GMT Observatory Requirements Document

GMT Requirements Document

Document ID: GMT-REQ-03214	**Revision:** Rev. E
Date: 10/04/2021	**Status:** Released
Authors: B. Walls, A. Bouchez, B. Goodrich, M. Cox, R. Milan-Gabet, J. Molgo, C. Peng, A. Santana, B. Sitarski, A. Souza, G. Angeli	

Signatures

Author

06/04/2021

A. Santana, Systems Engineer Date:

Approvers

10/01/2021

B. Walls, Project Systems Engineer Date:

10/02/2021

D. Ashby, Project Engineer Date:

10/01/2021

R. Bernstein, Project Scientist Date:

08/31/2021

W. Burgett, Deputy Project Manager Date:

10/04/2021

J. Fanson, Project Manager Date:

Revision Log

Revision	Date	Affected Sections	Change Request #	Comments	Change Author
A	04/06/2018	All	GMT-CR-03251	Authorized Release	G. Angeli
B	10/22/2018	All	None	Minor clerical and typo corrections. Ensure TOC and DocuShare links work properly. Added DocuShare links to documents in Applicable and Reference section that were non-existent at time of Authorize Release at Rev. A	A. Kocz / R. Paredes
C	04/07/2019	All	GMT-CR-04236	Wavefront Control NGAO Wavefront error (ORD) Environmental Conditions ORD/OAD changes and flowdown based on standard year statistics Logistics -> Move ORD and OAD into new template for export in DOORS. Underlying changes with small cosmetic effects on export. Seismic Related (ID Req 36688, 70772).	B. Walls, A. Bouchez, B. Sitarski
D	10/13/2020	All	GMT-CR-04416	ORD GMT Standard Handling New REQ-L4-ORD-93987 Requirement Regulations, Codes and Standards, and Removed previous Requirements. (Section 3.7) Observatory Conf by OP Mode updated KPP updated (Section 3.3) Definitions of Throughput and Effective Collecting Area (Section 3.3)	B. Walls, A. Bouchez, B. Sitarski, A. Santana
E	10/04/2021	3.3.3, 3.3.4, 3.3.5, 3.3.6,	GMT-CR-05003	Added TBC to REQ-L2-ORD-2572 and Updated value with flux ratio noise value that B. Nemati presented at the WFC	A. Santana, B. Sitarski,

		3.4.2, 3.6, 3.3.2, 3.3.4, 3.3.5, 7 1.7, 3.1.1, 3.3.1.1, 3.3.2, 3.3.4, 3.3.5, 3.4.2, 4, 7, 8, 3.3.1, 3.3.4, 3.3.6, 2.4.2		Architecture PDR (2 ppm). Added TBX Closure Plans for all Existent TBXs. It is in the table at the end of the document. Removed Section 4 since it is applicable to the SEMP document. Added new 2 Requirements: REQ-L2-ORD-110047, Base Facility, and REQ-L2-ORD-110869, Internal Communication System. Added paragraph in 3.3.1.1 with the explanation about the approach for Natural Seeing wavefront control mode in ORD. Rephrased the rationale for new Requirement added: REQ-L2-ORD-106537: On-Axis Effective Collecting Area Rephrased the rationale for new Requirement added: REQ-L2-ORD-110869: Internal Communication System Rephrased the new paragraph for Section 3.3.1 Observing Performance Modes about the Natural Seeing Wavefront control mode Rephrased the Section 3.3.4 Other Parameter Definitions.	B. Goodrich

For detailed revision history in DOORs, click here.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 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 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]) describes how the Observatory design described in the OAD will be operated by the Stakeholders during operation to meet ConOps objectives and SRD/ORD specifications. It is the high-level summary of Observatory behaviors and operator interactions.

1.2 Identification and Scope

The Observatory Requirements Document specifies the entire technical scope of the GMT construction project. However, it does not enumerate all the deliverables of the project, as those are captured in the Observatory Architecture Document and subsequent lower-level Design Requirements Documents.

This Section 1 includes information (metadata) about the document itself. Section 2 defines the GMT observatory in general terms, by describing its inputs, outputs, and functions. Section 2 does not have normative, numbered, verifiable requirements, but rather the basic definitions enabling the proper interpretation of the requirements.

Section 3 lists the individual requirements for GMT as design constraints, Observatory functions and performance, external interfaces, attributes (non-functional restrictions), as well as environmental, health, and safety considerations. The Section also addresses access, handling, and applicable standards.

1.3 Purpose

The Observatory Requirements Document is the highest-level engineering definition of the GMT Observatory. It captures the technical baseline for the subsequent design, construction, and commissioning of the observatory in a design agnostic fashion. The ORD characterizes the observatory as a “black box,” through its functionality, performance, and interfaces to the outside.

The intended audience includes the engineering community of the GMTO project, using it as the fundamental technical direction for design, construction, and verification of the system to be built. The ORD also advises the GMTO Board and the observatory’s scientific community (represented by the Science Advisory Council) on the ultimate scope of the project.

Last but not least, the ORD constitutes the highest-level technical basis for establishing project cost and schedule. Together with the cost and schedule, as well as the other Foundation Documents, the ORD is under formal project change control.

1.4 Definitions

GMT-REF-00362, *GMT Project Acronyms and Glossary*, contain definitions for the entire Project. The table below lists definitions specific to the current document.

Table 1-1: Definitions

Term	Definition
Deployed instrument	A scientific instrument that is in position and prepared to begin observations. (This excludes instruments that are mounted on the telescope but are not prepared or in position to begin observations.)
Dither	Move the telescope between two or more positions on the sky.
GMTO or GMT	For the purpose of this document, it is the aggregate of the delivered hardware and software, a synonym for the Observatory. It is not the construction project or the operating organization.
Guiding	Following one or more targets across the sky using optical feedback from stars to maintain telescope position relative to the stars. Guiding is also called tip-tilt

	correction, especially when the bandwidth of the correction is high (> 1 Hz).
Mosaic	Move the telescope from one position in the sky to another some distance away. It is assumed that a new set of guide stars is required for the move.
Nonsidereal	Tracking or guiding at a rate different than the rate of stars moving across the sky. This is useful for nearby objects such as those in our Solar System.
Observatory	For the purpose of this document, it is the aggregate of the delivered hardware and software.
Offset	Move the telescope from one position on the sky to another. It is assumed that the same set of guide stars is available for both positions.
Sidereal	Tracking or guiding at the rate at which stars move across the sky.
Tracking	Moving the telescope along the predicted track across the sky for a given object, without any optical feedback on the sky.

1.5 Acronyms

Table 1-2: Acronyms

Acronym	Description
AO	Adaptive Optics
ARP	Average Return Period
CAD	Computer-Aided Design
CMMS	Computerized Maintenance Management System
ConOps	Concept of Operations
CPU	Central Processing Unit
DGAC	Dirección General de Aeronáutica Civil
DL	Diffraction-Limited
DOORS	Dynamic Object-Oriented Requirements System
DRD	Design Requirements Document
EAM	Enterprise Asset Management
EH&S	Environment, Health, and Safety
EMI	Electromagnetic Interference
ENA	Equivalent Noise Area
FMEA	Failure Modes and Effects Analysis
FWHM	Full Width at Half Maximum
GL	Ground Layer-Corrected
GLAO	Ground-Layer Adaptive Optics
GLAO	Ground-Layer Adaptive Optics
GMT	Giant Magellan Telescope; for the purpose of this document, it is the aggregate of the delivered hardware and software, a synonym for the Observatory. It is not the construction project or the operating organization.
HC	High-Contrast
IQ	Image Quality

LSST	Large Synoptic Survey Telescope
LCO	Las Campanas Observatory
LCH	U.S. Laser Clearinghouse
NAD83	North American Datum of 1983
NFPA	National Fire Protection Association
NGAO	Natural Guide-star Adaptive Optics
NS	Natural Seeing
OAD	Observatory Architecture Document
OC	Observing Case
OLE	Operational-Level Earthquake
OPM	Observatory Performance Mode
OpsCon	Operations Concept
ORD	Observatory Requirements Document
PBS	Product Breakdown Structure
PGA	Peak Ground Acceleration
PI	Principal Investigator
PLC	Programmable Logic Control
PRV	Precision Radial Velocity
PSF	Point-Spread Function
PSSN	Point Source Sensitivity Normalized
RLE	Rigidity-Level Earthquake
RMS	Root-Mean Square
SLE	Survival-Level Earthquake
SNR	Signal to Noise Ratio
SRD	Science Requirement Document
SSSHA	Site-Specific Seismic Hazard Analysis
TBC	To Be Confirmed
TBD	To Be Determined
TWCC	The World Coordinate Converter
UTM	Universal Transverse Mercator
WFE	Wavefront Error
WGS84	World Geodetic System 1984

1.6 Applicable Documents

The following documents of the exact revision and date listed below form a part of this specification to the extent specified herein. An "Applicable Document" is one that is referenced directly by a numbered "shall statement" (requirement) in Section 3.0. The only portions of an "Applicable Document" that are binding by the authority of this document (and will be verified) are the specific sections or requirements called out by the "shall statements" of this document.

Table 1-3: Applicable Documents

Document Number	Title	Manage Link
N/A	Standard for the Installation of Lightning Protection Systems NFPA 780	N/A
GMT-DOC-01925	Emergency Response Plan — Chile	N/A
GMT-REF-00019	GMT Electrical Power Systems	https://bit.ly/3s3ZljS
GMT-REF-00626	GMT Proposed Chile-Based Operations Staffing	https://docushare.gmto.org/docushare/dsweb/Services/Document-11923
GMT-REF-00420	GMT Maintenance Time Allocation Budget	https://bit.ly/3l39hpb
GMT-DOC-01400	GMT Design EHS Requirements	N/A
MIL-STD-810E	Environmental Engineering Considerations and Laboratory Tests	N/A
MIL-STD-810G	Environmental Engineering Considerations and Laboratory Tests	N/A
GMT-REF-00191	GMT Electronics Standards	https://bit.ly/2TVcDyS
GMT-DOC-01061	Health, Safety, Security, and Environmental Strategy	https://bit.ly/3eKxQFr
GMT-DOC-00243	GMTO Health, Safety and Environmental Policy	https://bit.ly/3rVN0hb
GMT-REF-00229 (To Be Updated)	GMT Reference for Regulations, Codes and Standards	https://bit.ly/3esDxYk

1.7 Referenced Documents

The following documents of the exact revision (or version) and date listed below are referenced herein. A "Reference Document" is one that is referenced elsewhere within this document, but not in a shall statement. Reference documents are source of information that are not binding through the authority of this document

Table 1-4: Referenced Documents

Document Number	Title	Manage Link
GMT-DOC-03205	Concept of Operations Document (ConOps)	https://bit.ly/3eqUjqz

GMT-REQ-03213	Science Requirements Document (SRD)	https://bit.ly/2I9fX7b
GMT-REQ-03215	Observatory Architecture Document (OAD)	https://bit.ly/38dJcQU
GMT-OCDD-01776	Operations Concept Document (OpsCon)	https://manage.gmto.org/SWMweb/PropertyCard/Index/ q=2752I9O3mbms7aVzpVapQQXzjwDboDg5SW1QeYv CiC1HOaqUf6FbmLQmflnX1z8yS1yF+vPYxzvfbxVrkpK x7Sd9wRjUQApQ9B7MvyWJ5khB46pzwvJLux5iltClbXg WZpZjkWbberg=
GMT-DOC-00127	Site-Specific Seismic Hazard Analysis (SSSHA) report	https://bit.ly/34SkJ1k
GMT-DOC-01901	Telescope Motions in Science Operations	https://docushare.gmto.org/docushare/dsweb/Services/Document-47785
GMT-SE-REF-00144	GMT Environmental Conditions document	https://bit.ly/3gyN1nF
RWDI report #1502255	Extreme Wind Climate Assessment	https://docushare.gmto.org/docushare/dsweb/Services/Document-35950
GMT-DOC-03033	Image Quality Flow Down Analysis	N/A
GMT-REF-00518	Adaptive Optics System Image Quality Error Budget	https://docushare.gmto.org/docushare/dsweb/Services/Document-5945
GMT-DOC-03229	SRD to ORD Analysis	N/A
GMT-DOC-00006	GMT Test and Verification Plan	N/A
GMT-DOC-00028	GMT Integration and Commissioning Plan	https://docushare.gmto.org/docushare/dsweb/Services/Document-6305
B.J. Seo, Applied Optics 48, 2009		B-J. Seo, C. Nissly, G.Z. Angeli, B. Ellerbroek, J. Nelson, N. Sigrist, and M. Troy, *Analysis of normalized point source sensitivity as a performance metric for large telescopes*,

		Applied Optic, 48, No. 31, pp5997-6007 (2009)
G.Z.Angeli, Proc.SPIE 8127, 2011		G.Z. Angeli, B.-J. Seo, C. Nissly, M. Troy, *A convenient telescope performance metric for imaging through turbulence*, Proc.SPIE 8127, (2011)
G.Z.Angeli, Proc.SPIE 8336, 2011		G.Z. Angeli, K. Vogiatzis, D. MacMynowski, B-J. Seo, C. Nissly, M. Troy, M. Cho, *Integrated Modeling and Systems Engineering for the Thirty Meter Telescope*, Proc.SPIE 8336, (2011)
GMT-DOC-04931	GMT High Contrast Imaging Error Budget	https://bit.ly/37jFxiS

1.8 Definition of Requirement Terms

Throughout the document, requirements statements are clearly numbered to allow them to stand out and easily referenced. Statements preceded by "**Note:**" or "**Advice:**" are support text and statements preceded by "**Rationale:**" are the reasoning behind the requirements.

