

Giant Magellan Telescope - Overview

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ABSTRACT

The Giant Magellan Telescope (GMT) is a 25-meter optical/infrared extremely large telescope that is being built by an international consortium of universities and research institutions. It will be located at the Las Campanas Observatory, Chile. The GMT primary mirror consists of seven 8.4-m borosilicate honeycomb mirror segments made at the Steward Observatory Mirror Lab (SOML). Six identical off-axis segments and one on-axis segment are arranged on a single nearly-paraboloidal parent surface having an overall focal ratio of $f/0.7$. The fabrication, testing and verification procedures required to produce the closely-matched off-axis mirror segments were developed during the production of the first mirror. Production of the second and third off-axis segments is underway.

GMT incorporates a seven-segment Gregorian adaptive secondary to implement three modes of adaptive-optics operation: natural-guide star AO, laser-tomography AO, and ground-layer AO. A wide-field corrector/ADC is available for use in seeing-limited mode over a 20-arcmin diameter field of view. Up to seven instruments can be mounted simultaneously on the telescope in a large Gregorian Instrument Rotator. Conceptual design studies were completed for six AO and seeing-limited instruments, plus a multi-object fiber feed, and a roadmap for phased deployment of the GMT instrument suite is being developed.

The partner institutions have made firm commitments for approximately 45% of the funds required to build the telescope. Project Office efforts are currently focused on advancing the telescope and enclosure design in preparation for subsystem- and system-level preliminary design reviews which are scheduled to be completed in the first half of 2013.

Keywords: GMT, GMTO Corporation, extremely large telescope, overview, Giant Magellan Telescope

1. INTRODUCTION

1.1. GMT Organization

The Giant Magellan Telescope (GMT) is a 25-meter optical/infrared extremely large telescope that is being built by an international consortium of universities and research institutions. It will be located at the Las Campanas Observatory in Chile. The GMT Corporation has been formed to conduct this effort. The ten member institutions of the corporation are: Astronomy Australia Ltd., The Australian National University, Carnegie Institution for Science, Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Institution, University of Texas at Austin, Texas A&M University, The University of Arizona, and the most recent new member, University of Chicago. Together the members have committed approximately 45% of the completion cost for the GMTO Observatory and are working to raise the remainder.

The GMT Project is currently in the Design Development phase working towards a System Preliminary Design Review (SPDR) in early 2013. Currently the GMTO staff numbers 30 and continues to increase. The Project outgrew its Pasadena offices adjacent to Carnegie Observatories in 2011 and moved to new, larger office space a mile to the south. The project staff is augmented by design teams at the GMTO member institutions.

The Project Management and Systems Engineering tools and procedures necessary for a Project of this magnitude are being implemented and will be fully functional by the time of SPDR. A major fraction of these are already in place and operational ¹.

1.2. Science goals

The key attributes of GMT – its large collecting area, high angular resolution with adaptive optics, broad wavelength coverage, and a field of view up to 20 arcminutes – make it uniquely suitable for addressing many of the forefront scientific problems identified for the coming decade and beyond. The Giant Magellan Telescope Science Case ² presents the key GMT science goals in a number of broad areas:

- Star and planet formation
- Stellar populations and chemical evolution
- The nature of dark matter and dark energy
- The evolution of galaxies and intergalactic matter
- Black hole growth
- The first stars and galaxies

At the same time it is recognized that astronomy is a discovery science and that the range of questions that GMT will address will be much broader than what is currently outlined in the Science Case. GMT is being designed with the aperture and flexibility to move beyond the baseline Science Case as new opportunities arise. The research goals of the GMTO members and general astronomical community will ultimately decide the programs that will be undertaken over the 50 year design lifetime of the observatory.

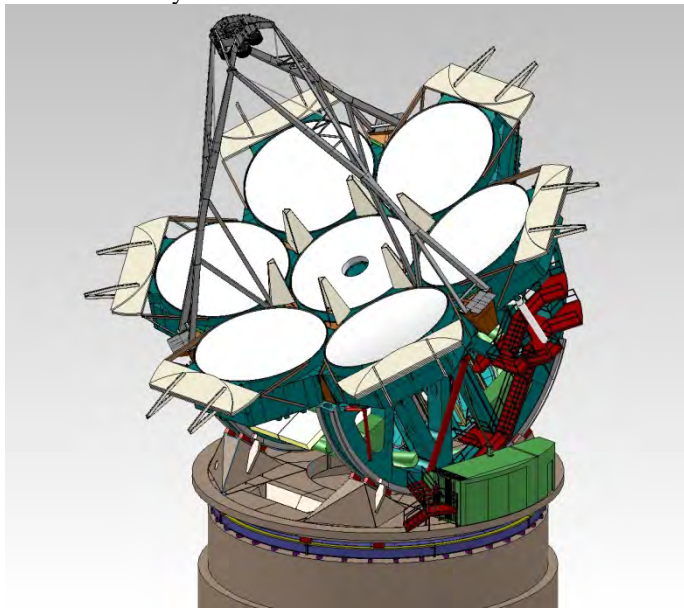


Figure 1. Giant Magellan Telescope (GMT)

1.3. Overview

GMT is an alt-az telescope designed around a 25 meter diameter primary mirror with a collecting area of 386 m². It consists of seven 8.4 meter diameter segments, arranged as shown in Figure 1, which define the 7 subapertures of the telescope. The secondary mirror is also segmented with the segments conjugated 1:1 with the primary. The mirrors are mounted in the Optical Support Structure (OSS) that is the upper moving part of the alt-azimuth mount. The OSS also carries other parts of the optical system (wide field corrector/ADC, tertiary mirror), the active and adaptive optics systems, and Science Instruments. Nasmyth platforms are not provided but instruments with high stability requirements may mount on the azimuth platform and be fed with an optical or fiber relay from the focus. Field de-rotation is provided for instruments on the OSS.

