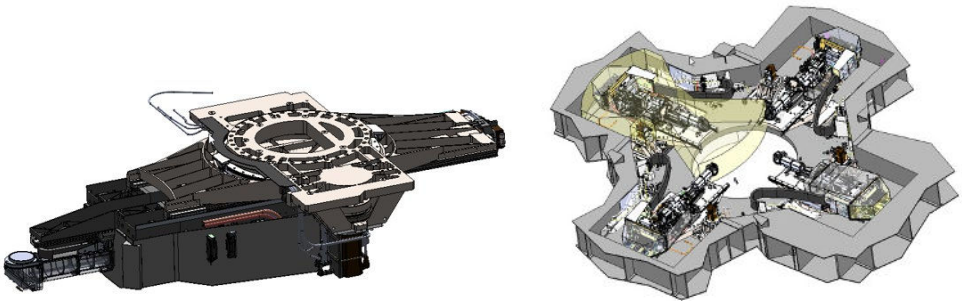


Figure 23. Top view of a single AGWS probe (left) and four probes mounted in the GIR slightly above Gregorian focus (right).

7. SOFTWARE AND CONTROLS

The Software and Controls (SWC) team is currently finalizing the designs for both the Observatory Control System (OCS) and Global Interlock and Safety System (GISS). To burn down remaining technical risk and validate key architectural and technological design features, two major prototypes are being built as part of the NSF Optical Control and Performance (OCP) award: the Observatory Control System (OCS) End-to-end (E2E) prototype, and the Real-Time Computer (RTC) Platform prototype. The (SWC) team is also responsible for the software implementation of the GMT Adaptive Optics and Phasing Sensor (GAPS) Testbed, that is being built in collaboration with the Wavefront Sensing and Controls team as part of the NSF-OCP award. Further details about the material in this section can be found in references 37 and 38.

Observatory Control System E2E Prototype

The E2E Prototype is an early implementation of the GMT Observatory Control System, using functional operations user interfaces and simulated telescope subsystem hardware to execute a set of basic observation sequences, including observation scheduling and execution, coordinated telescope control, basic active and adaptive optics control, and data acquisition and management. In addition to the science life cycle, the prototype demonstrates overall observatory status monitoring, system initialization and shutdown sequences, and fault management. The OCS E2E Prototype is scheduled for completion by the end of 2026.

The E2E Prototype implementation located in the new GMTO Pasadena, CA laboratory facility combines existing computing and networking hardware with new equipment. The lab's server room hosts four racks that contain not only the E2E Prototype hardware, but also the RTC Prototype hardware, GAPS Test Bed computers and Software Development, Test and Staging platforms. Mockups of external interfaces provide important artifacts at the boundaries of the OCS scope, including ingestion of approved proposals from NOIRLab, device control system simulators, installation and configuration of external catalogs, laser clearance system interfaces, and delivery of data products to the NOIRLab long-term science archive. A set of synthetic databases are used during testing to simulate real world conditions, including environmental conditions, discrete event simulation (for example, fault injection), and simulated observing data products.

Real Time Computer (RTC) Platform Prototype

GMT incorporates Adaptive Optics (AO) capability to achieve the best possible optical performance of the GMT. This capability requires extremely precise wavefront control spanning multiple subsystems, sensors and instruments. The Real Time Computer (RTC) platform sits at the heart of the AO system, providing the real time control infrastructure needed to implement both the independent Active and Adaptive Optics control loops. The RTC platform prototype is an important early implementation of the hardware, software and interfaces needed in the final system, and it is being used to evaluate design decisions and show compliance with performance requirements using technologies available today.

The SWC team completed a comprehensive requirements analysis to determine the necessary computing throughput, memory bandwidth, network bandwidth, and storage to meet the higher-level end-to-end loop latency and telemetry requirements. Trade studies were conducted of existing and emerging technologies, and four prototype configurations are being tested. The technologies studied included heterogeneous compute and networking acceleration, emerging programming language standards and metaprogramming techniques. These implementations abstract algorithmic implementations from specific hardware solutions and current paradigms and tool chains in existing adaptive optics RTCs. The chosen prototype hardware includes both CPU-based and GPU-based systems, camera interfaces used in several GMT wavefront sensor designs, and a hardware simulator module that mimics the interface with the Adaptive Secondary Mirrors on the telescope.

The RTC platform configuration test suites include a unit test for each compute block, integration tests for each pipeline, and distributed tests that evaluate components deployed across multiple computers connected through the low-latency network to the low-latency switch. The latter required implementation of a distributed test automation system to coordinate and monitor multiple processes running across different computers within the same test. Benchmark tests are used to analyze overall performance and individual optimizations as the prototypes are fine-tuned. The preliminary results are encouraging, demonstrating that each subcomponent in the communications and computation chain can meet their performance requirements when measured on their own, as well as when integrated. Performance testing and the final report is scheduled to be completed by the end of the Sep. 2026.