Terms should be used as specified below:

Table 1-5: Acceptable Requirement Terms

Term	Definition
"Shall"	"Shall" denotes requirements that are mandatory and will be the subject of specific acceptance testing and compliance verification.
"Can", "May", or "Should"	"Can", "May", or "Should" indicate recommendations and are not subject to any requirement acceptance testing or compliance verification by the supplier. “Should" is the preferred word to use to express a suggestion over "Can" or "May". The supplier is free to propose alternative solutions.
"Is or Will"	"Is" or "Will" indicate a statement of fact or provide information and are not subject to any requirement acceptance testing or verification compliance by the

	supplier.

1.9 Description of Verification Methods

The available verification methods are described in the table below — these methods are applicable only to the final verification of the requirements.

Table 1-6: Verification Type Definitions

Term	Definition
Analysis	Analysis is the use of established technical or mathematical models, or simulations, algorithms, or other scientific principles and procedures to provide evidence that the item meets its stated requirements. Analysis (including simulation) is often used to provide early verification of a requirement that is later verified by test, or used where verifying testing to realistic conditions cannot be achieved or is not cost effective.
Inspection	Inspection is an examination of the item against applicable documentation to confirm compliance with requirements. Inspection is used to verify properties best determined by examination and observation (e.g., paint color, weight, size etc.).
Test	A test is an action by which the operability, supportability, or performance capability of an item is verified when subjected to controlled conditions that are real or simulated. These verifications often use special test equipment or instrumentation to obtain very accurate quantitative data for analysis.
Demonstration	Demonstration is the actual operation of an item to provide evidence that it accomplishes the required functions under specific scenarios. Given input values are entered and the resulting output values are compared against the expected output values.

2 System Overview

2.1 Perspective

The Giant Magellan Telescope is one of a new generation of 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 will be located at Las Campanas Observatory (LCO). Located in the high-altitude, desert environment of the Chilean Andes, LCO is owned by the Carnegie Institution and has been operating as a world-class observatory site since 1969. 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.

2.2 External Interfaces

2.2.1 System Inputs

Scientific targets are the primary objects of study, and the primary light input into the Observatory. Collecting and processing data collected on scientific targets constitutes a large part of Science Operations.

Natural Guide Stars are astronomical targets (usually stars) used to lock the observatory to the sky, measure the effects of the atmosphere on image quality, and adjust telescope systems to compensate for those effects.

Disturbing light sources are sources of light that affect the quality of scientific data. These may be natural sources of light such as moonlight, light from the sky, bright stars (other than the scientific stars of interest), or artificial sources such as car lights, city lights, or lasers from other nearby telescopes.

Atmosphere is a source of distortion of the light from astronomical sources, also causing throughput loss and scattering. The Observatory will measure the effects of the atmosphere and partially compensate for or calibrate out the atmospheric effects. Another interface to the atmosphere is the use of Observatory laser systems to form artificial stars in the atmosphere to allow atmospheric wavefront distortion to be measured when no natural guide stars are available.

Local environment; The Observatory will monitor and partially control environmental parameters that affect scientific data and observing methodology, including wind, temperature, pressure, and precipitation.

Aircraft and space environment; The safe use of lasers pointed into the sky requires coordination with others using that environment, notably aircraft and satellites. The Observatory will coordinate interface with the DGAC for aircraft and the U.S. Laser Clearinghouse for spacecraft.

Utilities; The Observatory will interface with external sources of utilities such as power and communications network.

Observing programs define the measurements the system carries out, most prominently the science targets, guide stars, system configurations, and photon collection times. Interaction with scientists will be through the entire science operations process as described in the OpsCon, including observing proposal phases, time allocation committees, observing, data reduction, and archive use.

2.2.2 System Outputs

Scientific data products are the primary outputs of the observatory. Useful data products imply additional, tightly bound data required to remove instrument (observatory) signatures and compensate for atmospheric effects: flux and spectral calibration data, observing time, imaging performance (including AO), detector noise, status of telescope, instrument, and wavefront correction.

Note that the Observatory will also track scientific productivity metrics such as publications that are an end point for the scientific data but are largely outside the control of the Observatory.

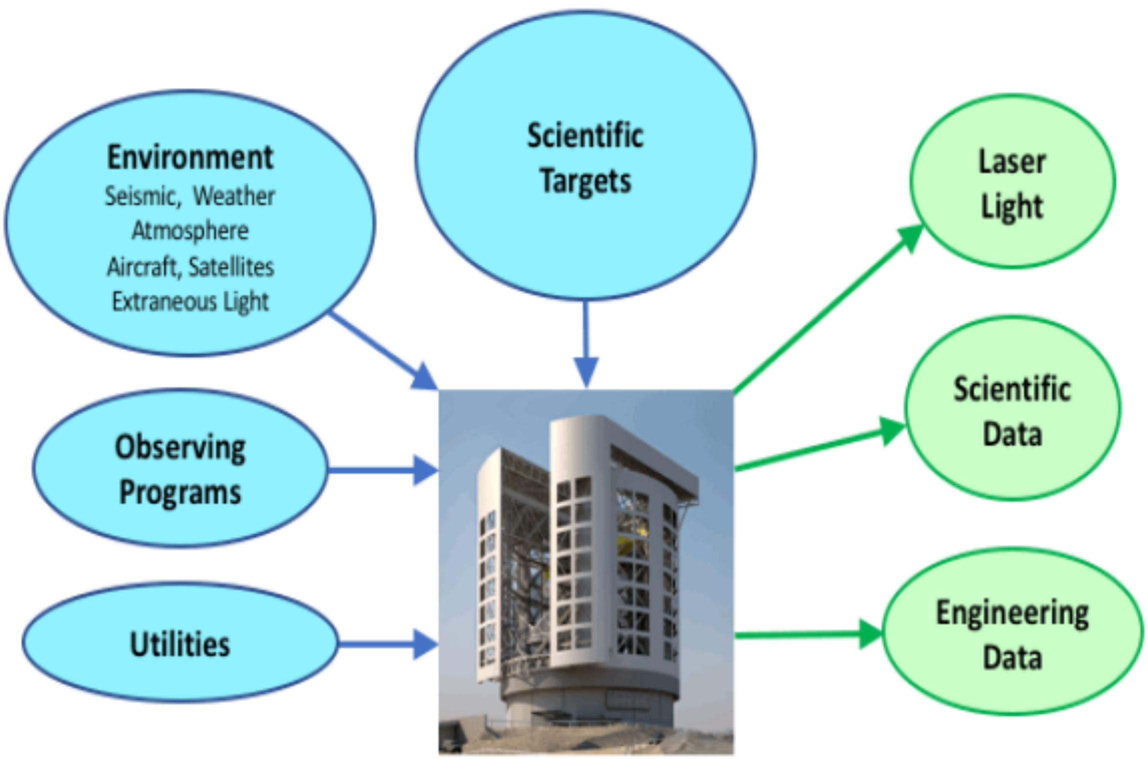

Figure 2-1: The GMT Observatory with its Main Inputs (in Blue) and Outputs (in Green)

Engineering data characterizing in detail the status of the observatory is necessary to maintain function and performance of the system.

Laser guide stars probe the atmosphere for tomographic characterization of the turbulence and corresponding wavefront error of the light propagating through the atmosphere.

2.3 System Functions and Modes

The basic functions of the Observatory are:

- Prepare for observation, including (i) providing scientists with tools to construct observing programs, and (ii) configuring, calibrating, and initializing the observatory;
- Collect the light of scientific targets and guide stars, and process the light through active and adaptive optics correction;
- Convert light into data and match that science data with calibration and other observatory status information;
- Process and archive both scientific and engineering (status) data.

The functions of the Observatory are carried out in operating modes. Night time Observatory Performance Modes (OPM) are defined in detail in Section 3.3.1. These Performance Modes are mapped into Observatory Configurations in the Observatory Architecture Document. Configurations are unique combinations of the basic building blocks of the Observatory assembled to carry out required measurements on the sky.

The required *Observatory Performance Modes* are:

1. Small Field Visible Natural Seeing
2. Small Field Visible Ground Layer Corrected
3. Small Field Visible Natural Seeing Precision Radial Velocity
4. Small Field Visible Ground Layer Corrected Precision Radial Velocity
5. Small Field Infrared Natural Seeing
6. Small Field Infrared Ground Layer Corrected
7. Small field Infrared Natural Guide Star Corrected
8. Small Field Infrared Diffraction-Limited 50% Sky Coverage
9. Small Field Infrared Diffraction-Limited 80% Sky Coverage
10. Medium Field Visible Natural Seeing
11. Medium Field Visible Ground Layer Corrected
12. Medium Field Infrared Natural Seeing
13. Medium Field Infrared Ground Layer Corrected
14. Wide Field Visible Natural Seeing
15. Wide Field Visible Ground Layer Corrected

An orthogonal projection of Observatory functions is mapping night time observing into *Operations*

Modes described in the Operations Concept Document (OpsCon):

- Classical, or PI-based observing
- Service observing
- Queue observing
- Monitored queue observing
- Targets of opportunity

Maintenance Mode is the state of the Observatory enabling both daytime and nighttime activities necessary to keep the Observatory functioning and performing. These activities are detailed in the OpsCon document.

2.4 User Characteristics

Users of the Observatory include:

- Partner institutions — provide strategic direction and oversight to the Observatory
- External scientists — apply for telescope time, define observing parameters, collect science data, analyze science data, use archived science data.
- Observatory Staff and Technical Operations
    - Operators — operate Observatory subsystems to produce science data, and to support maintenance
    - Maintenance staff — maintain, troubleshoot, improve, and calibrate Observatory subsystems
- Future developers — build new instruments or other subsystems to expand Observatory capabilities, upgrade existing subsystems to improve Observatory performance and/or maintainability

The OpsCon contains a description of how these users will interact with the Observatory.

3 Specific Requirements

3.1 System Constraints

3.1.1 Physical Constraints

REQ-L2-ORD-24961: GMT Location

The GMT Observatory shall be located on the summit of Las Campanas (Chile) at WGS84 (UTM) coordinates 6785453 N, 336216 E, Zone 19 at an altitude of 2514 meters.

Rationale: This is a direct flow down from the ConOps. The UTM coordinates translate into latitude S 29° 02′ 55.260″ (-29.0486834) and longitude W 70° 40′ 55.999″ (-70.6822220) using “The World Coordinate Converter” (TWCC) program with WGS84 datum.

Notes: These are the coordinates of grade level at center of the pier.

REQ-L2-ORD-24965: Summit Site Layout

The GMT summit layout shall not preclude the deployment of a second 25-m class telescope on the Cerro Las Campanas summit.

Rationale: This allows for the future expansion of the GMT Observatory. Requirement derived from GMT Board action.

REQ-L2-ORD-110047: Base Facility

The GMT shall provide and support a Base Facility in La Serena on the Las Campanas Observatory's El Pino campus.

Rationale: A Base Facility near sea level is required to support GMT staff whose work does not require travel to the mountain, avoiding the overhead of travel to and from the mountain. This also provides a convenient place from which to interact with the external world.

Notes: The Founder's Agreement (TARFA section 3.10) specifies that Carnegie Institution of Washington will supply a site for a GMT support facility within the El Pino compound.

3.1.2 Seismic Requirements

The site-specific hazard is defined in the Site-Specific Seismic Hazard Analysis (SSSHA) report (GMT-DOC-00127_A).

The following definitions are used in the specification of the seismic requirements:

The Average Return Period (ARP) is defined as the average period between recurrence of a seismic ground acceleration that exceeds a specified Peak Ground Acceleration (PGA).

The Rigidity-Level Earthquake (RLE) is defined for GMT as a seismic event with an ARP of 2 years, which corresponds to a 50% probability of exceedance in a one-year period.

The Operational-Level Earthquake (OLE) is defined for GMT as a seismic event with an ARP of 100 years, which corresponds to a 1% probability of exceedance in a one-year period and a 39% probability of exceedance in the 50-year life of the observatory.

The Survival-Level Earthquake (SLE) is defined for GMT as a seismic event with an ARP of 2475 years, which corresponds to a 2% probability of exceedance in the 50-year life of the observatory.

Onerous-to-replace equipment are items that would be extremely expensive, time-consuming or otherwise burdensome to replace.

REQ-L2-ORD-24974: RLE Response

The GMT Observatory shall be insensitive to ground motion up to and including the level defined by an RLE event.

Rationale: Ground motions up to the RLE level will occur frequently. To avoid significant downtime, it must not be necessary to perform repair, realignment or recalibration operations as a result of these events.

Notes: Since the RLE occurs frequently, it must not be necessary to perform realignment or recalibration operations as a result of an RLE or smaller event, and the Observatory must be capable of restarting operations immediately following such an event. This requirement is not intended to imply that the Observatory must satisfy nominal performance requirements during an RLE.

REQ-L2-ORD-70805: OLE Response

The GMT Observatory shall be capable of resuming all normal operations using available resources following ground motions up to and including the level defined for an OLE.

Rationale: It is expected that the Observatory will experience approximately 24 earthquakes between the RLE and OLE levels during the 50 year lifetime. To avoid significant downtime, there must be an operational plan to recover from these events.

