GMT Concept of Operations Document

GMT Document

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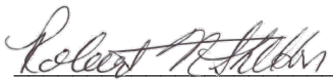

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Revision Log

Revision	Date	Affected Sections	Change Request #	Comments	Change Author
A	04/07/2018	All	GMT-CR-03260	Authorized Release	R. Bernstein
B	10/22/2018	All	None	Minor clerical and typo corrections. Ensure TOC and DocuShare links work properly. Added DocuShare links to documents in Reference section that were non-existent time of Authorize Release at Rev. A	A. Kocz / R. Paredes
C	12/10/2021	All	GMT-CR-05101	Editorial changes throughout including Chilean access, image quality requirements, and facilities use.	R. Bernstein

For detailed revision history in DOORs, click here.

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1 Scope

1.1 System Overview

The Giant Magellan Telescope is one of a new generation of optical/infrared ground-based “Extremely Large Telescopes” designed to provide unprecedented clarity and sensitivity for the observation of astronomical phenomena. The GMT will leverage cutting-edge optics technology to combine seven primary and seven secondary mirrors into a single optical system that can achieve the diffraction limit of the full diameter of the seven-segment primary mirror surface. The GMT Observatory will be located on Las Campanas Peak in Chile, land that is owned by the Carnegie Institution for Science and has been made available to GMTO through a long-term lease. The GMT is intended to execute cutting-edge scientific observations over the full optical and infrared spectrum in all fields of astrophysics with a lifetime of 50 years.

The GMTO Corporation manages the development, construction, and operation of the GMT Observatory. The GMTO Corp. is an independent, not-for-profit 501(c)3 that is recognized by legal agreement with the Government of Chile as an “Organization International,” with permission and authority to operate within Chile.

1.2 Document Overview

This document is one of the top-level formal documents, the "Foundation Documents," that define the GMT Observatory. These documents are projections of the Observatory's requirements database that is maintained using the DOORS software and have either been generated by or are identical to the content in DOORS. As these documents are more widely accessible than the database, they constitute the formally controlled Foundation Documents of the GMT Project. The scope of each document is as follows:

- The *Concept of Operations Document* (ConOps, GMT-DOC-03205) expresses the stakeholders’ and owners’ intention for the Observatory. Through high-level operational objectives and constraints, it describes what the observatory is expected to do.
- The *Science Requirements Document* (SRD, GMT-REQ-03213) quantifies the broad observational requirements needed to address the scientific goals of the Partnership, which are described in the GMT Science Book and the science cases for the first-generation instruments. As the product of the Observatory is the data needed to execute these scientific goals, the SRD is organized into Observing Cases —the data equivalent of Science Cases.
- The *Observatory Requirements Document* (ORD, GMT-REQ-03214) is the response of the GMT Project to the SRD. It contains the top-level engineering requirements for the Observatory that is to be built. It transforms the data specifications for each Observing Case in the SRD into technical specifications for the Observatory Performance Modes.

- The *Observatory Architecture Document* (OAD, GMT-REQ-03215) captures the top-level system design, consistent with the Observatory Requirements. It defines the subsystems and their interactions as they deliver the various System Configurations that enable the Observatory to implement the Observatory Performance Modes defined in the ORD. The OAD also enumerates performance and resource allocations among the subsystems.
- The *Observatory Operations Concept Document* (OpsCon, GMT-OCDD-01776) contains a description of how the operational objectives of the observatory will be met. Plans for staffing and other resources needed to support operations are described in the *Operations Plan* (GMT-DOC-03838).

2 Definitions, Acronyms, and Reference Documents

2.1 Definitions

Table 2-1: Definitions

Term	Definition
Contributors	Individuals or institutions who support GMTO Operations during a given year.
Founders	Founding institutions formed the GMTO Corporation, an independent, not-for-profit 501(c)3 to manage the development, construction, and operation of the GMT Observatory.
Participants	Persons or institutions contributing to the operating cost of the Observatory during any given year of the Operations Phase.
TARFA	*Third Amended and Restated Founders' Agreement* (TARFA) defines the functioning of the partnership and governance of GMTO.

2.2 Acronyms

Table 2-2: Acronyms

Acronym	Description
AAL	Astronomy Australia Limited
ANU	Australian National University
FAPESP	Fundação de Amparo à Pesquisa do Estado de São Paulo
GMT	Giant Magellan Telescope
GMTO	Giant Magellan Telescope Corporation
KASI	Korea Astronomy and Space Science Institute
LCO	Las Campanas Observatory
SAC	Science Advisory Committee

2.3 Applicable Document

Table 2-3: Applicable Documents

Document Number	Title	Manage Link

2.4 Referenced Documents

Table 2-4: Referenced Documents

Document Number	Title	Manage Link
GMT-CON-00873	GMTO Founder's Agreement (TARFA)	TBD
GMT-REF-00481	GMT Science Book 20218	https://bit.ly/2GDEa4U
GMT-REF-00362	GMT Project Acronyms and Glossary	https://bit.ly/3l4reUC
GMT-REQ-03213	GMT Science Requirements Document (SRD)	https://bit.ly/2I9fX7b
GMT-DOC-03227	GMT Science Case Analysis Document (SCAD)	TBD
GMT-OCDD-01776	GMT Observatory Operations Concept Doc. (OOCD)	https://bit.ly/3AEhI1e
GMT-DOC-03229	SRD to ORD Analysis Document	TBD
GMT-RVW-00410	Preliminary Design Review	https://bit.ly/3671BfA
GMT-DOC-01583	GMT Operations: Selecting, Scheduling, and Executing Science Programs	https://bit.ly/38uqeEE
GMTO-DOC-01582	GMTO Science Archive	https://bit.ly/3mPzgVa
GMT-DOC-01925	Emergency Response Plan	TBD
GMT-DOC-01584	GMT Metrics	https://bit.ly/2WEP1Tw
GMT-REQ-03215	GMT Observatory Architecture Document (OAD)	https://bit.ly/3t4ohbb
GMT-REQ-03214	GMT Observatory Requirements Document (ORD)	https://bit.ly/2JylZ1o
GMT-DOC-04038	Transition to Operations Plan	https://bit.ly/38bybOQ
GMT-REF-00144	GMT Environmental Conditions	https://bit.ly/3gyN1nF
GMT-DOC-00127	Site-Specific Seismic Hazard Assessment of Proposed Giant Magellan Telescope Site, Las Campanas Peak, Chile	https://bit.ly/34SkJ1k
GMT-DOC-00243	GMTO Environmental, Health and Safety Policy	https://bit.ly/3rVN0hb
GMT-REF-04976	GMTO EHS Management Plan	https://bit.ly/3t2S2t8
GMT-DOC-03838	GMT Operations Plan	https://bit.ly/2UIHW0h