The telescope is designed to operate in various observing modes over a wavelength range from the atmospheric cut-off at around 320 nm in the UV to the mid-IR up to 25 μm . The maximum field of view with the corrector is 20 arcminutes at visible and near-IR wavelengths. The corrector/ADC also compensates for atmospheric dispersion.

Various observing modes are provided by the active and adaptive optics (AO) systems for instruments designed for a specific wavelength range, field of view, and desired image size. These include:

- Natural seeing – Delivers images to the science instrument with image sizes limited by wavefront distortion of the light from the science targets passing through the atmosphere. Slowly varying effects due to optical misalignment and low frequency (<20 Hz) mechanical vibrations are corrected by the active optics and fast tip/tilt systems.
- Natural guide star AO (NGSAO) -- Delivers high Strehl (>75% K-band), high contrast images over a field of view limited by natural anisoplanatism using bright guide stars within the isoplanatic patch centered on the guide star.
- Laser Tomographic AO (LTAO) – Delivers moderate Strehl (>30% H-band) with broad sky coverage and field of view limited by natural anisoplanatism using multiple laser guide stars and one natural guide stars to achieve a high fraction of sky coverage.
- Ground-layer AO (GLAO) – Delivers AO seeing-enhanced images (<0.30 arcsec FWHM in K-band) over a 6.5 arcminute diameter field of view by correcting low-altitude atmospheric turbulence using either laser or natural guide stars for reference.

A varied suite of science instruments will be mounted on GMT at any given time. In general, these will be maintained in “ready mode” and available for use with minimal re-configuration of telescope. Switching between instruments will allow flexible scheduling of observing time and the ability to respond to transient events (“targets of opportunity”) and changing conditions. Stations for 8 instruments are initially provided with the ability to implement others in the future. The first-generation of science instruments will be selected based on a number of criteria: science impact, the ability to cover the full range of observing conditions (seeing, lunar phase, transparency), the scientific interests of the members, and the available budget. Synergy with other existing and future astronomy facilities will also be a factor. Six candidates for GMT’s first-generation instruments were selected from proposals submitted by both internal and external teams. Conceptual designs were completed for each of these and externally reviewed. The reports from the review committees were then evaluated by a selection board to arrive at a list of instruments recommended for further development. In the next phase, the selected instruments will advance through preliminary design ³.

The system software controls and data management systems for the GMTO observatory are being developed through the Project Office ⁴.

GMT will be located on Cerro Campanas at Las Campanas Observatory. The facility will include the telescope enclosure, technical and maintenance support buildings, roads and infrastructure, and dining and lodging facilities.

The top-level requirements for GMT are contained in the GMT Science Requirements Document (SRD) ⁵.

2. TELESCOPE

2.1. Optics

GMT is designed with a Gregorian optical prescription with an $f/0.7$ primary mirror focal ratio and an $f/8.2$ final focal ratio for the system. The fast optical system contributes to the overall compactness of the telescope structure and instrumentation. The 207.6 m focal length of the two mirror system gives a plate scale of 1.00 "/mm and a 1.2 m diameter for the 20' focal plane.



Figure 2 Polishing GMT1

The primary mirror segments are made of OHARA E6 glass with a honeycomb structure. They are cast, generated and polished at the University of Arizona Steward Observatory Mirror Lab (SOML) (Figure 2). The first off-axis segment, GMT1, was cast in July 2005. With 14 mm of aspheric departure peak-valley these mirrors are by far the most highly aspheric optics of their size and precision ever made. Fabricating them required the development of a whole new metrology system including redundant surface figure measurements using independent equipment. Much of the effort in producing GMT1 is associated with the development of this metrology, infrastructure and procedures, that are now in place for subsequent GMT segments ⁶.

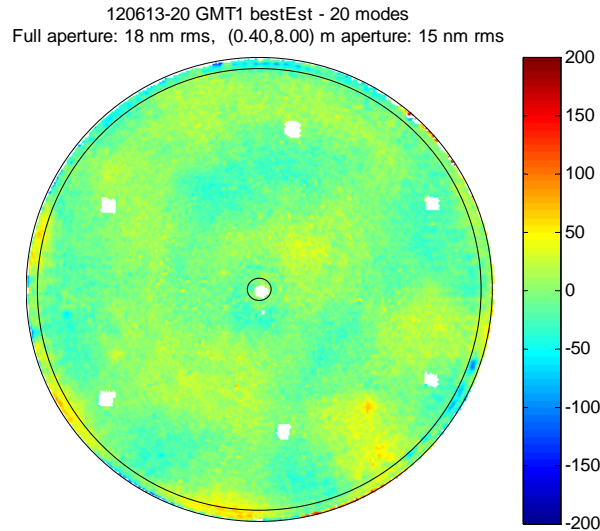


Figure 3 GMT1 surface map (13 June 2012)

The segments will be mounted in the telescope on active supports that apply bending forces to maintain the desired mirror figure within limits imposed by the maximum actuator forces that are allowed for figure control. Similar systems have been deployed on previous telescope using the SOML mirrors (MMT, Magellan, LBT). The design and prototyping of the GMT active supports is currently progressing within the project. Sensors in the active optics system continuously measure wavefront aberrations in the focal plane while observing and send the corrections to the segment controller.

These corrections are intended to compensate for various sources of wavefront aberration: thermal gradients in the mirror substrate, force errors in the supports, and figuring errors which themselves could arise from support and thermal effects in the lab. During figuring, 20 of the lowest bending modes are numerically removed from the raw figure measurements assuming that these aberrations will be corrected in the telescope by the active system. The amount of aberration that can be thus removed is limited by the maximum forces that will be allowed in the telescope for correcting manufacturing error.