Notes: As a goal, it should be possible to resume science operations within one month of an OLE event. Available resources include operational staff, equipment, spares, procedures and designated recovery funds.

REQ-L2-ORD-70806: SLE Response

The GMT Observatory shall protect personnel and onerous-to-replace equipment from ground motions up to and including the level defined for an SLE event.

Rationale: Ground motions between the OLE and SLE levels have approximately a 37% chance of occurrence over the 50-year life. The Observatory must be designed to mitigate the risk of catastrophic loss and should be recoverable from an SLE level event given sufficient resources. Onerous-to-replace equipment are items that would be extremely expensive, time-consuming or otherwise burdensome to replace.

3.1.3 Environmental Constraints

REQ-L2-ORD-24996: Condensing Conditions

Subsystems or components sensitive to condensation shall either be protected from condensing conditions (e.g. in a building or enclosure that is environmentally controlled) or placed into a safe state (e.g. powered off) during condensing conditions.

Notes: Condensing conditions are defined as a local ambient temperature less than 2 °C above the local dew point.

REQ-L2-ORD-24999: Precipitation Protection

No part of the Observatory shall be exposed to any precipitation (rain, snow, or hail), except the components providing environmental protection for the rest of the Observatory (e.g. building or enclosure).

REQ-L2-ORD-25001: Regular Operating Conditions

The GMT Observatory shall meet all functional and performance requirements, with the exception of image quality, under the Regular Operating Conditions specified in Table 3-1.

Table 3-1: Regular Operating Conditions Requirements

Night-time Environmental Condition	Value	Requirement
External air temperature range	-3 °C to +19.5 °C	REQ-L2-ORD-66752
External air temperature change over 30 minutes	−1.45 °C to +1.62 °C [1% and 99% points in the CDF as per data in GMT Environmental Conditions document (GMT-SE-REF-00144)]	REQ-L2-ORD-66753
External air pressure	743 mbar to 758 mbar	REQ-L2-ORD-

		66754
External maximum wind speed (1 minute average @ M1 height)	up to 17.0 m/s	REQ-L2-ORD-66755

Notes: The Observatory systems should operate safely and efficiently in nearly all environmental conditions. Regular Operating Conditions constitute 95% of potential observing time. This does not include technical and weather downtime.
Regular Operating Conditions define the ranges of environmental parameters over which all requirements, both functional and performance, are met (except image quality and unless otherwise stated in the requirement). The observatory is expected to produce scientifically valid data over these ranges, although scientific observations will be feasible outside of these ranges. Requirements are verified against these ranges.
Note that only night-time environmental conditions are relevant, since only during night-time will regular science operations be performed.
Regular Operating Conditions refer to parameter values outside of the enclosure. The defined external values, in conjunction with operational parameters may result in significantly different local conditions for a given subsystem or component of the observatory.

Rationale: The regular operating conditions ranges achieve a joint probability of occurrence of 95% based on the environmental data from the site survey, excluding condensing conditions, while minimizing cost. It was determined that wind speed is the most significant cost driver, leading this to be the most restricted parameter.

Extended Operating Conditions

The GMT Observatory shall meet all functional requirements under the Extended Operating Conditions specified in Table 3-2.

Table 3-2: Extended Operating Conditions Requirements

Night-time Environmental Condition	Value	Requirement
External air temperature range	–4 °C to +20.5 °C	REQ-L2-ORD-66756
External air temperature change over 30 minutes	–2.20 °C to +2.37 °C	REQ-L2-ORD-66757
External air pressure	743 mbar to 758 mbar	REQ-L2-ORD-66758
External maximum wind speed (1-minute average @ M1 elevation)	up to 20.5 m/s	REQ-L2-ORD-66759
Particulate count	up to 3.5 x 10^6 particles larger than 1 micron per m^3	REQ-L2-ORD-66760

Notes: Extended Operating Conditions define the ranges of environmental parameters over which the observatory is expected to safely operate, including science operations, but without full performance. For

safety, when the external maximum wind speed given above is exceeded, the enclosure should be closed and science operations terminated. High particulate count in the air is generally highly correlated with high winds, and does not count against the joint probability.
Extended Operating Conditions refer to parameter values outside of the enclosure. The defined external values, in conjunction with operational parameters may result in significantly different local conditions for a given subsystem or component of the observatory.
External wind speed higher than the specification in Extended Operating Conditions need not be considered for subsystems and components internal to the enclosure. However, local wind speed around some components may be higher than this limit due to induced turbulence.
As with Regular Operating Conditions, only night-time environmental conditions are relevant.
The external air temperature change over 30 minutes is the minimum and maximum observed in the 14-year environmental data set.
Wind gust speed for 3 seconds is expected to be 1.19 times the 1-minute average (RWDI report #1502255, *Extreme Wind Climate Assessment*).

Rationale: The extended operating conditions ranges achieve a joint probability of occurrence of 99% based on the environmental data from the site survey, while minimizing cost. It was determined that wind speed is the most significant cost driver, leading this to be the most restricted parameter.

Maintenance Conditions

The GMT Observatory shall enable all maintenance operations under the Maintenance Conditions specified in Table 3-3.

Table 3-3: Maintenance Conditions Requirements

Environmental Condition	Value	Requirement
External air temperature range	-8 °C to +27.7 °C	REQ-L2-ORD-66761
External air pressure	740 mbar to 758 mbar	REQ-L2-ORD-66762

Notes: Maintenance Conditions define the ranges of environmental parameters over which all individual systems are expected to operate to support servicing, troubleshooting, and maintenance. While system performance is not guaranteed, the components are expected to function reliably and safely. Maintenance Conditions apply both during day and night times.
Maintenance Conditions refer to parameter values in the direct vicinity of the given component, in the enclosure or in the laboratory. Any removed component is expected to operate in a room temperature laboratory at the summit or at sea level.
Components internal to the observatory buildings are not required to operate under condensing conditions. Components external to the observatory buildings must remain functional in a condensing environment.

Rationale: During daylight, or environmental conditions too extreme to open the Enclosure, maintenance will be performed. This includes maintenance requiring components to travel to sea level for testing or calibration.

Survival Conditions

The GMT Observatory shall survive repeated exposure to the Survival Conditions specified in Table 3-4.

Table 3-4: Survival Conditions Requirements

Environmental Condition	Value	Requirement
External air temperature range	–8 °C to +27.7 °C	REQ-L2-ORD-66763
External air temperature change over 30 minutes	–4.8 °C to +4.3 °C	REQ-L2-ORD-66764
External air pressure	740 mbar to 758 mbar	REQ-L2-ORD-66765
External maximum wind speed (3s gust @ M1 elevation)	up to 55 m/s	REQ-L2-ORD-66766
External rainfall rate	0.2 m/hour (maximum measured)	REQ-L2-ORD-66768
External snowfall	Column density up to 200 kg m^{-2}	REQ-L2-ORD-66769

Notes: Survival Conditions define the ranges of environmental parameters over which the observatory, as well as its individual subsystems and components, are expected to survive without damage and/or the need for optical realignment at the Site.
No prior warning or human interaction (switch off, to "safe mode", or to standby) is expected at the onset of Survival Conditions. The exception is the enclosure, which is assumed to be closed at conditions beyond Extended Operating Conditions (including in the presence of precipitation and/or condensing conditions). Survival Conditions refer to parameter values outside of the enclosure, except for condensing conditions (assumed both inside and outside the enclosure).

Rationale: The temperature range and minimum air pressure correspond to the expected 200-year return conditions, with an additional 5 °C added to the extreme high temperature to account for an observed trend extrapolated to the lifetime of the Observatory (see GMT-DOC-00144 for discussion). Where insufficient data exist to estimate the 200-year return conditions, the maximum measured have been used (i.e. for temperature change and rainfall rate.) The wind speed is the 50-year return value from RWDI report #1502255. Maximum sea level pressure has been included in the air pressure range. Snowfall column density is calculated as 1 meter depth times 200 kg m^{-3} (the latter being a conservative value for fresh snow deposited near 0 °C).

REQ-L2-ORD-25036: Lightning Protection

The GMT shall provide protection from lightning.

Rationale: Lightning strikes occur in the area and necessary protection systems must be in place.

REQ-L2-ORD-25039: Safe Return to Operations

After exposure to conditions beyond the Survival Conditions, regular operations staff shall be able to determine, after a maximum 6-hour inspection, whether the observatory is in a safe condition to return to science and technical operations.

Rationale: After extreme conditions, operational efficiency requires an assessment of the Observatory's readiness to return to normal operations within a day shift.

Notes: This does not apply to seismic events at or beyond an SLE.

3.1.4 Other Constraints

REQ-L2-ORD-25044: GMT Lifetime

The GMT shall be designed for a 50-year lifetime assuming routine maintenance of the telescope and facilities and periodic upgrades of field replaceable components and subsystems.

Rationale: This is a flow down from the ConOps

REQ-L2-ORD-25047: Performance Specifications Applicability

Optical performance specifications for GMT shall only apply from the end of astronomical twilight in the evening to the beginning of astronomical twilight in the morning.

Rationale: Stringent performance cannot be realistically applied to times outside this interval as temperatures inside and outside the enclosure are changing rapidly as is the sky brightness.

Notes: Image specifications are listed in the sections below for the various Observatory Performance Modes.

3.2 Functional Requirements

3.2.1 3.2.1 System Function(s)

REQ-L2-ORD-25053: Elevation Pointing Range

The GMT shall point in elevation from 30° to 90°.

Rationale: Enables maintenance functions to be performed with the telescope stationary at zenith. These include subsystem calibrations which require the enclosure to be open.

REQ-L2-ORD-25056: Elevation Operational Range

The GMT shall meet all performance requirements from 30° elevation to 89.5° elevation.

Rationale: Direct flowdown from goal value of REQ-L1-SCI-23062. Science operations should be enabled over the entire accessible sky, with the exception of near zenith where an alt-az mount has a high rate of change of parameters such as azimuth and field rotation.

REQ-L2-ORD-25059: Azimuth Operational Range

The GMT shall meet all performance requirements over the full 360° range in azimuth.

Rationale: Direct flowdown from REQ-L1-SCI-23062.

REQ-L2-ORD-25062: Nodding and Dithering Accuracy

The GMT shall offset between two or more positions on the sky separated by up to 60 arcsec with a pointing accuracy at each position of no greater than 0.1 × PSF FWHM arcsec RMS.

Rationale: Flowdown from SRD.

Offset Time Requirements

The GMT shall offset in times less than indicated in Table 3-5 and Table 3-6.

Table 3-5: Offset Time Requirements - Seeing-Limited

Distance (arcsec)	Requirement #	Seeing-limited
< 5	REQ-L2-ORD-25075	5 sec
5–30	REQ-L2-ORD-25080	10 sec
>30–180	REQ-L2-ORD-25085	20 sec

Table 3-6: Offset Time Requirements - Diffraction-Limited

Distance (arcsec)	Requirement #	Diffraction-limited
< 5	REQ-L2-ORD-25077	2.5 sec
5–30	REQ-L2-ORD-25082	5 sec
>30–180	REQ-L2-ORD-25087	10 sec

Notes: The offset time is the time to open the wavefront control loops, move the telescope, re-close the control loops, and stabilize the image. Near zenith this may be challenging due to the high rate of azimuth change.

Rationale: These are the maximum times to provide effective dithering and maximize observing efficiency.

REQ-L2-ORD-25091: Mosaicking Accuracy

The GMT shall offset between two or more positions on the sky separated by up to 180 arcsec, with a pointing accuracy at each position by less than 0.5 arcsec RMS.

Rationale: This assumes that different guide stars will be needed at different positions, and is intended to support mosaicking large fields of view together. Each pair of fields is assumed to have enough stars to provide precise overlapping and merging of images so as not to reduce final image quality in the mosaic by more than 5% of the PSF.

REQ-L2-ORD-25094: Non-sidereal Guiding

The GMT Observatory shall guide on targets moving at any non-sidereal rates up to 6 arcsec/min while meeting all image quality requirements, with no more than an additional 0.1 × PSF image elongation.

Rationale: Direct flowdown from REQ-L1-SCI-23050, expanded to include all wavefront control modes of the Observatory.

Notes: Higher non-sidereal guiding rates will be possible for targets sufficiently bright to use as NGAO guide stars.

REQ-L2-ORD-25098: Scanning

The GMT Observatory shall move the telescope at any non-sidereal rate up to 1 arcsec/sec with a pointing accuracy of better than the PSF FWHM in seeing-limited conditions, over a range of up to 90 arcsec.

Rationale: Flowdown from REQ-L1-SCI-23055. Enables slit scanning for seeing-limited spectrographs.

REQ-L2-ORD-25101: Sidereal Targets

The GMT Observatory shall meet all performance requirements while tracking targets moving at sidereal rates.

Rationale: Direct flowdown from REQ-L1-SCI-23053.

REQ-L2-ORD-25104: Observation Time Accuracy

The GMT Observatory shall be able to record the times at which an observation starts and ends with an accuracy of 10 milliseconds.

Rationale: Flowdown from REQ-L1-SCI-23066.

REQ-L2-ORD-25107: Field de-rotation

The GMT shall provide instrument mounting locations at which the apparent rotation of the science field of view is controlled and compensated.