3 Observatory Heritage and Vision

The GMT partnership formed in 2003 when the members of the Magellan Telescope consortium and other interested scientists began developing concepts for a next-generation optical/infrared telescope. Their goal for the GMT was to achieve a significant gain in sensitivity over the current generation of telescopes by using a significantly larger collecting area paired with full-time adaptive optics to reduce the impact of atmospheric turbulence in all observations and enable diffraction-limited observations of any source in the nighttime sky. As a broad-use, ground-based Observatory with a 50-year lifetime, the scientific mission of the GMT is to enable cutting edge visible and infrared observations in all areas of observational astrophysics — including exoplanet science, the origins of the chemical elements, the formation of the first stars and galaxies, the formation and co-evolution of black holes and galaxies, and the nature of dark matter and dark energy.

The GMT design incorporates many of the key features that have enabled the exceptional performance of the Magellan Telescopes: a Gregorian optical configuration providing high image quality over an exceptionally wide field of view; large, borosilicate mirror segments produced at the Richard F. Caris Mirror Laboratory at the University of Arizona Mirror Lab that provide high image quality and low scattered light; and adaptive secondary mirrors developed by the AdOptica consortium that provide full-time correction of atmospheric turbulence. Further capitalizing on the strengths of the partnership, the GMT Observatory will be built at the Las Campanas Peak in the southern Atacama Desert in Chile, within the boundaries of Las Campanas Observatory (LCO), owned by the Carnegie Institution for Science. This land has been made available to the GMTO by a long-term lease.

In order to fulfill its science mission, the GMT organization will provide services that include:

- Scientific operations – operating the telescope, scheduling, support for execution of observations, data archiving, and data reduction pipelines;
- Technical support – maintenance, servicing, technical documentation, development of new capabilities, and upgrades to facilities;
- Logistical support – transportation, lodging, dining, and observatory infrastructure.

The expectations of the GMTO Stakeholders in these areas are described here at a level that is intended to provide guiding principles and strategies. In general, we envision GMT these services will be efficient and cost-effective. Where possible, we indicate which Stakeholders have authority to decide how those expectations will be met and where those decisions will be documented.

4 GMT Stakeholders

4.1 Founding Institutions and Governing Bodies

In 2008, the founding institutions formed the GMTO Corporation, an independent, not-for-profit 501(c)3

to manage the development, construction, and operation of the GMT Observatory. The GMTO Corp. is recognized by legal agreement with the Government of Chile as a special international organization with permission and authority to operate within Chile. As of 2021, the founders include Arizona State University, Astronomy Australia Limited (AAL), Australian National University (ANU), the Carnegie Institution, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Harvard University, the Korea Astronomy and Space Science Institute (KASI), the Smithsonian Institution, University of Arizona, University of Chicago, University of Texas at Austin, Texas A&M University, and the Weizmann Institute of Science. Additional Partners are anticipated to join the GMTO before the start of operations.

The *Third Amended and Restated Founders' Agreement* (TARFA) defines the functioning of the partnership and governance of GMTO. As specified in the Founders' Agreement, the Founders designate representatives to the Board of Directors, which is the governing body of the GMTO Corp. The Founders' Agreement anticipates the future involvement of "Participants," which are defined as persons or institutions contributing to the operating cost of the Observatory during any given year of the Operations Phase. The role of Participants in governance will be determined by the Board. Founders and Participants during the operations stage are collectively referred to in the rest of this document as "Contributors."

4.2 Scientific Community

Scientific users of GMTO are critical stakeholders in executing GMTO's scientific mission as they propose, conduct, and publish the scientific results enabled by GMTO data. GMTO's primary scientific stakeholders are the astronomy faculty and staff at the Founding Institutions. Long-term stake holders also include Chilean scientists, who will have access to 10% of the time available for scientific observations through the University of Chile as part of operating agreement for GMTO Corp. in Chile. At the discretion of the GMTO Board, the user community will include "Contributors" — individuals or institutions who support GMTO Operations during a given year. The broader scientific community will impact the scientific productivity of GMTO through collaboration with our Founders, Participants, Collaborators, and potentially through use of the GMTO data archive.

The scientific user community is represented through the Science Advisory Committee (SAC) which plays an advisory role to the Board and to GMTO regarding scientific and operational issues during all stages of the development and operation of the Observatory. The SAC members are nominated by the Founders and approved by the Board, one per Founder Institution. The SAC also includes three individuals from the broader scientific community. These community representatives are nominated by the GMTO President and approved by the Board. The input of the broader community has been and will continue to be sought on advisory committees and technical reviews.

4.3 Observatory Staff

The Observatory Staff include staff located at the Observatory, at a sea-level facility in Chile, and at an operations center in North America. During the lifetime of the observatory, GMTO staff will manage,

maintain, and operate the Observatory and play the leading role in enabling the GMTO to meet its scientific and performance requirements. The Observatory staff will also play a central role in the continuous improvement of GMTO and expansion of capabilities that will be required to meet the productivity goals of the Observatory throughout its lifetime (see Section 6). As such the staff are critical stakeholders with unique insight and impact on the success of GMTO.

Technical operations are described in the *Observatory Operations Concept Document* (GMT-OCDD-01776). The structure and organization of the GMTO staff are be described in the *Operations Plan* (GMT-DOC-03838) and approved by the Board of Directors.

5 Facilities

The GMT Observatory will be located at Las Campanas Observatory (LCO) in Chile, which has been owned and operated as a working observatory by the Carnegie Institution for Science since 1963. LCO is located roughly 160 km north of the coastal town of La Serena. The GMTO site at Cerro Las Campanas has been leased to GMTO.