GMT Core Frameworks

The OCS E2E Prototype, RTC Prototype and GAPS Device Control System implementation also drove some important updates to the GMT Core Frameworks and Services. These include adding support for PLC Communications to test different protocols, tools and strategies, and implementing new multi-threaded computation support based on concepts developed for the RTC Framework. As a result three new frameworks are being implemented:

- *RTC Framework* – provides building blocks for hardware computing acceleration and high-performance I/O,
- *AO Framework* – built on top of the RTC Framework. It provides reusable adaptive optics computations,
- *AI Framework* – provides a standardized implementation of AI related applications, such as deep learning for data-driven dynamical systems and large-language model servers that use hardware acceleration.

The GAPS testbed required new functionality to execute a sequence of steps during calibration and testing, resulting in an initial implementation within the Sequencer Framework that can be extended to any type of activity such as coordinated control and data acquisition. These activities are now run from the user interface, providing an intuitive user-friendly mechanism for operators and scientists to perform common operations.

The GAPS testbed also required more nuanced handling of data products, including calibration and science data, which prompted an update to the Data Service. An activity can create one or more data products, which are stored in the database as either raw data or file system pointers to large files, e.g., Flexible Image Transport System (FITS) images. Data provenance is ensured, and all information related to the data product resides in the activity log. Both the Sequencer

Framework and Data Service implementations are key components of the OCS End-to-end Prototype. Early testing with the GAPS Test Bed is increasing the quality and ease-of-use of the system.

Interlock and Safety System

The Global Interlock and Safety System (GISS) is currently in the final design phase. The GISS includes all safety-related control functions (SRCFs) that affect two or more subsystems, and function completely independently from the Local Interlock and Safety Systems that may exist within a single subsystem. We have been working closely with Systems Engineering, the GMTO Safety Officer, the GMTO Safety Review Board and relevant subsystem stakeholders to review and update the System-level Hazard Analysis, and release project-level guidance on the implementation of functional safety across the project. The Safety Requirements Specifications for all SRCFs have been defined and is currently under review. GMTO follows the IEC-62061 standard for Functional Safety on the project.

The use of Artificial Intelligence (AI) tools at GMTO

Thanks to advancements in generative AI and Large Language Models (LLMs), the last 5 years have seen exponential growth in the adoption of AI-Assisted Software Engineering (AISE) across many industries. The potential for improved productivity in software development is clear, but there are also unique concerns and risks to be taken into account, including code quality, maintainability and technical debt; erosion of human understanding and knowledge, governance, trust and over-reliance; ethical, talent and workforce issues; regulatory and compliance risk, sustainability and possible security vulnerabilities. The Software and Controls team is starting to utilize AISE more in day-to-day development, documenting lessons learned and incorporating guardrails to adapt to new industry norms while minimizing risk.

As the Project advances toward major construction, artificial intelligence and machine learning (AI/ML) technologies are becoming increasingly relevant across engineering, scientific, operations, IT, and corporate functions of the organization. AI/ML offer significant opportunities to improve productivity, accelerate science return, and unlock new operational capabilities, while also raising legitimate questions about appropriate use, data security, ethics, intellectual property, workforce impact, and long-term reliability. In collaboration with partner institutions and broader-community stakeholders, we are conducting research and defining an overall AI Vision for GMTO to establish the principles and guardrails for current and emerging use of AI/ML at GMTO. This will also provide an evidence base from which to develop an internal roadmap, prioritize initiatives and define community engagement programs.

GMT-NOIRLab Integrated Product Team

The US Extremely Large Telescope Program (US-ELTP) brings together the Giant Magellan Telescope (GMT) with the established NOIRLab's science infrastructure that is supported by the National Science Foundation's investment in the next generation of ground-based astronomy. The science data life cycle, from proposal to publication, is supported by a collection of software products that function together as one integrated software solution. The NS2P-GMT Integrated Product Team (IPT) is a multi-organizational team that exists to deliver the software needed for GMT's end-to-end science data lifecycle. It combines the GMTO-developed Observatory Control System (OCS) and the NOIRLab-developed Science and Program Platform (NS2P) into a single, seamless product for observing proposal management, telescope operations and science data management. The IPT exists to ensure that integration is treated as a first-class engineering responsibility rather than an emergent property. By jointly designing the end-to-end architecture, interfaces and operational concepts, the IPT will reduce late-phase integration risk, sharpen the boundaries between component scope and produce a reference architecture that is portable beyond GMT.

8. SCIENCE INSTRUMENTS

As a reminder, the GMT can host up to ten instruments simultaneously that are located at focal stations that accommodate various instrument volumes, masses, and fields of view. Instrument exchanges are designed to facilitate rapid observation of transients and dynamic allocation of observing programs to match changing conditions. The initial suite of first-generation science instruments was identified through an open solicitation for concepts and that passed thorough Conceptual Design Reviews in 2012. Responding to scientific and technological opportunities, an extreme-AO system recently has been added to the first generation suite. The GMT first generation instruments are workhorse instruments providing most core capabilities as soon as they are commissioned. They also enable some key specialized capabilities such as precision radial-velocity (PRV) and Extreme-AO. Please refer to Reference 40–47 for the current status of the GMT first generation suite of science instruments.