Rationale: To avoid compromising image quality across a non-zero field of view, that field of view as seen by the instruments must rotate to compensate for the field rotation inherent in an alt-az mount design. The image quality allocation to field rotation error is provided in the image quality budgets in the

OAD. Other observing techniques will require a specific rotation of the science field of view with respect to the sky, the pupil, or elevation.

Notes: The GMT will provide various focal stations, including some at which field de-rotation is the responsibility of the instrument.

REQ-L2-ORD-25111: Time to Start an Exposure

The GMT Observatory shall be able to start a science exposure on a new target with any deployed instrument in less than 600 seconds from the initiation of slew.

Rationale: From REQ-L1-SCI-23092, -23226, and -23288.

Notes: The start of the 600 second time is the initiation of a slew to the target, and the end is the start of a science observation. This requirement is more stringent than required by REQ-L1-SCI-23226 and REQ-L1-SCI-23288. This includes the time to slew, image the field, identify the science target, and center the science target appropriately within the instrument field of view. It also includes setting up the instrument for the required observation. It only applies to deployed instruments; those that do not need to be moved into position to receive the optical beam from the telescope and are in an operational state.

REQ-L2-ORD-25115: Science Data Archive

The GMT shall provide an archive to curate all science data, including science calibration data, and associated metadata, for the lifetime of the Observatory.

Rationale: Re-use of the scientific data for purposes other than those of the original science increases the value of the data for relatively low cost.

Notes: The Science Archive will enforce data access rules for proprietary data according to partner institution policies.

REQ-L2-ORD-25119: Engineering Data Archive

The GMT shall provide an archive to curate all engineering data, including subsystem telemetry data and associated metadata, for the lifetime of the Observatory.

Rationale: Engineering data is important for troubleshooting performance and functional problems and improving operational efficiency.

3.2.2 System States

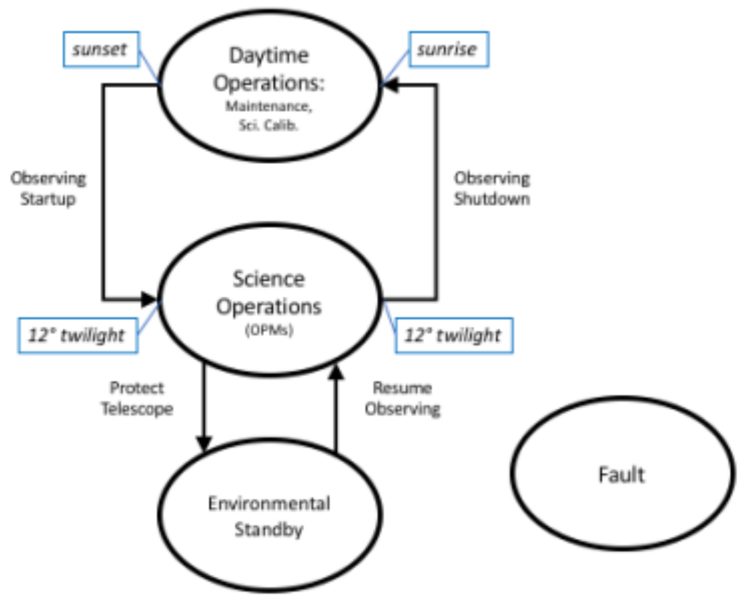

Figure 3-1: The Time Flow of Normal Observatory Operations, including Bounding Time of Day where appropriate.

The following states are defined:

Table 3-7: Observatory System State

State	Requirement	Rationale
Daytime Operations	REQ-L2-ORD-25130	While the Sun is above the horizon the Observatory will perform maintenance and daytime science calibrations.
Science Operations	REQ-L2-ORD-25133	Between 12° twilights the Observatory will generally conduct science observing and night-time engineering that requires dark skies and starlight. The Observing Performance Modes (see section 3.3.1) can be considered substates of the Science Operations state.
Environmental Standby	REQ-L2-ORD-25136	During night-time operations inclement weather can require the Observatory to enter the Environmental Standby state to protect the Observatory subsystems. Once the dangerous conditions have abated, the Observatory can transition back to Science Operations (assuming it is still night time). The Environmental Standby state may also be entered during an earthquake, as some

		subsystems may "safe" themselves during the earthquake.
Fault	REQ-L2-ORD-25139	At any time a fault (failure to meet a functional requirement) may put the Observatory in this state.

Notes: There is no "Off" state for the Observatory as a whole. A complete power outage, including failure of the power backup systems, is considered a fault.

3.2.2.1 State Transitions

The GMT Observatory shall carry out state transitions (named in Table 3-8), in the times allowed for each transition (in the following requirements).

Table 3-8: Observatory State Transition Times

Related Requirement	Transition Name	From	To
REQ-L2-ORD-25169	Observing Startup	Daytime Operations	Science Operations
REQ-L2-ORD-25172	Protect Telescope	Science Operations	Environmental Standby
REQ-L2-ORD-92244	Resume Observing	Environmental Standby	Science Operations
REQ-L2-ORD-25175	Observing Shutdown	Science Operations	Daytime Operations

REQ-L2-ORD-25166: Preparation for Observing Startup

The GMT shall transition from its Daytime Operations state to a state ready for on-sky Observing Startup in no more than 20 minutes.

Rationale: This transition will happen during the day, but should not severely impact the time available to daytime maintenance.

REQ-L2-ORD-25169: Time for Observing Startup

The GMT shall perform necessary on-sky initialization in no more than 45 minutes.

Rationale: This transition includes opening the facility to the sky, normally started at sunset, and obtaining on-sky system calibrations that require the telescope to see the sky. It should be accomplished in the time from sunset to 12° twilight. This assumes that preparations that can be made before sunset have already been made.

Notes: This is the transition called Observing Startup.

REQ-L2-ORD-25172: Time to Protect Telescope from Environmental Conditions

The GMT shall transition from Science Operations to an Environmental Standby state in no more than 3 minutes.

Rationale: Rapidly changing environmental conditions, such as the onset of precipitation, require a rapid response to protect the Observatory.

Notes: The time to change states counts as the time spent in the weather event, and is not counted towards technical downtime.

REQ-L2-ORD-92244: Transition Time from Standby to Operations

The GMT shall transition from an Environmental Standby state to Science Operations in no more than 10 minutes (TBC).

Rationale: The transition out of Environmental Standby may take longer than the transition into Environmental Standby, but should not be excessive.

Notes: This includes recovering from an RLE by correcting the pointing model, as well as opening the Enclosure after a weather event. The time to change states counts as the time spent in the weather event and is not counted towards technical downtime.

REQ-L2-ORD-25175: Time to Shut Down after Science Operations

The GMT shall transition from Science Operations to a prepared daytime maintenance state in no more than 10 minutes.

Rationale: The shut down time should not significantly impact the time available to daytime maintenance. Shut down should also aid daytime maintenance by preparing subsystems appropriately for the day's initial maintenance work, as requested by the daycrew.

Notes: This transition is called "Observing Shutdown."

3.2.3 Modes of Operations

REQ-L2-ORD-25179: Principal Investigator (PI) Science Mode of Operations

The GMT shall support the PI mode of science operations.

Rationale: Flowdown from ConOps

Notes: To support PI Science Mode of Operations, the GMT shall supply the appropriate tools that make it possible to define or alter an Observing Sequence during the observation execution, etc. This encompasses both on-site and remote PI-directed operations modes.

The exact nature of the PI Science Mode of Operations is defined in the Operations Concept Document (OpsCon).

REQ-L2-ORD-25184: Service Science Mode of Operations

The GMT shall support the Service mode of science operations.

Rationale: Flowdown from ConOps. Service observers must have access to details of the scientific proposal to allow good decision-making.

REQ-L2-ORD-25187: Queue Science Mode of Operations

The GMT shall support the Queue mode of science operations.

Rationale: Flowdown from ConOps

Notes: To support Queue Science Mode of Operations, the GMT will supply the appropriate tools to create an ordered queue of Observing Blocks to be executed during the night, taking into account timeline constraints, scientific rank or night conditions constraints. This tool will allow to re-order the queue by user demand, and it will be reactive to changing night conditions, etc.

The exact nature of the Queue Science Mode of Operations is defined in the Operations Concept Document (OpsCon).

REQ-L2-ORD-25192: Monitored Queue Science Mode of Operations

The GMT shall support the Monitored Queue mode of science operations.

Rationale: Flowdown from ConOps

Notes: Monitored Queue will require remote observing tools to allow a PI to monitor his or her queue observations in real time.

REQ-L2-ORD-25196: Target of Opportunity Science Mode of Operations

The GMT shall support the Target of Opportunity mode of science operations.

Rationale: Flowdown from ConOps

Notes: To support the Target of Opportunity Mode of Operations, the GMT will supply the appropriate tools to trigger a Target of Opportunity Observation, as well as provide the user the capability to define or alter an Observing Sequence during the observation execution, etc. The Target of Opportunity Mode of Operations drives the performance requirements for efficient Telescope and Instrument reconfiguration.

The exact nature of the Target of Opportunity Science Mode of Operations is defined in the Operations Concept Document (OpsCon).

3.3 Performance Requirements

3.3.1 Observatory Performance Modes

3.3.1.1 Introduction

Observatory performance requirements are specified in terms of Observatory Performance Modes (OPM), sets of requirements which must be met simultaneously to enable a specific SRD Observing Case (OC). Each OPM specifies a distinct field of view, wavelength range, and balance between image quality and sky coverage. Two additional OPMs enable the Precision Radial Velocity (PRV) observing case. Fifteen OPMs are required to fully comply with the SRD and ConOps (Figure 3-2). Note that Natural Seeing (NS) OPMs are marked as only partial compliant with the SRD, which provides image quality requirements for GLAO. This is manifest in the OPM requirements tables as relaxed PSSN requirements (from those defined for GLAO).

The image quality required in the SRD in "atmospheric resolution" cases (i.e., not in "high resolution cases") will be delivered in the best atmospheric conditions, or with partial (i.e., ground layer) adaptive optics correction. The Natural Seeing wavefront control mode defined here will be delivered with active optics only. It is intended to provide high image quality and photometric accuracy, but without turbulence correction. It will be the first mode available during initial alignment and AIVC, and provides performance requirements when a deformable mirror is not available.

ID	Observing Case
1	Small Field Visible - Atm. Resln.
2	Small Field Visible PRV
3	Small Field IR - Atm. Resln.
4	Small Field IR High Angular Resolution
5	Small Field IR High Resln. High Sky Cov.
6	Small Field IR High Contrast
7	Medium Field Visible - Atm. Resln.
8	Medium Field IR - Atm. Resln.
9	Wide Field Visible - Atm. Resln.

Observatory Performance Mode

Field of View	Wavelength	IQ	Other	ID	1	2	3	4	5	6	7	8	9
Small Field	Visible	NS		1	P								
		GL		2	X								
		NS	PRV	3		P							
		GL	PRV	4		X							
	Infrared	NS		5			P						
		GL		6			X						
		DL 50%		7				X					
		DL 80%		8					X				
		HC		9						X			
Medium Field	Visible	NS		10							P		
		GL		11							X		
	Infrared	NS		12								P	
		GL		13								X	
Wide Field	Visible	NS		14									P
		GL		15									X

P = Partial compliance to SRD
X = Full compliance to SRD

Figure 3-2: Mapping of SRD Observing Cases to Observatory Performance Modes (OPM)

The Small Field OPMs (with a field of view ≥3 arcmin diameter) are divided between visible-light configurations with throughput specified from 0.32 to 1.3 µm wavelength, and infrared configurations with throughput defined from 0.8 to 25 µm (some OPMs are more restricted in wavelength range). These two categories are further broken down based on the image quality and sky coverage which must be achieved. There are 5 image quality and sky coverage categories:

- Natural Seeing (NS) image quality, specified in terms of the minimum Normalized Point Source Sensitivity (PSSN) achieved over at least 99% of the sky, referenced to the uncorrected site atmosphere.
- Ground Layer-corrected (GL) image quality, specified in terms of the minimum PSSN achieved over at least 99% of the sky, referenced to the site atmosphere corrected by an ideal ground layer AO system.
- Diffraction-Limited (DL) image quality, specified in terms of the variance sum of the wavefront error on-axis, at different sky coverage limits.

- High-Contrast (HC) image quality, specified in terms of the minimum raw contrast achievable near a guide star of a given magnitude.

Medium Field OPMs (field of view ≥10 arcmin diameter) are similarly divided between visible and infrared NS and GL performance modes. Wide Field OPMs (field of view ≥20 arcmin diameter) are limited to visible light NS and GL performance modes.

Each OPM implies the use of an instrument, which could be either an imager or spectrograph. However, most OPM requirements apply at the telescope focal plane and do not include the performance of the instrument itself, as detailed in the next section.

3.3.2 Normalized Point Source Sensitivity and Standard Year

Image quality in the Natural Seeing and GLAO wavefront control modes is specified in terms of the Normalized Point Source Sensitivity (PSSN). The PSSN metric is based on the Equivalent Noise Area (ENA) of the Point Spread Function (PSF), which is the sky area around an unresolved source that provides the optimal photometric Signal to Noise Ratio (SNR) for sky background-limited observations. It equals the inverse of the integral of the normalized PSF squared, and is proportional to the FWHM squared. The proportionality factor depends on the shape of the PSF.

$$ENA = \frac{1}{\iint_{\infty} PSF^2} \propto FWHM^2$$

$$\iint_{\infty} PSF = 1$$

The PSSN is a normalized metric that relates the actual performance of the system expressed in ENA to a reference representing the best possible performance [B.J.Seo, Applied Optics 48, 2009][G.Z. Angeli, Proc.SPIE 8127, 2011]. The reference is the ENA of the atmosphere at the site observed with a perfect telescope,

$$PSSN = \frac{\iint_{\infty} PSF^2_{a+t+e}}{\iint_{\infty} PSF^2_{a+t}}$$

Where PSF_{a+t} is the long exposure PSF of the atmosphere and perfect telescope, and PSF_{a+t+e} is the long exposure PSF of the atmosphere and aberrated telescope.