The polishing/figuring process on GMT1 is just completed with final acceptance testing ready to start. Figure 3 shows the most recent surface map. The surface error over the full 8.36 m diameter clear aperture is 18 nm rms. Figure 4 shows the GMT1 PSF and encircled energy for the full clear aperture.

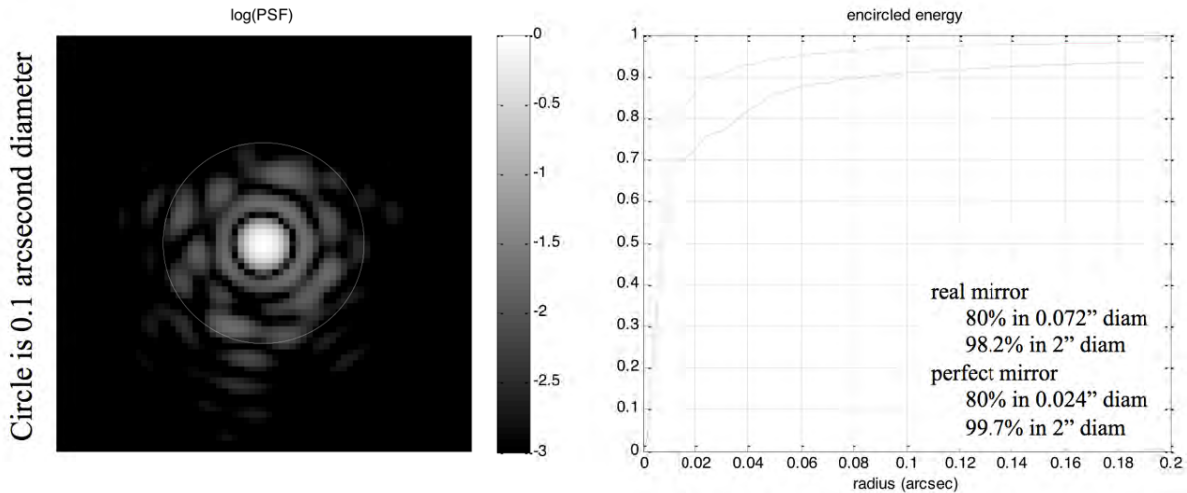


Figure 4 GMT1 PSF and encircled energy

The primary mirror segments are the pacing items in the GMT schedule. The Mirror Lab can process approximately four mirrors at a time in the production pipeline at SOML⁷. Currently there are two mirrors in the large mirror queue behind GMT1 and ahead of the second GMT off-axis segment, GMT2: the LSST 8.4 m mirror and the Mexican SPM 6.5 m mirror. GMT segments will be produced in a continuous series following them. The plan is to cast one segment approximately every 12-14 months to keep the production pipeline filled. GMT2 has already been cast and transferred to the clean-out fixture for removal of refractory material from the internal cores. The production of GMT3, another off-axis segment, has started with the purchase of glass and preparation of the furnace. The projected casting date for GMT3 is in July 2013.



Figure 5 Lifting GMT2 off the casting furnace (19 June 2012)

Two secondary mirror assemblies are being provided for GMT. They share the same optical prescription. The Fast-steering Secondary Mirror (FSM) consists of 7 light-weighted monolithic 1.1 m diameter mirror segments each supported by a set of 6 position actuators that provide individual alignment and focus control. Fast tip-tilt capability is provided to compensate for telescope wind shake and mechanical vibrations caused by motors, compressors, etc., up to around 20 Hz.

The Adaptive Secondary Mirror (ASM) will be used for all GMT AO operating modes and, in addition, for natural seeing operation whenever it is installed. The individual segments of the ASM are based on the adaptive secondary mirrors developed for the MMT, LBT, Magellan, and currently VLT⁸. In the case of GMT, each ASM segment will have 672 electromagnetic actuators supporting a 2 mm thick face sheet which provides the deformable surface for AO wavefront control. Seven segments make up the full ASM for a total of 4704 actuators.

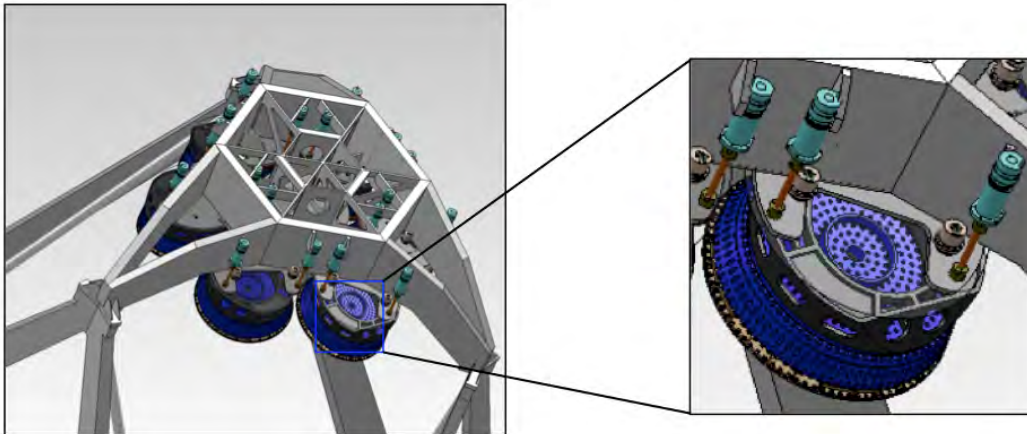


Figure 6 Top frame and Adaptive Secondary Mirror (ASM)

Both the FSM and ASM will be mounted in a frame that attaches to the main truss and comprises the top structure of the telescope. Figure 6 shows the ASM assembly. The two secondary mirror assemblies, FSM and ASM, will be exchanged by removing the entire assembly, including the top frame, with handling equipment provided in the Enclosure. Normally the ASM will be left on the telescope for both natural seeing and AO operation. The FSM is the telescope commissioning secondary mirror and will be used when the ASM is taken off the telescope for service.