8.1 GMT Consortium Large Earth Finder (G-CLEF)

G-CLEF is a seeing-limited (natural seeing or GLAO) visible-light echelle spectrograph designed for PRV capabilities.[42] The instrument is located at the telescope's gravity invariant station and is fiber-coupled to a dedicated front-end assembly mounted to the GIR. The G-CLEF spectrograph has completed final design, and many of its key components have been procured and are being assembled and tested (see Figures 24 and 25). Once completed, the spectrograph will be deployed for initial observing on one of the Magellan telescopes at the Las Campanas Observatory in Chile (adjacent to the GMT Las Campanas site). The G-CLEF front-end, fiber subsystems, and instrument-specific SW are in final design. G-CLEF can also be fed by the GMT fiber feed system (MANIFEST) to enable simultaneous spectroscopy of up to 40 objects with partial wavelength coverage.



Figure 24. Most of the major G-CLEF reflective optics for the spectrograph have been procured. Examples shown are (from left to right): M1 mirror, M2 mirror, Mangin mirror, and Echelle grating. The completed G-CLEF vacuum chamber awaiting delivery to SAO. (*Photos courtesy of A. Szentgyorgyi, Harvard-Smithsonian Center for Astrophysics*)



Figure 25. The completed G-CLEF vacuum chamber awaiting shipment to SAO. (*Photos courtesy of A. Szentgyorgyi, Harvard-Smithsonian Center for Astrophysics*)

8.2 GMT Wide Field Multi-Object Spectrograph (GMACS)

GMACS is a seeing-limited (natural seeing or GLAO) visible-light, moderate-spectral resolution, multi-object spectrograph.[43] Moderate resolution spectra (R~1,000 – 6,000) can be obtained for multiple targets distributed with a 6.5 x 7 arcminute field of view using 0.7 arcsecond-wide slits in a multi-slit mask. GMACS operates with a wide field corrector and atmospheric dispersion corrector unit (C-ADC-14), where the ADC minimizes slit losses due to spectral atmospheric dispersion and allows long observations of a selected field (see Figure 26). GMACS and the C-ADC-14 have been designed for high throughput into the UV (0.33 μm). GMACS can alternatively be fed by MANIFEST fibers or mini-IFUs to enable surveys across the full 20 arcmin field of view of the telescope and higher spectral resolution (~ 10,000). GMACS is in final design.

GMACS development is primarily by the Harvard & Smithsonian Center for Astrophysics with assistance from the Steiner Institute in Sao Paulo, Brazil. GMACS is planned to be the second instrument commissioned on the GMT, and it will likely be the most-used instrument as it satisfies the broadest range of science cases of GMT's first generation instrument suite.

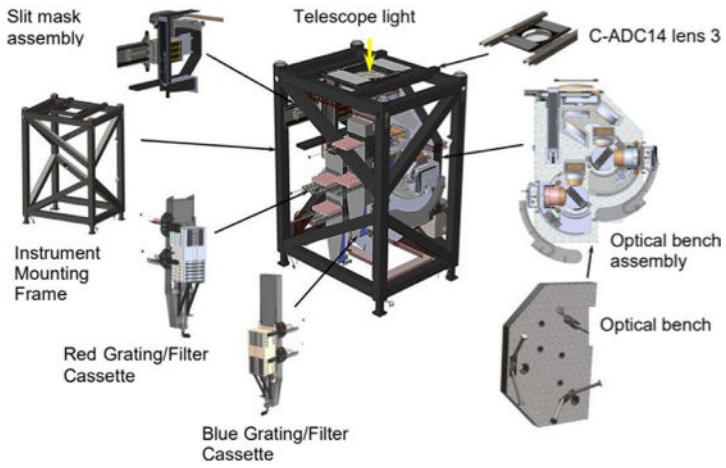


Figure 26. GMACS major sub-assemblies mounted on its instrument mounting frame (from Fabricant et al. 2025).

8.3 GMT Near-Infrared Spectrograph (GMTNIRS)

The GMTNIRS is a high spectral resolution infrared spectrograph selected as a first-generation instrument for the telescope.[44] This instrument will be a powerful tool for spectro-astrometry of young stellar objects disks and for characterization of exoplanet atmospheres, as well as additional science cases including galactic evolution through stellar abundances, gas kinematics and physics in star forming regions, and near field cosmology using globular clusters.

GMTNIRS is a collaborative development effort between The University of Texas at Austin and the Korean Astronomy and Space Science Institute (KASI). The six individual spectrographs inside GMTNIRS collectively cover the J, H, K, L, and M spectral bands (1-5 microns) in a single exposure – the highest "spectral grasp" of any existing or planned instrument in the world. Due to the use of silicon immersion gratings developed at The University of Texas at Austin, the design is uniquely compact for its capability. GMTNIRS is currently in Final Design with its FDR scheduled for the second half of 2027 (also see Figures 27 and 28 for HW being tested). There are plans to deploy the GMTNIRS spectrograph on one of the Magellan telescopes years before it will be integrated into the GMT (similarly to the plan for G-CLEF).