Ground-Layer AO correction reduces the equivalent noise area by partially correcting the low-altitude atmospheric wavefront error. While one could maintain the uncorrected atmosphere as the PSSN reference, this would lead to PSSN > 1. We instead reference the GLAO image quality to the atmospheric wavefront error after correction by an ideal GLAO system with a single deformable mirror 165 m above ground (the conjugate height of M2, and nearly ideal for the site turbulence profile).

The reference optical turbulence profile C_n^2 adopted for image quality specifications is defined in the GMT Environmental Conditions document (GMT-REF-00144). The uncorrected C_n^2 profile results in a Fried parameter of r_0 = 16.4 cm at 500 nm wavelength. After ideal GLAO correction with a single deformable mirror conjugated to 165 m (the GLAO reference atmosphere), the resulting Fried parameter is r_0 = 27.8 cm.

Image formation by the Observatory is inherently a stochastic process determined by predictable actions as well as by random effects [G.Z.Angeli, Proc.SPIE 8336, 2011]. Consequently, any metric describing system performance is a statistical variable that can be defined in stochastic sense only. While some aspects of the performance can be predicted in a deterministic fashion from a given set of inputs, these inputs themselves are usually statistical in nature.

A wide range of imperfections and external disturbances are truly random processes, either through time, or through realizations. Time varying processes include (i) wind buffeting, (ii) air turbulence and thermal variations in the optical path, (iii) air thermal variations around the optical elements and telescope structure, (iv) heat release by observatory components, (v) sensor/measurement noise and drift, as well as (vi) actuator repeatability.

The optical effects of gravitational and thermal deformations of the optical elements and their support structure (including the entire telescope structure) can be deterministically predicted. However, the gravitational load depends on the zenith angle of the telescope, which in turn is the function of the observing program carried out by observatory. The inputs to thermal deformation calculations are also random environmental and operational parameters. Even the statistics of true random processes, like wind buffeting depend on operational parameters: telescope and enclosure zenith angle and azimuth position relative to wind direction, as well as the level of enclosure venting.

The GMT Integrated Modeling Framework enables Monte-Carlo analysis of the Observatory performance through correlated time history of operational and environmental parameters, the Standard Year. The environmental parameters included in the Standard Year are (i) external wind speed and (ii) direction, (iii) ambient temperature, and (iv) relative humidity outside of the enclosure. A record of telescope azimuth and elevation angles has been obtained from the Magellan observatory located close to the GMT site (see the Environmental Conditions Document, GMT-REF-00144). The pointing record is for the same time period as the environmental data assembled for.

3.3.3 Key Performance Parameters

Key Performance Parameters (KPPs) are used to assess the technical performance throughout all stages of the Project. KPPs are reviewed quarterly and reported at all Project-level reviews and their evaluation is part of the expected compliance assessment. KPPs are budgeted and tracked by Project Systems Engineering. Requirements that flow-down to the subsystems from the KPPs should be presented at each major subsystem review.The active management of KPPs allows for early identification and resolution of issues while minimizing budget and schedule impacts.

A KPP is key technical requirement, derived from the science requirements, that can be used to track the most critical observatory performance to manage scope, schedule, cost, and risk and establish formal baseline change control. The KPPs are defined for all Observatory Performance Modes (OPMs) in the Observatory Requirement Document (ORD), which are mapped into Configurations in the Observatory Architecture Document (OAD). Performance budgets are used to develop and track the KPPs as the designs progress.

Objective values of KPPs define the capabilities that GMT is designed to achieve at the completion of construction and commissioning. For KPPs whose objective values are not met at the completion of construction and commissioning, plans shall be presented at the Operations Readiness Review for achieving the objective values in the operations phase of the observatory.

The values for KPPs are flowed down to the ORD from the Concept of Operations document and the Science Requirements Document (SRD). Image quality given in image FWHM (arc seconds) in these latter documents is converted to PSSN values at the ORD level. PSSN values can be meaningfully allocated to the subsystems and are unambiguously calculable for any PSF shape and size, thereby enabling error budgeting.

Image-quality-related KPPs fully describe image quality variation over the field and over time. Other KPPs (such as throughput and effective collecting area) are metrics that characterize telescope sensitivity. Another KPP is Target Acquisition Time, which is a measure of observatory efficiency.

The Key Performance Parameters tracked at the ORD level are as follows:

1) *Image Quality:*

a) *Median On-Axis PSSN:* The median on-axis PSSN over a representative ensemble of data at the telescope focal plane over 900 second integrations at 0.5 µm (OPMs 1, 3, 10, and 14) and 1.65 µm (OPMs 5 and 12). The PSSN in Natural Seeing performance modes is derived from the ConOps Image Quality Efficiency metric. Each value is referenced to the median image quality of the free atmosphere calculated from DIMM seeing (θ = 0.63 arcseconds at a zenith angle of 0°) with an assumed outer scale (L_0 = 25 m); the reference atmosphere is evaluated at the elevation angle of observations. Image quality errors that depend on seeing (r_0 and L_0) are evaluated with respect to the observed atmosphere. The Image Quality Flow-Down Analysis Document (GMT-DOC-03033) describes the derivation of PSSN requirements for the Natural Seeing wavefront control mode.

$$\text{KPP} = \text{median}_{\text{ensemble}}\,(PSSN\ (0{,}900))$$

b) *Median PSSN over the Field:* The median PSSN over the specified field of view at the telescope focal plane over 900 second integrations at 0.5 µm (OPMs 2, 4, 11, and 15) and 1.65 µm (OPMs 6 and 13). The metric of merit is the median value of the median PSSN over field angle over a representative ensemble of data. The PSSN in Ground Layer Adaptive Optics performance modes is derived from the SRD Image Quality specification of the parent Observing Case, which also defines the field of view. Each value is referenced to the median image quality of the free atmosphere calculated from DIMM seeing (θ = 0.63 arcseconds at a zenith angle of 0°) with an assumed outer scale (L_0 = 25 m); the reference atmosphere is evaluated at the elevation angle of observations. Image quality errors that depend on seeing (r_0 and L_0) are evaluated with respect to the observed atmosphere.

$$\text{KPP} = \textbf{median}_{\text{ensemble}} \left(median_{\vec{\theta}} \left(PSSN(\vec{\theta}, 900) \right) \right)$$

c) *Median Strehl Ratio:* The median, over a representative ensemble of mean Strehl ratios of 120-second observations at 1.65 µm. The flow-down from the Image Quality and Strehl Ratio for OPMs 7, 8, and 9 are described in each of the adaptive optics image quality error budgets.

$$\text{KPP} = \textbf{median}_{\text{ensemble}} \left(\langle \text{Strehl}\ (\vec{\theta} = 0), 120\text{s} \rangle \right)$$

2) *Median PSSN Spatial Uniformity:* The standard deviation of the PSSN across the field of view at the telescope focal plane expressed as a percent difference from the mean PSSN over a 900 second exposure at 0.5 µm (OPMs 1, 3, 10, and 14) and 1.65 µm (OPMs 5 and 12). This is a direct flow-down from the Image Quality Variation of the parent OC. PSSN uniformity variation from inherent telescope optical prescription (field-dependent aberration) is not included. The maximum allowed PSSN variation is equal to the median over a representative ensemble of data.

$$\textbf{KPP} = \textbf{median}_{\textbf{ensemble}} \left(100 \frac{\textbf{stdev}(\textbf{PSSN}(\vec{\theta}, 900))_{\vec{\theta}}}{\langle \textbf{PSSN}(\vec{\theta}, 900) \rangle_{\vec{\theta}}} \right)$$

3) *Median PSSN Temporal Stability:* The median over field position of the peak-to-valley temporal change in the PSSN over a 2-hour period (8 x 900 s exposures) expressed as a percent difference from the mean PSSN over time at 0.5 µm (OPMs 1, 3, 11, and 15) and 1.65 µm (OPMs 5 and 13). The 2-hour period represents an estimate of the time between taking PSF standard stars during spectroscopic observations. This is a flow-down from the *Relative Photometric Error* of the parent OC. The median allowed PSSN stability is equal to the median over a representative ensemble of data.

$$\widehat{PSSN}(\vec{\theta}, 900) = median_2\ \text{hours}\ (PSSN(\vec{\theta}, 900))$$

$$\text{KPP} = \text{median} \left(100 \frac{\max_{\vec{\theta}}[\widehat{\text{PSSN}}(\vec{\theta}, 900)] - \min_{\vec{\theta}}[\widehat{\text{PSSN}}(\vec{\theta}, 900)]}{\langle \widehat{\text{PSSN}}(\vec{\theta}, 900) \rangle_{\vec{\theta}}} \right)$$

4) *Minimum Throughput:* The on-axis, minimum allotted throughput of the telescope bandpass at effective wavelengths of common astronomical filters (λ_{eff} = 0.36, 0.44, 0.55, 0.67, 0.86, 0.89, 1.25, 1.63, 2.20, 3.45, 4.89, 9.54, 19.55 µm). It does not include the throughput of the atmosphere or instruments. The flow-down from the *On-Axis Sensitivity* specification of the parent OC is described in GMT-DOC-03229 (SRD to ORD Flow-down Analysis).

5) *Median Target Acquisition Time:* The median time to acquire a new target using any deployed

instrument. This is a direct flow-down from the ConOps. The time is calculated from the start of a slew to the start of centering on the science instrument and includes closing any wavefront control and alignment loops.

6) *Minimum Effective Collecting Area:* Minimum total on-axis collecting area of the observatory configuration given in square meters. The value is related to the total number of available segments and obscurations of the primary mirror. Note that the center segment will contribute the least amount of effective collecting area given the center hole and the obscuration from the secondary and its support trusses. The effective collecting area is directly related to the overall sensitivity.

3.3.4 Other Parameter Definitions

Minimum Wavelength: The lower limit of the wavelength range over which the throughput requirement applies, expressed in microns. This is a direct flow-down from the *Wavelength Range Lower Limit* of the parent OC.

Maximum Wavelength: The upper limit of the wavelength range over which the throughput requirement applies, expressed in microns. This is a direct flow-down from the *Wavelength Range Upper Limit* of the parent OC.

Field of View: The diameter of the telescope field of view over which all requirements apply, expressed in arcminutes. This is a direct flow-down from the *Minimum Field of View* of the parent OC.

Sky Coverage: The fraction of the sky above 30° elevation over which the performance requirements are met. For OPM 9, it is the fraction of guide stars with $R \leq 10$ visible from the site for which the contrast requirement is met. Both are a direct flow-down from *Minimum Sky Coverage* of the parent OC. Note that

Throughput Spatial Variation: The peak-to-valley spatial variation in throughput across the field of view at the telescope focal plane, expressed as a fraction of the on-axis throughput. This is a direct flow-down from the *Maximum Sensitivity Variation* of the parent OC.

Throughput Stability: The maximum change in the throughput at any location in the field of view over any 10 hour period, expressed as a fraction of the mean on-axis throughput. The peripheral region of the Wide field of view in which guiding systems may reside are excluded. This is a direct flow-down from the *Absolute Photometric Error* of the parent OC.

Stray Light: The surface brightness of stray light within the acceptance angle of the telescope exit pupil at the telescope focal plane, expressed as a fraction of the sky background. A circumscribed circular pupil is used for visible performance modes, while the segment profile pupil is used for infrared performance modes. This requirement is evaluated as the maximum over the field of view, median over the standard year telescope pointing and moon position database. Conditions in which the moon is within 15° of the telescope axis are excluded. The flow-down from the *On-Axis Sensitivity* specification of the parent OC is described in GMT-DOC-03229.

Emissivity: The emissivity of the telescope within the acceptance angles of the telescope pupil. This requirement is evaluated as the average over the field of view, median over the standard year. The flow-down from the *On-Axis Sensitivity* specification of the parent OC is described in GMT-DOC-03229.

Contrast/Flux Ratio Noise: The flux ratio noise at a wavelength of 3.8 μm at the telescope focal plane, 120 mas from an R ≤ 10 guide star in 3600 seconds. The performance is specified at a zenith angle of 30°. The flux ratio noise flows down from the *Contrast* specification of the parent OC as described in GMT-DOC-04931.

Field Distortion Stability: The peak-to-valley change in distortion at any location in the telescope focal plane over any 10 hour period, expressed as a fraction of the focal plane size. It is the percent separation between the position of an object in an undistorted field and the position of the same object in a field with distortion. It includes image scale modes and higher-order geometric distortion but does not include the effect of differential atmospheric refraction across the field of view. The 10 hour period is chosen as a reasonable cadence over which to calibrate geometric field distortion. Calibration is performed by observing a standard field with stars at known, highly precise relative positions. This is a direct flow-down from the *Maximum Astrometric Variation* of the parent OC.

3.3.5 Observatory Performance Mode Requirements

Small Field Visible Natural Seeing (OPM 1)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-9 when operating in OPM 1.