Other optics of the telescope include a tertiary mirror to feed instruments at the telescope Folded Ports (FP) and a Corrector/ADC that provides a 20' aberration-corrected science field of view with atmospheric dispersion compensation for wide-field visible and near-IR science instruments located at the Gregorian focus.

2.2. Structure

The GMT structure shown in Figure 1 is currently being re-optimized to incorporate the changes since the Conceptual Design Review in 2006⁹. These include:

- More detailed solid models for the telescope structure, mirror cells, etc.
- New designs for the primary mirror and secondary mirror support systems
- Re-balancing of the telescope OSS to take into account updated weights for instruments, the AO system, the new GIR and other structure.
- Updated analyses of the static and dynamic performance including wind shake and seismic disturbance^{10 11}.
- A new design for the Gregorian Instrument Rotator (GIR) and mounting provisions for science instruments.
- A change from carbon fiber to steel in the upper part of the main truss.
- A revised top frame structure.
- Preliminary designs for the main axis bearings and drives¹².

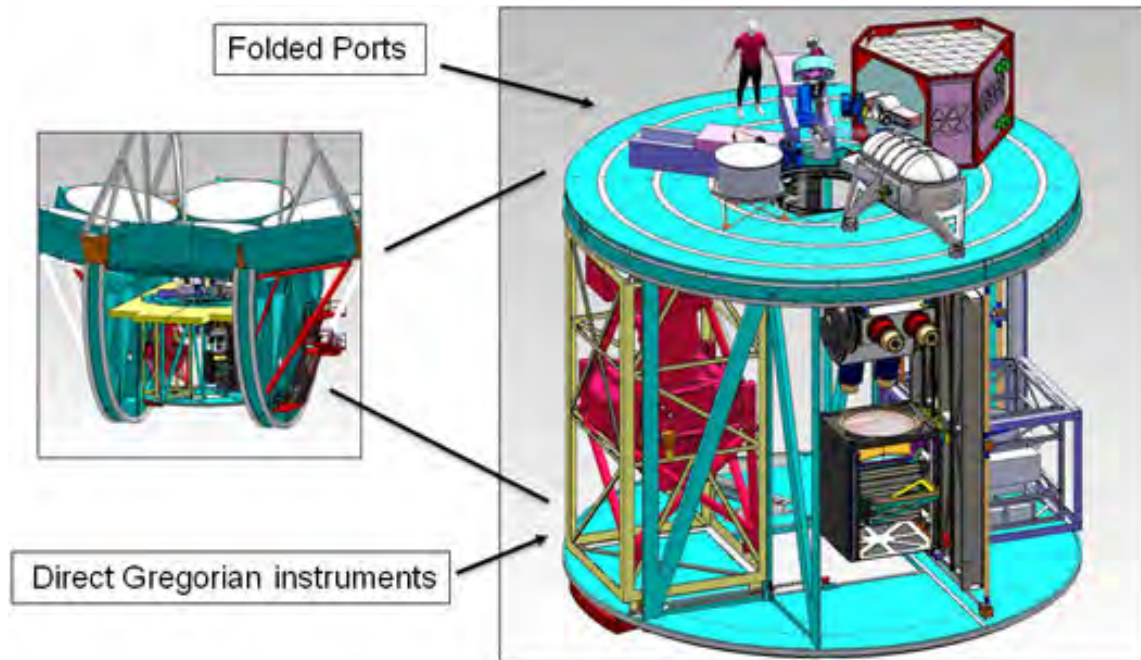


Figure 7 : GMT instruments in the Gregorian Instrument Rotator (GIR).

The GIR re-design is the most significant change since CoDR. The GIR is the large instrument-carrying structure located below the primary mirror that rotates about the telescope optical axis to compensate for field rotation caused by the alt-azimuth tracking of the telescope. Science Instruments are mounted at the Direct Gregorian (DG) focus inside the GIR and at ports (“Folded Ports”) on the top surface. A deployable steering mirror (tertiary mirror) directs the beam to the FP instruments. DG instruments are exchanged with a shuttle mechanism that moves the instruments into the beam from their stow positions in bays within the GIR. Four bays are provided, each able to accommodate a Science Instrument up to 2.8 m x 2.8 m x 5.5 m high and 11,500 kg. The top surface of the GIR is 9 m in diameter and divided in four quadrants: three for FP Science Instruments and the fourth for the tertiary mirror and GLAO wavefront sensor assemblies. The maximum FP instrument is 3.5 m x 5.5 m x 1.9 m high and 6,500 kg. The GIR also houses the Acquisition and Guide Assembly with guide cameras and wavefront sensors for the telescope active optics (AcO) system and Phasing Camera for the AO System.

An additional gravity-invariant instrument station (GIS) is provided on the top surface of the azimuth disk. An optical relay using either re-imaging optics, fiberoptic feed, or a combination of both is required to bring light to this station.