Facilities on the summit will be limited to those required to support and operate the telescope. Additional facilities for any activities that do not require immediate proximity to the telescope will be enabled at support sites off the summit. Living accommodations (lodging, dining, and recreation areas) will also be provided at off-summit sites at the Observatory to support the extended presence of GMTO staff and visitors.

In addition to GMTO staff, individuals at the GMTO working at the site during operations will include visiting scientists, instrument teams, and others not associated with scientific or technical operations (potential donors, students, officials from Founder and Participating institutions). Appropriate spaces for interaction with and observation of day and nighttime operations will be available at the Observatory to support these interactions.

5.1 Sea-level Facilities in Chile

Building on the experience of existing observatories in Chile, we envision off-site support for GMTO at “base” (sea-level) facility located in La Serena. The base facility will provide business, logistical, and administrative support (e.g., purchasing, accounting, personnel transportation, shipping, receiving, and human resources) for GMTO operations in Chile.

As much as possible, the base facility will be used for remote operation for both nighttime observations and daytime activities. The GMTO will be designed to support remote operation.

5.2 North American Facilities

A facility in North America is envisioned as the administrative center for GMTO throughout the life of the Observatory. We anticipate that this headquarters will be located at one of the Founding Institutions. Activities at this center will include basic corporate activities (e.g., business and human resources management, accounting, purchasing/receiving, and administrative personnel) as well as scientific operations and planning, and technical and engineering support.

We anticipate extensive use of virtual connections during operation of GMT for technical, administrative, and scientific purposes. If dedicated facilities for remote observing are deemed necessary when GMTO begins operations, we expect that that each founder will have dedicated facilities at their institution.

6 Environmental Conditions

6.1 Operating Conditions and Survivability

The conditions on the site are documented in the *Environmental Conditions* document (GMT-REF-00144). To enable the 50-year lifetime of the Observatory, the GMTO facilities will be designed and constructed to survive environmental conditions (air temperature, pressure, wind, rain, and snowfall) that occur on a 50-year recurrence timescale. The Observatory will be designed and constructed to enable safe scientific operation during environmental conditions that exist at the site 99% of the time and will be able to take data that meets the science performance requirements 95% of the time during operating conditions. Maintenance and operations will be planned to support these performance expectations.

6.2 Environmental Monitoring

Environmental forecasting and monitoring will be used to facilitate the scheduling of observations and enable real-time response to take best advantage of environmental conditions. This is particularly crucial for the anticipated “queue” or “service” operating modes (see Section 9.2). Monitoring will include, for example, measurements of temperature, pressure, humidity, precipitable water vapor, particulate count, atmospheric turbulence, and seeing. Scheduling and data simulation tools will be used to facilitate planning based on those measurements. Environmental data will be archived to facilitate planning as well as analysis of scientific data.

6.3 Seismic Requirements

Seismic activity at the site is described in the *Site-Specific Seismic Hazard Analysis* (SSSHA) report (GMT-DOC-00127_A). To meet the Founders’ expectations regarding the operability and lifetime of the Observatory, the GMTO will be designed and constructed to withstand earthquakes that have a 50% or

greater likelihood of yearly occurrence without impacting standard maintenance or servicing schedules. The GMTO will also be designed and constructed to survive an earthquake that has more than a 2% likelihood of occurring within 50 years, such that it can be returned to full operation with spares and materials on-site. Allowable time and cost to repair associated with these events will be determined by the Project based on risk and cost assessment.

7 Scientific Performance

The Founders' scientific goals for the GMTO include discovery in all fields of optical/infrared observational astrophysics. The scientific motivation for the GMT is detailed in the *GMT Science Book*, which was written in 2012 and updated in 2018 (GMT-REF-00481). The contemporary science cases identified by the Founders echo the "Decadal Review" reports published by the National Academies of Sciences and the National Research Council that reviewed the state of the field in 2001 and 2010. ("Astronomy and Astrophysics in the New Millennium," National Academies Press; "New Worlds, New Horizons in Astronomy and Astrophysics," National Academies Press).

Observing modes, performance capabilities, and data quality requirements needed to meet these science goals are specified in the Science Requirements Document. In the sections below, we describe additional expectations of the Founders related to scientific performance and operations.

7.1 Image Quality Efficiency

The spatial resolution required to enable the most demanding of the GMTO science cases are discussed in the *Science Case Analysis Document* (GMT-REF-03227) and documented in the SRD. In addition to those best-performance requirements, the scientific impact of the Observatory will depend on the median image quality delivered over time.

To guarantee the efficiency of the Observatory, the Observatory should not significantly degrade the atmospheric seeing in any standard operating mode. Specifically, the following image quality performance will be delivered in median environmental conditions (e.g., temperature, temperature gradient, atmospheric pressure, and wind).

- The GMT Observatory will be able to perform small field visible observations with an image FWHM <1.20 times natural seeing FWHM at 0.5μm at least 75% of the time.
- The GMT Observatory will be able to perform small field IR observations with an image FWHM <1.25 times natural seeing FWHM at 1.65 μm at least 75% of the time.
- The GMT Observatory will be able to perform medium field visible observations with an image FWHM <1.20 times natural seeing FWHM at 0.5μm at least 75% of the time.
- The GMT Observatory will be able to perform medium field IR observations with an image FWHM <1.25 times natural seeing FWHM at 1.65 μm at least 75% of the time.

- The GMT Observatory will be able to perform wide field visible observations with an image FWHM <1.25 times natural seeing FWHM at 0.5μm at least 75% of the time.

This image quality pertains to zenith angles less than 15 degrees and is expected to decline with airmass and with decreasing wavelength according to standard scaling laws.

7.2 Observing Efficiency

A wide range of functional performance factors will impact observing efficiency. In general, the GMT will be designed to facilitate on-sky observing efficiency and will monitor performance in operation to facilitate continuous performance improvement. The Founders' expectations for observing efficiency include the following:

- The GMTO will be able to move and acquire a new target anywhere on the sky in less than 600 seconds using any observing mode or instrument, and in less than 180 seconds when using the same observing mode and instrument used on the previous target.
- The GMTO will be able to move, acquire a new target, and begin observations rapidly when moving small distances on the sky using the same observing mode and instrument. Specifically, it will be possible to move by < 1 degree on the sky and begin an observation of a new target within 5 seconds, or by < 0.1 degrees to begin an observation within 2 seconds.
- To facilitate optimal scheduling of observations in dynamic environmental conditions, science instruments will be available for use when mounted on the telescope within 15 minutes for medium and wide field instruments and within 10 minutes for narrow field instruments.
- To the extent that it is scientifically useful and technically feasible, the simultaneous use of multiple instruments will be enabled.