Table 3-9: OPM 1 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25248	Min. wavelength [μm]	≤ 0.3	
REQ-L2-ORD-25252	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-25256	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25260	Sky Coverage	≥ 99%	
REQ-L2-ORD-25264	PSSN	≥ 0.8258	
REQ-L2-ORD-25268	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-24	
REQ-L2-ORD-25274	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25278	Throughput Stability	≤ 2%	
REQ-L2-ORD-25282	Stray Light	≤ 0.10%	
REQ-L2-ORD-25286	PSF Stability	≤ 1%	
REQ-L2-ORD-25290	Field Distortion Stability	≤ 0.007%	

Rationale: These requirements flow down from SRD Observing Case 1 and ConOps image quality requirements.

Small Field Visible Ground Layer Corrected (OPM 2)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-10 when operating in OPM 2.

Table 3-10: OPM 2 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25303	Min. wavelength [μm]	≤ 0.32	
REQ-L2-ORD-25307	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-25311	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25315	Sky Coverage	≥ 99%	
REQ-L2-ORD-25319	PSSN	≥ 0.8780	
REQ-L2-ORD-25323	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-24	
REQ-L2-ORD-25329	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25333	Throughput Stability	≤ 2%	
REQ-L2-ORD-25337	Stray Light	≤ 0.10%	
REQ-L2-ORD-25341	PSF Stability	≤ 1%	
REQ-L2-ORD-25345	Field Distortion Stability	≤ 0.007%	

Rationale: These requirements flow down from SRD Observing Case 1.

Small Field Visible Natural Seeing Precision Radial Velocity (OPM 3)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-11 when operating in OPM 3.

Table 3-11: OPM 3 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25358	Min. wavelength [μm]	≤ 0.32	
REQ-L2-ORD-25362	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-25366	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25370	Sky Coverage	≥ 99%	
REQ-L2-ORD-25374	PSSN	≥ 0.8258	
REQ-L2-ORD-25378	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-24	
REQ-L2-ORD-25384	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25388	Throughput Stability	≤ 2%	
REQ-L2-ORD-25392	Stray Light	≤ 0.10%	
REQ-L2-ORD-25396	PSF Stability	≤ 1%	

Rationale: These requirements flow down from SRD Observing Case 2 and ConOps image quality requirements.

Small Field Visible Ground Layer Corrected Precision Radial Velocity (OPM 4)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-12 when operating in OPM 4.

Table 3-12: OPM 4 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25409	Min. wavelength [μm]	≤ 0.32	
REQ-L2-ORD-25413	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-25417	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25421	Sky Coverage	≥ 99%	
REQ-L2-ORD-25425	PSSN	≥ 0.8780	
REQ-L2-ORD-25429	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-24	
REQ-L2-ORD-25435	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25439	Throughput Stability	≤ 2%	
REQ-L2-ORD-25443	Stray Light	≤ 0.10%	
REQ-L2-ORD-25447	PSF Stability	≤ 1%	

Rationale: These requirements flow down from the SRD Observing Case 2.

Small Field Infrared Natural Seeing (OPM 5)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-13 when operating in the OPM 5.

Table 3-13: OPM 5 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25460	Min. wavelength [μm]	≤ 0.8	
REQ-L2-ORD-25464	Max. wavelength [μm]	≥ 25	
REQ-L2-ORD-25468	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25472	Sky Coverage	≥ 99%	
REQ-L2-ORD-25476	PSSN	≥ 0.7888	
REQ-L2-ORD-25480	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-25	
REQ-L2-ORD-25486	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25490	Throughput Stability	≤ 3%	
REQ-L2-ORD-25494	Stray Light	≤ 0.10%	

REQ-L2-ORD-25498	Emissivity	≤ 22%	
REQ-L2-ORD-25502	PSF Stability	≤ 2%	
REQ-L2-ORD-25506	Field Distortion Stability	≤ 0.006%	

Rationale: These requirements flow down from the SRD Observing Case 3 and ConOps image quality requirements.

Small Field Infrared Ground Layer Corrected (OPM 6)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-14 when operating in OPM 6.

Table 3-14: OPM 6 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25519	Min. wavelength [µm]	≤ 0.8	
REQ-L2-ORD-25523	Max. wavelength [µm]	≥ 25	
REQ-L2-ORD-25527	Field of view [arcmin]	≥ 3.0	
REQ-L2-ORD-25531	Sky Coverage	≥ 99%	
REQ-L2-ORD-25535	PSSN	≥ 0.8494	
REQ-L2-ORD-25539	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-25	
REQ-L2-ORD-25545	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25549	Throughput Stability	≤ 3%	
REQ-L2-ORD-25553	Stray Light	≤ 0.10%	
REQ-L2-ORD-25557	Emissivity	≤ 22%	
REQ-L2-ORD-25561	PSF Stability	≤ 2%	
REQ-L2-ORD-25565	Field Distortion Stability	≤ 0.006%	

Rationale: These requirements flow down from STD Observing Case 3.

Small Field Infrared Diffraction-Limited 50% Sky Coverage (OPM 7)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-15 when operating in OPM 7.

Table 3-15: OPM 7 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25578	Min. wavelength [μm]	≤ 0.8	
REQ-L2-ORD-25582	Max. wavelength [μm]	≥ 5.0	
REQ-L2-ORD-25586	Field of view [arcmin]	≥ 0.5	
REQ-L2-ORD-25590	Sky Coverage	≥ 50%	
REQ-L2-ORD-25594	Strehl Ratio	≥ 0.30	at 1.65 μm
	Throughput	Table 3-25	
REQ-L2-ORD-25600	Throughput Spatial Variation	≤ 2%	
REQ-L2-ORD-25604	Throughput Stability	≤ 3%	
REQ-L2-ORD-25608	Stray Light	≤ 0.10%	
REQ-L2-ORD-25612	Emissivity	≤ 25%	
REQ-L2-ORD-25616	PSF Stability	≤ 2%	
REQ-L2-ORD-25620	Field Distortion Stability	≤ 0.001%	

Rationale: These requirements flow down from SRD Observing Case 4.

Small Field Infrared Diffraction-Limited 80% Sky Coverage (OPM 8)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-16 when operating in OPM 8.

Table 3-16: OPM 8 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25633	Min. wavelength [μm]	≤ 0.8	
REQ-L2-ORD-25637	Max. wavelength [μm]	≥ 5.0	
REQ-L2-ORD-25641	Field of view [arcmin]	≥ 0.5	
REQ-L2-ORD-25645	Sky Coverage	≥ 80%	
REQ-L2-ORD-25649	Encircled Energy 50% diameter [arcsec]	≤ 0.05	at 1.65 μm
	Throughput	Table 3-25	
REQ-L2-ORD-25655	Throughput Spatial Variation	≤ 2%	
REQ-L2-ORD-25659	Throughput Stability	≤ 3%	
REQ-L2-ORD-25663	Stray Light	≤ 0.10%	
REQ-L2-ORD-25667	Emissivity	≤ 25%	

REQ-L2-ORD-25671	PSF Stability	≤ 2%	
REQ-L2-ORD-25675	Field Distortion Stability	≤ 0.001%	

Rationale: These requirements flow down from SRD Observing Case 5.

Small Field Infrared High Contrast (OPM 9)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-17 when operating in OPM 9

Table 3-17: OPM 9 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25688	Min. wavelength [μm]	≤ 1.0	
REQ-L2-ORD-25692	Max. wavelength [μm]	≥ 5.0	
REQ-L2-ORD-25696	Field of view [arcmin]	≥ 0.5	
REQ-L2-ORD-25700	Sky Coverage	≥ 50%	Percent R ≤ 10 guide stars at $\theta_z \leq 35°$
REQ-L2-ORD-25705	Strehl Ratio	≥ 0.65	at 1.65 μm
	Throughput	Table 3-25	
REQ-L2-ORD-25711	Throughput Spatial Variation	≤ 2%	
REQ-L2-ORD-25715	Throughput Stability	≤ 10%	
REQ-L2-ORD-25719	Stray Light	≤ 0.10%	
REQ-L2-ORD-25723	Emissivity	≤ 25%	
REQ-L2-ORD-25727	Contrast/Flux ratio noise [parts per million]	≥ 2(TBC)	At 3.8μm, 120 mas separation from R ≤ 10 guide star in 3600 seconds
REQ-L2-ORD-25732	PSF Stability	≤ 5%	
REQ-L2-ORD-25736	Field Distortion Stability	≤ 0.001%	

Rationale: These requirements flow down from SRD Observing Case 6.

Medium Field Visible Natural Seeing (OPM 10)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-18 when operating in OPM 10.

Table 3-18: OPM 10 Requirements

Requirement	Parameter	Value	Note

REQ-L2-ORD-25749	Min. wavelength [µm]	≤ 0.32	
REQ-L2-ORD-25753	Max. wavelength [µm]	≥ 1.3	
REQ-L2-ORD-25757	Field of view [arcmin]	≥ 10.0	
REQ-L2-ORD-25761	Sky Coverage	≥ 99%	
REQ-L2-ORD-25765	PSSN	≥ 0.8258	
REQ-L2-ORD-25769	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-26	
REQ-L2-ORD-25775	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25779	Throughput Stability	≤ 1%	
REQ-L2-ORD-25783	Stray Light	≤ 0.10%	
REQ-L2-ORD-25787	PSF Stability	≤ 1%	
REQ-L2-ORD-25791	Field Distortion Stability	≤ 0.005%	

Rationale: These requirements flow down from SRD Observing Case 7 and ConOps image quality requirements.

Medium Field Visible Ground Layer Corrected (OPM 11)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-19 when operating in OPM 11.

Table 3-19: OPM 11 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25804	Min. wavelength [µm]	≤ 0.32	
REQ-L2-ORD-25808	Max. wavelength [µm]	≥ 1.3	
REQ-L2-ORD-25812	Field of view [arcmin]	≥ 10.0	
REQ-L2-ORD-25816	Sky Coverage	≥ 99%	
REQ-L2-ORD-25820	PSSN	≥ 0.8780	
REQ-L2-ORD-25824	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-26	
REQ-L2-ORD-25830	Throughput Spatial Variation	≤ 5%	

REQ-L2-ORD-25834	Throughput Stability	≤ 1%	
REQ-L2-ORD-25838	Stray Light	≤ 0.10%	
REQ-L2-ORD-25842	PSF Stability	≤ 1%	
REQ-L2-ORD-25846	Field Distortion Stability	≤ 0.005%	

Rationale: These requirements flow down from SRD Observing Case 7.

Medium Field Infrared Natural Seeing (OPM 12)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-20 when operating in OPM 12.

Table 3-20: OPM 12 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25859	Min. wavelength [μm]	≤ 0.8	
REQ-L2-ORD-25863	Max. wavelength [μm]	≥ 25	
REQ-L2-ORD-25867	Field of view [arcmin]	≥ 10.0	
REQ-L2-ORD-25871	Sky Coverage	≥ 99%	
REQ-L2-ORD-25875	PSSN	≥ 0.7888	
REQ-L2-ORD-25879	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-27	
REQ-L2-ORD-25885	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25889	Throughput Stability	≤ 3%	
REQ-L2-ORD-25893	Stray Light	≤ 0.10%	
REQ-L2-ORD-25897	Emissivity	≤ 22%	
REQ-L2-ORD-25901	PSF Stability	≤ 2%	
REQ-L2-ORD-25905	Field Distortion Stability	≤ 0.005%	

Rationale: These requirements flow down from SRD Observing Case 8 and ConOps image quality requirements.

Medium Field Infrared Ground Layer Corrected (OPM 13)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-21 when operating in OPM 13.

Table 3-21: OPM 13 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25918	Min. wavelength [μm]	≤ 0.8	

REQ-L2-ORD-25922	Max. wavelength [μm]	≥ 25	
REQ-L2-ORD-25926	Field of view [arcmin]	≥ 10.0	
REQ-L2-ORD-25930	Sky Coverage	≥ 99%	
REQ-L2-ORD-25934	PSSN	≥ 0.8494	
REQ-L2-ORD-25938	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-27	
REQ-L2-ORD-25944	Throughput Spatial Variation	≤ 5%	
REQ-L2-ORD-25948	Throughput Stability	≤ 3%	
REQ-L2-ORD-25952	Stray Light	≤ 0.10%	
REQ-L2-ORD-25956	Emissivity	≤ 22%	
REQ-L2-ORD-25960	PSF Stability	≤ 2%	
REQ-L2-ORD-25964	Field Distortion Stability	≤ 0.005%	

Rationale: These requirements flow down from SRD Observing Case 8.

Wide Field Visible Natural Seeing (OPM 14)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-22 when operating in OPM 14.

Table 3-22: OPM 14 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-25977	Min. wavelength [μm]	≤ 0.35	
REQ-L2-ORD-25981	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-25985	Field of view [arcmin]	≥ 20.0	
REQ-L2-ORD-25989	Sky Coverage	≥ 99%	
REQ-L2-ORD-25993	PSSN	≥ 0.7765	
REQ-L2-ORD-25997	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-28	
REQ-L2-ORD-26003	Throughput Spatial Variation	≤ 10%	Peripheral obscuration by guiders excluded
REQ-L2-ORD-26008	Throughput Stability	≤ 2%	
REQ-L2-ORD-26012	Stray Light	≤ 0.10%	
REQ-L2-ORD-26016	PSF Stability	≤ 1%	
REQ-L2-ORD-26020	Field Distortion Stability	≤ 0.006%	

Rationale: These requirements flow down from SRD Observing Case 9 and ConOps image quality requirements.