Figure 27. Immersion gratings for GMTNIRS. *(Photo courtesy of Ben Kidder)*



Figure 28. The J, H, and K-band cameras (left) and the L-, M-band cameras (right) for the GMTNIRS spectrograph.

8.4 Giant Magellan Telescope Integral Field Spectrograph (GMTIFS)

GMTIFS is a diffraction-limited (using natural or laser guide stars) imager and integral field spectrograph (IFS) operating across the Y, J, H, and K spectral bands (0.96 – 2.4 μm).[45] The spectrograph will provide spectral resolving powers of 5,000 and 10,000 over rectangular fields of view with four spatial scales that can fully utilize the diffraction-limited spatial resolution of the GMT, and lower spatial resolution modes that can provide greater sensitivity for extended targets (e.g., galaxies, resolved stellar populations). The imaging channel has a field of view of 20x20 square arcseconds and pixels that Nyquist sample the diffraction limited PSF at 2.2 microns. GMTIFS is in its preliminary design phase (see Figure 29).

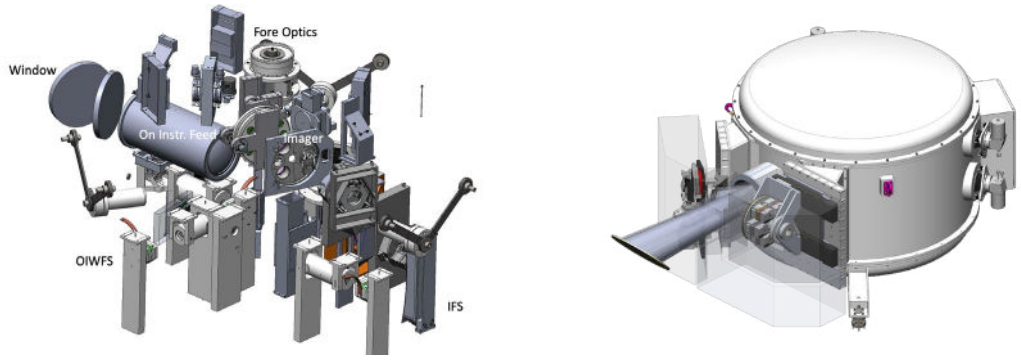


Figure 29. The PDR model of GMTIFS (left). The GMTIFS cryostat, also showing the external NGAO and LTAO wavefront sensors (right). Note that he GMTIFS optomechanical modules inside the cryostat are distributed between three chambers of the optical bench (not shown): feed optics (mid-level), imager (top-level) and on-instrument wavefront sensor and IFS (bottom-level).

8.5 Many Instrument Fiber System (MANIFEST)

MANIFEST is the GMT's facility robotic fiber feed system, designed to make the GMT's full 20 arcminute field of view accessible to any visible or near-IR spectrograph.[46] In its initial configuration, MANIFEST will use the GMT's 14 arcmin diameter FOV Corrector-ADC, and feed the GMACS and G-CLEF spectrographs. MANIFEST is in its preliminary design phase (see Figure 30).

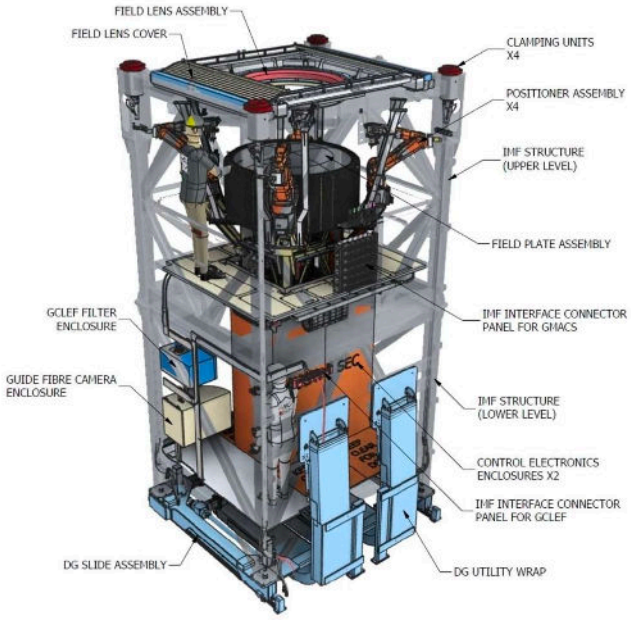


Figure 30. The CoDR design of MANIFEST in its instrument mounting frame (IMF). The top level of the IMF shows the field plate in the stowed position, ready for fiber placements by the four positioners (robotic six-axis arms).