Criteria relevant to evaluating operational efficiency are discussed further in Section 11.

8 Instrumentation

As described in the 2013 *System Level Preliminary Design Review Report* (GMT-SE-RVW-00410), the Founders selected a suite of first-generation instruments that provide broad capabilities for the first decades of GMTO operation, but does not include instrumentation to enable specialized observations for high contrast imaging of exoplanets, for example. The scientific impact of the Observatory over its lifetime will depend on the continuous expansion of observing capabilities through new instruments and potentially new observing modes. The GMTO will therefore support ongoing instrumentation development, guided by the SAC.

Experience shows that the most scientifically productive instruments are motivated and developed by scientists and instrumentation teams engaged in observing programs and observatory operations. To facilitate innovation, the GMTO will support and encourage interaction of scientists and instrument

teams through use of classical observing modes.

The GMTO Staff will coordinate development to the degree necessary to guarantee effective integration, operation, and maintenance at the telescope. The process for review and coordination will be approved by the SAC and Board before the Operations phase begins. At a minimum, all instruments will pass a pre-ship review before being delivered to the Observatory. Installation and commissioning of new instruments will be conducted in coordination with the instrument's development team and GMTO observatory technical staff.

8.1 Facility Instruments

Facility Instruments are those developed for standard operation and may be scheduled for observing programs by any GMTO user. We anticipate the development of new facility instruments and significant upgrades to existing instruments at a rate of one every three to five years during Operations. New Observing Modes (specified in the ORD) may be developed as needed and appropriate to support new instruments.

Solicited or unsolicited proposals for Facility Instrument concepts and upgrades may be submitted by instrument teams at Founders' institutions to the SAC for review. Proposals that are endorsed by the SAC and approved by the Board will be developed in coordination with GMTO staff. The details of this approval process will be developed and documented in the Operations Plan (OP), prior to the start of operations.

Funding for Facility Instruments may be allocated in the annual operations budget. External funding will also be encouraged. Founders will have a responsibility to contribute, technically and financially, to the development of new instruments. Strategies to balance these contributions will be approved by the Board prior to the start of operations. The SAC has endorsed the incentive of guaranteed observing time for the instrument teams.

The process for development and acceptance of Facility Instruments will be documented by the GMTO Project prior to operation. All facility instruments will provide documentation sufficient to enable experienced observers to plan and execute observations in all supported operating modes. This will include a description of the basic design of the instrument, supported observing modes, performance characteristics, calibration requirements, set-up procedures, and recommended observing strategies. Instrument teams will provide open-source, quick-look data tools and reduction pipelines to deliver science-ready data at the time of instrument acceptance.

The Operations Plan will define the process by which GMTO Staff work with the instrument teams to commission instruments. Commissioning activities will begin only after the instrument teams have demonstrated that all instrument modes meet technical requirements and all software tools, interfaces, data pipelines, and documentation are completed. Because of the complexity of the GMTO instrument interfaces, the GMTO Staff will take primary responsibility for guaranteeing the safety of personnel and equipment during commissioning. The GMT Observatory will have responsibility for instrument maintenance, minor improvements, and performance monitoring only after the instrument has completed

commissioning and is accepted for general use. The Operations Plan will describe a process by which GMTO staff are trained in the operations and maintenance of a new facility instrument (hand-over). GMTO Staff will also make arrangements with the instrument developers to provide on-going technical support beyond standard maintenance. Appropriate laboratory and storage space will be available at GMTO to support the assembly, commissioning, maintenance, and servicing of facility instruments.

8.2 Visitor Instruments

To broaden the scientific capabilities of the observatory, the GMTO will support “Visitor Instrument” program. The GMTO Staff will not assume the responsibility for instrument support or maintenance, but will have shared responsibility during all instrument handling, commissioning, and installation activities, and during observations to guarantee the safety of GMTO hardware and personnel. Visitor Instruments will comply with all safety requirements and interface specifications to ensure the safety of GMTO hardware and personnel and to assure that normal operations are not compromised by, for example, vibrations or electromagnetic disturbances. Visitor Instruments must pass a pre-ship review with criteria established in the Operations Plan and by the GMTO staff before arrival at the Observatory.

Data from Visitor Instruments will be archived, however the availability of that data to the GMTO partnership or broader community will be negotiated with the instrument’s PI before it is brought to GMTO and approved by the Board.

9 Science Operations

Science operations include a broad range of activities related to proposal submission and time allocation; scheduling and execution of observations; and data handling, archiving, and reduction. The current Founders envision an efficient and cost-effective operations model in the style characteristic of the privately funded U.S. observatories (e.g., Keck, Magellan, MMT, LBT).

9.1 Allocation of Observing Time

Guidelines for the allocation of observing time are provided in the Founders' Agreement. The scientists at the Founders' institutions have provided additional recommendations for both time allocation and operating modes (see the GMTO SAC white paper on *GMTO Operations: Selecting, Scheduling, and Executing Science Programs*, GMT-DOC-01583, Rev. A). The details of the time allocation strategy will be described in a report on the “Time Allocation Procedure,” which will be provided by the GMTO President for review and approval by the Board three years before the commencement of the Operations phase. Modifications are anticipated periodically during operations based on the experience of the GMTO staff and the Contributors.

Based on the above input, the majority of observing time will be allocated to individual investigators (or teams), with some time reserved for multi-year programs or "key projects." Proposals will be submitted to the appropriate GMTO-led and Partner-led Time Allocation Committees (TACs), with results combined by a Merging TAC. An observing schedule would be developed by GMTO staff based on the merged results. The details of the merging process, the fraction of time to be allocated by each TAC, and the strategies of the scheduling algorithms will be developed in the Operations Plan and Time Allocation Procedure report. The central goals of the allocation process will be to encourage collaboration between the scientists at Contributing institutions, to enable Contributing Institutions to meet their individual scientific and programmatic goals, and to balance time allocation between the Contributors per the Founders' Agreement. The details of this process will depend on the membership of GMTO Corp. at the start of operations and will no doubt be revised over the lifetime of the Observatory.