Wide Field Visible Ground Layer Corrected (OPM 15)

The GMT Observatory shall simultaneously meet all the requirements listed in Table 3-23 when operating in OPM 15.

Table 3-23: OPM 15 Requirements

Requirement	Parameter	Value	Note
REQ-L2-ORD-26033	Min. wavelength [μm]	≤ 0.35	
REQ-L2-ORD-26037	Max. wavelength [μm]	≥ 1.3	
REQ-L2-ORD-26041	Field of view [arcmin]	≥ 20.0	
REQ-L2-ORD-26045	Sky Coverage	≥ 99%	
REQ-L2-ORD-26049	PSSN	≥ 0.8259	
REQ-L2-ORD-26053	PSSN Uniformity	≤ 5%	
	Throughput	Table 3-28	
REQ-L2-ORD-26059	Throughput Spatial Variation	≤ 10%	Peripheral obscuration by guiders excluded
REQ-L2-ORD-26064	Throughput Stability	≤ 2%	
REQ-L2-ORD-26068	Stray Light	≤ 0.10%	
REQ-L2-ORD-26072	PSF Stability	≤ 1%	
REQ-L2-ORD-26076	Field Distortion Stability	≤ 0.006%	

Rationale: These requirements flow down from SRD Observing Case 9.

Small Field Visible Throughput

The GMT Observatory in OPM 1, 2, 3, or 4 shall have a minimum on-axis throughput averaged over each photometric band as specified in Table 3-24.

Table 3-24: Small Field Visible Throughput Requirements

Requirement	Wavelength (μm)	Throughput	Note
REQ-L2-ORD-26088	0.36	83%	
REQ-L2-ORD-26091	0.44	82%	
REQ-L2-ORD-26094	0.55	81%	
REQ-L2-ORD-26097	0.67	78%	
REQ-L2-ORD-26100	0.86	75%	
REQ-L2-ORD-26103	0.89	78%	

Notes: The photometric bands are defined in Appendix B: Filter Profiles.

Rationale: These throughput values are consistent with the *On-Axis Sensitivity* specification of OC 1 and

2 as described in GMT-DOC-03229.

Small Field Infrared Throughput

The GMT Observatory in OPM 5, 6, 7, 8, or 9 shall have a minimum on-axis throughput at each wavelength as specified in Table 3-25.

Table 3-25: Small Field Infrared Throughput Requirements

Requirement	Wavelength (µm)	Avg. Throughput	Note
REQ-L2-ORD-26116	1.25	90%	
REQ-L2-ORD-26119	1.63	91%	
REQ-L2-ORD-26122	2.20	92%	
REQ-L2-ORD-26125	3.45	92%	
REQ-L2-ORD-26128	4.89	93%	
REQ-L2-ORD-26131	9.54	94%	
REQ-L2-ORD-26134	19.55	94%	

Notes: The photometric bands are defined in Appendix B: Filter Profiles.

Rationale: These throughput values are consistent with the *On-Axis Sensitivity* specification of OC 3, 4, 5, and 6 as described in GMT-DOC-03229.

Medium Field Visible Throughput

The GMT Observatory in OPM 10 or 11 shall have a minimum on-axis throughput at each wavelength as specified in Table 3-26.

Table 3-26: Medium Field Visible Throughput Requirements

Requirement	Wavelength (µm)	Throughput	Note
REQ-L2-ORD-26147	0.36	83%	
REQ-L2-ORD-26150	0.44	82%	
REQ-L2-ORD-26153	0.55	81%	
REQ-L2-ORD-26156	0.67	78%	
REQ-L2-ORD-26159	0.86	75%	
REQ-L2-ORD-26162	0.89	78%	

Notes: The photometric bands are defined in Appendix B: Filter Profiles.

Rationale: These throughput values are consistent with the *On-Axis Sensitivity* specification of OC 7 as described in GMT-DOC-03229.

Medium Field Infrared Throughput

The GMT Observatory in OPM 12 or 13 shall have a minimum on-axis throughput at each wavelength as specified in Table 3-27.

Table 3-27: Medium Field Infrared Throughput Requirements

Requirement	Wavelength (μm)	Throughput	Note
REQ-L2-ORD-26175	1.25	92%	
REQ-L2-ORD-26178	1.63	93%	
REQ-L2-ORD-26181	2.20	93%	
REQ-L2-ORD-26184	3.45	93%	
REQ-L2-ORD-26187	4.89	94%	
REQ-L2-ORD-26190	9.54	95%	
REQ-L2-ORD-26193	19.55	95%	

Notes: The photometric bands are defined in Appendix B: Filter Profiles.

Rationale: These throughput values are consistent with the *On-Axis Sensitivity* specification of OC 8, as described in GMT-DOC-03229.

Wide Field Visible Throughput

The GMT Observatory in OPM 14 or 15 shall have a minimum on-axis throughput at each wavelength as specified in Table 3-28.

Table 3-28: Wide Field Visible Throughput Requirements

Requirement	Wavelength (μm)	Throughput	Note
REQ-L2-ORD-26206	0.36	35%	
REQ-L2-ORD-26209	0.44	67%	
REQ-L2-ORD-26212	0.55	69%	
REQ-L2-ORD-26215	0.67	65%	
REQ-L2-ORD-26218	0.86	59%	
REQ-L2-ORD-26221	0.89	61%	

Notes: The photometric bands are defined in Appendix B: Filter Profiles.

Rationale: These throughput values are consistent with the *On-Axis Sensitivity* specification of OC 9 as described in GMT-DOC-03229.

3.3.6 General Performance Requirements

REQ-L2-ORD-26227: Pixel-to-pixel Photometric Calibration

The GMT Observatory shall enable detector sensitivity calibration with an uncertainty in relative pixel-to-pixel sensitivity of no greater than 0.1% on spatial scales up to 10 times the PSF FWHM.

Rationale: Required to achieve the absolute photometric accuracy specified in REQ-L1-SCI-23114, -23146, -23183, and -23209. See GMT-DOC-03299, Section 4.7.

Notes: Most steps in photometric calibration will be conducted at night, using twilight sky or reference stars. However, achieving the high signal-to-noise required for accurate pixel-to-pixel flat field calibration requires light sources within the observatory.

REQ-L2-ORD-26231: Spectroscopic Wavelength Calibration

The GMT Observatory shall enable the calibration of spectroscopic observations with a maximum wavelength calibration uncertainty of 6.7×10^{-7} times the wavelength.

Rationale: Required to calibrate and monitor the minimum 10% spectroscopic stability (REQ-L1-SCI-23085) at the maximum spectral resolving power of R = 150,000 (REQ-L1-SCI-23083).

Notes: More accurate spectral calibration may be necessary for certain applications, such as the Precision Radial Velocity Observing Case (REQ-L1-SCI-23125). Such specialized capabilities must be provided by the instrument.

REQ-L2-ORD-106537: On-Axis Effective Collecting Area

The GMT shall have an effective collecting are of no less than 356 square meters, including the impact of any obscurations.

Rationale: This requirement is primarily intended to quantify the completeness of the observatory, as the primary impact on the collecting area is the presence of the seven primary mirror segments. In addition, it limits the allowable obscurations due to vignetting, baffling, or structural supports.

3.4 Interface Requirements

3.4.1 Operations Interfaces

This section includes interfaces to users physically outside the Observatory, such as scientists using the Observatory and archive users, but also Observatory staff who may be performing tasks from off-site.

REQ-L2-ORD-26238: Remote Access to User Interfaces

The GMT shall provide remote access to all science and technical user interfaces.

Rationale: External scientists will use science operations interfaces from remote sites, and technical support will use technical operations interfaces from remote sites.

Notes: Appropriate security must be defined and provided for each user interface.

3.4.1.1 Science Operations Interfaces

REQ-L2-ORD-26243: Observing Proposal Interface

The GMT shall provide software tools to create, submit, read and track observing proposals.

Rationale: External scientists will propose for observing time on the GMT, and GMT will archive and manage the proposals.

REQ-L2-ORD-26246: Time Allocation Committee Interface

The GMT shall provide software tools to facilitate the work of the Time Allocation Committees.

Rationale: The Time Allocation Committees contain external astronomers who will do much of their work from outside the Observatory's infrastructure.

REQ-L2-ORD-26249: Science Observing Interface

The GMT shall provide software tools to monitor and control observing in science operations.

Rationale: The GMT will support remote observing by external scientists.

Notes: This is particularly important for PI-mode operations, but will be used for all modes of operations.

REQ-L2-ORD-26253: Science Archive Interface

The GMT shall provide software tools to access the science archive.

Rationale: The science data archive will be used by both internal and external scientists to access existing science data.

REQ-L2-ORD-26256: Environmental Monitoring Interface

The GMT shall provide software tools to monitor current and predicted environmental conditions.

Rationale: Environmental information is important for tactical planning of observing.

3.4.1.2 Technical Operations Interfaces

REQ-L2-ORD-26260: Engineering Interface

The GMT shall provide software tools to monitor and control all subsystems.

Rationale: This supports efficient troubleshooting by experts both on and off the mountain.

REQ-L2-ORD-26263: Engineering Archive Interface

The GMT shall provide software tools to access the engineering archive.

Rationale: This supports efficient troubleshooting or other inquiries to maintain high performance efficiency. Remote access will be provided for experts who reside off the mountain to access information from the engineering archive.

REQ-L2-ORD-26266: Laser Light Safety Interfaces

The GMT shall provide processes and software tools to monitor and control laser light interfaces with external systems.

Rationale: In order to avoid interference with aircraft, spacecraft and other nearby observatories.

Notes: Satellite systems such as sensitive detectors can be damaged by the GMT laser light. The U.S. Laser Clearinghouse (LCH) works with observatories using lasers to coordinate laser observations with satellite positions Software tools that use information supplied by LCH help select scientific targets that will be minimally impacted by laser "closures" (when the laser will not be allowed to propagate to sky in specific directions).

Aircraft pilots can be startled or injured by the GMT laser light. The Observatory will coordinate its operational processes and policies with the DGAC. The Observatory will also provide hardware to detect aircraft approaching or in the laser lines-of-sight, and software to rapidly shutter the laser when an aircraft is nearby.

Other observatories in the vicinity of GMT may be affected by GMT's laser light, or may affect GMT by their laser light. The GMT will coordinate to determine the magnitude of these effects and will implement a software "laser traffic control system" if required.

3.4.2 External Resource Utilization

REQ-L2-ORD-26273: Commercial Power

The GMT shall provide an electrical interface between the Chilean power grid with sufficient capacity to operate the summit observatory

Rationale: Connection to the Chilean electrical power grid is expected to be the most cost-effective way to supply electric power to the site.

REQ-L2-ORD-26276: Water Systems

The GMT shall provide a water system interface to external water facilities for potable water and fire water.

Rationale: See GMT Water System Concept of Operations and GMT Site Water Tanks BOD for further details.

Notes: Primary water supply is the LCO water supply located on the summit of Las Campanas peak, backup would be external commercial suppliers.

REQ-L2-ORD-26282: Diesel Fuel

The GMT shall provide diesel fuel interface to external commercial providers.

Rationale: Diesel fuel is required for generators and other industrial equipment on the site.

REQ-L2-ORD-26285: Communications Systems

The GMT shall provide a connection to a commercial communications network.

Rationale: A connection to a commercial fiber-optic communications network will be the most cost-effective solution for providing data access to and from the GMT site. Nightly data rates for adaptive optics need the capacity to pass a minimum of 9TB of data over 12 hours.

REQ-L2-ORD-110869: Internal Communications System

The GMT shall provide an internal communications system.

Rationale: An effective communications system is important for safety and efficient operations and maintenance.

Notes: The system will include an internal computer network, phone system, an annunciator system within large buildings, as well as portable handheld devices such as two-way radios. It will not include a dedicated, GMTO-owned link between the Site and the Base Facility.

3.5 System Attributes (Non-functional Requirements)

REQ-L2-ORD-26289: Availability

The GMT shall be available to science operations 96% of the time under Extended Operating Conditions

Rationale: This allows for up to 4% technical downtime. The technical downtime requirement comes from the ConOps.

REQ-L2-ORD-26292: Maintenance Access

The Observatory shall provide adequate access to its components to carry out maintenance.

REQ-L2-ORD-26294: Maintenance Time

The GMT shall require no more than 37,500 staff hours to perform maintenance on Observatory systems.

Rationale: The number of staff hours is driven by the operational staffing model in GMT-DOC-03838 and the maintenance allocation in GMT-REF-00420.

REQ-L2-ORD-26297: Documentation

The GMT shall provide documentation necessary to operate and maintain the Observatory.

Rationale: User manuals and technical documentation is necessary for the efficient operation of the Observatory. This includes online guides, operation and maintenance manuals, drawings, and schematics generated by the construction project prior to transitioning to operations.

REQ-L2-ORD-26300: Computerized Maintenance Management System

The GMT shall provide a Computerized Maintenance Management System (CMMS) to manage maintenance and asset information.

Rationale: A computerized system is necessary for efficient maintenance and asset management. Information on maintenance is most easily generated when hardware and software are designed or purchased, and must be captured by the construction project to provide to operations.