3. ADAPTIVE OPTICS

3.1. AO modes

The Adaptive Optics System (AOS) will provide several AO observing modes to science instruments. The objective is to maximize the scientific productivity of the instruments while minimizing replication of functionality within the AOS. The capabilities are the following:

- **Natural Guide Star AO (NGSAO):** The Natural Guide Star Adaptive Optics (NGSAO) observing mode uses a single star and wavefront sensor to provide all of the wavefront correction information for the AO System. The wavefront aberration will be compensated by the ASM, providing diffraction-limited imaging at 0.9-25 μm wavelength over a field of view limited by atmospheric isoplanatism^{13 14}. The requirement is for a K-band Strehl of >75% and L'-band contrast ratios of $>10^5$ at 0.12 arcseconds radius ($4\lambda/D$).
- **Laser Tomography AO: (LTAO)** The Laser Tomography Adaptive Optics (LTAO) observing mode uses a ~ 1 arcmin. diameter constellation of 6 LGS to tomographically reconstruct the high-order components of the atmospheric wavefront aberrations in the direction of a central science target. One faint natural guidestar is used to

measure tip-tilt, focus, segment piston, and dynamic calibration terms. The wavefront aberration will be compensated by the ASM, providing diffraction-limited imaging at 0.9-25 μm wavelength over a field of view limited by atmospheric isoplanatism^{15 16 17}. The requirement is for an H-band Strehl of >30% over 50% of the sky at the galactic pole.

- Ground Layer AO (GLAO): The Ground-Layer Adaptive Optics (GLAO) observing mode uses a guidestar asterism (either LGS/NGS or NGS-only) to detect and correct wavefront errors common to sky objects within a large (up to 10 arcmin in diameter) field of view. These errors are mainly due to low (up to 1 km) altitude turbulent layers of the atmosphere. The wavefront aberration will be detected using multiple wavefront sensors and compensated by the ASM, resulting in improved natural seeing images over a field of view comparable to the GS constellation size. While providing some improvement in the visible, GLAO correction is expected to be particularly useful at wavelengths longer than 1 μm ¹⁸. The requirement is for a median image size in K band of less than 0.30 arcsec FWHM.

The AO requirements are described more fully by Trancho, et. al.¹⁹.

3.2. AO architecture

The GMT AO system design is based on an adaptive secondary mirror (ASM), and wavefront sensor assemblies (“AO front end”) replicated for each instrument²⁰. Figure 8 shows the layout of the AO system components. All narrow-field AO instruments (those using the NGS AO and LTAO observing modes) are located at a folded port (FP) focus and selected with a steerable tertiary mirror. Each instrument cryostat window is a long-pass dichroic and all visible-light wavefront sensing (LGS and NGS) is performed in the beam reflected by the window. This design provides very high throughput and low emissivity, with only 3 reflections between the sky and the science instrument.

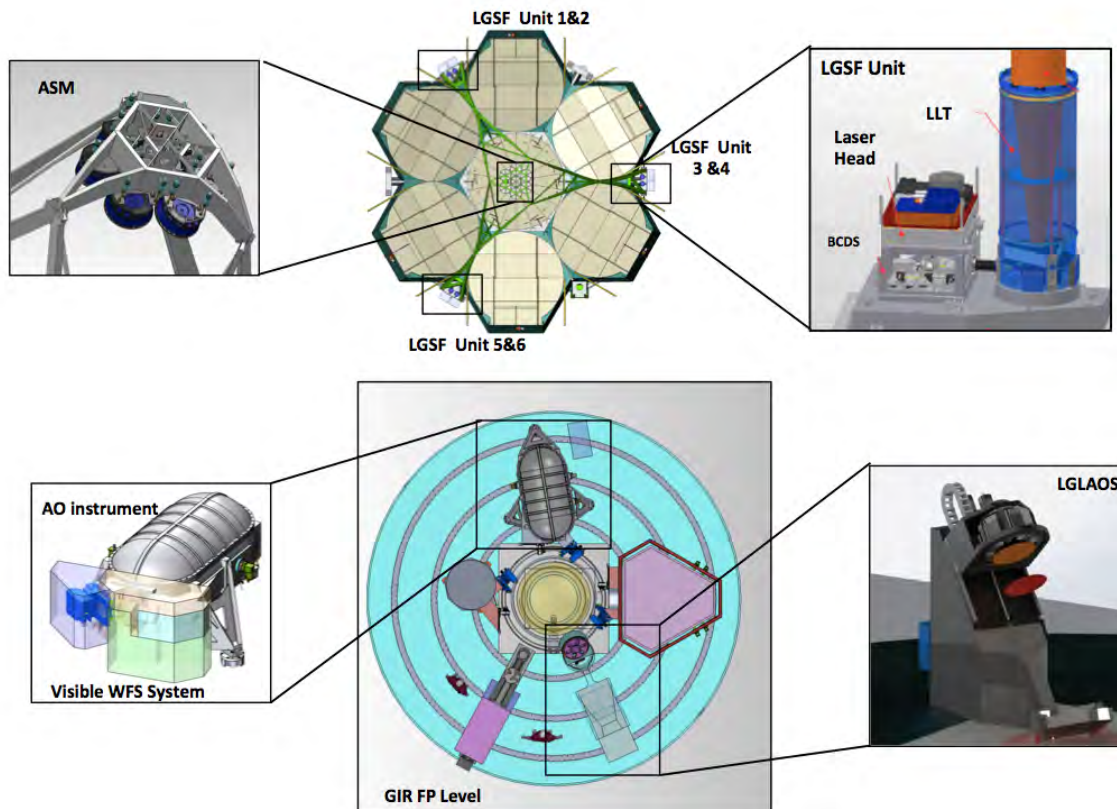


Figure 8 AO System Layout

The GLAO observing mode is used only by wide-field instruments which can be deployed at the direct Gregorian (DG) focus. The AO system therefore provides a single GLAO wavefront sensing assembly, intercepting laser guidestars and natural guidestars with a large dichroic and pick-off mirrors ahead of the instrument entrance window. The laser GLAO pick-off and wavefront sensor assembly (LGLAOS) is shown in Figure 8.