The majority of the observing time will be allocated to Founders, Participants, and Contributors, those individuals or institutions that have supported the capital cost of the facility and the annual operations cost. Founders' time will be allocated in proportion to their Founders' shares, derived from their time-weighted contributions to construction. Participants' time will be allocated in proportion to contributions to the annual operations budget. The relative weighting between Founders' and Participants' time will include time- and risk-weighted considerations over the life cycle of the facility. The allocations will be reviewed and approved by the Board annually. The Founders' Agreement allows for observing time to be allocated to groups that are neither Founders nor Participants (collectively, "Contributors") and other entities at the discretion of the GMTO Board.

9.1.1 Director's Discretionary Time

The Founders' Agreement allows for "President's Discretionary Observing," which is allocated by the GMTO President (or equivalently the Director of GMTO during operations) for projects, individuals, or to institutions. The GMT Founders' Agreement specifies that the total observing time allocated in this way will not exceed 5% after Engineering Time is deducted (see Section 11.3).

9.1.2 Proposal Process

The SAC has recommended that the proposal process include multiple phases to facilitate review and scheduling of proposals. A single, uniform proposal template will be used for proposals reviewed by all Time Allocation Committees for both the proposal phase (sometimes called "Phase 1") and the scheduling/execution phase (sometimes called "Phase 2"). The GMTO will develop the formats and templates for these proposals prior to operations.

9.1.3 Partner Share Balancing

Balancing time allocations of the individual Contributors, efficient scheduling of observations, and completion of observing programs within a single observing season are all in the interests of the

Contributors and their scientists, as well as GMTO. To optimize all these interests, partner shares may not be balanced in each observing season. The SAC has also recommended that the balancing of partner shares, including by season and moon phase, should be maintained on timescales no longer than three years to maximize the scientific return and operational efficiency of the Observatory with the fair distribution of observing time to the Contributors.

9.2 Operating Modes

Operating modes describe the ways scientists will be involved in collecting data during operations. (These are not to be confused with "Observatory Performance Modes," or OPMs, which describe the telescope wavefront-control strategies, such as natural guide star adaptive optics). While some observing programs can be clearly prescribed and executed according to a pre-determined schedule, others will benefit from dynamic planning that demands the involvement of the proposing scientists. A range of operating modes, described below, will therefore be supported by GMTO during steady-state operations with the goal of maximizing the scientific productivity of the Observatory for both routine data collection and more exploratory observing programs.

9.2.1 Automated Observations

In all operating modes, "scripted" blocks of telescope and instrument commands will be used to execute the observations to assure that observing time is used efficiently during nighttime operations. However, during all operating modes, accommodations should also be made for real-time adjustment of the observing programs based on the observer's judgement to improve scientific results.

9.2.2 Queue Operating Mode

The baseline operating mode for GMT will be Queue (or "service") Operating Mode. In this mode, GMTO staff observers will carry out observations that have been drawn from a suite of approved programs making best use of forecasted environmental conditions. Programs will be scheduled based on their TAC ranking, data requirements, and environmental conditions to optimize scientific impact and efficiency on any given night. The principal investigators (PIs) of any program will be alerted when their observations are scheduled within a given time period (1-5 nights).

PIs and their teams will be welcome and encouraged to participate as advisors or "watchers" of the observations, either on-site or remotely. This involvement will be important for the involvement of the community in GMTO, for future instrument development, for increasing coordination between the GMTO its Stakeholders, and for the overall scientific productivity of the Observatory.

This operating mode has been endorsed by the SAC for baseline operations.

9.2.3 Investigator-Directed ("Classical") Operating Mode

GMTO will support an Investigator-Directed Operating Mode in which specific hours or nights are allocated to an individual or team to execute a specific observing program. Investigators who are unfamiliar with the Observatory will be encouraged to travel to the site to direct all (day- and night-time) operations associated with data collection during their allocated time. Observations will be executed under the direction of the investigator, subject to safe operating limits of the facility.

This mode is required for commissioning of new instruments, but it is also important for long-term programs in which investigators develop techniques or experience that improves, for instance, data quality, data consistency, or observing efficiency.

Staff observers will be needed to provide support for scientists using the GMTO in Investigator Directed mode (see below). The default level of support will be similar to that needed in queue operations. In addition to telescope operators and instrument/AO specialists, GMTO staff observers will be available to assist Investigators with quick-look data reduction and otherwise facilitate efficient use of observing time. Experienced GMTO observers may lead this mode from remote sites or on-site. Their collaborators may participate on-site or from remote sites.

This mode is endorsed by the SAC for use a minority of the time and to the extent that it does not prevent efficient execution of queue-scheduled operations. This limitation will apply to individual Contributor as well as in the aggregate.

Some institutions may choose to provide their own "service observing" program within a block of time scheduled to a single Institution. This is operationally equivalent to an Investigator-Directed mode from the operations perspective and for the purpose of time allocation.

9.2.4 Remote Observing

Remote access for investigators will be supported in all Operating Modes during steady-state operations. Locations from which remote access is available will include at least one site at the North American Facilities and may include sites at the Founders' institutions. Access from a broader range of locations will be enabled at the discretion of the GMTO staff. Investigators may choose to participate remotely via a passive "eavesdropping" mode during Queue Operations. In standard operations, GMTO will provide the same level of support for remote and on-site participants in Investigator Directed operations. Remote operations sites will be developed collaboratively with GMTO staff and will comply with technical standards set by GMTO to ensure efficient and safe operations.

9.2.5 Non-Standard Operating Programs

The GMTO Contributors may be allocated time for non-standard programs, including large or long-duration programs for which scientific results require a complete data set, or programs for which an

"interrupt mode" is required to observe rare transient sources. Time for such projects may include the time allocations of any number of Contributors. Strategies for supporting such observing programs will be developed by the GMTO in the Operations Plan. GMTO will be designed and constructed to support rapid acquisition of such targets and switching between instruments to enable these science goals and facilitate efficient scheduling.