8.6 Giant Magellan Extreme Adaptive Optics (GMagAO-X)

GMagAO-X will be the GMT's first extreme adaptive optics instrument.[47] The GMagAO-X requirements are driven by the key science goal to characterize nearby mature, potentially habitable terrestrial worlds in reflected light. The design is based on a novel "tweeter" deformable mirror design that leverages the segmented (and unobstructed) GMT pupil. An optically distributed set of seven pupils, one per GMT segment, enables the use of high-density deformable mirrors that are commercially available today. Following the main AO system in the camera, visible and near-infrared science channels contain integrated coronagraphic wavefront control systems. The fully corrected and, optionally, coronagraphically filtered beams will then be fed to a suite of focal plane instrumentation including imagers and spectrographs. This may include fiber fed inputs from existing GMT facility instruments such as GMTNIRS and G-CLEF. GMagAO-X is in the final design phase with its FDR currently scheduled before the end of 2027. GMagAO-X is currently in its final design phase (see Figure 31).

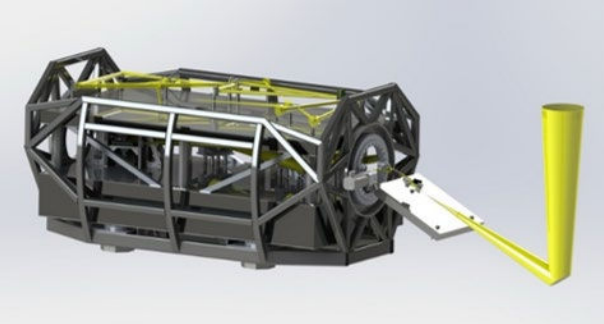


Figure 31. The PDR model of GMagAO-X, showing its dedicated tertiary mirror, the instrument mounting frame, and two-level optical bench – which rotates to maintain constant orientation relative to the gravity vector.

8.7 Telescope Commissioning Instruments

In addition to the science instruments described above, there are two additional cameras that will be used to facilitate telescope commissioning: the Commissioning Camera (ComCam) and the Adaptive Optics Test Camera (AOTC). Although not considered as facility science instruments, these cameras will have significant observing capabilities by themselves.

Commissioning Camera (ComCam)

ComCam is an all-refractive, focal reducing camera intended for evaluating telescope performance in both natural seeing and Ground Layer Adaptive Optics (GLAO) modes across a 6 arcminute diameter field of view. As the first imager for the GMT, ComCam also can support scientific and public outreach functions by enabling both narrowband and broadband imaging and photometric measurements at wavelengths between 360 and 950 nm. ComCam passed its PDR in 2025 and is currently scheduled to complete its FDR before the end of 2027 (see Figure 32).

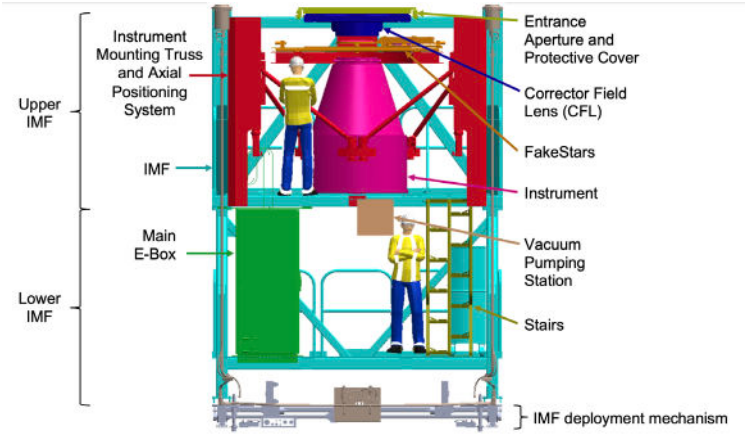


Figure 32. The PDR model of the ComCam.

Adaptive Optics Test Camera (AOTC)

We have developed an Adaptive Optics Test Camera (AOTC) to verify performance of the Adaptive Secondary Mirror and the wavefront sensing and control algorithms for both NGAO and LTAO modes. The AOTC is a surrogate for the On-Instrument Wavefront Sensors in the science instruments. The AOTC passed its PDR and is in its final design phase.

The three objectives of the AOTC are (1) to verify the instrument to wavefront sensor interfaces, (2) to carry out calibration and verification of the NGWS, LTWS and the ASMS, and (3) to verify the performance of the NGAO and LTAO control algorithms. The AOTC will first be deployed in the AdOptica test facility to calibrate the ASM along with the wavefront sensors for NGAO and LTAO modes. Calibration starlight sources will be mounted at prime focus in front of the ASMS to simulate the GMT while the AOTC and a 4D interferometer will detect reflected light at Gregorian focus. The AOTC, ASMS, wavefront sensors and calibration sources will ultimately be mounted on the telescope for commissioning on sky prior to the delivery of GMTNIRS and GMTIFS. Figure 33 shows a model of the AOTC and the Natural Guidestar Wavefront Sensor (NGWS) and the Laser Tomography Wavefront Sensor (LTWS).