High-order wavefront sensing in the LTAO and GLAO observing modes will be provided by 6 sodium laser guidestars. An extensive trade study compared the expected performance of on-axis and off-axis LGS launch architectures. The current baseline uses six 20 Watt Raman fiber lasers to be coupled directly to six 38 cm refractive launch telescopes, located at the ends of the stiff primary mirror cell connector frame as shown in Figure 8. The laser and launch telescope designs closely follow the Very Large Telescope AO Facility design.

Figure 9 shows block diagrams of the AO modes.

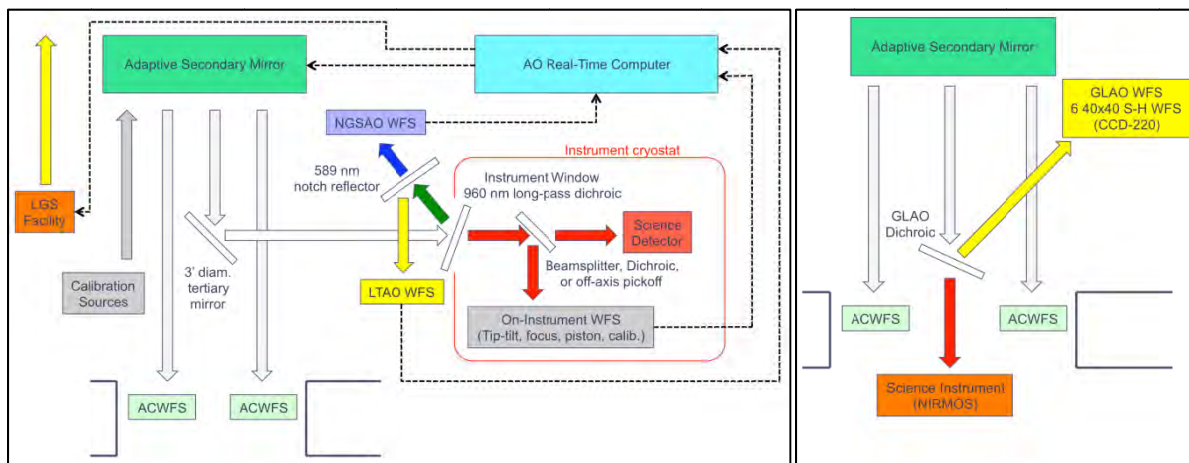


Figure 9 (Left) Block diagram of the NGSAO and LTAO modes. Light paths are shown with wide arrows, control signals with dashed arrows. (Right) Block diagram of the GLAO mode.

3.3. Phasing system

Achieving the diffraction limit of the 25.4 m GMT will require the primary and secondary mirrors to be phased to <50 nm RMS. Due to the large separation between primary segments (30-40 cm) and their construction of borosilicate glass with a non-zero CTE, capacitive or inductive edge sensors alone are not expected to be sufficiently stable over timescales longer than a few minutes. In the NGSAO observing mode, the NGSAO WFS can sense and correct segment piston at up to 1 kHz. However, only faint natural guidestars are generally available in the LTAO mode. GMTO has therefore designed a 3-stage phasing system consisting of a coarse optical phasing sensor with a large capture range to initially phase the telescope, primary and secondary mirror edge sensors to maintain alignment over short timescales, and a high-sensitivity optical sensor to correct long-term drifts in the edge sensors^{21 22}. Since the primary and secondary segments are matched one-to-one, errors can be rapidly compensated using the agile adaptive secondary mirror, then off-loaded to the primary or secondary segment positioning actuators as appropriate.

4. INSTRUMENTATION

4.1. Instrument concepts

Conceptual Design studies for six candidate instruments are complete. The list and instrument parameters are shown in Table 1. Those marked "*" have been selected to advance through a preliminary design study. The order of development and deployment on GMT will be decided on the basis of science impact, cost, schedule, and available budget³. Second generation instruments will be selected by the GMT Scientific Advisory Committee (SAC) starting in 2015.

Instrument	Function	λ Range, μm	Resolution	Field of View	Loc	Ref
GMACS *	Optical Multi-Object Spectrometer	0.36 – 1.0	1500 – 4000, 10,000	40 – 80 arcmin ²	DG	23 24 25
NIRMOS	Near-IR Multi-Object Spectrometer	0.9 – 2.5	2700 – 5000	42 arcmin ²	DG	26
G-CLEF*	Optical High Resolution Spectrometer	0.35 – 0.95	20 – 100K	7 x 1" fibers	GIS	27
GMTNIRS*	Near-IR AO-fed High Resolution Spectrometer	1.2 – 5.0	50 – 100K	Single Object	FP	
TIGER	Mid-IR AO-fed Imager and Spectrometer	1.5 – 14	300	0.25 arcmin ²	FP	28
GMTIFS*	NIR AO-fed IFU / Imager	0.9 – 2.5	4000 – 10,000	10 / 400 arcsec ²	FP	29
MANIFEST*	Facility Robotic Fiber Feed	0.36 – 1.0		300 arcmin ²	DG	30

Table 1 Science Instrument concepts

Instruments will be mounted at the DG, FP or GIS station as described above. A facility robotic multi-fiber feed to provide wide-field coverage for the optical and near-IR spectrographs is also planned. The GMT instruments and instrumentation development plan are described in the references in Table 1 and by Jacoby, et. al³.