Notes: This could be a CMMS or an Enterprise Asset Management (EAM) system. EAM systems contain within them CMMS functionality.

REQ-L2-ORD-61133: Fault Tracking System

The GMT shall provide a fault tracking system and user interface to log and track faults and responses to faults.

Rationale: Efficient and effective response to operational problems is required to maintain a high level of operational efficiency and low downtime during science operations.

3.6 Environmental, Health, and Safety

REQ-L2-ORD-26305: Observatory Safety Strategy

The Observatory shall comply with the Health, Safety, Security, and Environmental Strategy document (GMT-DOC-01061).

REQ-L2-ORD-26307: Environmental, Health, and Safety Policy

The Observatory shall comply with the Health, Safety and Environmental Policy (GMT-PM-DOC-00243).

REQ-L2-ORD-26309: Emergency Response Plan

The Observatory shall comply with the Emergency Response Plan (GMT-DOC-01925).

Notes: The Emergency Response Plan identifies potential emergencies (fire, lightning, seismic event), define crisis management roles and responsibilities, procedures for preparing for various emergencies, clear triggers for decision points, and procedures for responding to each emergency. This includes an independent emergency communications system.

REQ-L2-ORD-26312: Environmental, Health, and Safety Standards

The Observatory shall comply with all applicable local and national environmental, and occupational health regulations and standards specified in GMT-DOC-01400, GMT Design EHS Requirements.

Notes: Includes site restoration after demolition.

REQ-L2-ORD-26315: Personnel Security

The Observatory shall provide a secure environment for personnel expected at the Observatory

REQ-L2-ORD-26317: Equipment Security

The Observatory shall provide a secure environment for its equipment.

REQ-L2-ORD-26319: Functional Equipment Safety

The Observatory shall provide controls to prevent unsafe interactions between Observatory subsystems.

Rationale: Some combinations of equipment functions cannot be allowed, or must be closely monitored and controlled, so that the interaction between the functions do not cause an equipment or personnel safety hazard.

Notes: Controls can include software, limit switches, and proximity switches.

3.7 Other Requirements

REQ-L2-ORD-93987: Regulations, Codes and Standards

The GMT shall comply with all applicable codes and standards as described in GMT Reference for

Regulations, Codes and Standards (GMT-REF-00229).

Rationale: It establishes common technical rules across the GMT to avoid incompatibilities and ensure that at least minimum criteria are met. Standards can also lower costs as they are based on lessons learned and best practices.The GMT-REF-00229 addresses the selected standards. The tailoring, detailing, application and control of standards are referenced on flow down requirements where standard are applicable.

REQ-L2-ORD-26328: Handling, Transportation, and Storage Environmental Conditions

The GMT shall comply with handling, transportation, and storage conditions specified in MIL-STD-810E and MIL-STD-810G.

Rationale: These MIL-STD documents specify typical ranges of environmental parameters that are regularly followed by commercial shipping and handling companies. Adherence to these standards ensures safe handling of GMT components during shipment and storage.

Notes: We will use conditions and testing protocols described in MIL-STD-810E and MIL-STD-810G. These provide typical ranges of environmental parameters that are regularly encountered during commercial shipping and handling.

4 Appendix A: Accuracy Definition

The purpose of this Appendix is to establish a uniform understanding of measurement terms across the GMT project.

Definitions

Accuracy: The closeness of agreement between a test result and the accepted reference value.

Trueness: The closeness of agreement between the average value obtained from a large series of test results and an accepted reference value. The measure of trueness usually is expressed in terms of bias and computed as the difference between the expectation value of the test results and an accepted reference value. Bias is the total systematic error as contrasted to random error. There may be one or more systematic error components contributing to the bias.

Please note that in some terminology trueness is called accuracy.

Precision: The closeness of agreement between independent test results obtained under stipulated conditions. The measure of precision usually is expressed in terms of imprecision and computed as a standard deviation of the test results. Independent test results mean results obtained in a manner not influenced by any previous results on the same or similar test object. Repeatability and reproducibility conditions are particular sets of extreme stipulated conditions.

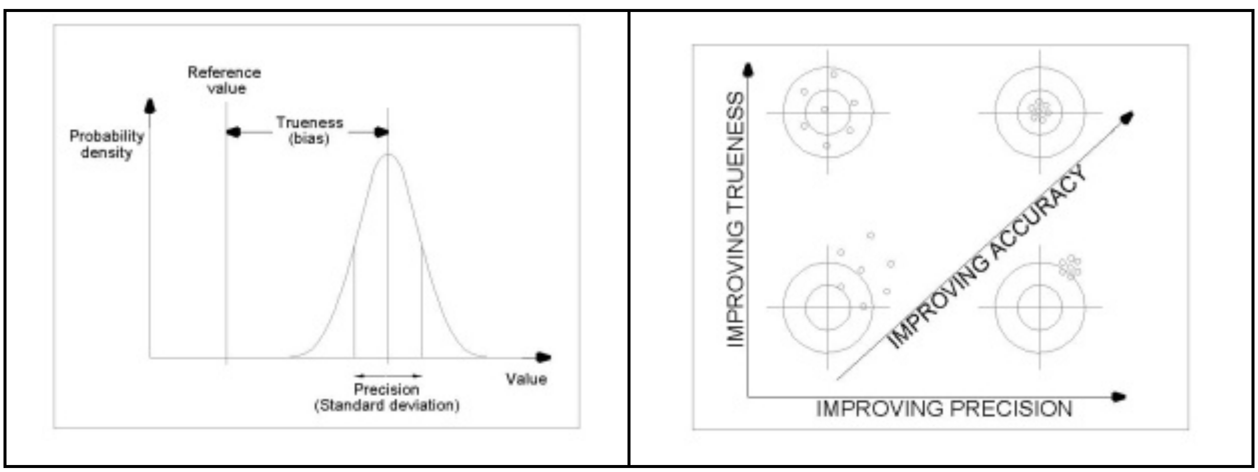

Figure 4-1: Graphical Interpretations of Accuracy Terms

Repeatability: Precision estimated under repeatability conditions.

Repeatability conditions: Conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time.

Reproducibility: Precision estimated under reproducibility conditions.

Reproducibility conditions: Conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

5 Appendix B: Filter Profiles

The filter profiles for a given band are used as weights in taking the average throughput over the band. The sources of the filter profile data are described in Table 5-1 and the filter profiles are plotted in Figure 5-1.

Table 5-1: Filter Profile Data Sources

Name of Filter	Origin of Data
U	Johnson
B	Johnson
V	Johnson
R	Johnson
I	Johnson
z	Sloan
J	UKIRT WFCAM
H	UKIRT WFCAM
K	UKIRT WFCAM
L	GCPD
M	GCPD
N	Gemini Michelle
Q	Gemini Michelle

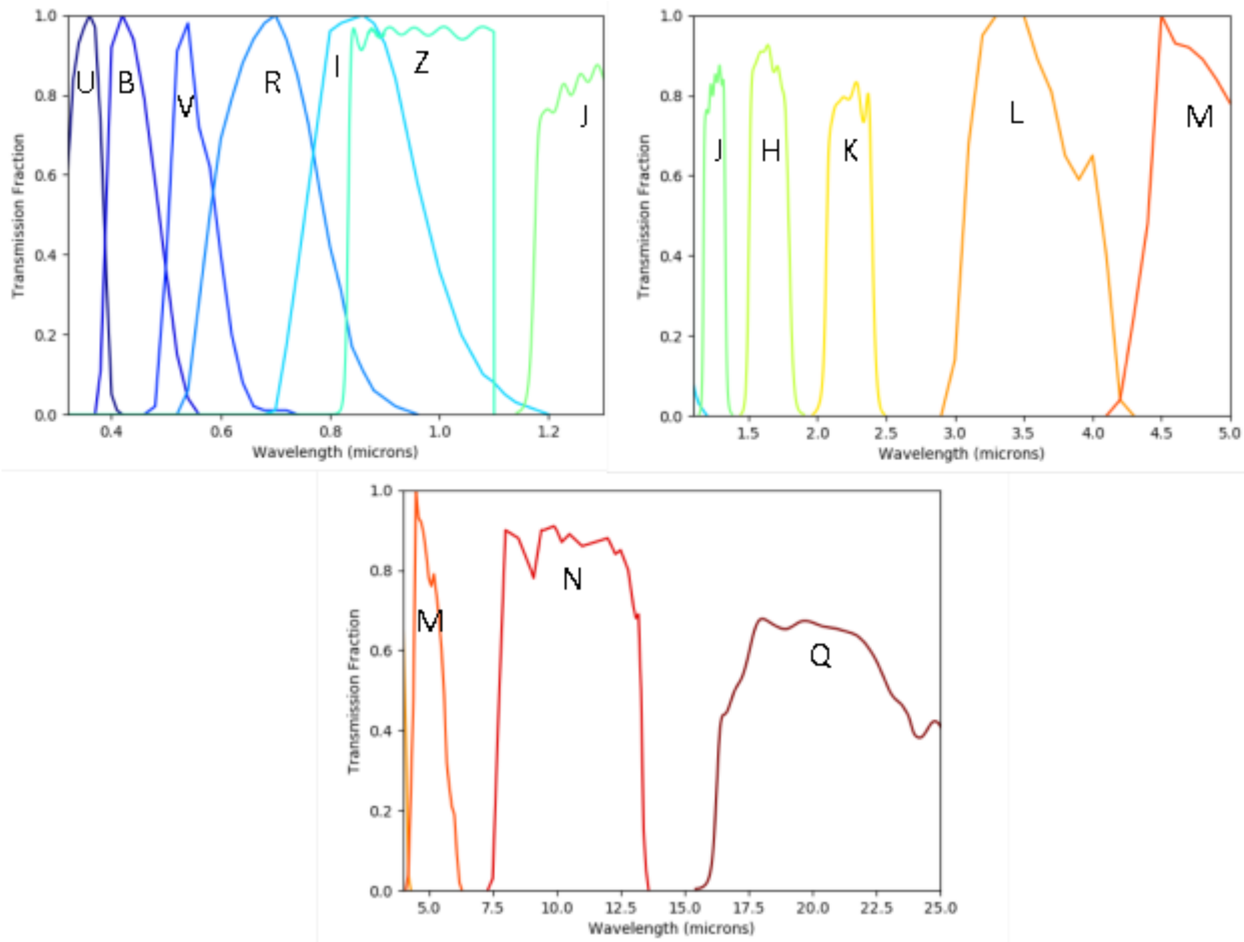

Figure 5-1: Transmission Curves for Filters Used in Throughput Calculations

References

ISO 5725-1:1994, “Accuracy (trueness and precision) of measurement methods and results, Part 1: General principles and definitions.”

ISO 5725-2:1994, "Accuracy (trueness and precision) of measurement methods and results, Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method."

ISO 3534-1: 1993, “Statistics – Vocabulary and Symbols, Part 1: Probability and General Statistical Terms”

6 Appendix C: Observatory Performance Modes Summary

Table 6-1: Observatory Performance Mode Summary

Field of View		**Small Field**									**Medium Field**				**Wide Field**	
Wavelength		**Visible**				**Infrared**					**Visible**		**Infrared**		**Visible**	
Image Quality		**NS**	**GL**	**NS**	**GL**	**NS**	**GL**	**DL 50%**	**DL 80%**	**HC**	**NS**	**GL**	**NS**	**GL**	**NS**	**GL**
Other				**PRV**	**PRV**											
OPM ID		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Parameter	**Unit**															
Min. wavelength [µm]	µm	0.32	0.32	0.32	0.32	0.8	0.8	0.8	0.8	1.0	0.32	0.32	0.8	0.8	0.35	0.35
Max. wavelength [µm]	µm	1.3	1.3	1.3	1.3	25	25	5.0	5.0	5.0	1.3	1.3	25	25	1.3	1.3
Field of view [arcmin]	arcmin	3.0	3.0	3.0	3.0	3.0	3.0	0.5	0.5	0.5	10	10	10	10	20	20
Sky Coverage	%	99%	99%	99%	99%	99%	99%	50%	80%	99% [1]	99%	99%	99%	99%	99%	99%
PSSN	N/A	0.86	0.84	0.86	0.84	0.83	0.65				0.86	0.84	0.83	0.65	0.81	0.72
PSSN Uniformity	%	5%	5%	5%	5%	5%	5%				5%	5%	5%	5%	5%	5%
Wavefront Error	nm							280	350	150						
Throughput	%	60%	60%	60%	60%	75%	75%	70%	70%	70%	60%	60%	75%	75%	55%	55%

ut																
Throughput Spatial Variation	%	5%	5%	5%	5%	5%	5%	2%	2%	2%	5%	5%	5%	5%	10%	10%
Throughput Stability	%	2%	2%	2%	2%	3%	3%	3%	3%	10%	1%	1%	3%	3%	2%	2%
Stray Light	%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Emissivity	%					22%	22%	25%	25%	25%			22%	22%		
Contrast	N/A									1.E+06						
PSF Stability	%	1%	1%	1%	1%	2%	2%	2%	2%	5%	1%	1%	2%	2%	1%	1%
Field Distortion Stability	%	0.007%	0.007%			0.006%	0.006%	0.001%	0.001%	0.001%	0.005%	0.005%	0.005%	0.005%	0.006%	0.006%
Spectral Stability	TBD			TBD	TBD											

Notes:

1. Sky coverage for OPM 9 is the percent of R≤10 guide stars above 30° elevation for which image quality must be met