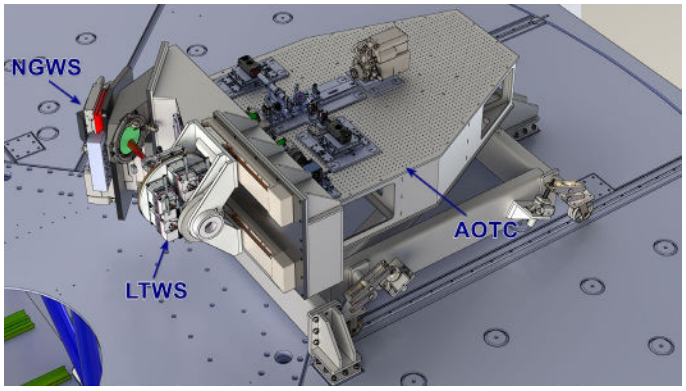


Figure 33. The PDR model of the AOTC and the NGWS and LTWS that it feeds.

9. ENCLOSURE AND SITE FACILITIES

The GMT Site Master Plan shown in Figure 34 has remained stable since 2024. The final design review (FDR) for the GMT Enclosure (including the Summit Utility Tunnel and Summit Utility Building) was completed in May 2024 and presented in detail at the SPIE Astronomy 2024 conference.[48] A follow-up FDR for the Enclosure pier lift and shutter latches subsystems was successfully completed in February 2025. Most of the GMT Site Infrastructure, Enclosure, and Facilities (SEF) design and development work since June 2024 has focused on design and trade studies for the Site Infrastructure (electrical power systems and IT infrastructure), the primary facility support building (the Summit Support Building or "SSB"), and post-FDR refinements to the Enclosure final design. Additional details about the work completed since 2024 are contained in Reference 49.

The scope of the GMT Enclosure design includes the foundations for the telescope and enclosure, the telescope pier, the telescope pier seismic isolation systems (SIS), the fixed lower portion of the enclosure, and the rotating upper enclosure. Although they are called out separately in Figure 34, the Enclosure, Summit Utility Tunnel (SUT), Summit Utility Building (SUB), water pad buildings, dry cooler platform (and the Utility Yard at SS1) have all been designed together under a single contractual statement of work. Beginning in early 2020, the enclosure Designer of Record has been the Architecture & Engineering (A&E) firm IDOM with offices located in Bilbao, Spain. Their conceptual renderings of the completed summit facilities are shown in Figure 35,

Following the completion of the enclosure design in 2024, GMTO awarded additional design tasks to IDOM, including design of the Summit Support Building (SSB) and the Site Information Technology (IT) physical network infrastructure. The SSB will house (1) the coating chamber and stripping and washing stations for the primary mirror segments, (2) AO integration and test lab, and a large M1 mirror and support system integration area. Figure 36 shows the current planned layout of the SSB ground floor. IDOM advanced the SSB design beginning with a conceptual design review (CoDR) in

July 2025, a preliminary design review (PDR) in November 2025, and a 60% maturity (critical) design review in May 2026. The SSB FDR is currently scheduled near the end of the 2026 calendar year.