9.2.6 Early Science Operations

Early science operations are assumed to take place between the time when "science first light" occurs and when the project has reached steady-state operations. This period is expected to begin within 12 months of the installation of four primary mirror segments and four secondary mirror segments on the telescope structure. Steady-state science operations will begin within 36 (TBC) months of the installation of seven primary mirror segments and seven secondary mirror segments on the telescope structure. The beginning of steady-state operations will be at the discretion of the GMTO Project and will be approved by the Board. The definition of early science and standard operations may be revised in the Project Execution Plan or Operations Plan during the Construction Phase.

10 Data Management

10.1 Data Formats and Compatibility

Science data collected with GMTO will be delivered in common data formats that are compliant with world-wide Virtual Observatory standards as defined at the time of the instrument preliminary design reviews. The baseline format will be the "Flexible Image Transport System" – FITS. The particular version(s) of FITS supported (e.g., multiple image extensions) will be specified by the GMTO Project as part of the instrument data system development.

10.2 Data Processing Tools

Data reduction tools will be available for all facility instruments to produce data products that enable capable observers to assess data quality within one minute of the completion of an exposure. Such "quick-look" tools will be provided by the instrument development teams for all supported observing modes.

Visiting instruments must demonstrate that data quality can be rapidly assessed during standard use on the telescope to ensure successful and efficient operations at the discretion of the GMTO staff. Quick-look tools will also be provided by the instrument teams to enable assessment and monitoring of instrument health and calibration by GMTO staff. For all standard observing modes, GMT Observatory will provide processed data appropriate for scientific analysis that have passed quality control within 24 hours of observations [goal: 1 hour].

10.3 Data Reduction and Calibration Pipelines

To facilitate publication of data and maximize the scientific impact of the GMTO, data reduction tools will be available to complete basic data reduction processing for any data taken with facility instruments in all supported observing modes. These data "pipelines" will remove instrumental signatures and perform basic data reduction steps such that the data are ready for scientific analysis and publication[2]. These pipelines will be developed and provided by instrument teams and maintained by the GMTO Staff throughout the lifetime of the Observatory. Completion criteria for data pipelines will be determined on an instrument-by-instrument basis by the GMTO Project during Construction or by the GMTO Staff during Operations. Pipelines will be made available to use off-site through the data archive. (See below).

[2] We refer to data reduction as standard data processing steps that are independent of the observing program and do not require the judgement of the scientific investigator to execute (e.g. bias subtraction, flat fielding, flux calibration, wavelength calibration, and data cube assembly). We refer to data analysis as steps which are observing-program specific or require the input of the investigator.

10.4 Data Archiving

GMTO will maintain a data archive for the lifetime of the Observatory. The essential functions of the data archive are: (1) to capture and curate raw scientific data for safe keeping, (2) to provide and associate scientific data with appropriate metadata, (3) to provide and associate data with the relevant data reduction tools, (4) to increase the scientific productivity of the GMTO by facilitating the efficient distribution and reduction of data, and (5) to facilitate the use of GMTO data beyond the originally-proposed scientific programs, for the assessment of Observatory operations, and for engineering diagnostics.

The SAC has produced a white paper, *GMTO Science Archive* (GMT-DOC-01582, Rev. A), which describes important characteristics of the data archive and potential strategies for achieving those capabilities. The archive will be developed and supported during operations with these guidelines in mind, balancing cost and performance.

10.4.1 Science Data

The data archive will include all data taken as part of any scheduled observing programs. Calibration data and metadata will be archived and associated with science data to support data analysis and evaluate the performance of the Observatory. Metadata may include such information regarding: the observing target; exposure details; the configuration of the enclosure, telescope, and instruments; environmental conditions; astronomical conditions (e.g., moon coordinates and distance from the science target); and proposal information. To facilitate rapid data reduction and publications of scientific results, data pipelines and quick-look tools provided by all instrument teams will be "open source" and available in the archive.

The Operations Plan will specify the extent to which the GMTO will support processed data products, such as publication- and analysis-ready data (individual science-ready exposures and final data products such as co-added or mosaicked images).

In addition to the archive, all science data obtained at the GMTO using any instrument will be stored in raw form by GMTO for at least the life of the instrument. These data will be available without requiring a network connection to either the sea-level facility or to the site of the primary data archive.

10.4.2 Engineering Data

GMTO will collect and archive selected engineering data from the telescope, instruments, and AO systems to assess the status of hardware, diagnose failures, refine observing processes, and assess operations. These will be accessed through an engineering data management system that will be developed during the construction phase of GMTO.

Engineering data will be archived for the life of the observatory.

10.4.3 Data Access

The GMTO will provide access to raw data and “quick-look” products to Principal Investigators and their collaborators within 1 hour of observations [goal: 5 minutes] from any location in standard operation. For data taken in all standard observing modes with facility instruments, GMTO will provide access to processed data products appropriate for scientific analysis within 24 hour of observations [goal: 1 hour]. GMTO will provide the support necessary to assure the quality of these data products.

The SAC has endorsed the implementation of proprietary data periods to protects the interests and investment of Principal Investigators and the Founder Institutions, and to protect students and postdocs conducting research critical to their career development. To maximize the scientific productivity of the GMTO, the SAC also endorses a policy of open data access that would include the Contributors and potentially the broader community after the proprietary period has passed. The data access policy is subject to approval by the GMTO Board.

11 Observatory Technical Operations

11.1 Lifetime

The Founders intend GMTO to be a long-lived, ground-based observatory with an operational lifetime of at least 50 years. It will be designed, constructed, and operated to enable high scientific impact throughout that lifetime. All GMTO facilities (e.g., enclosure, telescope structure, telescope optics,

instruments, and observatory infrastructure) will require routine maintenance and servicing and investment in new instrumentation and upgraded facilities to remain scientifically competitive throughout that lifetime. This will require continuous investment during the Operations phase, which will be part of the Operations budget.