5. ENCLOSURE AND FACILITIES



Figure 10 GMT Enclosure and Summit Facility

5.1. Site

GMT will be located on Cerro Campanas at Las Campanas Observatory (LCO). LCO is at the southern end of the Atacama Desert, approximately 170 km north of the coastal city of La Serena. Observing conditions at LCO are excellent with a high fraction of clear nights and good seeing. These are documented in the final report of the site characterization campaign and borne out through many years of observatory operation³¹. Figure 11 shows LCO with Cerro Campanas on the left and the Manquis ridge to the right where the Magellan 6.5 m telescopes, DuPont 100" telescope and Swope 40" telescope are located. The distance from the LCO lodge and Magellan telescopes to Cerro

Campanas is roughly 7 km by road. The road leading up to the site can be seen on the left in Figure 11 where it branches off from the access road coming up from the Pan American Highway, Route 5.

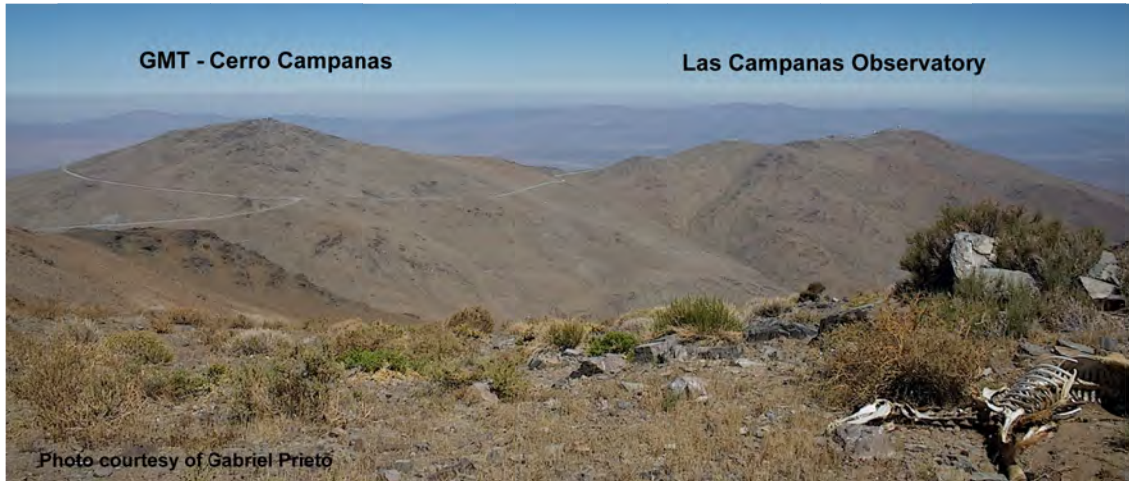


Figure 11 Las Campanas Observatory site

The existing support facilities at LCO have reached their capacity with the existing telescopes. GMTO will be providing its own facilities as shown on the Site Master Plan shown in Figure 12. The telescope Enclosure and Control Building will be located at the summit (elevation 2518 m). Facilities necessary for technical support will also be located here. These include the Facility Building where staff offices and labs will be located, the Auxiliary Building adjacent to the Facility Building that will contain large assembly bays for mirror cells and instruments, and the Equipment Building that will house equipment (compressors, electrical switch gear, etc.) used in the operation of the telescope. The primary mirror coating plant will be located in the Auxiliary Building with pumps and power supplies in the Equipment Building.

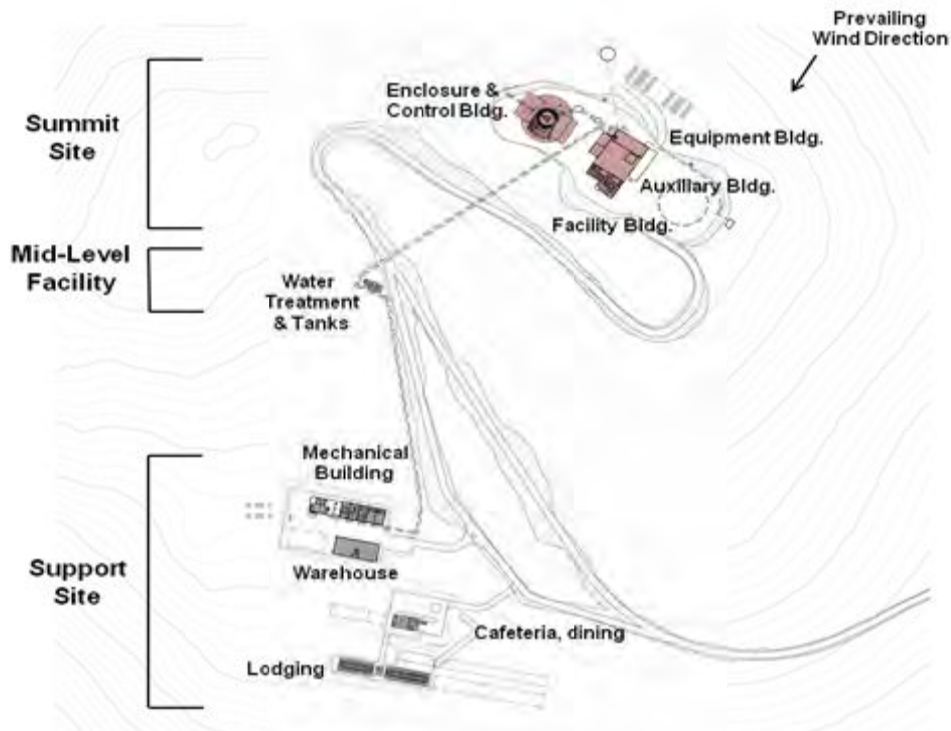


Figure 12 Master Site Plan

A support area with warehouse and mechanical shops, and a dining hall and lodging will be located 134 m and 157 m below the summit respectively.