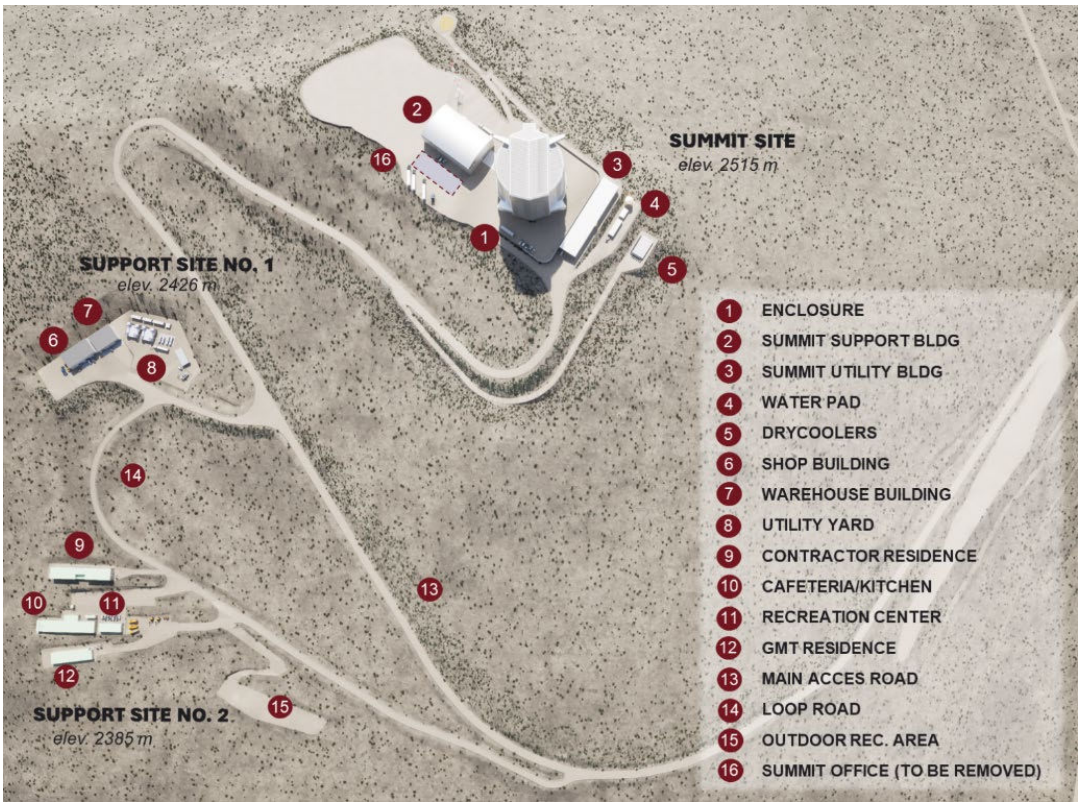


Figure 34. The GMT Site Master Plan as of May 2024.



Figure 35. Artist's conceptions of two exterior views of the future GMT Enclosure and summit support facilities. The Summit Support Building housing the M1 washing and coating facilities can be seen behind the Enclosure in the rendering on the left. *(Renderings courtesy of IDOM)*

Since 2024, a priority of completing the overall site infrastructure design has been the design of the electrical power infrastructure to support most of the major construction and science operations periods. The GMT observatory site currently maintains a 750-kW electrical power connection to the Las Campanas Observatory, supported by a set of diesel generators on the summit and at the GMT SS1 and SS2 support sites. Beginning during major construction, the GMT will require a minimum ~3MW power capacity provided via a new powerline that will also supply Las Campanas Observatory, for a total capacity of 4-5MW. GMTO plans to be supplied with renewable ("green") power, through a power purchasing agreement (PPA) or local generation (or both).