11.2 Nighttime Operation

The GMTO is being planned and designed for nighttime observing only. Nighttime here is defined as the time between the end of evening civil twilight and the beginning of morning civil twilight. At these times, the center of the sun is 6 degrees below the horizon. For Las Campanas, this time interval corresponds to an annual mean of 10 hours per 24-hour period in the mean. GMT will be operable outside those hours for calibrations, following the specifications in the *Observatory Operations Concept Document*. The GMT SAC has not identified any compelling science that requires daylight observations and none are included in the GMT Science Book.

11.3 Maintenance Time

Observatory maintenance and periodic servicing will periodically impact the availability of the telescope for nighttime science operations. Engineering nights will be scheduled regularly to perform such activities. The Observatory will be designed and constructed to enable the Observatory to operate with less than 10% of the total available nighttime hours allocated to engineering in standard operations. Maintenance Time and Commissioning Time are included as Engineering Time in the GMTO Founders' Agreement.

The annual allocation of nights for Engineering Time will be determined by the GMTO President (or Director), in consultation with the Board.

11.3.1 Engineering Time

Maintenance Time is defined as nighttime scheduled for routine maintenance operations that preclude science operation. Examples include mirror recoating, installation and assessment of a science instrument after initial commissioning, and testing and recalibration of telescope systems that must take place at night.

The GMT will schedule time on the telescope to carry out engineering and development activities, as well as preventive maintenance that is not time critical. Appropriate time for maintenance will be assessed by the GMTO Staff in operations and allocated such that downtime (due to unplanned technical failures or repairs) is kept within the prescribed limits, scheduled servicing and upgrading of the facilities can be supported, and new subsystems (including instruments) can be commissioned.

11.3.2 Commissioning Time

As a portion of the total Engineering Time allocation, time will be planned for commissioning new facility science instruments, AO system components, and other capabilities. In steady-state operations, the GMT Observatory will schedule no more than 15 nights (4% of the available nights) per year for instrument commissioning. This assumes no more than one new major instrument per year. Commissioning time for all facility instruments will be approved by the GMTO Board based on recommendation of the GMTO President (or Director) as part of the authorization process for new instruments and capabilities.

11.4 Down Time

Downtime is defined as any observing time lost due to unplanned hardware or software failures. The most efficient 8-m class observatories achieve technical downtime in the range of 2% in steady state operations. The GMTO will be designed, constructed, and operated with less than 4% [goal of 2%] of the total time available for science operations lost to technical downtime. Time allocated for Engineering time, lost to poor environmental conditions, or lost to non-technical interruptions will not be counted in this percentage.

11.5 Instrument Support

As described above, the development, maintenance, and operation of facility instruments and the use of visitor instruments will be supported by the GMTO throughout the lifetime of the Observatory. The details of this support will be described in the Operations plan consistent with the expectations provided below.

11.5.1 Instrument Lifetimes

Previous generations of ground-based observatories have shown that successful instruments with broad scientific capabilities are likely to be in high demand for more than 30 years and potentially throughout the lifetime of the observatory with appropriate upgrades to key components (e.g., detectors). Long instrument lifetimes allow the capabilities of the Observatory to build over time in a way that is both scientifically advantageous and cost-effective for the partnership. For these reasons, Facility Instruments will be designed, constructed, and maintained to have a scientific lifetime of at least 10 years.

11.5.2 Instrument Stations

The GMT will provide multiple instrument mounting locations that can support a range of observational capabilities as described in the SRD. Mounting locations will be such that instruments can be maintained

in an observation-ready state to enable rapid switching between instruments during the night and to minimize the frequency of daytime changes. Rapid switching between instruments will support time-critical observations and enabling the execution of observing programs matched to the environmental conditions. Time critical events include both predicted astronomical events such as exoplanet transits of their parent star and unpredicted transient events, also called “target of opportunity” observations.

11.5.3 Instrument Calibration

Facilities will be provided by the GMTO to enable the daytime calibration as required to facilitate efficient nighttime operations. This will include, at a minimum, strategies to enable wavelength calibration and flat-fielding of wide-field instruments, and the calibration and alignment of the telescope itself. The strategies (hardware, software, and operational procedures) will be such that observations of scientific targets may begin promptly at the start of astronomical twilight. “Quick-look” data tools will have access to the calibration information necessary to enable rapid data processing.

11.6 Support for Scientists

User support refers to the documentation and services provided to the GMTO community to facilitate scientific use of the Observatory and data archive. GMTO will provide assistance in at least the following areas:

- Proposal preparation and program planning (phase 1 and 2 tools as needed, web forms, software).
- Planning and execution of observing programs.
- Use of facility instruments.
- Data reduction and calibration for facility instruments.
- Data retrieval from the science archive.
- Logistics of travel to GMTO (e.g., ground transportation, lodging, computing support).

11.7 Safety

The GMTO Stakeholders are committed to providing a safe and healthy working environment for all those involved with GMTO. The philosophy, strategies, and procedures that will be implemented by GMTO regarding the health and safety of the Observatory, its personnel, and the environment are described in the *Health, Safety, and Environmental Policy Document* (GMT-PM-DOC-00243, Rev. A) and the *GMTO EHS Management Plan* (GMT-REF-04976, Rev. A).

As described in these documents, the GMTO will be designed to minimize risks to personnel and equipment. During the construction phase, all critical operations (e.g., primary mirror handling

procedures, instrument handling procedures) will be reviewed for safety. During the operations phase, strict safety practices and procedures will be defined for all operations and safety reviews will be conducted on a regular basis.

The GMTO will document environmental health and safety regulations related to construction and operations, such as emergency response plans, hazard analysis plans, and design regulations relevant to construction, shipping, work environment, and operations. GMTO will have safety personnel on site during construction to oversee and enforce all aspects of personnel and hardware safety and will conduct periodic reviews of the Safety Plan and compliance with it. Safety personnel will train all employees regarding personnel and hardware safety as appropriate to their involvement. The Observatory shall maintain a policy of "open reporting" with regard to all issues related to health and safety of the observatory and personnel.

Environmental conditions at the site will be monitored to ensure that the Observatory is operated only during safe conditions and is secured when conditions deteriorate outside of operational ranges. The GMT *Emergency Response Plan* (GMT-DOC-01925, Rev. A) will include evacuation planning to ensure the safety of personnel when necessary.