LCO has a reliable source of water that is pumped up to a cistern on the site from a well at the base of the mountain. Water treatment will be provided locally at the facility. Electrical power will be brought up from commercial sources at the base of the mountain on high voltage overhead lines. An existing 23KV line provides power to LCO. The service will have to be significantly upgraded in order to supply GMT's estimated 1.5MW average load. Commercial power will be backed up by diesel generators.

Clearing and leveling of the site started March 23, 2012. Approximately 55,000 m³ of rock and soil is being cut. Approximately 20,000 m³ of that will be used as fill on the site. The work will be completed in August. The platform when cleared will measure approximately 280 m long by 100 m wide. Figure 13 shows the site in May.



Figure 13 Clearing the GMT site. May 2012.

5.2. Enclosure

The GMT Enclosure is a quasi-cylindrical structure that houses the telescope. Large doors (“shutters”) in front and on top of the building retract to allow the telescope to observe with an unobstructed beam through its full range of azimuth and elevation angle. During observing, the shutters can be closed down around the incoming beam to shield the telescope from excessive wind and moonlight.

The enclosure is comprised of a rotating upper structure that sits on top of a fixed base. The range of rotation is unlimited allowing the shutters to be aligned with the telescope for any arbitrary azimuth setting of GMT. The telescope and enclosure rotate independently of each other through their full range of motion. A circular track at the top of the fixed base (the “ring beam”) and bogies beneath the major structural columns of the upper structure provide the rotation mechanism.

The overall height of the enclosure is 65 m above grade level. The Ring Beam is 14.8 m above grade and approximately level with the top of the GMT azimuth disk and Observing Floor. This puts the elevation axis of GMT at 25.5 m. A 75 metric ton bridge crane at the top of the enclosure will be used in the initial assembly of GMT and for servicing the telescope and equipment during operations. In particular, the crane will be used to exchange primary mirror segments and cells in the telescope for re-coating in the Auxiliary Building. It will also be used for instrument handling.

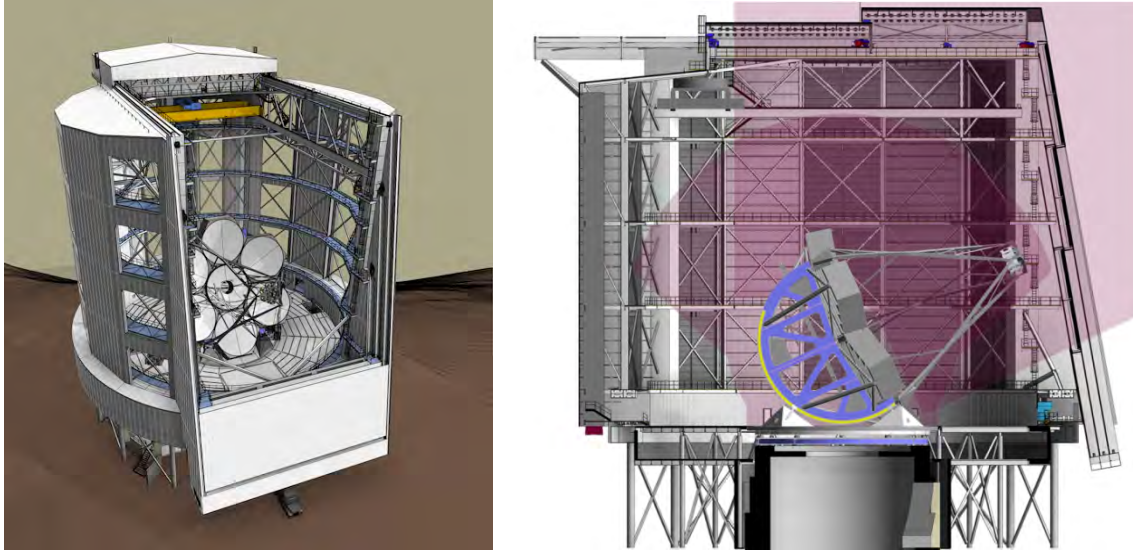


Figure 14 GMT Enclosure

The thermal environment in the Enclosure is critical for seeing-limited imaging. The measures being taken to minimize the effects of dome seeing include:

- Provide a high degree of wind driven flushing through the inclusion of ventilation openings and wide shutters. The current design has an approximately 30% open area with the ventilation windows and shutters fully open.
- Promote rapid equilibration of the enclosure structure by the use of thin cross section structural members. The goal is to achieve a less than 1 hour relaxation time for a major portion of the structure.
- Insulate the building to reduce heat buildup during the day. The walls are made of insulated metal panels and the floor will be insulated from below.
- Seal the openings to prevent air infiltration during the day.
- Select exterior coating to reduce radiative over-cooling at night.
- Cool or trap active sources of heat and exhaust the waste heat well away from the telescope line of sight.
- Actively exhaust the overhead arch girders and the enclosed areas below the telescope chamber.

Extensive wind tunnel testing and CFD modeling of the structure has been conducted. These models included the local terrain of Cerro Campanas and the telescope. The objective was to investigate the wind flow around and through the enclosure, interior flushing times, and compute wind forces on the building and telescope. Various configurations of the shutters and vents ranging from fully open to fully closed have been investigated over a range of wind speed and wind direction. Under the least favorable (10th percentile 3 m/s) low-wind conditions with the enclosure and telescope pointed downwind, complete flushing occurs within approximately 3 minutes in the current design. The method and results of the wind flow studies are described by Farahani, et. al. ³².

6. PROJECT STATUS

6.1. Schedule

GMT is currently in the Design Development Phase leading up to a System Preliminary Design Review in 2013. Subsystem PDRs will be conducted leading up to that. The Project schedule is shown in Figure 15. The schedule is based

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