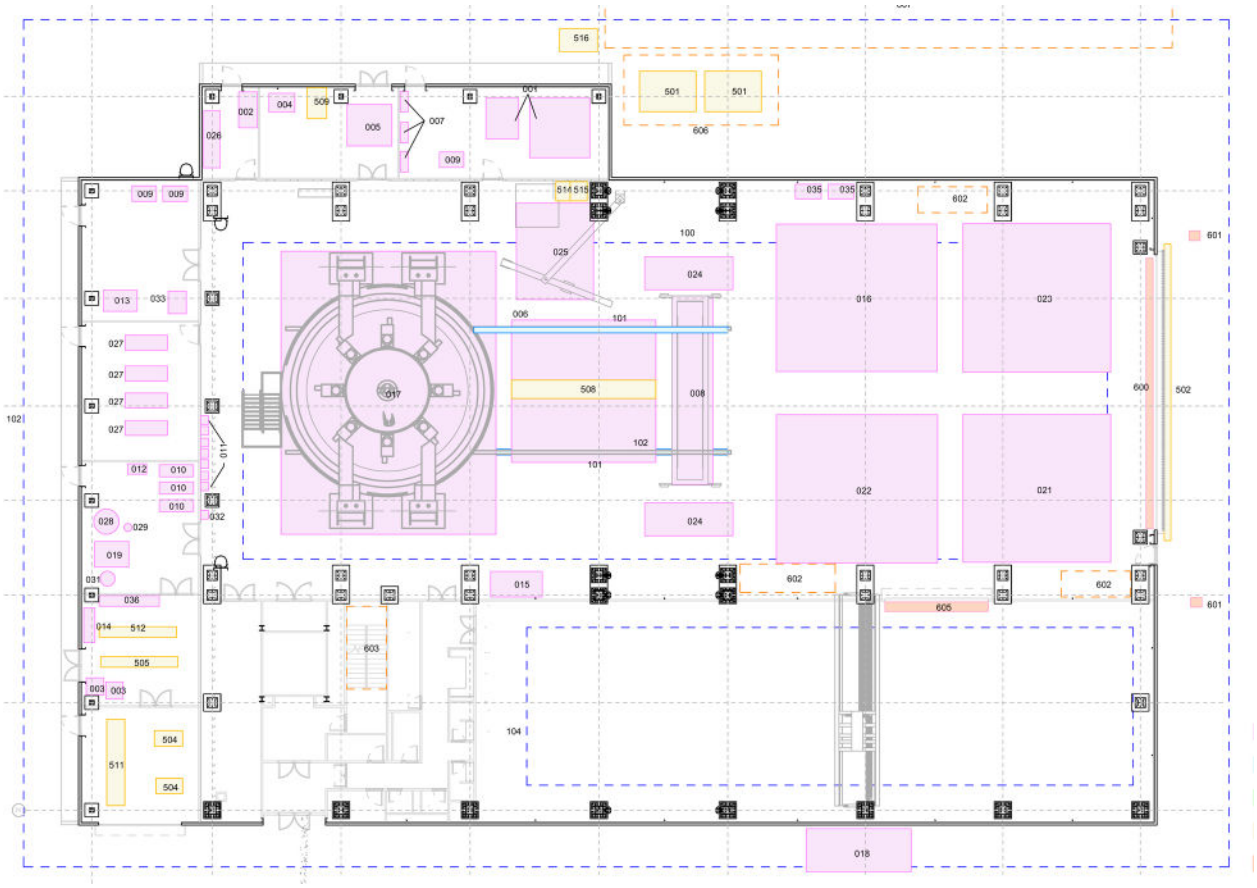


Figure 36. The Summit Support Building ground floor layout showing the location of the coating systems (upper left), the M1 integration area (upper right), the AO integration and test laboratory (lower right), and an office area (lower left). *(Architectural layout courtesy of IDOM)*

GMTO conducted a power systems trade study in 2024 and 2025 with the Chilean consulting firm INODU to evaluate the costs and benefits of construction of a new powerline, a photovoltaic (PV) plant, and with or without a supplemental on-site battery storage system (BSS). The conclusion of the study was that GMTO should proceed with arranging subsidizing the construction of the new powerline and procure renewable power through a PPA. INODU recommended that the option to implement a on-site PV capability with or without BSS should be reevaluated in the early operations phase. That approach will allow for the actual power demands to be better understood, and when build-out of commercial PV plants in Chile will be more mature, and the currently trend of price reductions of PV and BSS systems should have further reduced PV construction costs.

The design of the Site IT network planned for science operations following construction complete has also advanced significantly since 2024. This critical site infrastructure will include a new fiber optic connection from the GMT site to the Chilean internet, along with microwave and satellite back-up connections. The Site IT Network Infrastructure design has advanced from the delta-CoDR completed in June 2025 to the PDR completed in April 2026, and the FDR is expected by the end of the 2026 calendar year.

During the next year, the SEF team's work will be concentrated on completing remaining design work, planning for a post-FDR prototyping effort of critical Enclosure components, preparing for the NSF FDR, and beginning the procurement process leading to the selection of the Agency Construction Management contractor and the General Contractor for the major site construction efforts scheduled to begin in 2028. The process for selecting the GC will kick off with a multi-day Industry Briefing to be held in Los Angeles, CA. The primary purpose of the Industry Briefing is to introduce potential GCs and selected subcontractors to the site construction scope of work, requirements, and timelines.

10. SUMMARY

In addition to the extensive engineering development being conducted by GMTO, the GMT site at Las Campanas contains fully operational residential facilities, fully operational infrastructure to support major construction, and a summit area ready to begin the next stages of major construction (see Figure 37). Although the GMT summit area proper has not been in major construction since hard rock excavation was completed, there is a full time Site Operations team that operates and maintains the site to preserve and protect the GMTO investment and be ready to begin construction again efficiently and quickly. We appreciate and accept our responsibilities to be a good tenant for our Las Campanas host, the Carnegie Institution for Science and their Las Campanas Observatories.



Figure 37. A view of the GMT site summit plateau area. The residential facilities at Support Site #2 are in the top center while Support Site #1 is to the top right of center.

GMTO's commitment to a Safety First work culture applies to all who enter the site (GMTO staff, contractors, and visitors). Our Safety Program is driven by proactive continual improvement processes including frequent safety assessments and implementation of measures such as the use of GPS trackers to monitor vehicle speed (repeat violators can be, and have been, banned from the GMT site). GMTO has recently implemented a new Driver Fatigue Alert safety program to further reduce the risk of accidents on the site roads. Security measures continue to be enhanced to protect the site. In addition to physical security at the site, GMTO continues to implement the strongest possible cybersecurity across the entire GMTO corporation.[50]

In summary, this paper has provided an overview of the status of the Giant Magellan Telescope project as of June 2026. Most of the major subsystems are either in Final Design or construction. The Project will be ready for a system-level final design review within the next year. Technical risk reduction work continues in optics fabrication and optical performance including the optimization of AO phasing. Using the RFCML Test Tower, the integrated S3+Test Cell demonstrated active optics capabilities to control the surface figures of the primary mirror segments to required levels. Construction of the Mount azimuth structures is proceeding well. With the completion of the Enclosure design, and the readiness of the GMT site infrastructure to support the beginning of Enclosure construction, it will be possible to pour concrete for the Enclosure foundations when funding becomes available. Overall, GMT project execution remains focused on achieving GMT's Science First Light as soon as possible while simultaneously controlling risks, minimizing cost growth, and ensuring that system performance will enable the transformative science that the astronomy community expects.

Acknowledgments

The Giant Magellan Telescope is being developed by the GMTO Corporation, a 501(c)(3) nonprofit, and an international consortium of 16 universities and research institutions from the United States, Australia, Brazil, Israel, South Korea, and Taiwan, in partnership with our host country, Chile. GMTO is a partner in the U.S. Extremely Large Telescope Program (US-ELTP).

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