During the construction and operations phases, the health and safety of GMTO personnel and equipment is the responsibility of the Board and President of GMT. To the extent that they are involved with development of GMTO subsystems, Founders' will govern the activities at their institutions, however subsystems must be designed and fabricated to safety standards established by GMTO.

12 Performance Assessment and Improvement

The GMTO is committed to meeting the scientific goals of the Founders through a process of continuous improvement that incorporates feedback from the Founders, scientists, and staff. The SAC has produced a White Paper (*GMT Metrics*, GMT-DOC-01584, Rev. A) that describes the performance criteria that are of interest to the scientific stakeholders, including potential metrics by which those criteria could be monitored. The GMTOs operations planning, evaluation, and continuous improvement strategies will incorporate these and other criteria for assessing the scientific and technical performance of the GMTO, following the specifications below.

12.1 Assessment of Technical Performance

The GMTO will develop a strategy for consistent monitoring and tracking of Observatory performance to support maintenance, troubleshooting, and performance improvement. Tools and strategies will be developed to enable the status of all critical subsystem to be monitored from a single control "station" (physical or electronic) to facilitate the prompt identification of long-term performance problems that may impact nighttime operations.

12.1.1 Daytime Operations

The GMTO Project will develop processes for assessing the health of the Observatory and all subsystems, including facility instruments, during routine daytime operations. These will incorporate the operational strategies and recommendations of the subsystem development teams as well as feedback from Observatory staff during commissioning.

Metrics will be developed to monitor the efficiency and effectiveness of daytime operations. These will include:

- Maintenance efficiency – time spent engaged in reactive engineering efforts (in response to failures or errors) as opposed to time spent proactively improving performance or developing new capabilities.
- Telescope and instrument release times – the time of day at which the telescope and instruments are made available each day for scientific operations.
- Time spent on instrument calibration during daytime versus nighttime operations – the effective use of daytime for preparation of the instruments.

12.1.2 Nighttime Operations

The efficiency and effectiveness of nighttime operations contributes directly to the scientific impact of the Observatory. Statistics related to all functional and scientific performance requirements for the Observatory are of interest. A subset of metrics that will be developed include the following:

- Efficiency of nighttime initialization procedures for all subsystems.
- Instrument switching times
- Instrument configuration accuracy, efficiency, and completeness
- Target acquisition efficiency, including enclosure positioning, telescope slewing, and guiding initiation.
- Time required for and accuracy of instrument calibration.
- Total open-shutter time on the scientific targets.

12.2 Assessment of Scientific Performance

12.2.1 Data Quality Metrics

The GMTO will monitor all characteristics for which science requirements have been defined. Those that can be measured using “quick-look” data tools will be monitored as part of nighttime operations. The

most important of these are throughput, image quality, and astrometric stability. Throughput of the instruments and telescope will be monitored separately to support maintenance of each. Image quality characteristics that will be monitored during observations will include, for instance, encircled energy (or PSSN), Strehl ratios in diffraction limited modes, and PSF characteristics (stability, uniformity, etc.) at the focal plane of the telescope and instruments. Additional metrics will be developed utilizing processed data products that can be used to monitor the performance of instruments (e.g., fiber throughput or instrument flexure) and support their maintenance. The GMTO staff will be responsible for identifying performance trends.

12.2.2 Time Allocation and Scheduling

The GMTO will develop a Time Allocation Plan that includes strategies for accounting of observing time to each Contributor, including moon phase, season, and total time allocations. The Observatory will maintain statistics regarding the total distribution of observing time per instrument, per Observing Performance Mode (e.g., diffraction-limited vs. seeing-limited small field IR spectroscopy), and per observing mode (e.g., queue vs classical). Additional statistics relevant to the effective use and planning of observations will be tracked. These will include, for example, the percentage of completed scientific programs, the total observing time invested per program, the effectiveness of the queue-scheduled observations, and the fraction of time spent on “interrupt” observations (“target of opportunity” observations for which other scheduled observations are interrupted). Metrics related to the effectiveness of queue observations may include, for example, the effective utilization of environmental conditions and the efficient completion of programs.

12.2.3 Archive Use

The Observatory will track the use of the archive, as it does in operating modes, to assess the effectiveness of the archive for science. Potential metrics include the total number of papers produced, the number of citations to the archive, the total number of observations extracted, searches executed, total uptime, and the number of unique users.

12.2.4 Scientific Productivity

The fundamental product of the Observatory is data. Scientific publications that result from those data can only be produced by scientists, and the rate of those publications will be influenced by the policies adopted by each Contributor to encourage rapid publication. In addition, the scientific metrics that are of most interest to each Contributor will vary. With those caveats, the scientific productivity is of great interest to the GMTO and its Founders, and the GMTO will monitor a wide range of metrics with the goal of developing strategies that will increase that impact. Such metrics will include:

- The number and impact of publications for standard and long-term science programs.
- The number and value of external grants associated with GMTO science programs.

- The number of PhD theses based significantly on GMTO data.
- The number of undergraduates at GMTO institutions involved in GMTO science programs.
- The number of Contributor institutions collaborating per proposal.
- The number of non-Contributor institutions collaborating per proposal.

The SAC has also advocated that GMTO invest in higher risk scientific programs that may have higher impact on short timescales. Such proposals could be explicitly identified and time allocation committees may choose to allocate some fraction of observing time to programs which have high scientific merit regardless of their estimated risk of success, be it scientifically, technically, or operationally.

12.3 Assessment of Contributor Satisfaction

Feedback will be collected regarding all Observatory services, including the application process, the scheduling process (sometimes called “phase 2”), execution of observations, data quality, data completeness, the data archive, and data processing. The GMTO may choose to develop a “user committee” to provide users with a channel for communicating with the GMTO staff and Board if the SAC does not serve this purpose during Operations. The GMTO will also solicit staff feedback during operations.

12.4 Assessment of Public Relations

It is in the best interests of the GMTO and the Contributors’ institutions to develop and maintain visibility with the public and the scientific community. This effort should be assessed by professional development and outreach staff, and may include the following metrics:

- The number of Press Releases issued per month that refer to GMTO.
- The number of K-12 students, undergraduates, and graduate students participating in GMTO-related outreach and/or education programs.